Rammed Earth Conservation

Editors:
C. Mileto, F. Vegas & V. Cristini

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RAMMED EARTH CONSERVATION

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PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON RAMMED EARTH CONSERVATION, RESTAPIA 2012, VALENCIA, SPAIN, 21–23 JUNE 2012

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C. Mileto, F. Vegas & V. Cristini

Universitat Politècnica de València, Spain

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Preface

The rammed earth technique, in all its variants, is widespread all over the world, although in some areas, such as the Iberian Peninsula and northern Africa, it is more commonly found than in others. The enormous prevalence of this building technique constitutes an important richness of varieties both in its application and in the materials used. For some time now, many varieties of this type of construction techniques (earthen, lime-crusted, brick-reinforced, gypsum-reinforced, lime concrete, etc.) have been studied in depth and yielded important results, but it is interesting to take an overall look at the subject to demonstrate the diversity of this construction technique and how it is adapted to different territories, materials, climate conditions, etc.

Interventions on historic rammed earth buildings have also been carried out in all the geographic areas where these structures are found. This historic heritage has undergone diverse works of reconstruction, conservation, repair, substitution, structural consolidation, etc. The criteria followed have also been numerous: conservation of material authenticity, minimum intervention, compatibility, formal and volumetric retrieval, recuperation of the construction technique, expressive renewal, reversibility, etc. The different criteria applied require different techniques, materials or intervention works. The results of the interventions have also been manifold, regarding both the impact on the building and the technical and material durability.

In view of these issues, in the frame of the Instituto de Restauración del Patrimonio (Heritage Restoration Institute) of the Universitat Politècnica de València it has been organised RESTAPIA 2012—International Conference on Rammed Earth Conservation, which has taken place at that university on 21st, 22nd and 23rd June 2012. It is an international congress about rammed earth architecture and its restoration, and, in a more general way, about the construction techniques and restoration of all earthen structures. The aim of this event is to pool knowledge of building techniques (both rammed earth and earth in general), and to share experiences of restoration of monumental and non-monumental architectonic heritage carried out in the Iberian Peninsula and the rest of the world, so that we can all learn from this experience and draw conclusions and construct perspectives for the future. To this end, four major themes with different subsections were proposed: rammed earth architecture and construction (traditional and modern rammed earth building methods; rammed earth architecture the world over; rammed earth architecture in the Iberian Peninsula); restoration of rammed earth architecture (study cases; intervention criteria; intervention techniques); earthen architecture and construction (traditional and modern variants of building methods; earthen architecture in the world; earthen architecture in the Iberian Peninsula); restoration of earthen architecture (study cases; intervention criteria; intervention techniques).

The scientific committee is made up of the most notable researchers into the subject of earthen architecture, rammed earth architecture and architectural restoration from the Iberian Peninsula and abroad. All the contributions to the congress, both the abstracts and the final texts, have been subjected to a strict peer-review evaluation system by the members of the scientific committee or other external consultants. This volume contains more than one hundred of papers that were deemed worthy of publication, six of which are lectures delivered by guest researchers, prominent experts on the subject: Hubert Guillaud (CRAterre, École Nationale Supérieure d'Architecture de Grenoble, France); Mariana Correia (Escola Superior Gallaecia, Vilanova de Cerveira, Portugal); Frank Matero (University of Pennsylvania, US); Francisco Javier López Martínez (Universidad Católica de Murcia, Spain); José Manuel López Osorio (Universidad de Málaga, Spain) and Javier Gallego Roca (Universidad de Granada, Spain).

The congress is under the aegis of by institutions of great international prestige in this discipline, whose support and confidence we are most grateful for: UNESCO Chair Earthen Architecture, building cultures and sustainable development; CRAterre—ENSAG, Grenoble, France; ICOMOS—ISCEAH, International Scientific Committee for Earthen Architectural Heritage; Red Iberoamericana Proterra.

The organisation, publication and implementation of the congress have been possible thanks to the aids received from the former Ministry of Science and Innovation, currently the Ministry of Economy and Competitiveness, the Generalitat Valenciana and the Universitat Politècnica de València. We have also received the support of other institutions such as the Escuela Técnica Superior de Arquitectura, the Máster Oficial en Conservación del Patrimonio Arquitectónico y la Cátedra Cerámica de la Universitat Politècnica de València and the Fundación Antonio Font de Bedoya, associations of companies like ARESPA – Asociación Española de Empresas de Restauración del Patrimonio Histórico, and companies such as Tarma – Restauración & Patrimonio, Antique – Conservación y Restauración, E.I. Artola s.l. Constructora and Rubiomorte – Restauración / Construcción.

Finally we would like to express our gratitude to all the authors of the texts who have presented their work for this congress, contributing to its success, for the special involvement of the researchers of the Res-Tapia project (BIA 2010-18921), both in submitting their work to the congress and in collaborating in its diffusion, for the important work of the Scientific Committee during the painstaking review process and the Organising Committee in setting up the congress, the language and style reviewers and all those collaborators who have worked hard to have everything ready in time.

C. Mileto, F. Vegas & V. Cristini
March 2012

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"Pisé": Evolution, innovations, resistances and future directions

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ABSTRACT: The "pisé" technology has been used by builders for about three thousand years and with no major technical evolution up to recent times. A true cultural revolution occured after the Second World War, starting in Australia and the U.S.A. with the use of new types of formworks and ramming tools that led to the development of new concepts of construction and architectural design in structural systems and spaces. Then, this step gave birth to the precasting of pisé walls for a better productivity on the working sites. Nevertheless, today, the surviving of this millenary building culture valorizing the direct use of earth "at the bottom of the wall" seems to be threatened by the pressure of the economy (productivity), but also by the fast evolution of the construction standards (safety, energy, …) that are impacting the traditional technology of pisé and its architecture. On the other hand, recent trends in the fundamental research, and research and development (R&D) are testing and developing new types of earthen poured concrete that could accelerate the disappearance of pisé. Is there really a future for pisé and for what viable reasons?

1 BRIEF HISTORICAL OVERVIEW

The construction process consisting in ramming local raw earth in wooden formworks has been used since Antiquity. In the Mediterranean region, the scientific community recognizes the invention of this massive earth construction process (*opus formarium*) by the Phoenicians who founded the colony of Carthage, in 814 B.C., on the famous hills of Byrsa (actual site of Tunis). This does not preclude this building process having been imagined elsewhere, by other cultures and in other times, or transferred (Latin America, United States, Australia). But, on this question, no exhaustive balance has been made. At Carthage, though the local construction way has been recognized as very eclectic, mixing several materials (notably stone and earth) filling a construction system in masoned pillars (*opus africanum*), pisé was commonly used until the destruction of the city by the Romans, as it has been clearly shown with the archaeological report on the excavations undertaken during the 1970's by Serge Lancel and Jean-Paul Thuillier (1982). The Mediterranean and North-African substratum of the pisé culture was laid down and, without any doubt, influenced the Roman earthen construction practices that are then described in Varron's writings (*De Res Rusticae*, I, 14, 40) and those of the Spanish Columelle (*De Re Rustica*, X, 1, 2 et XI, 3, 2), during the 1st Century A.C., and then in Palladius' writings during the 5th Century (*Opus Agriculturae*, I, 34). This cultural substratum will be reappropriated by numerous Iberian authors who are bearing witness of a great and blooming architectural culture in Spain (Isidore of Sevilla, and during the Moorish epochs with Al Razi, Al Bakri, Al Himrayi, Ibn Jaldùn and others), as research that has been published by the Art historian Juana Font Arellano (2007) are testifying. All these texts are already known by the researchers who are interested in the subject but we must point out that the "technical" dimension of the pisé has not been always fully and precisely described. With the Renaissance, L.B. Alberti (*De Re Aedificatoria*, trans. J. Martin, 1553, pp. 48–49) still stays not very eloquent on this dimension as also Charles Estienne and Jean Liébault will be in their famous treatise «La Maison Rustique» (1564 and numerous reprints during the next two centuries). Discussion about pisé is mainly focused on its economical purpose. Then, the communications and erudite essays from the Academies of Sciences, Arts and Humanities that multiplied in Europe during the 18th Century, and the first treatises of rural architecture that were published during the second part of this same century, point to an increasingly technical interest. Maybe because the society of this time is requesting the earth to be "at the bottom of the wall" for improving the constructions which are in majority made of wood and wattle and daub, and very exposed to fire (these arguments are valorized). The famous "Mémoire" written by G.M. Delorme, who presented it in Amiens (France) on March 17th 1745, is astonishingly precise regarding the description of pisé. It takes place before other writings that are now very famous as the "Art du Maçon Piseur" (1772) of G.C. Goiffon, the "Journal de Physique" (1772) and the "Cours Complet d'Agriculture" (1786) of the French Abbot Rozier in which the Lyonese architect François Boulard (at the request of the Abbot) offers a more methodical description of the technique (quality of the soil, tools and construction process). With his famous "Cahiers d'école d'architecture rurale" (1790 et 1791), François Cointeraux will take place in this long line of generalist, technical and economical essays on pisé that will become fully recognized with the "Traité théorique et pratique de l'Art de Bâtir" of Jean-Baptiste Rondelet (1840) describing the pisé construction method traditionally used in the region of Lyon and Dauphiné. So, it is on this ancient Mediterranean substratum, then modern and European (translations of François Cointeraux), that the technical pattern of the traditional pisé, was passing through centuries and was at the same time transferred to far away continents and countries, but without any fundamental questioning nor innovation, just accepting some regional or local variations. The Industrial Revolution of the 19th Century initiated a declining process of the traditional pisé technique that was lately confirmed in France with the extermination of carpenters (traditionally in charge of building in pisé) who were mobilized for timbering the trenches during the First World War and many of them were killed. This declining process came to an end in the 1950's. Today, pisé mainly exists in developing regions where the building culture is still alive and where the intensive manpower is cheap. Even if there was a revival of pisé in France (P. Dufournet, 1950), and in Australia (G.F. Middleton, 1953), it is only during the 1970's that we can observe a rebirthing of pisé construction resulting of the two successive energy crises (1973 and 1979). A process of new experimentations and innovation closely associating technique and economy, contributes to the development of new types of "climbing" formworks and then new techniques for prefabricating pisé blocks *in situ* (N. Meunier, 1987), or pier walls (M. Rauch, 2001). All these innovations were directed at lowering the executing costs in regions where the intensive manpower for building in pisé is very expensive. Today, contractors wishing to go on building in pisé, in industrialized countries, are facing an economical handicap of the technique and also a limited market, despite new arguments in favor of pisé being promoted. If economical arguments, more than ever before, are still very influent, energetic considerations seem to supplant them with the paradigm of sustainable development. The thermal properties of the material (mass, inertia) and the comfort control (hydrous transfer) are much more valorized. Therefore, we observe new trends in favor of the use of pisé in outer or inner envelope, or skin and, more ahead, in the direction of new techniques for building in massive earth from the use of poured earthen concrete as soon as the rheology (the pouring of the material) will be better controlled. Outside the regions of the world where the traditional pisé is still used and viable, the hybridization of the materials and building systems is taking the lead and stimulates the development of research and development (R&D) programs (see the "Grands Ateliers", in Villefontaine, France, and enterprises that are taking out patents), as much more contemporaneous architectural achievements are showing (U.S.A, Australia, South Korea, …). So, with the promised development of the new "clay" concretes, new technical, economical, construction and architectural perspectives are opened. In counterpart, this inevitable evolution could act for the disappearance of the "old pisé" at the advantage of a true "new pisé" to which François Cointeraux, also inventor of the compressed block, was already dreaming.

2 "PISÉ": PERMANENCE, EVOLUTIONS AND INNOVATIONS

2.1 *A semantic and technical substratum together universal and specific*

In previous research, and we dealt with the semantic filiation of the nomenclature of the technique (Aurenche et coll. 2011). Here we want to point out once more the importance of the Arabic filiation from the vocables *Otob* and *toub* that gave birth to *tabîya* used in Iberia by the Moors, that gave birth to a remarkable popular, military and knowledgeable heritage that is counting among the best architectural ensembles as the famous Alhambra of Granada, or the numerous medieval fortifications of Murcia, Estremadura, and Andalusia. This Arabic filiation was directly influencing the modern Spanish and the Portuguese with the words *tapia*, *tapial*, *taipa*, but also the «langue d'Oc» (old Provençal) with *tàpie*, *tepa*, *tépe,* and even other declinations in the patronymy or the toponymic nominations in the French-Provençal area (Baudreu 2007). For *pisé*, *pisey*, *pisay*, it is really to the latin vocable *pinsare* (to beat, to hit) that we have to refer to, and here also with numerous declinations in the French-Provençal area, as are confirming Baudreu's research. Elsewhere in the world they are proper vocables belonging to the vernacular and modern languages that are designating the technique, inviting to refer to the scientific and technical literature.

In other respects, there is recognition today of the existence of a technical substratum that is shared between the different pisé building cultures existing in the world, as well in Europe, in Latin America, Asia, as in North Africa, all main regions where pisé construction was and is still practiced. Nevertheless, this «universal» dimension of pisé is declining in various specificities that are anchored in the diversity of the local cultural identities. Concerning the European context, the technical description of pisé, in the old writings, and even in the modern ones, was scarce and gave very few indications on the quality of the soils, the ramming process in successive layers, or on the description of the formworks that were reduced to simple shutters or «planks». The first more detailed and illustrated descriptions, were given by essays that were published at the end of the 18th Century, then in treatises of construction edited during the 19th Century that we previouly identified. Finally they are more recent publications, from the 1970's up today that are describing with a very precise way the construction process in pisé. Beyond the first publications of reference (Doat et al., 1979; Houben et Guillaud 1989), the literature which is produced after, in Spanish, Portuguese, English, German, now constitutes a very impressive corpus.

We remind here the universal characters of the technique that we will briefly outline in their historical and traditional aspects that basically did not evolved until the modern era, to be renewed by technological innovations during the last forty years, only! This is really a new historical step for pisé which is evolving in a context of economical pressure (cost of the intensive manpower, productivity), on a background of environmental preoccupations that are shared worldwide, which are directly impacting, and could be detrimental to the popular, social and economical interest that the technique was conserving during its long history of use. This is also an evolution which is modifying the main old construction and architectural characters with a direct impact on the structure, the shape and the composition of the space. Therefore, with this step of evolution the «survival» of pisé seems to have to impose a much more radical evolution of the project design and construction processes, a new construction and architectural imagination and intelligence that would promote the association of pisé—but also of other earthen construction materials as unbaked bricks, cob, earth and straw, wattle and daub—with compatible industrial materials. This new step of evolution seems to be able to better make use of most proper qualities and performances of the raw earth and of the material as the texture, the colour of the grains, the energetic qualities (grey energy savings), or the ambient comfort (hygrothermal regulating). In other respects, recent research undertaken on the «material in grains» (Fontaine et Anger 2010) are opening other perspectives, with the development of the poured earthen concretes that could even contribute to a recession, or even to a disappearence of this millenary technique which could no more answer to imperatives of economical earnings, because it is expansive in manpower, and accountant in human working energy and tiredness for the workers (to those who are ramming the earth in the formworks!).

2.2 *Universal characters of a construction culture: Shared knowledge and know-how*

Facing a wide set of points of view that are crossing together for classifying the different modes of use of earth in the constructions, and based on the difficulty to combine them, Olivier Aurenche et coll. (2011) have proposed an «attempt of classification according the working site implementation» which is based on the notion of «earth to build with». The authors are distinguishing three entries: i) the «massive» earth that corresponds together to the stacked earth or cob; ii) the stacked earth in formwork, or coffered cob, and, iii) the rammed earth in formwork or pisé. If we accept here the universal characters of the construction process in pisé that are widely adopted by the different construction cultures which are worldwide identified, we can easily set apart three characteristic elements: i) the nature of the soil, or «raw» earth, that is commonly used by the builders; ii) the nature of the tools—or formwork and rammer—and the ramming process of the earth in successive layers in the formwork.

Therefore, the soils to build in pisé are rather of sandy nature, rich in gravels, or even pebbly, and finally not so much clayey. Most of the time they are cleared out of plants being collected under the grassy surface. Such kind of soils are commonly called "earth with structure" and can not be easily moulded because insufficiently plastic. For such reason they are distinct from soils that are used for cob or adobe. They are implemented at their natural state of humidity, thus at a no high water content which is here again an essential distinction regarding to earth that are moulded or directly shaped in place (adobe or cob). Their ramming in successive layers in the formwork is done with a massive wooden tamper which is connected to a handle, also made of wood. The shapes of these wooden tampers vary according regional and local cultures.

The most commonly used formwork consists in two shutters made from long wooden planks that are connected together with vertical braces nailed on the outer facing of the shutters. These two shutters are laid on wooden timbers (logs or sections of rafters), more recently made of metal (tubes or flat iron bars), that are laid horizontally on the base of the walls and then on the rammed earth blocks after having removed the formwork. To resist to the pressure of the compaction of the earth in the formwork, the shutters of the formwork are supported on their outer side by small timbers, or small posts, that are linked to the horizontal wooden timbers, most of the time with a connection in tenons and mortises, and wedges. Inside the formwork and in its high part, a piece of wood is wedged between the two sides of the formwork giving the width of the wall. Twisted ropes link the high parts of the outer vertical small posts contributing to the device of resistance to the pressure of compaction and to the maintaining of the formwork in position. This type of formwork that has been elaborated during time was clearly described at the end of the 18th Century in the fourth "Cahier d'école d'architecture rurale" of François Cointeraux (1791), widely disseminated through the translations of this essay and then taken up again by the encyclopaedists and by Jean-Baptiste Rondelet in his famous "Traité théorique et pratique de l'Art de Bâtir" (1840). We have previously studied this international influence of François Cointeraux and the transfer of the technical pattern to other distant regions (Guillaud 1997). These tools, that are identical to those of the of the Iberic tradition, as well as in the Maghreb (Morocco, Algeria), inherited from Arabic and Moorish practices was previously transferred to Latin America, beyond the colonization of the "New World", from the 16th Century.

The other variant of traditional formwork was also described by François Cointeraux as well as by the Earl Lasteyrie du Saillant (1802; 1820). They are the «Bugey» and the «iséroise» methods (French territorial divisions of Ain and Isère), consisting of a process of maintaining the formworks—that are similar to those previously described—with high squared off trunks that are deeply pushed in the soil and strengthened at their bottom part by leaned struts. In this device, the formwork is still moving horizontally. This process has been also identified in the Chinese tradition. But, in this case, the moving of the formwork is done vertically and the pisé walls are made in successive piers. It can be still observed on the Plateau of Tibet in the region of the natural reserve of the Sources of the Three Rivers (Qinghai). However the Tibetan rammed earth builders have accomplished this process and its optimal use, imagining a formwork which is together integral and climbing, and mobilizing for the construction several teams which are working simultaneously. Both of these processes are really the two historical and traditional faces of the pisé technique that have conserved their permanence during centuries, in far away regions distant from each other, and without major change, whatever are the regional and local cultural variants.

2.3 *Pisé: From technical evolutions to innovations: Towards a new construction and architectural culture*

The recent use of the integral formwork, directly derived from the concrete technology, does not change the construction process in pisé, in continuous and monolithic mass. The only difference is the possibility to immediately move out the formwork, for the pisé, that means to use fewer surfaces of formworks. The remarkable evolution is the disappearance of the horizontal moving of the formwork to the benefit of the vertical progression and to the construction of separated walls, and dissociating the solid (pisé walls) from the void (bays or other building elements filling the void). This trend is more particularly developed in the Australian or North American contexts from new types of formworks that were invented by John Harcourt, at Eltham, in Australia, then by par David Miller (1980) in the U.S.A. These formworks are more and more adopted in Europe. Finally, only imagined twenty years back (Meunier 1987; Rauch 2001), the prefabrication of walling elements in pisé, either *in situ* or in workshop, can be considered as a true revolution. Nevertheless, this evolution is contested by a radical ecologism when the piers in pisé are made in workshop and then transported to the working sites (energetic cost of the transport). We can also note that other types of special formworks that would improve the productivity, or for building in pisé in seismic areas (Minke 2001), or even for particular building elements (in "L", "T" or "U" shape) have been also developed (Middleton 1953). But their use seems to have been mainly restricted to experimental or pilot projects. In this landscape of creative evolutions, that are attempting to update the technology for addressing other needs, many times we think that the traditional building process in pisé that we can still observe in the presaharan valleys of Morocco, still remains of a really exceptional intelligence and efficiency. Yes indeed, rarely we have seen such easiness to build walls in pisé with tools that are perfectly adapted to the physical effort and so easy to transport, to manipulate!

We think that it is much more important to point out the impact of the technological evolution on the design of the structures and on the composition of spaces, and also to point out the new use of the aesthetic and energetic qualities of the material.

In a previous publication (Guillaud et al., 1987), we proposed a typology of the building systems in pisé linking together five main factors acting on the architectural design. It was: i) the «block» of pisé itself; ii) concepts of structure (traditional monolithic envelope, stepped and buttressed walls, independant and abut piers); iii) types of openings (either in the mass, or filling a void between two self stable pisé walls, or two piers); iv) resources of the plan acting on the composition of the space (either a "contained" space by the monolithic envelope, or a outlined space by frontiers, or a "delimited" fluid space); and, v) the relation with the types of roofing (roofs on traditional carpentry, vaults, domes, or terraces). This typology still remains valid if we refer to the history of the pisé building culture, and to its evolution. But, the most recent trends—beyond the *continuum* of the traditional practices that are remaining in various regions of the world, and beyond some cultural resistances, or even folklorist identities that are linking the contemporaneous impetus to these traditions and to their mental representations, or to their construction and architectural patterns—seem to considerably reduce this typology of building systems in the production of a new pisé architecture. This is what we can observe in the U.S.A, in Australia, in South Korea and on more rare European projects (France, Germany, Portugal, Spain). Indeed, the actual trend looks to embark on two directions. Either in the direction of a kind of "hybrid" construction and architectural design, where tradition and contemporaneity are close together, notably on the relation between structure and space (projects of Rick Joy in Arizona, desert of Soñora), or in the direction of a true "liberation" of the plan that is taking advantage of the self stability of independent walls and piers, and valorizing the resources of the frontiers and limits of the spaces (projects of Jones Studio in U.S.A.). Otherwise, on more recent projects, but still rare, the trend for the hybridization is overpassing the unique link between structure and space, tradition and willing for a contemporaneous expression. It also valorizes new constructions logics that are associating the pisé with other natural materials: wattle and daub or earth and straw, adobe or CEB, for inner partitions. We also observe a tendency to the willing limitation of the use of pisé that preferably valorizes the energetic performance of the material (mass and thermal inertia). So, several recent projects in straw bales that are plastered with earth are effectively integrating in the inner space big walls in pisé that are contributing to an efficient regulation of the hygrothermal comfort. Other researches and experimentations that are undertaken in the direction of the prefabrication are targeting the design of outer or inner envelopes or "skins" in small prefabricated elements in pisé that are used for filling wooden or metallic skeletons (prototype of "Armadillo box" of the Solar Decathlon 2010). But, the fragility of these elements when they are transported on the working sites still remains not solved without an excessive stabilisation with cement. We must also point out the aesthetic interest taken by project designers who are valorizing the texture, the «grain» and the colours of the material (layers of colours or textures with different sizes of the grains). In this purpose, Martin Rauch, in Austria, was also a guide.

In this synthesis we would like, even briefly, to evoke the crucial question of the rehabilitation of the pisé heritage and the practices of restoration which are today facing the requirement for an energetic balance which is imposed by the "factor 4"of the new labels and standards, corresponding to a decrease by four of the energy consumption, or a global balance being equivalent to 50 Kw/h/m^2/an, and even less. This requires the development of new solutions for the thermal insulation of the pisé walls that are directly impacting the valorization of the material, the aesthetics of the built frame, the visibility of the material, of its texture and its colouring, particularly for the option of the outer insulation. The twin option between the inner or the outer insulation has not been settled yet because the thermal studies are still divided. Today, research for solutions seems to favour the use of compatible material with the pisé as panels made of reeds plastered with earth, hempen bricks, integration of heating and cooling systems in the thickness of linings in such compatible natural materials.

2.4 *New explorations of the science: Towards the poured earthen concretes*

Recent fundamental researches on the earth material that have been undertaken by CRAterre in partnership with ESPCI ParisTech (PPMD SIMM Lab) INSA of Lyon (MATEIS Lab) are showing that earth is naturally a material with change of phases. This quality notoriously explains the feeling of seasonal comfort of the pisé houses that the popular sayings describes as being warm in winter and cool in summer (phenomenon of condensation and evaporation of the hold water). Otherwise, research is also showing that this hold water plays an essential mechanical part acting as a «paste» of the clays, insuring the cohesion of the material. So, the researchers are engaging themselves in two directions. On one hand for a better working of the walls for energy storage and lag time restitution, and on the other hand for a better mastering of the piling up of the grains (from the apolonian to the spaced piling up), and of the rheological properties of the earth in order to develop the poured earth concrete. So, the research is focusing on the possibility of improving the fluidity and the solidifying of the clayey muds by acting on the acid or basic aqueous middle, on the salinity, or even on the presence of organic molecules in order to act on the viscosity. The mastering of these aspects must also integrate the control of the linear shrinkage and the velocity of the drying, particularly in the thickness of the material. Recent experimentations are very encouraging and suggest we can develop these new «green» concretes. Other paths of research consider the natural property of hardening under the air (induration by oxygenation) for certain types of soils belonging to the family of laterites. This means a mastering of the oxydo-reduction phenomenon that contributes to the precipitation, concentration and crystallisation of new constituents, the sesquioxydes. Finally, a completely different research direction explores the possibility of an organic consolidation, from the use of vegetable or animal molecules, principles that have been already developed in numerous traditional building cultures but not so far scientifically explored. This is the adding of straw rich in cellulose, vegetable oils, or the soaking of seeds, cloves or husks, the adding of animal blood, dejections or urine, the adding of casein, all kind of products and processes that are releasing biopolymers as it is confirmed by the physico-chemistry.

3 CONCLUSION

Therefore, it seems that we have more visible facts, in the practices of the project in pisé as well as in the evolution of the research that could give credence to the emergence of a new pisé construction and architectural culture. Could the ramming and the pouring of earth cohabit together? This new culture of the "earthen concrete" (pisé and poured earth) would not be only emerging from some kinds of social and cultural resistances, nostalgic or even folklorist, but could possibly be the fruit of a true creativity in front of new society challenges that are imposed by the paradigm of sustainable development. Henceforth we could wish that this «renaissance» would not be only brought by too exclusively technician and economic arguments, or framed by the «norm» (the energetic performance in particular), and that it could be able to instruct further more an other relation to mankind, and contribute to the reconciliation between Man and Nature, as it has been proposed by Michel Serres with his "Contract with Nature" (2003). Other conditions remain indispensable: the value of the work must be better recognized and, at last, supplant the market value of money. Another policy would have to more concretely valorize the ecological imperative and return more «value» to the "natural" materials in the construction area. One shouldhave understood the part of the social and cultural innovation that constitutes the recovery of the human relation to the work, the direct earnings from the valorization of the local resources of the territories (knowledge and know-how), the return to the self-production and the self-construction for new forms of habitat (cooperative, participative or grouped). But, also, the results of the doing «better with less» that the ideologists of the political ecology have strongly wished to come (Gorz 2008). If this could happen, it could be favourable to a revival of interest for the pisé, and even more widely for the earthen construction and architecture.

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Which course of action for earthen architectural heritage preservation?

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ABSTRACT: This paper addresses courses of action to consider for best practices in earthen architectural heritage preservation. The research methodology of this investigation is based in a case study strategy using qualitative methods. Following a multi-method approach, a combination of sources was used for data collection concerning conservation of earthen architecture, crossed with data emerging from three World Heritage earthen sites, selected as case studies. As a result, four approaches were established to address courses of action in order to preserve and conserve earthen architectural heritage: 1) Education, awareness and research; 2) Anthropological conservation; 3) Scientific conservation; and 4) Preventive conservation. This paper will contribute for an overview of findings to consider in earthen heritage preservation.

1 INTRODUCTION

There is very little literature or research that deals with the earthen heritage conservation process and even less, with the theoretical approach to conservation. The literature is restricted concerning the assessment of conservation framework. The few existing assessments covering earthen built heritage conservation and preservation are generally addressed in the International conference proceedings (Terra 2000), in their Post-proceedings or Recommendations (Terra 93) (Terra 2000) or in the few literature reviews covering the field (Guillaud and Avrami, 2003) (Avrami *et al.*, 2008). Besides, in comparison with other materials, the literature concerning the preservation of earthen built heritage is still insufficient. This entails a need for a consistent evaluation and review of the literature in the preservation and conservation of earthen built heritage, but especially the response to a prominent gap in conservation intervention dealing with failure, lack of procedural approach assessment and conservation planning for courses of action.

2 RESEARCH METHODOLOGY

The research methodology of this investigation is based in a case study strategy using qualitative methods. Following a multi-method approach, a combination of sources was used for data collection: published literature, reports from international organisations, collection of local data, field studies with sites observations, open interviews and survey questionnaires concerning conservation of earthen architecture, crossed with data emerging from three World Heritage earthen sites, selected as case studies. A questionnaire survey was addressed at a selected group of stakeholders and international key-experts in earthen built heritage conservation. The survey approach provided a real overview of the present reality in the field of earthen built heritage conservation. The triangulated approach made it possible to correlate results from case studies with expert's perspectives, encompassing the framework of failure, strategies, courses of action, planning systems, methodology of intervention, conservation practice, criteria for intervention, and conservation theory significance. This paper addresses specifically the courses of action to consider for earthen heritage preservation.

3 COURSES OF ACTION

Through the analysed surveys and case studies, four approaches emerged as best practices for the preservation of earthen heritage:

- 'Education, awareness and research', which also integrates publications and dissemination, inventories and terminologies;
- 'Anthropological conservation' covering anthropological approach, craftsmanship, cultural and social aspects, empirical approach, know-how and intangible knowledge and tradition;
- 'Scientific conservation' including consolidants, diagnosis, intervention, physical condition and treatments;
- 'Preventive conservation' which deals with maintenance, monitoring and follow-up, continuous management and preventive approach.

The last approach regarding preventive conservation was considered by 40% of the international key-experts, but also some of the site questionnaires experts to be a major need. All four approaches enjoyed a growing interest by different organisations through the years.

4 EDUCATION, RESEARCH AND AWARENESS

In this category, five themes were identified as fundamental to be addressed:

4.1 *Awareness*

50% of the international key-experts questioned supported the need to raise more public awareness towards the significance of earthen architecture, in terms of sustainability, ecology, heritage, etc. 60% of the international key-experts questioned confirmed that there has been an increase of interest and awareness regarding earthen built heritage preservation, especially from international institutions. However, more awareness has to be promoted in society, communities, stakeholders, international and national institutions, and governments, by explaining the benefit of the earthen building technology, but also the values associated with earthen architecture. 30% of the international key-experts that were questioned even argued for the need of more active publicity, branding and dissemination directed at stressing the importance of earthen architecture.

4.2 *Education*

In the last two decades there has been a slow increase of efforts directed at the need for education in earthen architecture. 45% of the international key-experts that were questioned underlined the importance of addressing earthen architecture in specific education programmes. But 25% emphasised the need for more post-graduate courses devoted to conservation of earthen structures at international and national levels. An interesting 50% of the international questioned key-experts called attention to the need to include more training courses in earthen architecture conservation direct at masons, as well as qualified professionals, such as architects and engineers. According to 60% of the international questioned key-experts, communities should be more involved in capacity building for preventive maintenance. Furthermore, 25% of the international questioned key-experts supported an increase of awareness of the benefits of earthen architecture at all levels of education, even among children. This is interesting to note when analysing conference proceedings that there is a growing interest in courses, workshops and exhibitions related to earthen architecture that are directed at children. The importance of education could be noticed, even in sites, where training courses concerning earthen built heritage conservation were developed for different sectors of the public. Earthen sites can become resourceful opportunities for educational programmes. There is a need to further develop the educational strategy on this field.

4.3 *Inventories and terminology*

In spite of modest attention given to this issue, it is important to further develop a clearer understanding in the development of inventories and terminologies, including definitions and taxonomies. In terms of interpretation, this will avoid misconceived concepts and mixed interpretations. Additionally, 15% of the international questioned key-experts agreed with the need to create and contribute to national inventories concerning earthen architecture, but also to promote earthen sites through an inventory of existing information. Furthermore, the creation of data bases with open access through the Internet and available in different languages would allow universal access to knowledge in this subject.

4.4 *Publications and dissemination*

In the last decade there has been an increase of research and intellectual production as can be seen by the multiplicity of conferences, seminars and exhibitions, as well as conference proceedings and books dedicated to earthen architecture. However, it is generally noticed that publications and conference papers concentrate in building methods and case studies. The reality is that there are too few publications focused in earthen architecture conservation. More assessment and impartial evaluation of conservation approaches has to be undertaken and published in order to disseminate best practices approaches. During the visits to the case studies, it was noticed that conservation coordinators and professionals working on site had a lack of access to information concerning earthen architecture publications. Besides, the Internet did not always provide the best conservation intervention data about earthen built heritage. Therefore, beside publications, the need for an effective dissemination of information addressing accurate conservation practices was discerned. This was supported by 25% of the international questioned key-experts.

4.5 *Research*

Presently, the framework addressed in the conservation process entails anthropological and physical approaches, but also a combination of both. Research in anthropological conservation is starting to evolve and will certainly produce useful findings in the next years. There is a general need to address research to develop local knowledge understanding concerning mixtures of plasters and of materials. It is also relevant to devise research projects to identify and understand the know-how related to measures and procedural methods of earthen construction, local seismic measures, vernacular architecture, local building culture and its adaptation to context, climate, etc. in order to try to understand why buildings were built in a certain way, and how masons or inhabitants built in reaction to factors such as earthquakes, intense weather conditions, etc. Therefore, a research data base should be created relating to social and cultural key issues that includes aspects such as intangible (local) knowledge (to collect and conserve this immaterial knowledge); knowledge transfer (how are skills and knowledge passed between generations); social participation (individual or family actions, community actions, etc.); and other components. There is still a vast amount of research to address regarding anthropological conservation. In what concerns the physical and scientific conservation, there is a tendency to concentrate research on soil mechanics and engineering performance. However, it was recognised by 25% of the international questioned key-experts that there is a need for further research related to study and testing of materials, including laboratory analysis, performance tests, field tests, etc. There is also a need for tests to analyse and optimise the resistance against abrasion because of erosion; and against running water because of rain erosion; but also to integrate tests of soaking, fermentation and addition of stabilized additives, to try to reduce shrinkage; to try to understand how the water affects earth structures and the way of dealing with it concerning moisture from the ground and in the air, mechanical action of rainfall, the cycles of freeze/thaw, etc. It is relevant to note that both approaches, anthropological and scientific can also be combined in research. There are investigations that can be made that are based on a common foundation, such as: to analyse in the laboratory chemical admixtures used in the past; to address the performance of key-elements used during centuries in local seismic conditions (counter-arches, horizontal reinforcements, linear connections at angles, etc.); or for instance, to address scientific research concerning historic repair techniques in earthen vernacular contexts. It is essential that the research carried out throughout the world has a clear impact on intervention and on the advance of knowledge. This is possible through strategic research, but also depends of continuing research, as confirmed by 20% of the international questioned key-experts. In this investigation field, cyclic research developed from repetitive investigations of projects that is without impact on earthen architecture or the advancement of earthen knowledge, should be avoided. Unfortunately, results often do not have further applications following the research project's conclusion. Responding to the questionnaire, Isabel Kanan even bemoaned that research results are, most of the time, due to individual efforts or personal academic research and not institutional or governmental efforts. John Hurd also stressed in the questionnaire response that earthen architecture research should be more rigorous.

5 ANTHROPOLOGICAL CONSERVATION

Throughout the last years, there has been an increasing interest in an anthropological approach to earthen architecture, which might be due to the actions of Africa 2009 programme, but also due to a growing international interest in vernacular architecture. This tendency was perceived in some of the papers of Terra 2003 Proceedings, but become more noticeable in Terra 2008 papers, presented in Mali. Anthropological conservation has had a more academic approach emphasising the need to give relevance to local populations and their know-how, through traditional building, craftsmanship, and empirical knowledge. Additionally, the anthropological approach gives significance to the value driven process.

5.1 *Craftsmanship*

25% of the international questioned key-experts confirmed the need to address the rehabilitation of traditional craftsmanship. In fact, for some decades, the denigration of traditional works occasioned by industrialisation promoted a lack of general consideration for craftsmanship. In the last years there has been a growing recognition of the importance of good craftsmanship in architecture and conservation practice. Enrico Fodde in the questionnaire response even emphasised the need for a balanced approach between empirical experience, laboratory work and traditional craftsmanship, as well as the need to address a proper use of traditional materials in repair. Good craftsmanship has an important contribution to make in conservation intervention, but craftsmen should be given back their relevant role in conservation practice.

5.2 *Cultural and social aspects*

It is interesting to note that just 10% of the international questioned key-experts emphasised the relevance of cultural and social environments when approaching conservation intervention.

In vernacular architecture, these aspects have a profound impact on local building cultures, which have very rich building typologies. Cultural and social aspects are also at the core of local sustainability and local integrity. Community involvement associated with neighbourhood engagement helps integrate people in society, supports traditional ways of life keeps social cohesion and gives sustained local values and a sense of belonging to the local population.

5.3 *Empirical approach*

During the last years, there has been more recognition for the importance of empirical knowledge. Through thousands of years, building and maintenance were based in empirical experience and knowledge transfer. With increasing attention addressed to scientific methods, knowledge transferred from generation to generation lost its relevance, if it was not explained by science. The increasing interest in an anthropological and social approach brought more understanding for the erudition emerging from empirical knowledge. However, more research has to be carried out in this subject within communities that actively maintain their inhabited structures and sites, as in the case of Mali. Conservation coordinators, experts and professionals should try to aim research towards the analyses of their empirical experience and of the community's empirical knowledge. Investigation should then inform conservation intervention and give more consistency in the empirical approach to intervention.

5.4 *Know-how and intangible knowledge*

40% of the international questioned key-experts supported the view that there is an increase need for specialised know-how in earthen architecture. 30% of the international questioned experts also mentioned that oral history and know-how should be valued and revived. An example can emerge from knowledge transfer among generations, which can encourage traditional values and respect for the building know-how of the elderly generations. Furthermore, 30% of the international questioned key-experts believed that priority should be given to local building knowledge. If there was more research and training concerning this matter, conservation intervention would probably have less universal solutions when addressing earthen architecture. It is also relevant to note that professionals are giving increased importance to intangible knowledge. 25% of the international questioned key-experts stated that it is equally important to conserve the material heritage and the intangible knowledge. The fact is that on the last years, the importance of intangible knowledge has become a relevant type of evidence when assessing heritage. Jeanne Marie Teutonico also confirmed it, in the international key-expert questionnaire response, stating that in recent years, 'the field has shifted strongly toward anthropological and social issues and away from scientific research'.

5.5 *Tradition*

Recently, there has been more significance given to local know-how and intangible knowledge, which has had an impact on the relevance of traditional values. 20% of the international questioned key-experts agreed that for conservation authenticity it is fundamental to make all possible efforts to keep the uniqueness of tradition. 25% also agreed that there should be more awareness for local population's traditional knowledge. This means that, as much importance should be given to the conservation technique as to the value of the traditional methods and materials from the ancient structure or site. Unfortunately, this does not always happen, as there is a tendency for the application of universal conservation solutions, even if it is in an earthen technique. Local traditional know-how is an important resource that can be applied in conservation intervention. Mostly, it is not even acknowledged and more importance is given to international expertise, which is sometimes not aware of the local building cultural traditions. 10% of the international questioned key-experts confirmed this evidence. Experts from the open interviews supported the same evidence.

6 SCIENTIFIC CONSERVATION

Scientific Conservation has been directed to the approach based on cause-effect phenomena and has developed little in the appreciation of the significance of process. In spite of being more costly than anthropological conservation, scientific conservation acquired major importance through the years, especially by saving from irremediable loss properties that were in a serious threat.

6.1 *Consolidants*

It is now commonly accepted that there are chemical products that are compatible and are less costly than some years ago. Pamela Jerome responding to the questionnaire argued that Peru has had a 35-year track record using chemicals, such us ethyl silicate, consolidating ancient polychrome earth murals in relief. Therefore, the use of chemical products can be justified in societies with a recognized field experience in the field.

There are also different opinions regarding the use of consolidants. Morales Gamarra argued that only consolidants that did not alter the earthen fabric should be used, even if irreversibility had to be considered (1983: 112–114). However, Pamela Jerome in the questionnaire response stated that if the right chemical consolidants were used and the porosity of the original material was maintained, then the alteration to its composition would be an acceptable compromise. Also to consider, the fact that according to the questionnaires analysis and the case studies, to some experts, ethyl silicate as a consolidant and lime as stabiliser are often used solutions for conservation problems. More assessment of carried out interventions, advantages and disadvantages of conservation methods, materials, treatments and consolidants should be undertaken and disseminated.

6.2 *Diagnosis*

During the assessment of physical condition, there is a tendency to evaluate pathologies and devise a course of action almost immediately, without a previous careful diagnosis directed at structures and sites under intervention. This was also confirmed by 15% of the international questioned key-experts that underlined the lack of full analysis and diagnosis. For instance, following major hazards, it is important to have different teams dealing with recording and surveying of the earthen sites, assessment of condition including diagnosis, and conservation practice. For more conservation process consistency, these components have to be more interconnected.

6.3 *Physical approach*

Physical approach is addressed through scientific methods of conservation, concerning the analysis of modified earthen materials encompassing stabilisers, additives, adhesives; organic and inorganic consolidants; structures stabilisation that can include surface coating, and intrusive or non-intrusive techniques, amongst others. Moreover, as physical and scientific approaches rely on exact sciences, there is a tendency to use laboratory and engineering solutions to repair and retrofit. Difficulties emerge when combining physical and anthropological approaches.

6.4 *Physical condition*

To address the physical condition of a structure or site was considered essential by 40% of the international questioned experts, with 30% being directly concerned with the assessment of pathologies. This is an important issue particularly relevant at in danger sites. Besides, the identification of the causes for failure leads to diagnosis, followed by an adequate solution for the pathology. According to 15% of the international questioned key-experts, the response should be appropriate to local conditions. Following major earthquakes, physical assessment has to be carried out intensively and in short period of time, due to the beginning of the recovery.

6.5 *Treatments*

Conservation treatments in earthen built heritage have been much analysed during the last years (Terra 2000) (Terra 2003) (Terra 2008). However, there should be more accuracy in the selection of treatments to implement. It is frequent that treatments are used as they had good results in other sites, in very different conditions and contexts, and without a real assessment of the impact of the treatment on the earthen fabric. Besides, it is also relevant when developing a conservation plan to include a phased treatment approach. On the questionnaire response, Anthony Crosby also stressed that attention should be drawn to adequate conservation treatments, as 'their role is to protect the values of the structure or site'.

7 PREVENTIVE CONSERVATION

Preventive conservation relates to introducing, preventative measures at the present time to avoid future damage of the structure or site.

7.1 *Maintenance*

Continued maintenance was considered important by 40% of the experts questioned. However, maintenance has to be properly understood to avoid unexpected failure. When well kept, maintenance becomes one of the best evidences for long-term successful conservation. This is why 45% of the international key-experts that were questioned mentioned the need to consider maintenance capabilities when addressing the conservation process, which justifies the approach of capacity building in this respect. Furthermore, 35% of the international questioned key-experts considered crucial to address continuous maintenance. This also explains why preventive conservation and maintenance plans should be integrated as a component of a successful methodology of intervention.

There is a strong focus to deal only with daily maintenance for site protection. Most of the times, there is no preparation of maintenance plans or preventive conservation considered. Sometimes short-term actions are even not considered. It is essential to have a straightforward approach dealing with medium and long-term site preventive maintenance. Then, a site management with a proactive approach would address a preventive conservation plan.

7.2 *Monitoring and follow-up*

In earthen structures or sites, monitoring is of vital importance, so that conservation intervention arrives on time to reduce, and if possible, to stop the causes of decay. A general need for structures and sites to be constantly monitored and followed up were supported by 30% of the international questioned key-experts. Even after maintenance is addressed, monitoring should be carried out in a systematic way by experts, conservation team members or by the local community. As mentioned by Sébastien Moriset responding to the international key-expert questionnaire, 'the population should be trained to monitor and report changes to whoever is responsible for the site conservation'. Additionally, it is relevant in world heritage earthen sites to assure that there is a national and international expert's monitoring and follow-up, which will contribute on one side, to a more effective assessment from different view points, and on the other side, following-up will entail continuation of the conservation process.

7.3 *Continuous management*

The decision-making process is part of the daily management of conservation practice. It is crucial to involve the local community also in management decisions. However, decision-making regarding conservation intervention and its connection with the site's statement of significance should be tackled, through the management planning process and specifically during the management meetings. This does not always happen, as sometimes the assessment of value does not relate directly with conservation intervention. It is important that decision-makers continue with a holistic approach, and a more proactive attitude rather than reactive.

Integrated in management is also the implementation component, important for the achievement of good management. Full implementation of conservation projects and management systems is essential for the achievement of the overall process.

There is the need for long term objectives related with the preparation and implementation of planning systems. This follows most of the times, the imposition that all the World Heritage Sites develop a planning system. The problem arises from the fact that after the plan is concluded, often it is not implemented, or at least not entirely.

7.4 *Preventive approach*

25% of the questioned international key-experts supported a preventive approach to conservation. This encompasses the integration of a maintenance plan, and a disaster preparedness plan, but also addresses preventive measures and precautionary principles during management and conservation practice. Preventive measures can include reburying, in case of archaeological remains; use of shelter; application of protective coatings; the use of sacrificial layer of gravel; erosion control as happened at the three analysed sites; and other preventive methods.

Additionally, it is interesting to note that the engagement of the population in preventive maintenance was supported by 55% of the international key-experts that were questioned.

8 CONCLUSIONS

Some heritage entities relate to the anthropological approach, contributing with a community participatory process. In this case, experts base the conservation approach on experience and empirical knowledge of local communities. Other approaches relate to scientific conservation, and have a more technical and engineering background leaning towards laboratory and physical condition assessment and intervention. Frequently, the anthropological and scientific approaches are not directly connected. The difficulty arises when trying to combine these two approaches. Due to the complexity, very few entities and experts manage to have a holistic approach combining all the components.

By recognising gaps and needs, establishing priorities, integrating opportunities, defining targets, long-term objectives and short-term aims, it becomes easier to identify courses of action within the strategy. However, it is fundamental to embrace the different scales and components addressed throughout the conservation process holistically and comprehensively. These components encompass a multifaced process, with components interrelated to each other, all composing a sustainable system. To take a limited view can jeopardise the survival of the fragile earthen fabric and earthen architecture in general.

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Earthen architecture: Clay feet or a feat of clay

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ABSTRACT: Earth as a building material has long held a reputation as fragile, weak and vulnerable. Despite this pronouncement, earthen construction has long been employed by every major civilization, and for countless generations in the erection of monumental public buildings and small private structures alike. Its almost universal occurrence, incredible versatility, and adaptability to local conditions and uses support its persistence as the oldest and one of the most widespread building methods in the world. The recent ascendency of sustainability and the green building movement have done much to increase the visibility of earth as a viable construction system yet the material and its technologies remain isolated from everyday contemporary design and building practice. The advantages of earth as a construction material are by now well known to a growing global audience. Low-cost production, technological and contextual versatility, good thermal performance, fire-resistance, and ultimate recyclability are all beneficial qualities. Alternatively its disadvantages of water sensitivity and low strength (unamended), especially in shear and tension, have tended to dominate when such properties are promoted as absolutes. What is often not discussed is the benefit of its repairability. This is a concept foreign to most contemporary design/build strategies unless it includes unitized replacement which favors the economic benefits of material replacement over labor. Despite the many ways earthen materials can be traditionally weatherproofed or the material itself re-engineered, the material will always require an attitude and regime of inspection and maintenance that is rarely promoted or valued in contemporary industrialized society. Earthen architecture, as a material and system, is one of the most creative forms of building with readily available resources. n the heritage conservation field, few material technologies have had the ability and influence to reconnect the processes and concerns of building, and conserving.

'Thou, O king, sawest, and, behold, a great image. This image's head was of fine gold, his breast and arms of silver, his belly and his thighs of brass. His legs of iron, his feet part of iron and part of clay. Thou sawest till that a stone was cut without hands, which smote the image upon his feet that were of iron and clay, and brake them to pieces.' (The Book of Daniel 2:31–40).

Thus the prophet Daniel described and interpreted this troubling dream of King Nebuchadnezzar as a premonition of the weakening and eventual destruction of his kingdom to dust and its replacement by the kingdom of God. Compared to the noble metals gold and silver, and even brass and iron, unfired clay has long held a reputation among construction materials as fragile, weak and vulnerable even when compared to ordinary fired brick or stone. Despite this pejorative pronouncement, earthen construction has long been employed by every major civilization, and for countless generations in the erection of monumental public buildings and small private structures alike. Soil's universal occurrence, incredible versatility, and adaptability to local climate support its persistence as the oldest and one of the most widespread building methods in the world. This is clearly borne out by the now oft quoted factoid, "One half of the world's population, approximately three billion people on six continents, lives or works in buildings constructed of earth."

Despite such credentials, earthen construction remains a venerable tradition with a suspicious past. Like the very metaphor Nebuchadnezzar's dream inspired, earthen buildings are much admired but ultimately seen as fatally flawed in their inability to comply with contemporary definitions of durability, immutability, and high performance, much like the heroes of long ago. Ten international conferences on earthen heritage over the past forty years and the recent ascendency of Sustainability and the green building movement have done much to increase the visibility of earth as a viable construction system yet the material and its technologies remain isolated from everyday contemporary design and building practice. This is especially egregious given the long and largely forgotten history of the rediscovery of earthen architectural traditions in Europe at the end of the eighteenth century and the dawn of the modern movement. Francois Cointeraux in France and

Juan de Villanueva in Spain devoted much of their professional activity toward the promotion of earth as a modern construction system. Cointeraux in particular advocated for the use of pisé de terre (tapia, rammed earth) through his public and private projects, publications, and the founding of a rural school of architecture in Paris.

Interest in the possibilities of earth as a total construction system during the early twentieth century is no less evident despite the period's promotion of pre-fabricated materials and industrial processes and the biases of modernist historiography for the innovative and the avant garde. The possibilities of earth as a timeless and neutral material, capable of diverse applications and the ability to take on a myriad of forms depending on its production, found expression in the experimental works of many modern masters: Gaudi, Loos, Schindler, Wright, Costa, and even Le Corbusier, all of whom considered its versatility and low cost, a model material for achieving a modernist agenda. Even more relevant to the interests of this conference than the avant garde's experiments with earth as an old material in new guises, is the influence and direct contributions of the ancient technology of rammed earth to early concrete. Here both an empirical knowledge of rammed earth's optimal performance through the study of soil granulometry, as well as perfection in the design of wooden formwork moved the development of beton forward at a rapid pace during the last quarter of the nineteenth century. Few seemingly disparate construction systems (i.e., earth and concrete) display such a connected historical and material genealogy as rammed earth and concrete; yet comparison reveals each material's unfortunate inherited associations, with the primitive, obsolete, and inferior on one hand, and the modern, current, and superior on the other.

The advantages of earth as a construction material are by now well known to a growing global audience. Low-cost production, technological and contextual versatility, good thermal performance, fire-resistance, and ultimate recyclability are all beneficial headliners on most advocates' lists. Alternatively its disadvantages of water sensitivity and low strength (unamended), especially in shear and tension, have tended to dominate when such properties are promoted as absolutes. What is often not discussed (at least in a positive sense) is the benefit of repairability.

Repair is an old response to that which is worn, damaged, or broken yet the global nature of today's challenges is unprecedented whether considering the physical, social, or cultural environment. Conservation of natural and cultural resources, in today's parlance, "heritage" has always been about repair whether it is ecological restoration, building rehabilitation, or urban revitalization. While conservation of the natural environment has had a longer track record and greater visibility in terms of its scientific study and advocacy, the preservation of the historic and traditional built environment has had a less effective influence on how we should think about current concerns such as sustainability, human equality, and social and cultural stability. In this regard, interest in earthen heritage and its continued relevance as a contemporary building method has much to offer.

Anyone who deals with buildings at close range is fully aware that architecture is not static but like the world it reflects, is changing at an accelerated pace. Repair cycles that might span 50 or more years in construction systems designed to resist visible weathering such as traditional masonry or brick, and newer construction technologies are compressed in earthen buildings due to their low weatherability. Historical and regional methods of addressing weatherability vary but all earthen construction systems recognize and accommodate the need for cyclical repair. This is a concept foreign to most contemporary design/build strategies unless it includes unitized replacement which favors the economic benefits of material replacement over labor. Despite the many ways earthen materials can be traditionally weatherproofed or the material itself re-engineered through amendments, hydraulic compression, and reinforcement, the material will always require an attitude and regime of inspection and maintenance that is rarely promoted or valued in contemporary industrialized society.

If there ever was a moment to advocate the conservation of built earthen heritage and the continued exploration and adoption of earth as a contemporary building system, it is now. For the general public and most building professionals, earthen architecture and its preservation are about the past. They are considered irrelevant because the assumption is that any true progress must be based on that which is new. And that which is novel is the essence of creativity. That which is existing or old is far from the new and therefore not part of real progress or progressive solutions. Of course this is untrue; both conservation and the promotion of earth as a viable building system are both creative and progressive. In today's climate such interests are in fact subversive in their concern with the old or existing and in mending the flawed rather than in discarding and starting anew. As Elizabeth Spelman has aptly observed, the capacity of professionals to repair things can scarcely be valued in any society whose economy is based on the production of and the desire for the new. Repair is at odds with the imperative of a capitalist society.

Creativity has always been valued as a human accomplishment. To be creative has meant to see or do something not done or thought before. The result is new in its vision and impact. To bring together the past and present by thinking and acting in ways different from the original processes that create new works, and to forge a new approach that is sensitive to all contexts are the goals of conservation. As an act of intervention it seeks to mediate and in that mediation, it is creative. Conservation/preservation is about change because it understands and seeks to reconcile that change responsive to the existing or historic environment.

Not everything that is broken can or even should be repaired. But the concept of conservation begins first with considering the benefits of retaining or recovering all or part of the existing. It considers the functional, aesthetic, and associative values embodied in the existing work and it possesses a remarkable set of knowledge and skills unique to it alone to discover, revive, and reuse. Its concerns and methods of analysis, intervention and especially prevention are part of the definition of sustainability and it has much to offer all professionals and the public in the ascendancy of that concept. But like the definition of creativity itself, sustainability has been cast as a new concept with new ideas and so conservation has had limited recognition or influence in its contributions to the current debate. Clearly this invisibility must change.

Earthen architecture, as a material and system, is one of the most creative forms of building with readily available resources. Floods, earthquakes, industrialization, urbanization, modern building technologies, politics and a lack of education all threaten the viability of earth as a way of building and living.

In the heritage conservation field, few material technologies have had the ability and influence to reconnect the social and environmental processes and concerns of building and conserving. The lessons of maintenance and repair are traditions intrinsic to both and in that recognition, earthen heritage and its contemporary expression enjoy a common ground that is all too absent in an increasingly specialized world.

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Restoration of rammed earth structures

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ABSTRACT: The thesis defended in this paper is that, in general terms, restoration of rammed earth architecture should be made using techniques and materials coherent and compatible with the original ones. This does not disdain or condemn the use of other methods, especially taking into account the complexity of architecture. The exposition below is intended as a discourse, an approach to the restoration of rammed earth works, but only one of several possible approaches. In Spain, from the eighties onwards, the restoration of rammed earth works, usually forming part of ramparts or other large walls in buildings related with defence, involved the evaluation of its construction aspects. It is not fortuitous that the restoration of rammed earth structures is linked with construction in the full meaning of the word and not to mere treatments to the mass or the surface. Although the decisions are always partly subjective, in the restoration of rammed earth architecture I think construction is the principal solution.

1 PRELIMINARY WARNING

We have based our paper on the following premises:

- Restoring means enhancing something, that is, bringing it back to a positive situation that has been lost or undermined, and even improving it. It involves identifying and safeguarding its meaning as a symbol and a historico-cultural document.
- When we speak of the restoration of rammed earth buildings, we refer to constructions made with a given technique and we implicitly accept that this technique lends interest to the work and constitutes one of the features to be valued.

The exposition below is intended as a discourse, an approach to the restoration of rammed earth works, but only one of several possible approaches, since I myself could suggest others. It is scientific in that it is based on observable facts, but the description is based, above all, on my personal experience. My principal idea is to share my reflections and experience.

2 FOREWORD

In Spain, from the eighties onwards, the restoration of rammed earth works, usually forming part of ramparts or other large walls in buildings related with defence, involved the evaluation of its construction aspects. There are two especially meaningful referents in this sense: the restoration of the Ramparts of Niebla, by the architect Ismael Guarner González, and the restoration of the Palace of Toral de los Guzmanes by the architects Eloy Algorri García and Mariano Vázquez Espí.

Despite the provisions of article 39 of the Spanish Historic Heritage Law currently in force, where it says that in the interventions "attempts at reconstruction will be avoided", in the case of rammed earth works, where the mass is a connatural necessity, where one of the principal materials that form it is usually soil, and in any case these materials are only intended for use as part of an amalgam and not individual components, it is difficult to achieve a decorous and didactic conservation without resorting to their technical or material resources. (We understand as components materials which have a precise form that is not changed in the work, and they are capable of assembling and disassembled). I think this is one of the key points in a discussion about the restoration of rammed earth works. Therefore, it is not fortuitous that the restoration of rammed earth structures is linked with construction in the full meaning of the word and not to mere treatments to the mass or the surface. Although the decisions are always partly subjective, in the restoration of rammed earth architecture I think construction is the principal solution.

Consolidation, a word that is severely misused, responds more to wishful thinking than to a real possibility. Architecture is constructed, and when it is in a poor condition, has lost stability or partially collapsed, it is impossible to repair it without using construction; in my opinion materials can be consolidated but not architecture, which can only be consolidated to correct some aspect that only affects the substances that comprise the materials before the damage has gone so far as to cause loss of mass, mechanical instability or the disappearance of elements. Built architecture is rather more than "chemistry", and in this sense it is necessary to repair, reinforce, refashion, replace or rebuild, but even though it is important and sometimes indispensable, it will not be sufficient to consolidate the materials.

After these first works of construction (or reconstruction), we have seen how on other occasions a superficial treatment has been applied for restoration, but, make no mistake about it, surface treatment is an ingredient of architectonic practice and emphasising superficial expressivity is no substitute for construction. In these cases, the difference resides in the depth of the intervention (depending on the original state) or in the importance attached to the textures. As examples of this type of procedure, we can cite the south façade of the Iglesia de la Merced, in Murcia, by the architect Alfredo Vera Boti, and the Cerca de Don Gonzalo in the Nasrid Wall in Granada, by Javier Gallego Roca with the collaboration of José Manuel López Osorio.

If we admit that restoring a rammed earth building or wall requires, in general, not only knowledge of the history of architecture and construction but also practical knowledge of the craft, we shall come to the conclusion that the development of the restoration of rammed earth walls has evolved at the same rhythm as the people (architects, technical architects and masons) have grown more interested in rediscovering, reinterpreting and learning the trade. The question is there has not been enough time to learn and, more often than not, the process starts afresh in each case, unfortunately for the monuments. It would be beneficial and fundamental that the few rammed earth workers who still live in Spain dedicated themselves to this restoration work, and I do not mean refurbishing castles but constructing and teaching their trade.

At the end of 1992 another small intervention was carried out on a tower in Calle de la Merced in the Wall of Murcia that formed part of the party wall of the site and was going to be left inside the building that was about to be built. In this case, not knowing whether rammed earth would be the solution, most of the intervention was made out of modern brick, which covered the remains conserved, which were only left naked if they conserved the original surfaces (either belonging to the first construction or the repairs made on it in medieval times).

It was also in 1992 that a bolt of lightning struck down the south-east corner of the only tower still standing in Siyasa Fortress. The following year the missing corner was reconstructed and a framework was added to tie the four walls together and shelter the interior from rain. The work was performed with a mixed white cement and lime concrete; the characteristic rammed earth formwork technique could not be used because of the location of the intervention.

In 1993 work began on the village of Siyasa, the remains of an Islamic medieval town abandoned in the 13th century. A large part of its structures are rammed earth walls (sometimes with a crust, sometimes with *brencas* (undulated reinforcement), sometimes with masonry repairs or reinforcement, of which only the masonry bases and many incomplete walls remained). In this case, as we have explained on other occasions, an attempt was made, on the one hand, to consolidate with lime wash, that is, to improve the cohesion and adhesion of the materials of the fabrics and, on the other hand, to rebuild walls up to the partially conserved levels using the demolished earth. After these initial works, several others were carried out

Figure 1. Murcia. Iglesia de la Merced.

Figure 2. Murcia. Tower of the Wall, in Calle de la Merced.

Figure 3. Siyasa. Tower struck by lightning.

Figure 4. Wall rebuilt with its own rammed earth as Siyasa.

in the two thousands, using lime concrete on the rammed earth walls as a longer-lasting solution to shelter from the elements.

The first time that formwork was selected outright and wholeheartedly was in the restoration of the Verónicas section of Murcia City Wall in 1995–1996, as part of a global project of the architect Fernando de Retes with the collaboration of the author of this article. The proposal here was to rebuild longitudinally the half of the wall that had been removed when building a convent and to leave the timber putlogs visible for aesthetic purposes. At the end of the day, all the interventions involve an approach to rammed earth architecture and have a great deal to do with personal experience and discoveries.

From that time onwards, the general choice was to reconstruct the rammed earth walls leaving naked putlogs as a recurrent, and often false, image. It must be taken into account that putlogs form part of the rammed earth technique as an auxiliary method for building walls and sometimes scaffolding. The typical presence of putlog holes in historic rammed earth works is the result, above all, of their deterioration, but never an architectonic goal.

Figure 5. Murcia. Verónicas section of the wall.

It is true that restoration as we understand it today has a didactic function and, in this sense, certain licences can be justified, but construction logic should never be undermined. The Verónicas part of the wall had a sculptural and pedagogical value in a cultural project that was the Legado Andalusí, which was a reason to leave the putlogs, but it is a resource that has been too often used since then. I myself have been unable to resist the banal temptation to leave naked putlogs in places where it was not appropriate, suggesting a provisional state that later became definitive.

Another way of acting on a rammed earth structure, which can be defended where Access is impossible, is projection. This was the option chosen for a wall of Monteagudo Castle in 1995. On this occasion, the putlogs made sense since they were used as reinforcement for the lime concrete mass that was applied to the remains of the ramparts.

One year later, in 1996, there was another intervention on the same castle to fill in the gaps with lime concrete rammed earth walls with rubble in a stretch of the wall in danger of collapse. In this case the putlogs were left on view, in the knowledge that they could be removed later, although that has not been the case so far.

In 1998, the main tower of Pliego Castle was restored. The work was performed from an archaeological point of view, that is, the building itself provided plain answers to the constant questions that arose. It was an intervention carried out harmoniously, by a team with which the building itself

Figure 6. Monteagudo. Putlogs reinforcing the lime concrete.

Figure 7. Monteagudo. View of the two interventions.

seemed to collaborate. The employment of the rammed earth technique as a restoration method was even rather forced in some instances, such as the completion of the crust in places where the gaps were relatively shallow.

That same year another small intervention began on the Castillo de la Luz. The situation there was quite different, both due to the damage caused and the issues to be solved. The initial state was characterised by the loss of the base of a tower to a surprising degree and the collapse of the rammed earth walls, many of which had been moved about like toy building blocks. In this case the base was filled in by replacing the crust with rubble, in principle a more coherent solution than adding rubble in horizontal execution. As regards the gaps formed by the movement of the rammed earth pieces, they were simply filled in to provide the ensemble with continuity but without concealing the singularity of the rammed earth pieces almost transformed into ashlars.

The earthquake that took place in 1999 also made it necessary to perform several restoration works. In the castle of Puebla de Mula, part of the structure of the door collapsed. This was a case where rammed earth pieces together with other fabrics were the solution to rebuild it in an

Figure 8. Pliego. Main tower.

Figure 9. Specifications. Replacement of the crust.

attempt to understand the original. The rammed earth technique and brick were combined to solve the problem of the dwelling and corridor spaces of the propped entrance. The rammed earth method in the restoration achieved more and more construction purity not without details and liberties that emphasised certain meanings.

In the decade of the two thousands some interventions began with the intention of reconstructing buildings so that they could be used or visited by tourists. Examples of this are Lorca Castle, Lorca Wall, Puerto Lumbreras Castle, Blanca Castle, Calasparra Castle and Alhama Castle. In cases that seek the exact opposite result, such as Molina de Segura, the remains are left and a building is erected on top to interpret the ramparts.

In the case of Alhama Castle in Murcia, one of the large fortresses conserved in the valley of the River Guadalentín, work has been going on for the last ten years in an attempt by the Council to turn it into an enclosure open to the public, so that they will be able to understand the fortress, the mountain it stands on and the territory around it. The instability of some elements, the alterability of the remains conserved, the need to create itineraries and enclose a controlled space all led to the replacement of large masses of rammed earth pieces to restore an authentic idea or ideal image of the castle, always following an archaeological

Figure 10. Murcia. La Luz. Rammed earth pieces placed on top of one another.

Figure 11. Castle' door of Puebla de Mula. Door, from inside.

method. In these cases, located right in an urban centre, we need to be aware of possible controversy related to the change of images that were consolidated in the collective memory of the town in relatively short periods of time.

3 RAMMED EARTH WALLS: CONSTRUCTION OR RESTORATION

As I pointed out above, I am inclined to consider the restoration of rammed earth architecture from a cultural point of view, as the retrieval of a skill; from a technical point of view, as a construction problem and from an architectonic point of view, as a compositional, semantic and philological problem.

Speaking of construction, it is important to admit that it is not the same thing to build a rammed earth wall as to restore it. Constructing is a more natural thing; the builder has to use his knowledge and skill, the best materials, the best tools and accessories. Restoration, on the other hand, requires other variables, some of which are more difficult to handle, such as the meanings, the safeguard and conveyance of certain information …, but we must

Figure 12. Alhama Castle (Murcia). North rampart (J. Baños).

never forget, not only for functional reasons but in honour of the authenticity of what we are making, that restored architecture must *be* architecture or, perhaps, *go back to* being architecture.

Building rammed earth walls is a thing our grandparents knew how to do and that we have to remember. Repairing rammed earth structures was an act performed with common sense and the materials available. However, restoring a rammed earth wall is something that, as regards meanings and intentions, often fails to have the strength and the logic of something natural. Even from a technical point of view, new solutions need to be found.

For example, the solution involved in building a rammed earth structure by placing putlogs, doors, vertical ribs, reinforced planks, struts, quoins and ropes or similar items is something that has been learned and perfected by centuries of experimentation; but the addition of a missing crust, the thickening of a rammed earth wall by means of formwork without any means to attach it, the desire to show missing putlogs, the execution of a rammed earth wall without any possible settlement, with all the variations we like, require solutions that, although they are inspired in rammed earth architecture, are entirely different. Examples of circumstances that involve thorough reflection about traditional building methods. On some occasions, the whole rammed earth wall cannot be replaced as high as the original because there would be no room to pour and compact the material inside. On others, they cannot be made as long as the original because new obstacles have appeared that were not there at the time of the original construction. The rammed earth pieces can very often not be pressed against the existing wall because of the deformations it has undergone. In many cases, putlogs cannot be installed directly but need to be anchored. It may not be possible to ram the earth vertically but it will have to be done horizontally. To solve some of the problems mentioned, I resort to sections that are assembled plank by plank, and not with the whole piece of formwork.

The formwork ribs are the elements that join the different planks together, a task the *barzón* (nailed post) used to perform before. Both the planks and the ribs are perforated at regular intervals so that they can be fixed at many variable points. I use flexible, extensible putlogs that can be anchored to a sufficiently hard and resistant base. The formwork must make provision for the holes through which the putlogs are to be introduced so as to adapt to a great variety of situations without forsaking construction technique or logic.

4 BY WAY OF CONCLUSION

Rammed earth architecture in general forms part of the values to be protected and transmitted in restoration works. The restoration of rammed earth architecture must not relinquish its fundamental building techniques, which are: applying formwork and compacting. The traditional technique provides enough details and resources for us to adapt to the different situations that can arise during restoration. In order to apply the rammed earth method in an acceptable manner, a certain amount of practice is necessary. Learning to apply it as one goes along is an inefficient procedure. We must not forget that the object to be restored is not usually just a rammed earth wall, but a complex building where the rammed earth part is only one of the elements. When we speak about the restoration of rammed earth buildings, we implicitly assume the value of this type of construction, where the technique has made such a great impact that nowadays at least we consider the architecture and the construction inseparable. Although each case is different and we cannot establish general rules, I would say that, in general terms, a rammed earth work should be restored by using methods and materials that are in keeping with the original in order to achieve the continuity, impact, seriousness, expression, opacity, shapes, colours, textures and functionality that are its due. Current examples like the intervention made by the architects Jesús Basterra Pinilla on the Alcazaba in Almería, and Antonio Jiménez Torrecillas on the Nasrid Wall of the Albaicín Alto in Granada are interesting counterpoints to this affirmation.

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The Nasrid ramparts of the Albaicín (Granada, Spain): An analysis of materials and building techniques

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ABSTRACT: This paper presents a material and constructive study of the Albaicin ramparts in Granada (Spain), a XIVth Century wall also known as Cerca de Don Gonzalo built to protect the Northern suburbs of the medieval city. Over one kilometer of its original extension still exists today. It is one of the outstanding examples of rammed-earth urban ramparts of al-Andalus. A hypothesis of its building process is presented in the context of an ongoing research project under the leadership of Camilla Mileto, Ph.D., entitled: *Rammed-earth architecture restoration in the Iberian Peninsula: Criteria, techniques, results and perspectives* (Proyecto de Investigación y Desarrollo [I+D] BIA 2010-18921).

1 INTRODUCTION

Rammed-earth construction is a traditional building technique with a very long history that, in our context of interest, has an important development in the Almohad period and reaches its height in the Nasrid period, the moment the Albaicín ramparts are built, with the introduction of significant improvements in the technique.

Rammed-earth technique in the Iberian Peninsula has been the subject of many researches (Font & Hidalgo 1990, Cuchí 1996, López 1997.) Specific works on Islamic andalusi rammed-earth building techniques are less frequent, however, at least from the constructive and architectural point of view adopted here (López 2007, Gurriarán & Saéz 2002, Rodríguez 2008, Márquez & Gurriarán 2008, Graciani 2008, Graciani & Tabales 2008).

The Nasrid ramparts of Granada have been the subject of research from different venues, mostly by local researchers (Malpica 1992, Gallego 1992, Gallego & López 1993, Bosi 2000, Orihuela 2001, 2002, Martín 1985–87, 2005, Ontiveros et al., 2008, Fernández, in press). The results of this previous research have been taken into consideration in the descriptions forwarded below and in the discussion of results.

2 THE RAMPARTS OF THE CITY OF GRANADA: THE HISTORICAL AND URBAN CONTEXT

The total length of the ramparts of Granada at the end of the XVth Century, the final moment of the Nasrid dinasty, is estimated at over eight Km. Of them roughly two kilometers are still standing, although with an unequal fortune: lowland areas of the city barely contain any remains, whereas the Albaicín houses the overwhelming majority of them. The unequal preservation of the walled perimeter partly explains the uncertainties over its original location and extension.

Figure 1 shows a hypothesis of the evolution of the medieval ramparts of Granada according to the consensus of scholars (Seco de Lucena 1975,

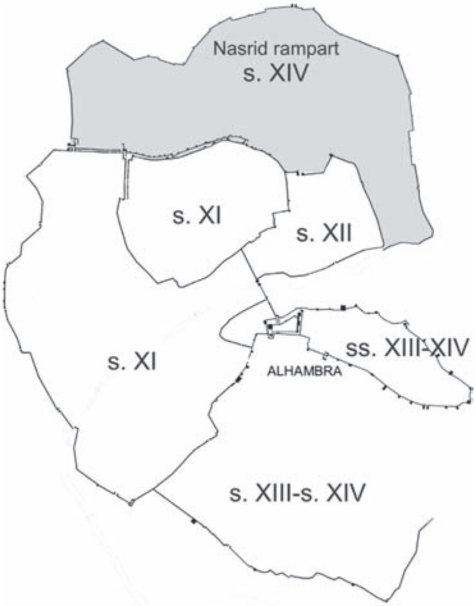

Figure 1. A hypothesis of the evolution of the medieval ramparts of Granada. (Source: author.)

García 1996, Orihuela 2001, 2002). The walled nucleus of the Islamic city on the Albaicin hill dates to the Zirid period; by the end of the XIth Century and the beginning of the XIIth it extends to the lower parts of the city and reaches the opposite banks of the river Darro. In the XIIth Century ramparts were expanded and in the Nasrid period, from the first half of the XIIIth Century, two big extensions gave its final shape to the ramparts of the city.

One of them was the walls of Rabad Nayd (Quarter of the Slope), later called the Realejo quarter, built at the turn of the XIV Century. The other, the subject of this study, was the building of the outer walls of Rabad al-Bayyazin (Quarter of the people from Bayyaza) or Cerca de Don Gonzalo, started and executed between 1338 and 1354. This walled perimeter enclosed on its North and East sides the Albaicin quarter, a name that is given today to the whole of the Islamic quarter of Granada but that in the XIVth Century referred specifically to a more reduced area.

3 TYPOLOGICAL AND MORPHOLOGICAL DESCRIPTION

The Cerca de Don Gonzalo ramparts are a fine example of a specific morphological type since they are the result of a single construction project. Walls, built in lime reinforced rammed-earth, were originally 2300 m long and enclosed some 45 ha, of which 1300 m have survived. No significant modifications in its execution have been detected, XVth Century onwards demolitions and XXth Century reparations aside.

Wall thickness is regular along its layout (average: 125 cm). Its height depends on the topographic conditions of each sector and was calculated by the builders in wall sections, wall section being that portion of the wall formed in any one completely filled form which has been rammed to capacity, and the form removed. These sections have an average height of 80 cm; heights ranging from 75 to 90 cm have been documented. The number of wall sections varies from seven to ten rows. The full height of the walls on their outer side included the parapet and crenellations, which makes a total average height of about 10 m.

As Márquez & Gurriarán (2008) have pointed out it is difficult to find a standard modulation of the height of the wall sections across different rammed-earth walls. Height is either a factor of the limitations of the constructive system itself or the result of local traditions (Cuchí 1996); besides, the height of the forms used does not correspond with the final height of the built wall.

Walls were topped by a battlement walkway consisting of a crenellated parapet. Nowadays these elements have disappeared almost completely and it is difficult to know its original shape and dimensions. Traces of the battlemented parapet can be found in the Western sector of Cerro de San Miguel; east of the Puerta de Fajalauza some crenels do still survive (Fig. 2).

In the North sector between Puerta de Fajaluza and Puerta de San Lorenzo the remains of a lime mortar floor have been documented that might correspond to the floor of the battlement walkway. The strong slope of the terrain, particularly at the Cerro de San Miguel area, forced a stepped disposition that fits the height of each wall section that conform the wall (Fig. 3).

The layout shows an irregular disposition with sectors that change direction or present a zig-zag layout; corners present a beveled buttress. Thirteen square or rectangular towers (and a polygonal one located by Puerta de Fajalauza) have been preserved. These towers are 30 to 60 m distant and in most cases are joined to the walls. The wall sections that form the towers are not always aligned to those of the adjoining walls.

A number of gates gave access to the interior. Of these only Puerta de San Lorenzo is still standing; the rest have disappeared. Gates being relatively complex functionally and constructively, they were built in brick in order to form jambs and vaults.

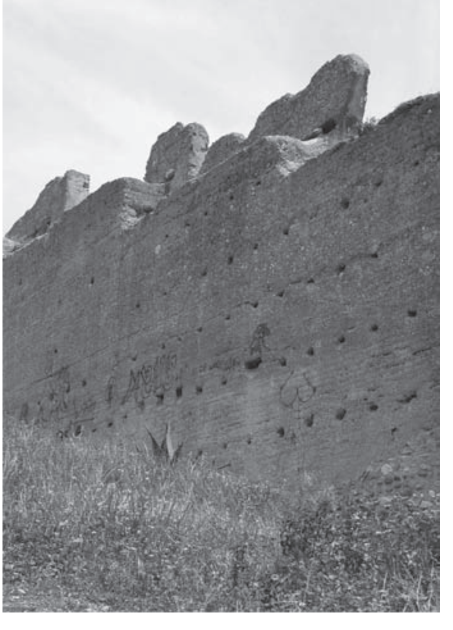

Figure 2. Traces of the crenellated parapet of the Nasrid ramparts. (Source: author).

Figure 3. Stepped disposition adapted to the slope of the terrain. (Source: author).

4 MATERIALS AND CONSTRUCTIVE TECHNIQUES

The materials and techniques used to build the Cerca de Don Gonzalo, as those of most urban ramparts of al-Andalus, were different of the ones used in domestic rammed-earth construction. Building an urban rampart in the context of public works promoted by the Nasrid administration meant a high degree of logistic planning, considering the scale of the project and the necessary speed of execution.

A description of the constructive process of lime reinforced rammed-earth Nasrid walls will be presented that focus on its singularities and differences *vis à vis* domestic rammed-earth construction. The hypotheses suggested here are based on observation and analysis of the traces of impressions left by the formwork on the wall. A certain amount of guess work is involved, supported on the personal knowledge of similar contemporary constructive processes (Fig. 6).

4.1 *Placement of stays and anchoring sticks*

The need to build walls 1,25 cm thick, as is the case of the Nasrid ramparts of Granada, introduces the first difference between them and domestic rammed-earth buildings, since in a wall over 1,00 m thick it is difficult to extract the stays that support the forms: temporary stays cannot thus be used. The solution is placing opposite pairs of wooden stays that do not cross the whole wall and that will be kept in place once the ramming ends and the forms are removed. This allows us to know their dimensions and disposition: stays with a 2 × 7–9 cm rectangular section and about 50 cm long have been identified (Fig. 4a). Stays were aligned on notches cut on the top of a previously built wall section and originally protruded slightly over the wall. A beak shaped hole was made at the protruding end to fit the stiffbacks that embraced the forms. Stays were anchored on the top side of the lower wall by two or three wooden sticks 15–20 cm long (Fig. 4b).

4.2 *Installation of forms*

The high degree of logistic planning involved in building an urban rampart meant the introduction of *ad hoc* modifications of the usual domestic rammed-earth construction system based on building independent prismatic wall sections. The formwork of the ramparts consisted instead of several pairs of opposite forms that were not closed at their ends; end stops or bulkheads were not needed. The procedure, a sort of multiple, continuous formwork, allowed building rows of wall sections without vertical joints and facilitates the simultaneous ramming of larger portions of wall. The only joints visible on the wall surface are those that resulted from taking up the work, either from day to day or seasonally. These joints are to be found at a considerable distance from one another and may show a sloped or stepped profile. The rows of wall sections have a horizontal slope that ranges from 2 to 4%, an inclination that parallels that of the slope and that probably facilitated the shifting of the formwork.

Forms were supported by stays placed a few centimeters below the horizontal surface of a previously built, supporting wall section; this allowed the necessary overlapping of the forms over the existing wall. Once the forms were placed on the stays, stiffbacks were inserted in the latter on both sides of the formwork and were tied to one another with an esparto rope knotted to the sticks that anchored the stays (Fig. 4a). During the ramming process the rope works by traction and absorbs the horizontal forces exerted on the forms by the process of earth filling; stays are thus freed from these mechanical efforts and their only role is to support the weight of the forms. Forms documented at the

Figure 4. Stiffbacks and wooden sticks. (Source: author).

Cerca de Don Gonzalo ramparts are 250 cm long and 85 cm tall, which allowed building wall sections about 80 cm tall (Fig. 5). They consisted of three wooden planks 4 cm thick joined together by two bonding strips that, differently to the domestic rammed-earth formwork, are placed on the outside face of the forms. The bonding strips were nailed with flat-head cast-iron nails 4 to 5 cm in diameter.

The impressions of the head of the nails can be seen on those areas of the walls where no finishing was applied, the same spots where the impression of the planks can also be seen. Planks were deliberately placed a few millimeters apart from one another in order to facilitate a slight swelling and moving from being in contact with moist earth (Cuchí 1996).

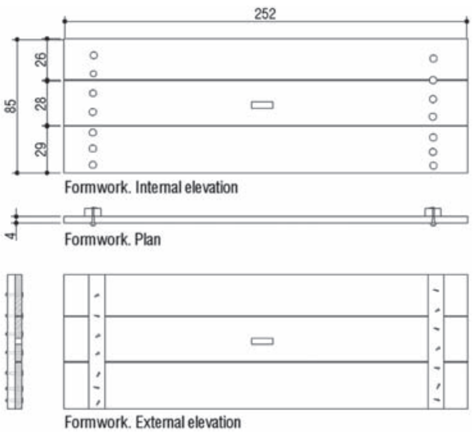

Figure 5. Formwork used in the Nasrid rampart as revealed by the impressions documented. (Source: author).

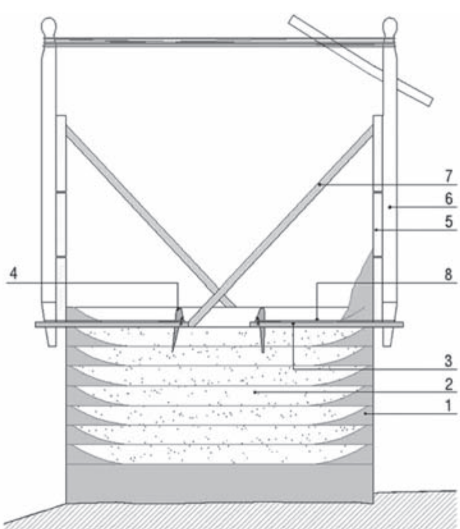

Figure 6. Installation of the formwork: 1-Crust; 2-Earth mass; 3-Stay; 4-Sticks; 5-Formwork; 6-Stiffback; 7-Inclined spacer; 8-Rope. (Source: author).

The forms documented were embraced by five stiffbacks placed at an average distance of 50 cm, as shown by the separation existing between the holes that lodged them. In order to avoid the opening of the formwork during ramming, stiffbacks placed onopposite sides of the formwork are tied together by pairs with a strong esparto rope fitted into small notches made at the end of the stiffback, and are then tensed by a tourniquet. In order to avoid forms from falling inwards, spacers are placed into the formwork, occasionally with a horizontal inclination of ca. 45° (Fig. 7). Impressions of this spacers have been identified inside the walls in the shape of circular orifices 3 cm in diameter that seem to rest on the wooden stays and that disappear beyond two thirds of the height of the wall section, since once this height was reached during the ramming process, spacers not being necessary anymore, they were cut and only its buried portion remained in place. A well-known Kashmir illustration dated to the 1850s shows the use of these inclined spacers, scissor-shaped in this case. The shape and disposition of inclined spacers is another distinctive feature of the procedure compared to domestic rammed-earth building, where only horizontal spacers are used.

The embracing system just described is perfectly suited to the construction of rampart walls. This procedure, however, does not solve the problem of building turns, towers or complex structures like gates or wickets. In such situations a number of solutions are adopted depending on the geometric constraints present: in addition to the spacing and

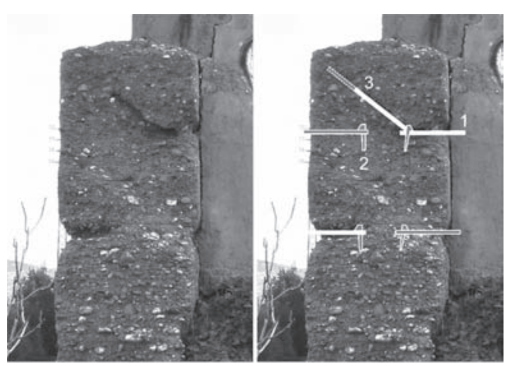

Figure 7. Impressions documented in the wall mass: 1-Stiffbacks; 2-Sticks; 3-Inclined spacer. (Source: author).

tensing systems described others are implemented inside the structure. Impressions left by them have been identified during a recent archaeological superficial inspection of the top of the Puerta de San Lorenzo.

4.3 *Materials used and ramming process*

As pointed out above, the Cerca de Don Gonzalo rampart is built in lime reinforced rammed-earth, a technique that, although found in domestic architecture, is a constructive model especially suited to building rampart walls since it allows building a rammed-earth wall with an inner earth mass protected by a lime mortar crust. The procedure permits huge savings in lime during the construction process compared to lime mortar rammed-earth, and its durability is ensured by a highly resistant finishing that protects the core of the wall against atmospheric agents.

In the Nasrid ramparts of Granada, the earth mixture of the wall mass, as well as that of the surface crust, was obtained from the *Alhambra formation*, the geological conglomerate on which the Albaicín hill rests. The lime needed for mortars and for stabilizing the earth mixture was probably obtained from nearby lime furnaces. Elaboration of the earth mixture that forms the wall mass is relatively straightforward since it involves a light kneading and moisturizing of the earth, which is stabilized with lime in varying proportions that should not exceed 15%. The crust mortar is composed of lime and sand in a 1:2/1:3 ratio, the mineralogical composition of the latter being that of the wall mass but having gone through a process of selection that results in a smaller, more balanced granulation. The dominant component is sand, although gravel size elements can also be found. It was sift above sieve number 8 ASTM (2,5 mm) and had a very small amount of finer materials (Ontiveros et al., 2008).

Some lower sectors of towers and walls were occasionally built with slipform lime concrete, used to build either the first layers of a wall section in contact with the terrain, or all of the section. In these cases granulation is bigger and the presence of gravels increases considerably.

Execution of a lime reinforced rammed-earth wall starts by applying a crust mortar layer of dry consistence on the inner side of forms, up to the height of one or two layers. The earth mixture that composes the wall mass is then poured in, with the occasional addition of stones up to 20 cm in diameter. The mixture is rammed with a wooden ram and the process is repeated as necessary until completion of a wall section. Considering that each layer is 6 to 8 cm thick, 10 to 13 layers are needed to build an 80 cm section. The earth mixture and the mortar crust become one single body by ramming: the process gives the wall a characteristic wedged section that improves its anchoring and is the result of the differential pressures exerted on the crust mortar when pressed on the forms (Fig. 8). The top surface of the wall section just built was probably hand-rammed, or rather tapped, with the help of a hand-rammer in order to obtain a regular surface.

Removal of the formwork was done once the crust mortar presented a minimum of initial resistance. Medium term resistance is the result of carbonation, necessary to stand the aggressive impact of water and freezing of the first winter season. This means that, in the case of Granada, work must have started in spring and stopped by the end of summer. Once forms are removed the protruding ends of the stays and the ropes that tensed the stiffbacks are cut several centimeters inside the wall surface. At this stage the surface of the wall section just rammed shows the holes of the stays and other imperfections produced during removal of the forms. Also, the impressions of the wooden planks that make up the forms, the nail heads of the bonding strips that hold them together, and the horizontal joint between different section rows are all visible.

4.4 *Finishing*

The construction of the wall ends with a finishing that erases the traces of the construction process and creates a homogeneous, continuous surface. Personal observation of rammed-earth construction procedures in contemporary Morocco (see López et al., in these Proceedings) leads me to think that the first operation was filling the existing holes with handfuls of the same mortar used in the crust. A wet hand-rammer must have been used to finish the vertical sides of the wall by tapping

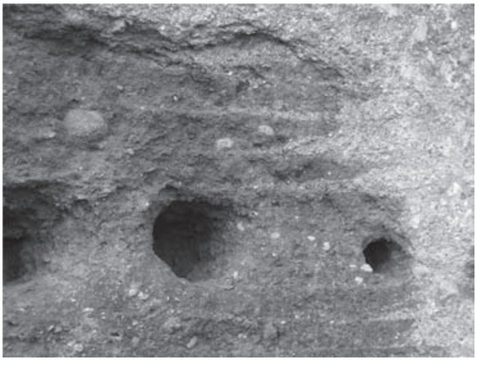

Figure 8. A detail of the crust that protects the earth mass of the wall. (Source: author).

until they are perfectly smooth. This layer is not to be considered a coating since it was applied exclusively on localized spots before the full hardening of the crust mortar. A hand-rammer similar to the one used to finish the sides of the wall, although smaller, may have been used to tap also the top surface. Finishing hides the traces of the modular nature of the construction process, making unnoticeable the contact areas between the original crust and the reparation mortar, closes pores and improves impermeability. It must have been applied while the surface lime mortar was hardening, before the carbonation phase; this involved moisturizing the wall and keeping it fresh until the whole sector being built was finished, parapet and crenels included. The whole process was probably carried out without scaffolding: stays with an extra length may have left temporarily in place to support the planks that allowed workmen to carry out the finishing operation (Martín 2005).

5 CONCLUSIONS

The construction of the Nasrid ramparts of Granada was a complex project that involved the concourse of specialized workers under the unified management of a central administration. The use of two technical improvements, lime reinforced rammed-earth and continuous formwork, facilitated the construction process as it allowed quick, relatively inexpensive building of thick earth walls with a hard lime mortar crust. The procedure was effective from the standpoint of structural reliability and ensured protection against atmospheric agents. Ramparts, provided with evenly spaced towers, were topped by a battlement walkway and a crenellated parapet. The high lime content of the surface crust gave them a smooth, whitish appearance. Finishing erased any trace of the construction process, made unnoticeable the impressions left on the surface by the formwork, and hid the holes left by the cutting of the outer end of the wooden stays. The present aspect of the ramparts is the result of the loss of its crenellated parapet and the deterioration process that affects the base of the walls, exposing their earth mass and the holes of the stays that were meant to be hidden.

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Torres Bermejas: Conserving the past

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ABSTRACT: The complex of the *Torres Bermejas* (The Crimson Towers) is one of the lesser known defensive structures within the citadel of the Alhambra. The approach of our proposal, conducted from the specialized and interdisciplinary perspectives required, was based on one essential premise: the need to link the Basic Project and Execution stage to the methodological strategy outlined in the Preliminary Studies. To be precise, we aimed to base our Project on the historical and archeological data gleaned in those Studies and at the same time endow conservation with an essential instrument for the better knowledge of these architectural structures. This is why it is necessary to "historize techniques", as R. Bonelli pointed out, and, if we wish to use well-known testing systems which we have at our disposal as a basis for Scientific Diagnosis by which to guide subsequent critical intervention planned from a critical stance.

1 DESCRIPTION OF THE BUILDING

The complex of the *Torres Bermejas* (The Crimson Towers) is one of the lesser known defensive structures within the citadel of the Alhambra. Its location and the techniques used in its construction date from the times the hill was first occupied but we really do not know its function or its relation to the rest of the *Alcazaba* (*citadel*). It was an advanced fortress within the precincts of Granada and one of the city's first military defences. Nothing is known for sure about the primitive construction except that the most ancient remains date from the end of the VIII and the beginning of the IX centuries.

In the XI century these remains were strengthened and joined to the *Alcazaba* by means of a city wall, linking both structures to the walled-in enclosure of Granada. After the Christian re-conquest they were again restored and once more in the XIX century (1854–1858). For many years they were used as a prison and a barracks for a long time.

Figure 1. Aerial view of the architectural complex of *Torres Bermejas*.

Figure 2. General view Torres Bermejas (c.a. 1857 J. Laurent).

2 ANALYSIS OF THE EDIFICES

2.1 *Andalusí period*

The remains of the walls from this period can be identified on the eastern side of the smallest of the Crimson Towers. They were *tapiales* (or multilayered walls rammed with earth and pebbles), and encased with brick at the end of the XV century.

Mention must also be made of an impressive *tapial* structure of limestone mortar, whitish in color. The caisson sections (or rows of molds) of this structure were separated by bricks, whose remains are to be found at the base of the eastern and northern sides of the main *Bermejas* tower. We do not know if this was a tower or a split in the city wall, but we can definitely say that it did have a gate or large window on the northern face, the remains of which can still be seen inside the tower.

The smallest tower also appears to be from the Andalusí period and it seems that it flanked the nearby access. Its *tapial* walls were likely to be of mortar made from reddish layered limestone.

The existence of another tower can also be established. This tower, greatly transformed and originally hollow, is located at the southern point of the complex. It determined the building of the Christian stronghold, and became an integral part of it. We believe that it was also constructed of *tapial* walls, although it is difficult to specify more data about its construction.

2.1.1 *The period after the conquest by the Catholic Monarchs*

The first phase relates chronologically to the reconstruction of the large central tower, which to a certain extent exploited the remains of the old Andalusi structures. It was built completely from *tapial* walls of limestone mortar and has openings with stone and brick joists in the curve of its lower arches.

However, the succession of works on this fortification must have been carried out extremely quickly, with numerous extensions and restorations and/or renovations. For example, that noble tower would be repaired hastily with mixed masonry of stone slabs and bricks, including the reconstruction of the scaffolding and of the openings on the northern façade. We can already see the same equipment being used in the initial layout phases of the stronghold complex, from the definitive access to the castle and on the wall which joins the southern flanking tower to the large central tower.

From that period, or a little later, masonry was characterized by the use of wooden caissons between rows of bricks, as well as bricks alone. They appear as a reinforcement on the corners of the main tower and define several structures of the strongholds, together with a poor-quality *tapial* wall made from a mixture of lime and pebbles. The next restoration process involved the reinforcement of the northern flanking tower with rows of bricks, which at the same time were finished off with the construction of new parapets and tops of stone coping.

Figure 3. View of the architectural complex of *Torres Bermejas*. Alhambra.

Figure 4. Facade of the Main Tower with facing *tapial*.

Figure 5. Cavity of the main Tower with different textures of materials.

2.2 *Modern-contemporary period*

A large part of the *tapial* wall in the northern flanking tower which is still visible was strengthened with brick, as was the filling of some eroded surfaces in other parts of the fortified complex.

We have identified another procedure undertaken with brickwork which solved conservation problems at different points on the edifices, as well as the application of a fine limestone finish on the outer surface of the main central tower, which can still be seen in some places.

2.2.1 *XIX and XX century restorations*

Amongst the most notable work was the re-adaptation of the layout of all the zones outside the stronghold, areas of ground and terraces, and the reconstruction of parapets.

Amongst other restorations, we may point out the solution used to conserve the *tapial* walls, which consisted of adding a layer of brick to the most eroded areas. Similarly, the *tapial* surfaces were protected by a new layer of bastard mortar.

Other interventions involved using a reinforcement of brickwork, as we may observe at several places on the main tower.

3 *TAPIAL* BUILDING TECHNIQUES: WALLS OF "*CAL Y CANTO*" (LIME AND PEBBLES) AND "*CALISCASTRADO*" WALLS (EARTH, LIME AND VEGETABLE FIBERS)

The walls are of two types. The first is a *cal y canto* wall which is whitish in color in which the lines of caissons are separated by rows of bricks (a technique similar to the one used in the city wall which joins the Towers to the Alhambra Citadel). The second is *calicastrado* and is reddish in color, in which the openings are made of brick. We find travertine on the upper terrace of the Tower. This travertine is possibly from the *del Rey* quarries at the village of Alfacar, Granada, and is well preserved. The inscriptions on some of the pieces of limestone we have examined suggest that they are fragments of re-used gravestones. We also find numerous *maqqabriyas* and graffiti, which we are shall study in detail (documenting them and conserving those which are of historic or artistic value).

The eastern tower is the second largest, and was built of brick, while the western one was built using caissons of masonry. These towers are joined by a wall of *calicastrado,* similar to that employed in the central tower, and have brick openings apparently dating from the Nasrid era.

On the north-eastern façade, which faces the city, there is a small sloping semi-circular bastion. Inside there are three large parallel rooms. At the end of the central room there is a hollow space that is almost square. It used to be the water cistern of the castle, but today it is full of rubble. Finally, next to the western tower there is a huge trapezoidal room, divided into two smaller rooms by two parallel arcades.

In the first layout phases of the stronghold complex we see constructions of mixed masonry of stone slabs and brick, combined later with the use of caissons between rows of brick. It presents different types of exterior and interior coatings applied in different interventions over time. There are outstanding masonry vaults on the upper floor of the main tower, as well as arches and objects of engraved wood.

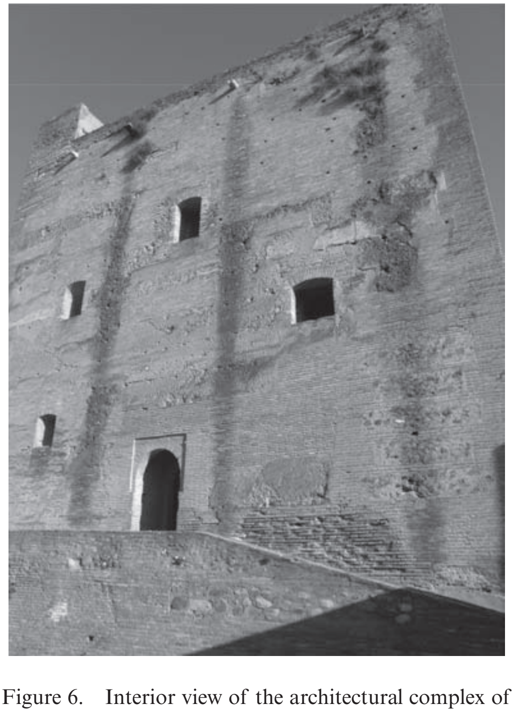

Figure 6. Interior view of the architectural complex of *Torres Bermejas*. Alhambra.

Figure 7. Cavity of the door of the main Tower in the interior with diverse repairs.

4 PATHOLOGICAL ANALYSIS

4.1 *Tapiales (Multi-layered walls rammed with earth and pebbles)*

The *tapiales* we have examined are very varied. In general, we may say that there are three main types.

Some *tapiales* contain different-sized fragments of schist, grains of quartz and occasionally small rutile crystals. The clays used in their construction have a high iron content, which gives them a reddish hue. There are also *tapiales* whose *árido* or dry building material is dolomite. In general, in both kinds of *tapiales* some limestone was added, making them very porous.

There are also *tapiales* in which earth adheres firmly to pieces of rock, indicating that a greater quality of limestone was added. The size of the *árido* used in this case is much smaller, and is suggestive of a coating material.

4.2 *Archeological study*

In our archeological intervention on the *Torres Bermejas* we carried out archeological surveys in nine areas, on the inside as well as on the outside of the towers, and analyzed the walls as a whole, which complemented the analysis of the subsoil. The aim of this procedure was to document the historical evolution of the building in order to ascertain the different phases of the construction and occupation of the *Torres Bermejas* complex, as well its relationship with the Alhambra and the city of Granada.

This survey has allowed us to find evidence about the oldest stage of the Crimson Towers fortification thanks to our analysis of the technique used in building the multi-layered *tapiales*, that is, walls built by pouring a mixture of earth and varying quantities of lime into a succession of wooden molds. We have been able to relate *Torres Bermejas* with the *Alcazaba* (Citadel) of the Alhambra, which has been dated from the XI century in the Zirid period, and which appears in other sections of the city wall such as the one which goes down from the Alhambra to the *Puerta de las Granadas* (Gate of the Pomegranates) and which goes up from there to *Torres Bermejas*. To this period we attribute the original foundations of the three towers which were constructed in a trench dug at ground level. The walls were built in a similar way, and were powerful structures of mortar whose whitish color is due to its high lime content and whose caissons (each row of molds) are separated by lines of bricks which in some cases appear to have been given a careful finish to protect them from the damp. To this day we can see traces of the building process of these walls, such as the marks left by nails and beams. It is noteworthy that in all the walls under examination there are numerous impressions left by the struts which vertically

Figure 8. Tapial wall corresponding to the oldest phase of the Torres Bermejas fortification.

Figure 9. *Tapial* wall conserving the imprints of the construction process, such as the marks of wood and nails. It is noteworthy that on all the walls there are numerous imprints of the costales which joined vertically the wood of the frames.

Figure 10. Section in ruins of the wall, constructed in *tapial calicastrado,* which was the union of the three towers.

held together the wooden sides of the molds. These elements are usually situated towards the outside of the caisson, leaving an impression of nail heads, but in this case they are turned towards the inside, as may be seen in other sections of the city wall or in the Alhambra itself.

On this foundation rise walls of poorer construction, made from reddish earthy material with a very low limestone content, except the central tower, which, perhaps due to its greater width, has a *tapial* which is richer in limestone not only at its base but up to a certain height. Here we observe at many points a *calicastrado* wall, which is characterized by limestone toward the surface and mainly earth toward the core. This wall also presents rows of bricks between the caissons.

The three towers used to be joined by a surrounding *calicastrado* wall, a demolished part of which has been found. This fortification would have been part of the city's defenses, joining the *Alcazaba* of the Alhambra to the *Realejo* neighborhood, closing off the city to the southwest.

We do not know the exact configuration that the Crimson Towers complex will have had during the Nasrid era, but in our investigation we have excavated two Islamic burial sites which are situated towards the outside of the complex, near the second tower. They were probably part of the Nasrid cemetery of the *Sabika* hill or of the *Campo del Príncipe* (Field of the Prince) outside the city walls, and a later boundary of the cemetery at this point.

In Christian times, the towers complex underwent a series of restorations which gave it the general configuration we see today. The Christian stages are perfectly identified thanks to documentation and material analysis, and are easily recognized thanks to numerous *maqabriyas* (Islamic gravestones) which were almost certainly taken from nearby burial sites and re-used. These are made from a yellowish sandstone from the surrounding areas of the village of La Malahá. This period saw the demolition of some parts, and certainly the building up of part of the central tower, as well as the construction of the present-day armory square with embrasures and a bastion with a water cistern. The building of the stables also belongs to the post-conquest period.

These constructions make it difficult to identify the medieval configuration of the Crimson Towers, as do the XX century restorations which have covered the original materials. What is clear is that with the Christian Re-conquest the use of the *Torres* changed: from being a section of the city wall with outward-facing towers, as would correspond to the defenses of a medieval town, it began to face the city with its bastion as a defense against the city itself.

5 INTERVENTION CRITERIA: CONSERVING THE PAST *VERSUS* MINIMUM INTERVENTION

In June, 2007, we conducted several Preliminary Studies and then we drafted the final consolidation and restoration project for *Torres Bermejas*. In June 2009, we wrote a Diagnostic Report, the aim of which was to design an intervention strategy in real time which would allow us to plan the work of conservation, restoration and adaptation for the use of *Torres Bermejas*.

The approach of our proposal, conducted from the specialized and interdisciplinary perspectives required, was based on one essential premise: the need to link the Basic Project and Execution stage to the methodological strategy outlined in the Preliminary Studies. To be precise, we aimed to base our Project on the historical and archeological data gleaned in those Studies and at the same time endow conservation with an essential instrument for the better knowledge of these architectural structures.

The second procedure was supported by intervention criteria, which we based on the reading of the authenticity of materials and on the significance of this architectural space, in order to recover "with interventions looking toward history" the architectural space (conservation), as well as integrating or renovating it (transformation). The reality of the space of the Crimson Towers goes beyond its adaptation for a new use, and is part of a history whose traces we must not erase. These traces linger and may be examined from a modern intervention perspective within our architectural heritage, without resorting to false historicisms or destroying values that live on.

In response to the expression "knowing in order to conserve", we would suggest "conserving in order to know", proposing wall stratigraphy techniques as a way to widen and deepen our knowledge. The task of the architect who faces intervention on the architectural heritage is to give account of his/her decisions to him/herself and to the community at large. The archeology of walls, a consolidated discipline within the critical understanding of architectural texts, gives us a partial answer to the problem of the conservation project. In the field of historical architecture, the task of archeologists must be exemplary. For them, architectural elements and their configuration are not "values to confirm or deny", but rather they are a "system of material signs". From their point of view, a wall is not really a "shape", but rather it is a "topography", that is, a "place" implied by a kind of "writing" or "spelling". By means of non-destructive analyses and through fundamentally topological research, they practice a kind of reading that enables them to interpret the building

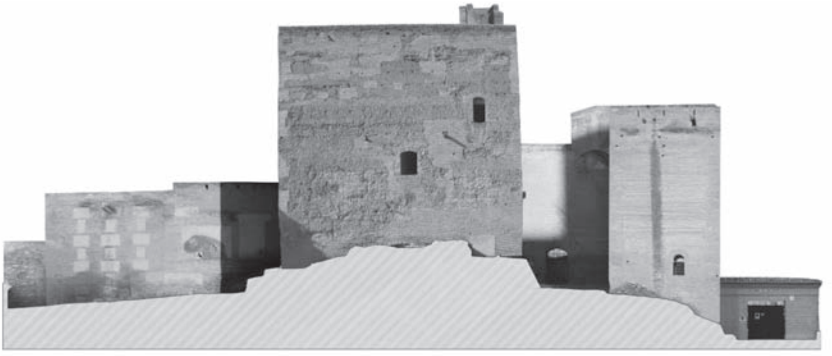

Figure 11. Confrontation representations of *Torres Bermejas*_metric_critical_photomap_degradations- intervention criteria.

phases of the whole and its parts, the knowledge and the material tradition that occurred over time, the vicissitudes and accidents that marked their existence, until they reach a definition of relative and absolute chronologies.

Archeologists teach us that careful investigation can be extended to the formal and constructive composition of the building process as a whole, as well as to the most minute detail of a brick, to the lacerated edge of a fragment of plaster, to the residues of an ancient fire, to the tree growth rings of a wooden beam, to the composition of mortar, and to signs that are evidence of age. So the edifice appears to us as an enigma whose mysteries become clearer under the scrutiny of analysis, with the broadening of scientific curiosity, and with the improvement of research instruments.

The consolidation of edifices, where episodes of historic-artistic value are manifest, is part of restoration as a technical means towards the ultimate aim of conservation. Consolidation and restoration, seen through a common operation, at the base of which is knowledge, understood in the widest sense of theterm. We wish to point out that consolidation, adaptation, and reinforcement do not explain a merely technical function, but intimately blend with the monument and influence life.

This is why it is necessary to "historize techniques", as R. Bonelli pointed out, and, if we wish to use well-known testing systems which we have at our disposal as a basis for Scientific Diagnosis by which to guide subsequent critical intervention planned from a critical stance.

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Rammed earth architecture and construction

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Methodological proposal for rammed-earth wall characterization: Understanding of material in preliminary studies

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ABSTRACT: Propose is a series of analyses and tests to be carried out in historical studies for wall characterization. There are three types of tests: a) classic methods that are well referenced and widely used for other building materials (mortars, soils, aggregates, etc.); b) instrument techniques such as XRF, SEM-EDX, XRD, etc.; and c) adaptations of normalization methods mainly corresponding to UNE-EN standards for application of these materials. Five large groupings can be established based on wall properties: chemical and mineralogical composition, physical and hydric properties, mechanical properties, granulometry, and dating. A correct interpretation of the results obtained allows non-analytical researchers (e.g., historians, archaeologists, restorers, architects, and so on) to expand their knowledge of the material's culture or its history.

1 INTRODUCTION

1.1 *Background*

The research group "Materials and Construction", classed as TEP-198 by the Andalusian Plan for Research, Development, and Innovation (PAIDI, its acronym in Spanish) of the Junta de Andalucía, studies and characterizes traditional masonry materials. For the last 10 years, this group has developed a research line focusing on rammed-earth walls. The group has wide-ranging experience deriving from participation in projects from the National Research and Development Plan (such as "Proposal for the maintenance, assessment, and conservation of historical rammed-earth construction in the province of Seville (ref. BIA2004-01092)" and over 15 research contracts for characterizing rammed-earth walls in archaeological excavations and heritage monuments (Martín et al., 2008). This scientific experience has allowed the group to establish a method for characterizing rammed-earth constructions in preliminary studies, which may serve as a reference for other researchers.

2 PROPOSED METHODOLOGY

2.1 *Sampling*

Sampling arises from the need to characterize the rammed-earth wall. That is, to determine its composition, its properties, and the processes and reactions that might be producing deterioration. Sampling cannot be arbitrary nor random for representative results, so a sampling plan must be set up taking into account the following points (Martín, 1990):

a. Maximum representativity. Rammed-earth walls are building elements whose composition can vary widely due to multiple factors such as imprecise manual measurements, variations in components, imperfect batching, non-standard manual applications, and so on. Consequently, efforts should always be made to ensure the samples collected are representative of the structure.
b. Number of samples. In sampling, it must be taken into account that, if only one sample is taken, the results will provide only preliminary data without any comparative value. Therefore, in order to affirm that a wall is typical of a building or building element, at least three samples should be taken from different locations. Once analysed, these samples should produce results falling within a suitable range keeping in mind the heterogeneity these materials can present.
c. State of samples. Samples may be taken in two ways: compact or fragmented (as powder). The difference is that compact samples allow the analysis of chemical and mineralogical composition and physico-mechanical properties; in contrast, fragmented or powder samples only offer the possibility of chemical and mineralogical analyses.
d. Sample amount. This is a function of several factors such as: 1) Limitations due to damage inflicted; 2) wall homogeneity (Figs. 1 & 3) sample requirements for each assay or determination.

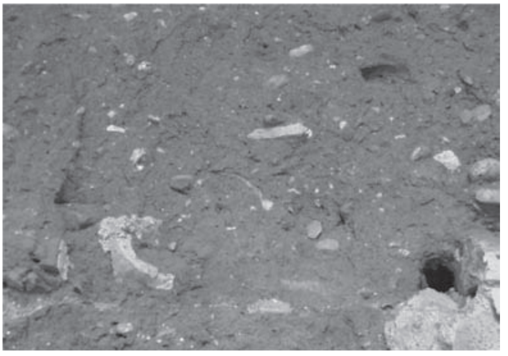

Figure 1. Fragments of bricks and tiles on a rammed-earth wall.

Figure 2. Manual extraction system with chisel and hammer.

As a general rule, amounts can range from hundreds of grams to several kilograms.

e. Collection site. The depth at which a sample is collected in a wall is extremely important. The deeper it is, the greater the probability that it is original, unsubstituted, and unrepaired. In addition, it will be less altered by environmental impacts. In contrast, when the sample is collected near the surface, it is more likely to have been partially substituted or repaired, in addition to being more weathered by atmospheric agents. It is common to find patinas, crusts, efflorescences and more on the surface. The collection site may also reveal different means of execution producing uneven binder distribution (e.g., lime-crust walls—*calicastrado*).
f. Location of extraction site and sample identification. Once the samples have been collected, the precise location must be noted (photographs and drawings) and they must be identified by a suitable system allowing rapid, clear identification to prevent confusion. This prevents problems when comparing results amongst the distinct rammed-earth walls in the building.

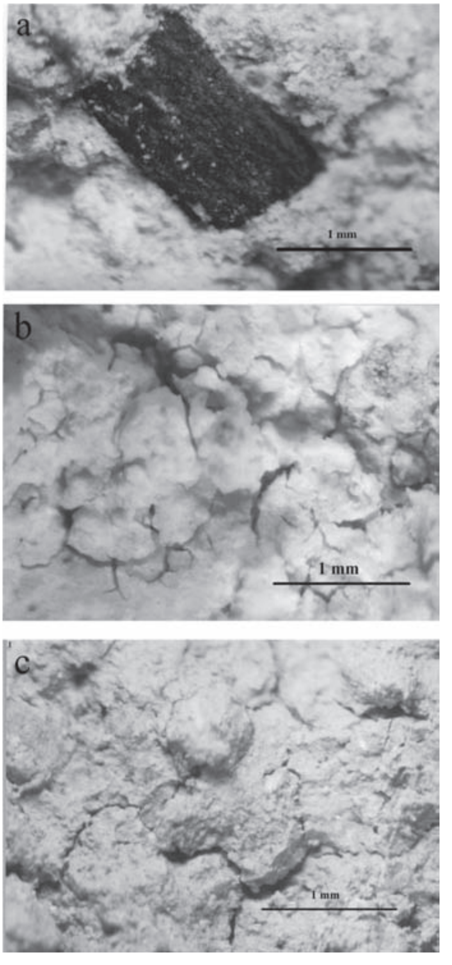

Figure 3. Photographs taken with a binocular microscope of a charcoal fragment (a) lime nodule (b) and plastic retraction microfissures (c) in various rammed-earth walls.

The extraction system can be manual (with chisel and hammer) (Fig. 2), semi-manual (pneumatic drill), or using a rock drill with diamond cups.

2.2 *Chemical analysis*

A study of the chemical composition requires an analysis of the major and minor elements (e.g., silica, aluminium, iron, titanium, calcium, magnesium, sodium, potassium, and sulfur) expressed as percent by weight and as oxides (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, Na_2O, K_2O, P_2O_5, and SO_3, respectively), as well as the determination of weight loss on calcination at 900ºC (WLC). These parameters can be complemented with the determination of trace elements (Cl, Pb, Zn, Cu, Ni, Co, Mn, Ba, Cd, Li, Sr …).

The soluble salts in a rammed-earth wall (formed by Cl^-, SO4 $^=$, NO_3^-, Ca^{+2}, Mg^{+2}, Na^+, K^+, Fe^{+3}, etc. ions) that can be involved in weathering may be analysed occasionally. However, this type of analysis is more commonly reserved for new materials to be used in restoration since, if present in high concentrations, they could be dangerous for the other building materials they are in contact with.

The analytical techniques that can be used to determine the chemical composition are quite varied, ranging from classic methods consisting of gravi-metry and volumetric analysis to those using instrument techniques more commonly applied at present such as X-ray fluorescence (XRF), X-ray microfluorescence (μ-FRX), plasma spectrometry (ICP), absorption spectrophotometry (atomic, ultraviolet, infrared), and more.

Carbonate determination (expressed as $CaCO_3$) through the Bernard calcimeter (UNE standard 103200-93) is valid for approximating the original lime content ($Ca(OH)_2$) in walls made with it since over time the lime carbonates and becomes calcium carbonate ($CaCO_3$). However, it must be recalled that both the earth and the aggregates used in its manufacture may naturally contain carbonate fractions. Therefore, the entire carbonate content is not always attributable to the addition of lime.

Determining the sulfate content (expressed as SO_3) according to the UNE–EN 1744-1:2010 standard has also been suggested. This evaluates the presence of gypsum in the wall, which may have been intentionally added as a conglomerate or be present as an impurity of the raw materials or as an alteration product of them. This parameter can also offer information on the presence of salts containing sulfates ($SO_4^{\,=}$).

2.3 *Mineralogical analysis*

The aim of studying the mineral composition is to gather information on the distinct crystalline mineral phases in the wall. These phases derive from the raw materials, from the reactions produced between them, and from the transformations occurring when they enter into contact with other materials in the environment and that can produce new products from alteration of the existing ones.

X-ray powder diffraction (XRD) has been proposed for determining overall mineralogy. To identify the minerals in the clay fraction, the < 2 micra fraction must be separated, the orientated aggregate technique used, and subsequently it must be solvated with ethylenglycol (EG) and dimethyl sulfoxide (DMSO) and heating to 550ºC as routine treatments (Brown, 1961).

The mineralogical analysis can be completed by studying the thin-sections by polarizing microscopy (PM) and image analysis, which allows the principal components of the rammed-earth wall (binder and aggregate) and the mineralogical constituents of the aggregate to be determined in relative terms.

2.4 *Textural analysis*

The study of the texture of the wall components is of interest to determine the distribution of aggregate grains, their shape and alteration, as well as the state of the aggregate-binder interface. The textural analysis of the binder reveals information about its crystallization, the presence of lime nodules, remnants of charcoal, ashes, and so on (Fig. 3). It is also useful for observing the presence of pores and fissures and their geometry and distribution.

The binocular microscope is useful for this study, using magnification intervals of 20X to 60X. Scanning electron microscopy (SEM) and polarizing microscopy are also complementary techniques for the textural study.

2.5 *Determination of physical properties*

The physical properties included in a routine rammed-earth wall characterization are real density, apparent density, and water-accessible porosity, which all provide information on the material's structure.

The real density is the relation between the wall's mass and impermeable volume. It is an intrinsic property that depends on the real density of the minerals in the wall.

The apparent density is the relation existing between the mass and the total volume of the wall sample.

This material property depends in turn on various factors such as the real density of the minerals comprising it, the water-accessible porosity, the closed porosity, and so on. In short, it is strongly linked to the wall structure.

Finally, the water-accessible porosity is the ratio between the volume of water-accessible pores and the total volume. This property provides information on the wall's conservation status, the amount of water used in its manufacture, and the structure's compactness. It also exerts considerable influence on other physico-mechanical properties such as mechanical strength, hardness, permeability, and so on.

The techniques for determining these three properties are based on saturating the sample with water in a vacuum and the use of a pycnometer. The only thing necessary is a representative fragment of wall, whether even or uneven. There are two methodologies used for rocks that are extrapolable to rammed-earth walls: that of the RILEM TC 25-PEM (1980) commission and the UNE-EN 1936:2009standard.

2.6 *Determination of the hydric properties*

This section includes the main properties related to the presence and movement of water through the wall's porous system.

Water absorption by immersion or saturation coefficient is the volume of water present in the sample pores after immersion in water at atmospheric pressure for 48 hours compared to the total volume of accessible pores. This property compares the wall's natural capacity to absorb water and its total open porosity and it depends on the porous structure (pore size and distribution).

The capillary suction curve is obtained by measuring the amount of water uptake over time by a dried sample in contact with a water surface. This technique basically determines how fast water can penetrate the wall by absorption.

The drying curve is obtained by measuring a sample's loss of mass when subjected to drying under set conditions. The drying process is quite complicated, being dependent on the initial water content and its distribution as well as on the sample dimensions and permeability to water vapour.

The methods proposed by the RILEM TC 25-PEM (1980) commission for rocks may be extrapolated to walls to determine these three properties. These assays require representative wall samples with a regular shape.

2.7 *Determination of mechanical strength*

The most important mechanical property to be assayed in rammed-earth walls is compressive strength. Numerous factors influence compressive strength, from the distinct types and qualities of the components used to proportions of binder and batching water, means of execution, curing conditions, and so on. Not to forget the evident factor of aggressive agents over time.

Determination of the wall's compressive strength is as in the previous step, extracting a sample (using one of the systems in Section 2.1) and considering these aspects:

a. Orientation. The test specimen must be extracted vertically, in the same direction as the wall compaction during its construction. In addition, this coincides with the wall's main direction of load.
b. Geometry. The shape will be irregular if extracted by hand or semi-automatically. In this case, it must be shaped in the laboratory to a regular shape (usually cubic) using diamond saw blades. If cylindrical cups are used, cylindrical cores of varying diameter are obtained, which then need their bases cut.
c. Size. Taking as a reference the UNE-EN 12504-1:2009 standard for concrete, the ratio between the maximum aggregate size and the test specimen diameter/edge heavily influences the strength determination when the ratio is over 1:3. In order to suitably estimate the diameter or edge of the sample, we must first know the maximum aggregate size.
d. Capping. Regardless of the type of core obtained, the ends are not usually flat enough, parallel enough, and perpendicular enough to the vertical axis. To resolve this problem, the use of capping of the core by one of the methods in Appendix A of the UNE-EN 12390-3:2009 standard is advisable, the most suitable in our experience being sulfur mortar or cement mortar (Fig. 4).
e. Loading rate. Keeping in mind that walls are not usually characterized by high mechanical strength, it seems reasonable to use the rate established for mortars at 50 N/s to 500 N/s (UNE-EN 1015-11:2000standard).

2.8 *Granulometry determination*

As is known, granulometry consists in grouping aggregate grains or particles according to size in given ranges. To do so, a series of meshes of decreasing mesh spacing are used. The mesh series to be used is that of the UNE-EN 12620:2003 standard for concrete aggregates, comprising mesh spacings of 63 mm, 31.5 mm, 16 mm, 8 mm, 4 mm,

Figure 4. Photographs of three cubic wall cores capped with sulfur.

2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm.

The data from determining the granulometric curve is ample and of great interest in carrying out comparative studies between different walls as we can assess aggregate compactness, its size, the percentage of fine fraction under 0.063 mm in diameter, and so on.

When the wall's aggregate is in a conglomerate, it must be separated from the binder before performing the granulometry test. Traditionally, the sample is attacked with hydrochloric acid (HCl) to separate the two (Martín, 1990). The main problem with this technique is the lack of accuracy when the wall contains carbonate aggregates since they are also attacked by the acid. The insoluble fraction remaining after the acid attack and subsequent washing to remove excess HCl primarily comprises siliceous aggregate (quartz) and silicate aggregate (feldspars, micas, clay minerals, etc.) as they are unaffected by the acid.

In the case of walls made without binder (lime), it should be taken into account that the mainly earthen composition will easily crumble in the water. It would be of interest to study the viability of a method involving manual fragmentation of the wall sample to a certain size and then crumbling with water, dispersants, and shaking.

2.9 *Rammed-earth wall dating*

Although some might have doubts about including dating techniques within wall characterization, it must be recalled that they provide data on a differentiating characteristic (age or period of manufacture) and therefore its inclusion is logical.

Analytical instrument techniques currently available for dating are based on different fundamentals and require the presence of different components in the rammed-earth wall.

a. C14 dating based on the law of exponential decay or disintegration of the carbon-14 isotope. The amount present in various substances is determined to assess the age of the elements made with them. It is particularly useful for dating organic matter elements, which includes wooden tools, textiles, paper, bone remains, coal, and so on. Samples up to 50,000 years old may be thus dated.

   There are currently three different techniques to measure the amount of the radioisotope carbon-14 in a sample: gas proportional counting, liquid scintillation counting, and the accelerator mass spectrometry method (AMS). This last technique is the most modern and involves ionizing the sample and introducing it in a particle accelerator. The resulting beam is deflected by strong magnetic fields and, since each carbon isotope has a different mass, the angle of deflection is slightly different for each one. The relative concentrations of each can be measured in order to determine the $^{14}C/^{12}C$ isotope coefficient. Since it does not depend on sample activity and is insensitive to natural radioactivity, this method provides the highest-quality measurements. Advantages compared to other radiocarbon dating techniques are a decrease in the sample amount necessary (tens of milligrams) and a decrease in measurement time (typically 45 min). Rammed-earth walls commonly contain charcoal nodules (Fig. 1a) from the incorporation of ashes or lime impurities, remnants of wood from the horizontal timbers of the formwork, or even carbonate lime nodules (Fig. 1b) that can be used for dating.

b. Thermoluminescence. This method is based on the physical phenomenon of light emission as a result of raising the temperature in a crystalline mineral such as quartz, calcite, or feldspars (minerals accompanying clays in ceramics). These minerals must have been previously exposed to ionizing radiation deriving from the disintegration of the natural radioactive elements such as uranium, thorium, and potassium, whose isotopes are present in rocks in trace amounts. The electron layers bordering the thermoluminescent materials and the electrons released by the method are ionized. Some remain trapped in the crystal's defects or traps and cannot break free unless they are supplied with a certain amount of energy. The electron's stay in the trap depends on several factors, including temperature. As temperature increases, the electron's energy level increases and, at a certain level, it can break free. Once free, the electron can recombine with a "luminescent centre", which is what produces the luminous emission. The intensity of this emission is directly proportional to the number of trapped electrons, which depends, in turn, on the amount of radioactive dose the material has received. That is, the time elapsed since the structure formed or was first heated if the radiation was constant over time (Fernández, 1992; Aitken, 1985). Evidently, to perform this type of dating, there must be ceramic remains in the wall.

c. Rehydroxylation. This is the most novel technique of those described (Wilson et al., 2009). It is based on the progressive, slow chemical recombination of the ceramic with water from environmental humidity (rehydroxylation). The rate of rehydroxylation follows a power $(\text{time})^{1/4}$ law, so that a ceramic sample can be dated by heating it to determine its gain in

Figure 5. Temperature measurement of pottery fragments embedded in a rammed-earth wall.

water weight over its lifespan and subsequently exposing it to water vapour to measure its rate of regain in water weight and hence its rehydroxylation kinetic constant. If we know the total mass of water it has gained over its lifespan since it left the kiln, we can extrapolate its age. The rehydroxylation constant depends only on temperature (Fig. 5), so we have to know the average temperatures through estimations from historical and meteorological data. This is the temperature to which the sample must be subjected during the new rehydroxylation process. As for thermoluminescence, ceramic remains must be present in the rammed-earth wall.

3 CONCLUSIONS

The aim of this work was to establish a methodological routine to perform the characterization of historical rammed-earth walls in order to determine compositive parameters of physical, hydric, mechanical, granulometric, and chronological properties that will allow a more absolute classification of these walls to carry out comparative studies of them.

Since there are no specific test methodologies for rammed-earth walls, it has been necessary to use general techniques or those applied to other building materials. They have been selected so that the results will allow non-analytical researchers (e.g., historians, archaeologists, restorers, architects, etc.) to expand their understanding of the history of material culture.

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The formalization as an identification process of a constructive way: The rammed earth of Cherchell (Algeria)

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ABSTRACT: In Algeria, rammed earth is an ancestral way of building. Traditionally, it was used for military buildings, religious or public ones as well as for housing. This study tries to identify this technical way of building through its formal and physical characteristics while defining different variants found in some cities and mainly in Cherchell. A comparison with two other Northern Algerian cities will help to establish similarities between observed variants. Adding other materials to earth in different configurations forms the bulk ofthese variants where the goal is to answer questions related to rammed earth construction. Proposed solutions and the implement of materials in the formwork, show the pragmatic building way of traditional construction.

1 INTRODUCTION

In Algeria, as soon as the theme of earthen construction is approached, it is systematically to the South that one turns. It is true that the *ksour* of the desert are a beautiful example on the matter, but this should not eclipse another reality with a patrimonial dimension equally important. The fact is that earthen construction is very present in traditional architecture of northern Algeria. Earthen construction is an ancient heritage. Alack of studies about constructive typologies and the existence of this know-how in the northern cities of Algeria, has led to nearly its extinction.

Through this study, it is propose to bring rammed earth architecture in Northern Medina of Algeria, into the open. Rammed earth, as a building method is generally present in all of central Northern Algeria. It also seems to have been widely used in Northern Medina. The rammed earth technique was used in military, religious and public buildings, as well as in residential architecture, which represents the main component of the urban fabric.

The study was based on the city of Cherchell located on the central coast of Algeria, 100 kilometers from Algiers (capital). Cherchell is an ancient city, which has been rebuilt by refugees who came from Andalusia at the end of the 15th century. A large part of the traditional residential buildings of the city are made in rammed earth.

This study spread to two other Northern cities on the central coast region. Ténès and Koléa were founded at the beginning of the 16th century. One part of the traditional buildings of these two cities is also made in rammed earth similarly to Cherchell. All three cities share similarities about building and constructive (details) typology.

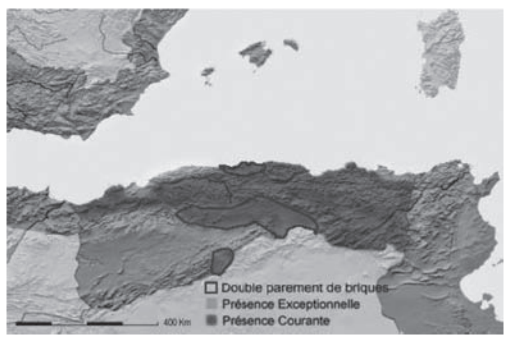

Figure 1. Existing rammed earth construction in the Northern part of Algeria. (MEDA CORPUS, 2002).

2 BUILDING TYPOLOGY

The traditional residential buildings in the Medina are mostly courtyard houses. They have one or two levels. The entrance is either through a transition area or straight into the courtyard, which is connected with all the surrounding rooms of the house. In case of a second level, the staircase starts from the courtyard and leads to one or two rooms. All the windows of the house open to the courtyard, with the exception of a few small ones turned towards the street. Therefore, the façades are blind, with neither openings nor ornaments except on the

Figure 2. Aerial view of the building fabric located in the neighbourhood of the great mosque of Cherchell. (Chennaoui, 2007).

main entrance door. The entrance shape is made of a lancet arch or full arch surrounded with a carved frame.

The roof of the building is covered with curved red tiles and the slope is oriented to the courtyard. Tiles lie on a layer of soil, about 15 cm wide and spread out on either wooden plank or fixed reeds on logs or wooden joists, which are fixed on bearing walls. Floors are also made of a wooden structure and soil filling. The floor pavement is fixed with a lime mortar. The walls are generally all bearing. They are made either of blocks, which are roughly carved filled with lime mortar; or fired bricks like in the case of Tènès; or retrieved stones like some houses in Cherchell; or made of rammed earth, which is what this study is about.

3 VARIANTS OF RAMMED EARTH IN THE CITY OF CHERCHELL

Rammed earth construction is predominant in the city of Cherchell. People migrating from Andalusia built this technique at the end of the 15th century. They not only brought the architectural language of their home region, but also know-howthat existed in in the field of fine arts and architecture, especially rammed earth.

In Cherchell, two variants of rammed earth in residential buildingswere observed. One is made of layers of mortar on wall facing, which was easily identified. Another is composed by horizontal parallel layers of mortar, with equal intervals, between the layers of rammed earth. The walls are 50 cm thick and are constructed on a base of stones. Their extension above ground is slight or not perceptible.This may be, because it is usually used for interior walls not exposed to rain water.

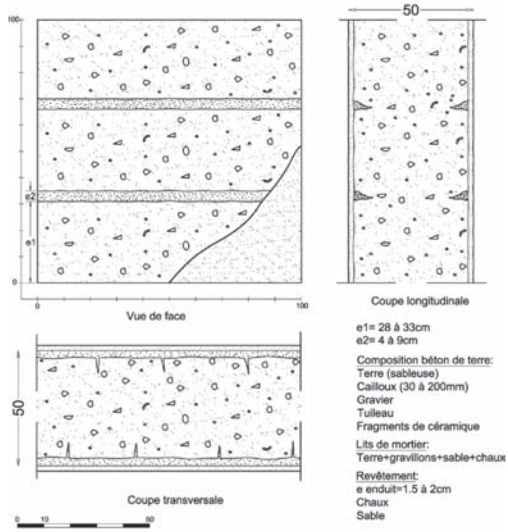

Figure 3. View of a wall with mortar joints—plan and sections. (Alliche. S., 2011).

Figure 4. Separation walls alternating mortar joints in Cherchell. (Alliche. S., 2011).

These walls have layers of mortar of 4 to 9 cm high. The size variation between these layers is about 30 cm (28 to 33 cm). There is an average of 5 cm height between mortar layers. At the angles and sometimes between two lifts, mortar layers increase and appear every 10 cm or in each compaction layer. Mortar is made of lime, sand, soil and gravel. The walls are made of rammed earth composed by earth with loose stones, gravel, pieces of pottery, lime pieces and sometimes, animal bones. The limits of lifts are perceptible with difficulty. Vertical limits where mortar lines stop can be deduced. Horizontal limits are made of one mortar layer out of two. This leads to 70 to 80 cm high for formwork and 200 cm wide. The use of mortar joints on the wall face can be explained by the attachment of plasters, which are not easy to use on rammed earth walls, especially if it is sandy. Mortar layers assist the plaster to bond.

The second variant of rammed earth found in Cherchell is a wall face with alternated bricks and lime mortar. Most often it is found in exterior perimeter walls and more rarely interior walls. They are always 50 cm thick. The walls have a cinder blocks base sometimes mixed with stone and cracks are filled with crushed bricks and tiles. The base height varies between 50 to 110 cm for perimeter walls. The average height, measured in most cases, is 70 cm. The general look of the wall appears as if the bricks are arranged randomly, as the distances between the bricks are not uniform. Bricks are 10 to 20 cm apart horizontally from each other and 8 to 12 cm vertically. The sheer size of the bricks does not seem to be identical, with lengths ranging from 9 to 15 cm, width between 9 to 11 cm and about 3 cm thick. They are always arranged in stretcher bond. The bricks have colours and dimensions similar to those of ancient monuments of the city therefore they seem to be roman bricks. They would have been acquired from ruined sites of the city and reused in the buildings of Andalusia-Ottoman period. The different brick lengths used in the rammed earth walls leads to the belief that the bricks have not been used totally but they have been cut in two or three parts in order to save material. It must be mentioned also that the brick dimensions have a reduced surface because the brick is actually covered, all around with the mortar. This mortar encases the bricks, and makes them look withdrawn from the face of the wall. The rather smooth outside has indentations inside. This particular arrangement is related with the way it is executed. This gives an idea about mortar use, as well as bricks inside the formwork. Visible sections of the walls certified that bricks give patterns to the wall. These walls are composed by a soil, full of pebbles with different diameters, gravel, small tiles, broken bricks and sometimes-small pieces of lime. There was will for improving the soil mechanic characteristics. High proportion of pieces of earthenware in soil composition would mean that pieces of ceramic from ancient era were numerous, existing everywhere in the city and would have been taken off the soil that was used in construction of rammed earth walls. Some walls have the two different variants on opposite faces. The interior face had mortar layers and exterior face had alternating fired bricks and lime mortar. This arrangement leads to the conclusion

Figure 6. Section of a wall face with alternating layers of brick and lime mortar: plan and sections. (Alliche. S., 2011).

Figure 5. Party wall with alternating mortar layers pattern in Cherchell. (Alliche. S., 2011).

Figure 7. Trace of the formwork side on a wall face with alternating fired brick and lime mortar. (Alliche. S., 2011).

Figure 8. Arrangement of bricks in the wall according to the variant with facing alternating brick and mortar. (Chennaoui. Y., 2007).

Figure 9. Exterior walls are partially collapsed. (Chennaoui. Y., 2007).

that bricks have a protecting role against erosion in rammed earth walls.

4 VARIANTS OF RAMMED EARTH IN TENES AND KOLEA

Rammed earth technique with alternated facing made of fired bricks and lime mortar has been found in traditional buildings of the city of Tènès. Except for some ruins and some parts of collapsed walls of a few houses, which reveal the use of a rammed earth variant, most of the religious and civil buildings seem to have been built with this technique. The walls of the Moorish bath also revealed the characteristics of this technique. The base is built on block masonry and the walls are made of layers of fired bricks arranged in spike of 60 to 90 cm high. Walls are also 50 cm thick, with alternating brick and mortar layers of 6 to 10 cm thick with matching compaction layers. The fired brick are arranged in horizontal intervals

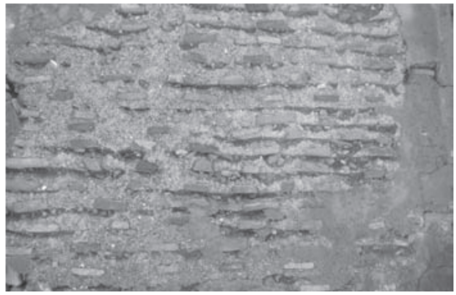

Figure 10. Bath wall built with alternating brick and mortar in Tènés. (Alliche. S., 2011).

Figure 11. Rammed earth tower in Ténès. (Alliche. S., 2011).

of 15 to 23 cm. The centre of the wall appears to be a dark colour soil full of pebbles and small stones and pieces of earthenware. The formwork phases are easily readable. The dimensions are 75 cm high and 205 to 225 cm long. Fired bricks, arranged in stretcher bond, have irregular dimensions. They vary between 9 and 17 cm long, 10 cm wide and 3 cm thick. The apparent mortar on the surface is based on lime and thick sand.

Another variant to consider is located in ancient fortifications of the old city of Tènès (city walls, gates and towers). The rammed earth of these constructions seems to belong to a period before the 16th century reconstruction of the city. It could perhaps go back to the building period of the medieval city in the 9th century, on which El-Bekri describes the ramparts and the gates. The rammed earth is composed of light colour sandy soil, full of different size small stones and parts of pottery. It is very compact and very strong, maybe because they added a significant quantity of lime to the soil. Very thin films of lime also appear on the surfaces of the compaction layers of the city walls. Wood logs were put inside of the rammed earth, very often in angles to strengthen the wall link. Regarding this kind of buildings, walls are very thick, varying from 120 to 160 cm. Walls are built on bases made of ancient cinder blocks of 40 to 70 cm high. Horizontal limits of lifts are marked by putlog holes 1 m high apart. Their width is the one of the building. Regarding the towers, putlog holes are 50 cm spacing, and the compaction layers are 20 cm apart.

In the city of Koléa the same variant as in Cherchell and Ténès was found. Rammed earth walls are built on a 60 to 80 cm high stone base, which is sometimes mixed with bricks. Walls are always 50 cm wide. Soil used for the building wall has a thin and silky texture and is full of gravel and pieces of pottery. Bricks are arranged in stretcher bond and have lengths differing between10 to 26 cm. They are 3 cm thick and between 10 and 12 cm wide. Horizontal spaces between bricks vary between 7 and 20 cm and in some walls until 30 cm. Vertical distances are between 7 to 15 cm, matching with compaction layers. Bricks are alternated in the wall face with lime mortar mixed with thin sand and a proportion of clay.

In Cherchell, as well as in the two other studied cities, the variant made of alternated fired brick and lime mortar is predominant, which brings interest in the study of this technique.

Figure 12. Rammed earth wall with facing made of fired bricks and lime mortar in Koléa. (Alliche. S., 2011).

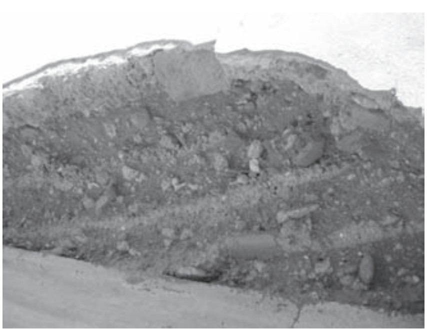

Figure 13. Interior of a rammed earth wall with facing made of bricks and lime mortar in Koléa. (Alliche. S., 2011).

5 IMPLEMENTATED RESTITUTION OF RAMMED EARTH VARIANT WITH A FACING ALTERNATED WITH BRICKS AND LIME MORTAR

This study has been based on different chosen cases in Cherchell, as well as in Ténès and Koléa, in order to understand the dissemination of the lift. Some partly collapsed walls with exposed material revealed elements that lead to understand the wall construction. The construction steps can be sum up as follows: after the formwork is set and the lime mortar and bricks prepared (either acquired in ancient sites or from bricks ovens), the mason starts with casting a layer of lime mortar all along formwork sides about 5 to 7 cm wide and about 5 cm high. Then, he arranges fired bricks on the lime mortar bed. The bricks are laid down with the longer face parallel to the formwork side and alternating an average of 15 cm. Once all the bricks are arranged, a layer of soil, about 15 cm high, is added inside the formwork. With a simple wooden rammer, the compacting action would start, first from the centre and then on the sides. Bricks would slide out of place and mortar would push up and in, against the formwork, partly covering the bricks and pushing the earth layer away. The result will be those indentations that were seen on wall sections. Once the earth layer is compacted, the mason repeats this action layer by layer, until the formwork is filled totally and a "lift" is completed. The stripping of formwork could be done now: removing the ropes, uprights and then, formwork sides and horizontal timbers off. Holes left by horizontal timbers in the wall will be filled with bricks or lime mortar. The mason then mounts the formwork beside the completed lift and repeats the steps of the previous stage until he finishes the wall. Several materials, as brick, mortar and earth, are placed inside the formwork. Walls surface lets appear fired bricks and a lime mortar coating, without the earth material being exposed. The wall

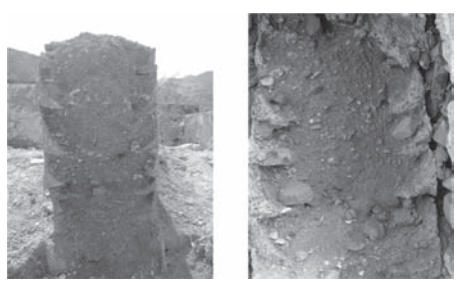

Figure 14. Section of a rammed earth walls with facing made of bricks and lime mortar in Ténès. (Alliche. S., 2011).

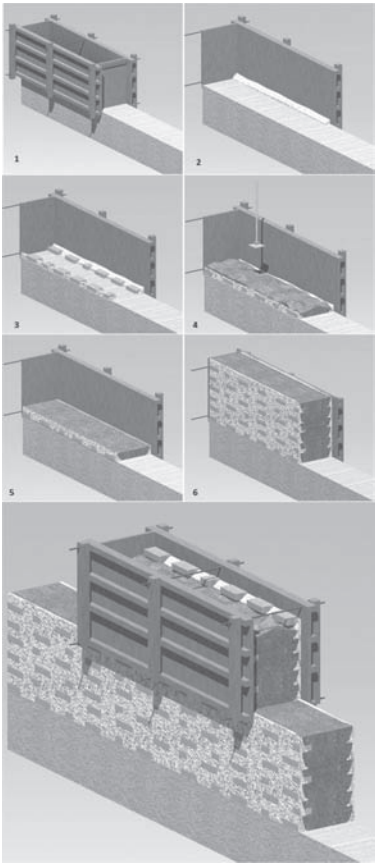

Figure 15. Construction stages of rammed earth wall lift with the face of alternating bricks and lime mortar. (Alliche. S., 2011).

finish is made at the same time, as the construction of the wall. It is one advantage of this rammed earth variant.

6 CONCLUDING REMARKS

The presence of rammed earth variants in these studied cities demonstrates the complete understanding of this method of building in the time of its use (especially from 16th to 19th century), but also, the good knowledge regarding weaknesses in rammed earth construction. Whatever the treatment of the wall, with layers of lime mortar, fired bricks or adding lime to the soil, the principal aim was to bring a solution to technical problems. Rammed earth pathologies can be severe, as is the case of wall erosion caused by rain water streaming down; high level of humidity; problems of wall plasters bonding; and resistance difficulties caused by bad quality soil. Ancient technical solutions reveal the high level of building efficiency of builders in that time period. The relation in the formwork of the earth mixture with other materials reveals that the real question concerned the construction of the *tabiya* (Bazzana, 1992), which is a shaped material executed with formwork (Van Staevel, 1999). Even if the word does not exist anymore in the studied cities today, it was a choice to study it again, in order to reveal this building process.

Rammed earth walls with a facing of alternating fired bricks and lime mortar is a recurrent variant in the mentioned Algerian cities, with great similarity to the Spanish *Tapia Valenciana*. This could raise questions related with the origin of this technique. Andalusia people who came to settle on the Algerian coast, especially in Cherchell, probably brought the know-how of this building technique with them. But this hypothesis will just be confirmed, if Algerian and Spanish rammed earth techniques are compared in a systematic way.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Traditional braces for rammed earth walls constructions in La Manchuela albaceteña, Castilla-La Mancha, Spain

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ABSTRACT: Structurally, soil as a building material performs well against compression forces but has a low tensile strength. Usually, in earth construction, floor slabs and roofs are not connected to walls with horizontal and vertical reinforcements. Due to this, structural elements are independent under external loads. Traditionally in Spain, improvements have been made by modifying earth composition (adding lime) or by bettering the constructive method (steel wall, cemented wall, etc.). These improvements increase resistance but they do not solve the weakness caused by the lack of traction resistance in the uppermost corners and the joints between walls. This is solved by bracing the walls. In the region of La Manchuela albaceteña, Albacete, Spain, there is a brace solution called reeled brace. This paper show origins and evolution, components (brace, pins and wedges), classifications, construction systems and structural behavior compared to other traditional braces, and its application in rehabilitation and new buildings.

1 INTRODUCTION

In Spain, earth constructions have been in place since before the arrival of the Romans (Plinius Secundus, 77). It appears more often in the central and southern areas of the peninsula where the natural composition of the earth provides a strong base for its use in construction. The adobe and rammed earth walls structures were present in all types of constructions, from defensive strongholds and public buildings to family homes and partition walls.

Structurally soil as a building material performs well against compression forces but has a low tensile strength. Therefore it is important to mold and condition the material towards compression and avoiding tensile forces. Another problem is the necessary thick and the poor joining of rammed earth wall sections. This means that any horizontal action (wind and seismic activity) could prove extremely dangerous for users if appropriate security measures are not taken. Improving soil for either adobe or rammed earth walls, will improve its characteristics and structural strength (Binici et al., 2005; Galán-Marín et al., 2010; Hossain et al., 2011; Turanli et al., 2011; Yetgin et al., 2008).

Another structural aspect of the construction design which is concerning is that usually in earth construction, floor slabs and roofs are not connected to walls with horizontal and vertical reinforcements. Due to this, the floor slabs or roofs do not connect directly to the framework and thus do not distribute pressure nor reinforce the building. Walls become independent structures positioned under external loads. This worrying issue of horizontal pressure is also increased in areas of regular seismic activity.

Traditionally in Spain great improvements have been made to the behaviour of earth walls by modifying its composition (adding lime) or by bettering the constructive method (steel wall, cemented wall, etc.) (Font et al., 2009; Graciani et al., 2008; Castilo et al., 2003). Although these improvements increase resistance in constructions, they do not provide the solution to the weakness caused by the lack of traction resistance in the uppermost corners and the joints between walls. The solutions to this problem are three types of corner bracings: placing ashlars or rough stone into the corners in place of earth; using ring beams whether they be reinforced into the corners or not; embedding wooden struts into the walls.

Throughout the region of La Manchuela albaceteña in Albacete, Spain, they developed their own techniques for bracings which are traditionally used in family homes, the reeled brace.

2 REELED BRACE (“TIRANTA ASPADA”)

2.1 *Description*

From the historic and compositional vision of the Historian and Museolog D. Manuel Jorge Aragoneses about the elements behind the reeled brace and its classification (Jorge, 1984), the

Figure 1. House with reeled brace.

Figure 2. Façade detail of the house with releed brace.

Figure 3. Releed brace. View from the outside. Cut-out in the axis of the brace. Brace, pin and wedge. Halfures lap joint assemble. Brace, pins and iron wedges.

cataloguing of these elements is being developed and expanded to bring an architectural, constructive and structural vision.

It is usually used in corner buildings or blocks and on sloped ground in order to absorb the

Figure 4. Releed brace. View from the inside. Brace.

traction pressure and the consequent movements between the corner wall.

The system is made up of three elements: the brace, the pins or arms which cross to the exterior and the wedge which hold them in place. It consists of reeling the walls together using wooden struts and pins on the exterior of the wall limiting their movement. This was thought up as a way of absorbing traction pressure localised to the uppermost corners of the wall joints where no beams are found, taking advantage of the compression pressure exerted by the brace and the pins.

The brace is normally a straight tree trunk, in the same way that the trunks form beams, tiebeams, lintels etc. of the building. With the bark removed and with a radius of around 10 and 25 cm (depending on the house). At both ends a cut out is made (the oldest and most traditional solution) to fit the pins, this is around 30–40 cm from the end so as not to tear the post.

The pins are straight or curved, made of wood (squared-off trunks or sawn-off planks) or metallic (ploughtails). They are placed in the cut-outs on the side, parallel or perpendicular to the floor for an easier placement and hammered into position.

The wedges are used during construction to fasten the pins into place in the cut-outs, either with one wedge, or with two (one on top of the other crossing over at the points). Throughout the lifespan of the construction, either due to weather conditions or just old age, the wood warps and any problems can be avoided by simply adjusting the pins against the walls and adding new wedges. Load bearing wedges are usually used to fix the pins to the half lap joint hooks.

The dimensions of the different elements vary greatly. A greater distance, a greater length and a greater diameter. The braces vary in length from 1.50–3.80 m for diagonal braces and 3.50–5.80 m for perpendicular braces and have diameters from 0.10 to 0.20 m; the pins are around 0.50 to 0.75 m long and about 0.12 m wide or in diameter; and the wedges are usually 0.15 to 0.20 m long with heads of 0.05×0.05 m. These are placed at a distance of 0.70 to 1 m from the deck.

Looking at the history of bracings we have found out that the builders who used rammed earth were used to the mechanics of compression bracing and its different elements. The pressure put on the earth during the implementation of rammed earth walls over timbers was counteracted by the wooden crossbeams, iron struts or esparto fixings in order to create spaces to be filled with earth. Therefore, it is possible to borrow and transfer these stability elements and the framework of the timbers and use it in rammed earth wall constructions to counteract the tensile pressure in the corners.

The oldest and most important of all earth constructions had wooden struts embedded in the corners or the ring beams and this was their implemented bracing system. In some cases a brace was placed diagonally and this joined the elements in the corners. It is worth mentioning the city of Chinchilla de Montearagón in Albacete as an historical city there are numerous examples of public buildings with these systems in place, like: the Tercias Reales, San Julian Hospital, the Santa Maria del Salvador church and the Rosario chapel in the cloister of Santo Domingo, all these are buildings from the 14th to the 16th Centuries (Pretel, 1992). The referenced origins until now of the reeled brace, are confused with these systems. On the other hand, the reeled brace was limited to the Manchuela region and to humble living quarters, they were a much simpler interpretation of the embedded struts or the ring beams. In the houses built for farmers or humble families, economic possibilities were fewer. The reeled brace fulfils all necessities and is an ingenious and simple wall brace using few materials and labour is also reduced. Another advantage worth pointing out is that as they remain in sight, they can be easily checked and their performance maintained.

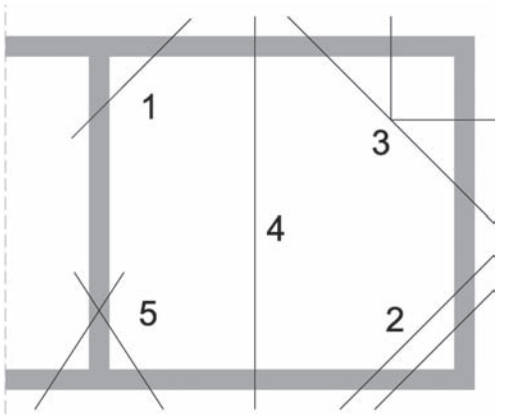

Figure 5. Schemes of reeled braces. 1 Diagonal single. 2 Diagonal double parallel. 3 Diagonal reinforced double. 4 Perpendicular single. 5 Diagonal (Façade and load bearing wall) single.

2.2 *Classification*

Reeled braces can be classified in many ways highlighting the position and configuration of the brace which is after all, what defines the reeled brace as a system of bracing. From the houses analysed for this project we can simplify all the scenarios into a combination of two classifications, highlighting the structural and constructive nature of the system and this is shown in Figure 6.

Position of the brace:
The brace can be positioned at a 45º angle from the bracing walls (diagonal bracing) or at a 90º angle (perpendicular bracing.). The diagonal bracing joins two perpendicular walls whereas the perpendicular brace joins two parallel walls.

The diagonal bracing could be between two walls which form the corner of a building (the two walls of a façade, a façade with a partition wall) or even a façade wall with an intermediate load bearing wall.

Configuration of the brace:
The brace can be a single; that is one single brace holding together two walls, this is the most common configuration. If the loads or spaces are larger to cover, a double brace can be used instead, this means two parallel braces or a single reinforced brace.

Two parallel braces are different and can join the walls together at different points, and therefore provide a better connection and stability. The reinforced brace consists of placing a couple

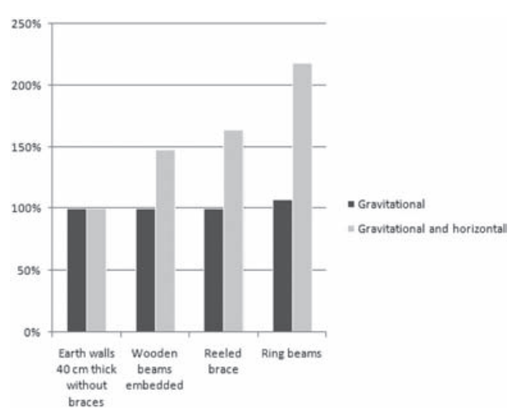

Figure 6. Coefficient breaking reference.

of secondary braces which connect the walls to the primary brace and the half lap joint. This way there are more anchor points which reduces the amount of space to cover.

Other complimentary classifications:
The material which the pins are made of defines the type of attachment. The pins are mainly made out of wood whether from the same trunks as the braces or from sawn-off planks, but always ensuring they are the perfect size necessary to be assembled along with the cut-outs. These pins can be attached into place using normal wedges or wrought iron nails. In some cases, plough tails (metal pins) instead of wooden dowels and wedges.

The configuration of the rod defines the crossbeam which limits the movements between the brace and the walls. The ideal configuration would consist of one single pin, ensemble perfectly to fit into the cut-out without the use of wedges. Another option would be a component of pins already fixed in place by wedges. And finally, carrying out a crossbeam with two opposite wedges, one from above and the other from below whose extremes are located inside the cut-out. These two last options must not be confused with adjusted dowels with new wedges having been fitted due to wear and tear and the warping of the wood. In the adjusted rods, the original pin is always present but the room in the cut-out where it is to be fitted requires that a new wedge is used to achieve a perfect fit.

The assemble of the brace and the pin is carried out in a rectangular cut-out or conical to achieve a stronger attachment. This cut-out is found in the centre of the axis of the brace and near the end, but separated just enough to avoid splitting of the heads due to the pressure. This layout is the oldest and most traditional, although previously there came about a type of assembly in a half lap joint on one of the sides of the brace. The half lap joint assemble allowed the use of straight pins which were set in place with iron wedges.

2.3 *Causes of disappearance*

Currently few examples of the reeled brace construction remain; this is down to the fact that many houses have had work done to them or they have been completely refurbished and are now in a perfect condition. There are different reasons for the disappearances of this bracing system in the Manchuela region.

Firstly and most importantly, the earth have become obsolete in construction materials because it has been replaced by industrialised construction systems brought about with the appearance of new materials around the 20th Century.

The second cause is the disappearance of rammed earth homes built using reeled braces due to building demolition and replacement by modern construction systems on the same site, or because they have been left abandoned or in a state of disrepair. Being left abandoned has brought about the ruin of these buildings and as a result the wearing-away of linings allowing the filtration of damp and humidity both into the walls as into the wood leading to deterioration and collapse.

It must be pointed out that rehabilitation earth buildings with reeled braces and eliminating this system or the elements found on the facade (pins and the end of the brace) would free up the crossbeam stopping compression the joint between the walls and therefore creating cracks due to lack of lateral stability in as little as 1–2 years. This way the joint becomes weal, cracks appear and the general structure begins to weaken possible resulting in collapse.

2.4 *Advantages and disadvantages*

From a constructive and structural point of view, the reeled brace is a simple connection for walls (both parallel and perpendicular), which absorbs tensile pressure which is produces in the uppermost part of the joints. Being in sight, this system allows for easy maintenance of the wood and, if necessary, the pins can be easily readjusted or replaces when subjected to wear and tear.

Disadvantages would be that firstly, without adequate protection of the brace heads, there the pins are inserted, and the wood will rot and call for adjustment or even replacement later on in the life of the structure. Secondly, there are disadvantages from an aesthetic point of view, having the ends of the braces with their pins and wedges in sight in the uppermost corners of the facades, as with having the brace in sight in the interior too hindering the use of that space on the top floor.

3 OTHER TRADITIONAL BRACES

3.1 *Wooden beams embedded in the corners on top floors*

Wooden beams embedded inside the wall as a reinforcement of the corners. While joining the corners of the walls together, wooden struts are inserted in the longitudinal direction of the walls that are interconnected for reinforcing the corners. It is important to ensure the partnership between bracing wood and earth walls for is aided by a proper tied corner. We must also control the composition, density and thickness of the walls to prevent moisture, insects and fungi rotting the wood.

3.2 *Ring beams*

Wooden beams placed on the top of the walls reinforcing all the walls together and distributing the roof loads. Ring beams, bond beams, tie beams or perimeter beams.

Like the model *Wooden beams embedded*, it is important that the ring beam and the walls work together to ensure the proper bracing in the walls and the load sharing. We must also control the composition, density and thickness of the walls to prevent moisture, insects and fungi rotting the woods.

4 EXPERIMENTAL

The tests performed in laboratory supported by computer analysis show an increasing of the overall resistance of the rammed earth wall structures with braces.

100% is the usual maximum load in the life of the building, increasing loads until they collapse, thereby obtaining the collapse load for each model referenced in Table 1. With all the results and using model *Earth walls 40 cm thick without braces* as a reference, we can compare the overall response of each of the models. This table gives a simple and direct comparison between the models analyzed. They show the different performances, assessing and quantifying their effectiveness and also graphics for a better understanding.

5 RESULTS AND DISCUSSION

The models *Wooden beams embedded, Reeled brace* and *Ring beams*, although the joints between the walls crack, separating the walls from one another, the braces supply some reinforcement allowing the walls to continue to work together, limiting the collapse due to failure in the joints.

The models *Wooden beams embedded* and *Reeled brace* produce a significant increase in resistance against cracking at the top of the corners due to the effect of being attached to each other. As result, there is a redistribution of tension along the wooden strut, acting only at the joint between the walls. But in the case of model *Reeled brace*, better results are produced due to it being bound and braced.

In the model *Ring beams*, the placement of a wooden beam attached to the top of the earth walls ensures a greater join between the different walls and thus a better structure overall. Moreover, the ring beam provides a better sharing and distribution of the loads. These solutions slightly increase the resistance to gravity loads and are the ones that work best against horizontal loads.

Under gravity loads, the table shows that all models are in the same range of values, with models braced slightly above unity due to their walls being 40 cm thick. Increasing their thickness will increase the resistant area and hence its resistance to these loads.

Under gravitational and horizontal loads (wind) we can see that any bracing system substantially increases the overall resistance of the structure. Reinforcement with wooden struts increase the overall resistance to these loads between 48% and 118% depending on the system.

Braces that act at the corners considerably increase the resistance. Model *Wooden beams embedded* increases by 48%, while model *Reeled brace* has an increased resistance of 64%. This implies that with the same materials that floor slabs are made of (wooden struts), intertwining the corners at the top, greatly increases the overall strength of the structure in comparison with the same building without any kind of brace. Simply acting directly on top of the joints between the walls, the areas where a usual bending failure would occur in an earth construction.

Model *Ring beams* doubles the global resistance of the model without braces increasing by 118%. This is a result of monolithic structure and the redistribution of pressure. Beams placed at the top of the walls (wooden beams of the same characteristics and dimensions as floor slab beams) allow the whole structure to work together in a more uniform distribution of weight throughout the structure and increasing its overall strength.

Table 1. Coefficient breaking reference.

	Gravit.	Gravit. & Horiz.
Earth walls 40 cm thick without braces	100%	100%
Wooden beams embedded	100%	148%
Reeled brace ("Tiranta aspada")	100%	164%
Ring beams	107%	218%

6 CONCLUSIONS

The soil based constructions, and in particular rammed earth walls and adobe, are vulnerable to tensile forces which are derived mainly from important horizontal external loads. This is accentuated in the case of earthquakes: earthquakes with 0.20 g acceleration can bring soil based constructions without braces to the brink of a collapse; and these kinds of earthquakes are frequent in area of high seismic activity where people continue to live and build earth constructions.

The common failure of these buildings comes from the top of the joint between walls, becoming independent, losing lateral stability and giving way to collapse.

Traditionally, bracing systems have been used with the aim of reducing this problem, which becomes more or less important depending on the characteristics of the building and weight to be borne.

Two aspects of the braces which need to be checked are: correct anchoring between the reinforcing element and the wall to prevent slippage and separation that would otherwise not work together; and in the case of wooden struts or reeds inside the walls, the control of the composition, density and thickness of the walls to prevent moisture inside and the possible rotting of the wood-reed.

Among the models that act only in the corners, *Wooden beams embedded* and *Reeled brace*, do not show big differences. Although model *Reeled brace* has more resistance and can be controlled better due to the fact that it remains seen.

Model that act on the entire building, *Ring beams*, is the one with the best performance. It acts on the whole structure and promotes collaboration between all walls and provides a better distribution of weight. It is necessary to ensure that the joint between the wooden beams and the walls is adequate therefore eliminating possible differential movement. This solution is part of all seismic guidelines of soil based constructions being reinforced horizontally or vertically.

As shown, the bracing of the walls significantly increases their ability to withstand horizontal loads by creating an adequate joint between two walls. Braces are a necessity for global stability and monolithic nature of the earth buildings, and is an essential security element in seismic areas.

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Godelleta's watchtower (Valencia, Spain)

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ABSTRACT: The Tower of Godelleta (Valencia, Spain) is a defensive construction of the Muslim period. It was once part of the defensive line of Valencia. These towers were usually built in isolation, although later on, they were surrounded by other buildings. It was typical, that the constructions around the tower were torn down over the years and the tower itself returned standing alone. In this particular case, the annexation of dwellings has remained. The main constructive system of this tower is mud wall. This article presents a historical survey of this typology, as well as the materials used and the construction techniques applied in the system.

1 INTRODUCCIÓN

La torre se encuentra en el centro de la población de Godelleta (Fig. 1), parcialmente adosada a viviendas particulares. Se encuentra sin restaurar, en un estado de semirruina, y en una propiedad privada muy cerca de la iglesia parroquial del pueblo (Fig. 4).

2 SITUACIÓN

2.1 *Estructura urbana*

El pueblo de Godelleta se generó como una alquería ligada al tejido agrícola que poco a poco se consolidó como un municipio en la ladera de un pequeño macizo, por ello podemos observar que las calles se desarrollan en dos direcciones: una paralela a la ladera de la montaña y otra perpendicular a ésta. Además se observa una calle Mayor paralela a las líneas de altimetría donde se concentran los comercios y viviendas más notables del pueblo. Perpendicularmente a ésta se encuentra una calle que llega hasta la huerta y hasta la carretera regional de acceso al pueblo.

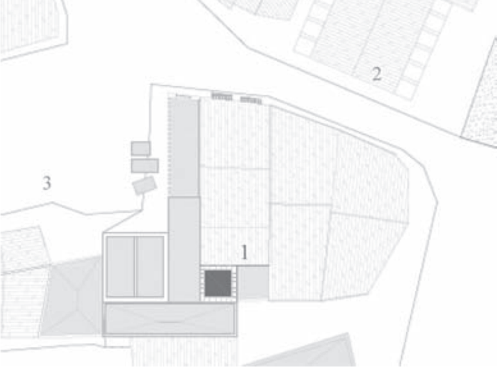

Figura 1. Emplazamiento de la torre. Situada en entorno urbano con viviendas adosadas. 1-Torre, 2-Iglesia parroquial, 3-Calle del Ayuntamiento. (Autor: realización propia).

2.2 *La Huerta*

Probablemente La Huerta de Valencia sea uno de los paisajes históricos más complejos de las tierras valencianas tanto por su morfología espacial como por la densidad de arquitecturas, espacios y huellas que se han ido acumulando en su seno a lo largo de los siglos. Esto se debe, en buena medida, a encontrarse situada en el entorno de la ciudad más grande del antiguo reino de Valencia y de la capital del Sharq al-Ándalus durante el período musulmán, lo que ha provocado una larga y fecunda interrelación entre mundo urbano y mundo rural, pero en ello también ha influido, sin duda, su larga historia. Se debe tener en cuenta que este paisaje específico de regadío tiene una antigüedad de alrededor de 1200 años, pues sus orígenes se remontan a la instalación de los grupos tribales musulmanes que empezaron a llegar a la Península Ibérica a lo largo del siglo VIII alrededor de la, entonces muy pequeña, ciudad episcopal romano-visigoda de Valentia.

Aunque se ha argumentado en tiempos pasados sobre los orígenes romanos de este espacio agrícola, fueron los campesinos musulmanes los que crearon la primera Huerta de Valencia así, con mayúsculas, los que diseñaron y construyeron sus primeros sistemas hidráulicos, probablemente la acequia de Rovella, quizá la de Favara, junto a las de Petra, Rambla y Algiròs, y fundaron también los primeros poblados: las alquerías andalusíes.

Para terminar con lo que respecta a la huerta comentaremos la red hidráulica, esto es, la reconstrucción formal y jerarquizada de la trama de cada uno de los sistemas hidráulicos que conforman esta huerta. Esta primera red es la que construyó el paisaje de forma más significativa en sus orígenes andalusíes, aunque adaptándose en mayor o menor medida a un espacio natural con sus irregularidades físicas que debía sortear y solucionar.

2.3 *Línea defensiva*

Actualmente todavía se puede detectar la presencia musulmana en Valencia gracias a la existencia de algunas torres, casi todas de base cuadrada y que pueden alcanzar una altura de hasta 26 metros. Muchas de estas torres formaban parte de la línea defensiva de la ciudad de Valencia. La torre de Godelleta es una de ellas.

En algunos casos, unos siglos después de la conquista cristiana en el siglo XIII, las alquerías quedaban despobladas por diversas circunstancias. Hoy en día pueden verse las solitarias torres aisladas de lugares como Buñol, Chiva, Macastre o Turís. En algunos de los casos, la torre había sido el origen de una población permanente como sucedió en Paterna, Silla, Torrent o Benifaió, sin embargo, en Godelleta o Bofilla la alquería existía antes de la construcción de la torre.

3 TIPOLOGÍA

La torre de Godelleta es una torre defensiva musulmana que se empezó a construir en el siglo XII y que continuó su realización hasta el siglo XIII. Sin embargo, la alquería que iba a defender era originaria del siglo XI. Pertenece a un conjunto de torres de vigilancia que se realizaron a propósito de defender los núcleos de población existentes. Íntimamente ligadas a las torres de l´Horta estaban las alquerías.

Centrándonos en nuestro caso, la alquería de Godayla (que más tarde sería el pueblo de Godelleta) disponía de una torre vigía. Era la torre principal de las fortificaciones que defendían la alquería musulmana, ya que en sus proximidades se han encontrado vestigios de amurallamientos que parecen probar la existencia de una pequeña fortaleza.

En primer lugar consideramos conveniente hacer una descripción de la forma y las partes principales de las que constan estas torres. Presentan plantas cuadrangulares o rectangulares, de gruesos muros de tapia y aspecto esbelto, con alturas desde los 16 metros hasta superar en ocasiones los 20 metros. Disponen de un único acceso elevado sin huellas aparentes de haber existido ningún sistema fijo para acceder, lo que muestra su carácter defensivo. Este acceso se resuelve con un hueco de pequeña dimensión que no permite el paso erguido de una persona. Al acceder se observa que bajo esta planta aparece normalmente otra planta destinada a aljibe y/o almacén. En sentido ascendente se suceden las plantas, normalmente en número de tres y sin más aberturas al exterior que aspilleras destinadas a la defensa. Al acceder a la azotea de la torre nos rodean las almenas y vanos formando la crestería que nos protege al tiempo que nos permite repeler ataques enemigos (Fig. 2).

En concreto, la Torre de Godelleta es de planta cuadrangular y su parte superior se defiende con parapeto coronado de almenas. Fue construida con muros realizados con la técnica del tapial (piedra y argamasa). Este tipo de fortificación poseía un pequeño recinto amurallado donde se cobijaba la población y sus ganados en caso de peligro. En tiempo de paz se utilizaba como granero comunal. La planta baja es la que daba servicio a estos usos. Siguiendo el esquema general explicando anteriormente, la puerta de acceso se encuentra en la primera planta, bastante elevada sobre el suelo (Fig. 2), llegándose a ella desde el adarve del

Figura 2. Alzado este. En esta fachada se encuentran la puerta de acceso original en primera planta, las aspilleras en segunda y tercera altura y las almenas rematando la torre. (Autor: realización propia).

recinto adosado. La segunda y tercera planta son cámaras de habitación con techs de madera y la cuarta forma la terraza defensiva almenada. En el interior hay una serie de salientes adosados a las paredes que son restos de la escalera que servía para acceder a las ventanas y a las almenas a la hora de prevenir posibles invasiones.

Sobre la relación que existe entre la tipología y la línea defensiva a la que pertenece, podemos comentar cómo se comunicaban entre las distintas torres. El emplazamiento de las numerosas torres, no muy distantes entre sí, les permitía transmitirse cualquier noticia por todo el territorio en poco tiempo mediante señales de humo durante el día y de fuego durante la noche. La penetración de las tropas de Jaume I en tierras musulmanas suponía un gran riesgo para la población; inmediatamente, según apuntaba Jaume I en su *Crónica*, las torres empezaron a hacer señales de humo comunicándose la amenaza que llegaba. Por esta razón, el rey Jaume I evitaba siempre que le fuera posible encontrarse con la red de torres, aunque por otro lado, también encontró una poderosa razón para saquearlas: el botín. Después de conquistada la torre describía el botín conseguido.

4 FUNCIONALIDAD

A estas torres se les atribuyen varios valores estratégicos: Por un lado, un valor genérico de vigía y protección a los núcleos de población dispersos o alejados; por otro lado, otro valor particular por pertenecer al "cinturón defensivo de la ciudad de Valencia". Una misión importante de este tipo de construcción, en relación con el resto de los bastiones de la huerta de València, era el de comunicarse cualquier tipo de acontecimiento que tuviera lugar en ese momento.

También cabría preguntarse acerca de las motivaciones que guiaron su construcción, es decir, cuáles fueron sus funciones.

Respecto a esto podemos afirmar que todas las construcciones fortificadas enumeradas cumplen una función defensiva, ofensiva, política y cultural.

La función defensiva se manifiesta como la más obvia y primordial. Ante un ataque enemigo, una fortificación nos da resguardo y nos facilita avituallamiento.

La función ofensiva deriva en principio de la propia defensiva, dando realidad a la máxima que afirma que "la mejor defensa es un buen ataque". Basándose en este postulado los diseños de los castillos y torres han ido evolucionando para que, al tiempo que ofrecen un inexpugnable cobijo, puedan dar también respuesta a su atacante y causarle el mayor número de bajas posible.

La función política de estas construcciones se puede comprobar cuando se integran dentro de un sistema administrativo del territorio, pasando a formar parte del engranaje centralizado, ya por su dependencia directa, ya por sus acuerdos de servicios.

La última función apuntada es inherente a cualquier manifestación arquitectónica. La función cultural incluso ha sobrevivido al paso del tiempo y, de hecho hoy, en el siglo XXI, se tratan y se ponen en valor a estas construcciones. Se podría afirmar que estas arquitecturas trascienden lo meramente formal.

5 SISTEMA CONSTRUCTIVO

Los muros de la torre de Godelleta son de tapia de tierra y cal. En la parte más alta, se observa un mayor deterioro de la costra, dejando expuestos los mampuestos con los que ha sido reforzada la masa interior de la tapia.

El muro de tapia es tecnológicamente autónomo, ecológicamente estable y por tanto, duradero; el aporte energético necesario para su construcción es mínimo y su capacidad aislante del frío y el calor, excelente.

Para su ejecución se utilizaba un encofrado o tapial, que se iba rellenando progresivamente con tongadas de tierra mezclada con una cierta proporción de cal y piedra.

5.1 *Proceso constructivo de La tapia*

El tapial se construye a menudo sobre un zócalo de otra fábrica que le protege de la humedad. Sobre este zócalo se montan los encofrados o tapiales, siendo la separación de tableros el espesor que tendrá el muro.

Los operarios que intervenían en la ejecución del tapial solían ser cinco por tablero: dos apisonadores, un amasador y dos peones. El amasador suministraba la tierra en baldes a los apisonadores que estaban dentro del tapial, y éstos extendían la primera tongada de tierra de 8 a 10 cm de espesor, apisonándola (Fig. 3). En el proceso de apisonado, se produce la migración de finos y de cal hacia el exterior que genera un acabado más fino y liso.

5.2 *Construcción de La torre*

Los muros de la torre tienen un grosor de 1.20 metros en la parte inferior, y se van estrechando progresivamente conforme aumenta la altura de la torre, llegando a una sección aproximada de 0.80 metros. Este cambio de sección se realiza a través de un escalonamiento que permitía el apoyo de las vigas de madera que soportaban los forjados (Fig. 5).

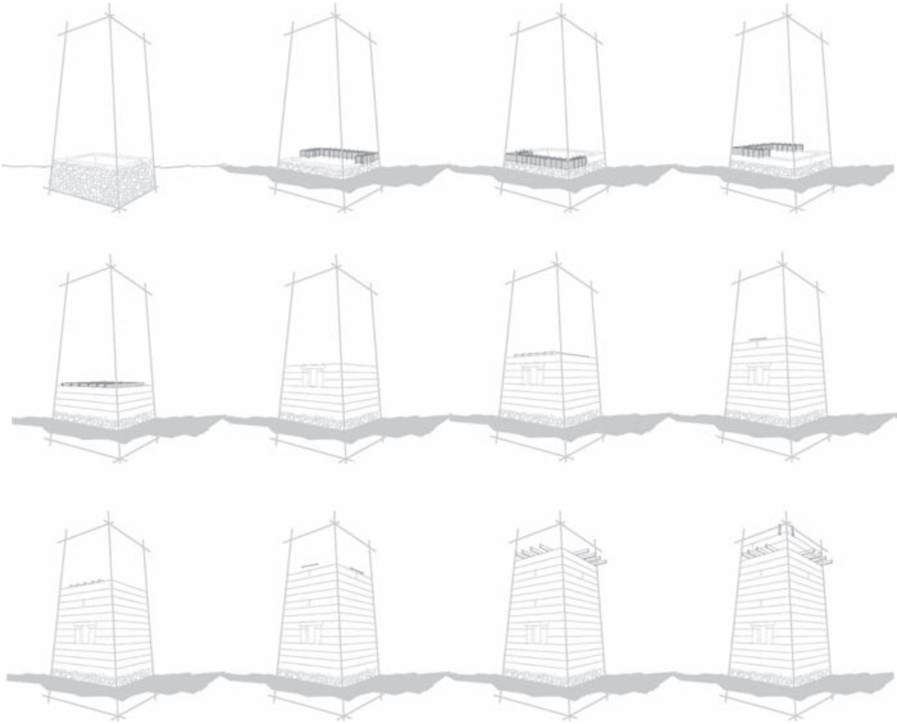

Figura 3. Proceso de construcción de la torre. (Autor: dibujo de realización propia).

Figura 4. Alzado sur. Vista de la torre en su entorno. En esta fachada se aprecia su deteriorado estado actual con enormes grietas y pérdida de material. (Autor: realización propia).

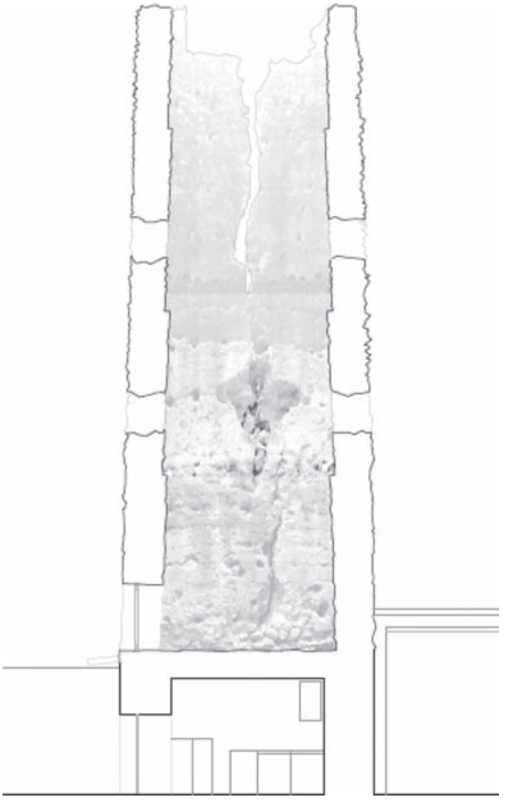

Figura 5. Sección de la torre. Los forjados originales ya no están y se aprecia la cocina en la base de la torre y el patio de la vivienda a la que pertenece. (Autor: realización propia).

En la cimentación los muros pueden llegar a ser de 1.40 metros de espesor. Las tapias, de cinco tablas, miden 0.80 y 1.05 metros de altura. Existen tapias de distinta medida ya que corresponden a diferentes etapas de la construcción como detallaremos más adelante.

En los muros todavía pueden verse las marcas de las tablas y las perforaciones hechas por las agujas de madera, características de esta técnica constructiva. Esto se aprecia significativamente en el interior de la torre donde todavía se conservan algunos fragmentos de madera.

En los muros exteriores, excepto en la fachada norte que se muestra ciega, se abren dos aspilleras en cada alzado, una aspillera en la primera planta y otra en la segunda, situándose en la tercera planta las almenas (Figs. 2, 4). En total hay seis aspilleras.

La puerta de entrada original se abre a la altura de la base maciza, a 3.5 metros. La abertura tiene una altura de 1.5 metros y 0.80 metros de ancho. El dintel y las jambas están formados por bloques monolíticos de piedra caliza, algunas de forma irregular, probablemente aprovechadas de otras construcciones. Se sabe que ésta es la puerta original, puesto que no se observa ningún cambio de material en los muros laterales que indique que se abrió un vano posterior a la construcción de la torre para colocarla.

En el interior llama la atención la claridad del sistema constructivo. La planta se aprecia aparentemente cuadrada (Fig. 1), aunque al medirla apreciamos que en realidad es ligeramente trapezoidal.

5.3 *Evolución del sistema constructivo en la torre*

Una edificación tan antigua y cuya construcción es costosa se ve expuesta a sufrir alteraciones en sus técnicas constructivas. Nuestro esfuerzo por desentrañar cuáles fueron sus fases de construcción nos ha llevado a deducir que tanto el tipo de tapia como los materiales han ido variando a medida que la torre se iba elevando. Como se comentó anteriormente pues, en la torre de Godelleta se pueden apreciar diferentes etapas en su construcción.

El arranque de la torre fue construido con tapia reforzada con piedra. Esta técnica es la misma en las seis primeras hiladas. Se pueden apreciar las perforaciones dejadas por las agujas, con una separación de 0.80 metros, hecho habitual en las tapias musulmanas del siglo XI. El paso del tiempo ha ido arrastrando la costra de la tapia y dejando al descubierto el tamaño y la forma de las piedras que se incorporaban con la intención de que la tapia adquiriera más resistencia. A continuación encontramos unatapia de transición, con la que entendemos que se pretendió dar una base más sólida para continuar la edificacion.

con muro de mampuesto realizado con encofrado, éste correspondiente a la última etapa de la construcción tras la Reconquista, ya en manos de los cristianos. Esta última fase se aprecia en las cuatro últimas tongadas separadas entre ellas 1.05 metros. La proporción entre piedra y áridos, el aumento de tamaño de la piedra, y la separación entre las perforaciones de las agujas nos ha permitido llegar a esta conclusión.

6 ESTADO ACTUAL

La torre de Godelleta es particularmente especial por su emplazamiento. Como se comentaba al principio de este artículo, la torre se encuentra integrada en un núcleo urbano tal y como originalmente se insertaban en las alquerías para proporcionar seguridad y un sistema de defensa eficaz.

No ocurre lo mismo con el resto de torres de esta época, las cuales se hallan exentas por diversas circunstancias como que las edificaciones menos resistentes no han podido sobrevivir.

Esta peculiaridad de encontrarse rodeada de construcciones ha hecho que la torre pasara a ser propiedad privada y se le diera un uso totalmente diferente, ya que ahora forma parte de una vivienda, estando la cocina de la misma en la zona inferior de la torre (Fig. 5), y por lo que se ha investigado y contrastado, esta cocina se encuentra ahí desde hace más de un siglo.

Para poder acceder a la cocina con mayor comodidad se abrió un segundo acceso desde planta baja haciendo un gran hueco en la base del muro de tapia. Esto ha podido ser la causa de muchos de los daños estructurales que hoy en día sufre la torre. Dichos daños alcanzan en determinados puntos un tamaño considerable, apareciendo grietas con una abertura de hasta 45 cm con gran pérdida de material (Fig. 4).

Las actuaciones en las viviendas colindantes también han provocado problemas en la estructura debido a movimientos del terreno y los asientos diferenciales, provocando incluso la caída de una almena.

El primer forjado, el que actualmente es el techo de la cocina, es el único que hoy existe y está realizado en hormigón, habiéndose perdido el resto de forjados originales que eran de madera.

Todas estas intervenciones, que han perjudicado a la torre, al mismo tiempo nos demuestran la alta resistencia de este sistema constructivo.

7 CONCLUSIÓN

Para terminar cabe hacer una breve reflexión tras el estudio de esta construcción.

La torre de Godelleta es un ejemplo único debido a que se conserva sin haber sido intervenida en cuanto a su restauración se refiere.

Esta torre, a pesar de ser importante por su historia y sus características, ha estado olvidada hasta el punto de alcanzar un estado de semirruina que hace peligrar el documento histórico que supone. La degradación de los materiales y las intervenciones que ha sufrido a manos de diferentes propietarios ponen en peligro una arquitectura hoy en día, única.

La torre de Godelleta tiene un valor más que suficiente como para ser objeto de un serio estudio y de un proyecto de consolidación debido a su deteriorado estado. Todo esto, con el fin de dar valor a una construcción de más de ochocientos años de antigüedad y de evitar la pérdida del documento que nos aporta, tanto para la historia de la arquitectura, como para la historia de la ciudad.

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Earthen architectural heritage in the South Piedmont area (Italy): Strategies for its re-evaluation and for local territorial sustainable development

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ABSTRACT: Novi Ligure (in the province of Alessandria) is a small Italian town in the South Piedmont Region. This area is characterized by an important rammed earth heritage. In recent years the Novi Public Authority decided to preserve and revalue it, defining a specific programme (called Earth Lands-Terre di Terra). The submission of a thematic ecomuseum was another strategy carried out by Novi Ligure in partnership with others local stakeholders. The main interest is focused on promoting and setting up permanent actions of preservation, re-evaluation, training and dissemination, in order to place it in an economic system, strictly correlated to the best territorial exploitation policies. At the same time all these scheduled actions find a reference in regional policies as the Regional Law concerning the conservation of earthen heritage.

1 THE CONTEXT

1.1 *The fraschetta area*

The lower part of the Alessandria province (Piedmont Region, Italy) and the so-called Monferrato territory are the richest areas in Piedmont of earthen buildings; here old farmhouses, as well as private and public buildings (schools, etc.) still coexist. This unique heritage in Italy (apart from the Sardinia and Calabria Regions) marks both urban (and historical) centres (palatial mansions, churches, public buildings, etc.,) and rural landscapes.

This territory is defined by three different areas: the area of unfired handmade bricks, the area of rammed earth and a mixed technology area, where adobe and rammed earth are used together for load bearing structures. These building techniques can be designated to three specific geographical areas: the main one is the so-called Fraschetta Plain, extending amidst the towns of Tortona, Alessandria and Novi Ligure in the south. Here the rammed earth constructions are more than 50% of the buildings: sometimes they show strengthened corners with fired bricks, or load bearing structures of fired bricks (as pilasters). The second area concerns the southern part of the province of Alessandria, situated among the small towns of Casalcermelli, Castelspina, Sezzadio, Predosa and Castelnuovo Bormida, while the third one is located among Castelferro, Basaluzzo and Novi Ligure (Fig. 1).

The Fraschetta area, Novi Ligure has strategic importance; first because its territory is characterized by all the afore-mentioned techniques which produced valuable urban mansions and houses as well as farmhouses in the surrounding countryside, along with schools and churches; harmonious

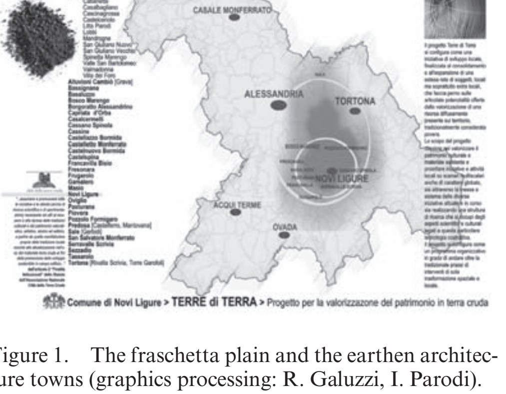

Figure 1. The fraschetta plain and the earthen architecture towns (graphics processing: R. Galuzzi, I. Parodi).

Figure 2. The earthen architectural heritage (photo: G. Bollini).

architectures that testify with no doubt the dignity and the reliability of earth as a building material.

Secondly, because Novi Ligure is the only Municipality in the Fraschetta area that started a strategy of local development focused on the valorisation of its own endogenous resources and staking on the characteristics of its territory. The earthen architecture heritage is part of it. The Municipality has also been a member of the Associazione Nazionale Città della Terra Cruda since 2004.

In this sense, speaking about developing policies based on earthen architecture heritage in the Fraschetta area, means speaking about the local Novi Ligure strategies.

Here the old farmhouses represent the most consistent part of earthen buildings; a lot of them are still inhabited but can hardly be recognised, because the earthen walls are often covered with plasters. Nowadays they have a normal residential function, but once they were strictly connected to the local rural world. In this sense they were marked by a proper architectural language, and specific technological details as well as social meanings. In fact these buildings had clear cultural references and well codified functional reasons as well: the family, the livestock, the fields, and the earth. And it's precisely this local earth, used as a normal building material that points out the unique character of this rural and urban architectural heritage; its cultural and testimonial value is unquestionable and belongs to the identity of Novi Ligure and the Alessandria territory. All this explains the goodwill of the Novi Municipality to defend and promote it (Fig. 2).

1.2 *First step: Identification of local priority*

The starting point was the parallel analysis of local problems, necessities and strengths as well. They are:

Problems:

- There's an excessive coming apart among the urban, extra-urban and rural context owing to the existence of indeterminate peri-urban basins;
- The rural environment is often lived as a "dis-value" and not as a resource;
- There's a lack of participation or sense of belonging towards the territory and/or its history (understood in the widespread sense of the word);
- The historical architectural heritage is often in a state of decay due to the changed agricultural cultivation methods;
- People, the institutions and the local stakeholders are lacking an ecological and sustainable cultural pattern.

Necessities:

- Re-connecting the different levels of use and perception of the territory;
- Re-discovering and re-defining the territorial peculiarities (landscape, nature or architecture);
- Re-establishing a connection with the territory in order to be a sustainable development of itself;
- Re-defining a coherent pattern to read urban, peri-urban and extra-urban areas as a continuum;
- Promoting professional upgrading and the creation of (new) extra-agricultural occupations, (new) jobs focused on the possibilities offered by a different management of the territory.

Strengths:

- The possibility to exploit a typical technology that can greatly contribute to green building policies as planning and realising high energetic efficient buildings, defining new green materials and renewing the traditional building process;
- The great possibility to use the earthen architectural heritage to promote a systematic and sustainable development of the whole town (and of its territory);
- The possibility to have a close relationship with competent Regional Departments and offices;
- The topicality of the theme and its correlated high ecological meaning.

On these bases, to stake on the diffusion of earthen architecture and its knowledge heritage still existing could lead to (new) jobs, closely based on specialised occupational figures.

In order to re-evaluate its earthen heritage and its territory, Novi Ligure has recently defined a specific program, called Terre di Terra (Earth Lands).

2 THE STRATEGIES

2.1 *The Terre di Terra (Earth Lands) program*

This program aims to be an innovative initiative to promote local territorial development, in order to strengthen and to increase a large network of local and non local subjects, focused on the various possibilities that such a particular resource can offer. This resource is the traditional earthen architectural heritage that is locally widespread.

The goal of "Terre di Terra" is to exploit the local material and immaterial heritage. The entire "Terre di Terra" project emerges as a management program, which wants to go beyond the traditional territorial transforming plans. It provides in short:

1. The proposal of a thematic *ecomuseum* interesting both the Novi Ligure territory and all the Fraschetta area;
2. A systematic training, information and awareness action-plan;
3. A deeper knowledge of local earthen architecture heritage;
4. A systematic communication plan.

Everything inserted in a more general sensitivity towards green architecture, where earth as a building material, tested by centuries of use and revised according to a modern approach, can be reasonably considered an effective answer to the actual environmental problems to which the contemporary world of building and architecture has to reply.

2.2 *Tron and Trunere: Earth ecomuseum*

Novi Ligure, the Municipality of Bosco Marengo and the local Associazione Amici della Biblioteca della Fraschetta, submitted the design of a local *ecomuseum* (called *Tron e Trunere: ecomuseo della terra cruda*) to the Regional Administration.

The *ecomuseum* aims to define a process, meant as a strategy, allowing the local community to be just that, to recognise itself in the traditions and in the memory of all the people that "are" the community as such in those signs defining both the landscape and territory (anthropic and natural ones).

In such a sense the first goal of *Tron and Trunere ecomuseum* (*Tron* is the local name of the unburned handmade brick, while *Trunera* identifies the rural rammed earthen house), is to promote and to set up real and permanent actions of preservation, restoration and re-evaluation of local and traditional earthen heritage, in order to reinsert it in an economic system, which is strictly correlated to territorial exploitation policies. The *ecomuseum* area is marked by a various cultural, historical and natural heritage: the agricultural landscape, with its tracks, the old Napoleonic paths and the fluvial habitat of the Scrivia torrent.

The goodwill of inserting the local earthen architectural heritage in this specific territorial design underlines three definite goals:

– To give back to the earth its building material dignity;
– To emphasize its natural and sustainable characteristics;
– To solve a territorial lack of tourist receptivity, that at present is neither specialized nor innovative;
– To define thematic and integrated routes (country/city foot and cycle paths, greenways etc.), connected to culture and to historical, social and traditions of the territory.

All these actions will contribute to redefine the local rural architectural outline and the use of both rural and fluvial spaces.

In other words the earthen building technique and earthen architecture are both the reason and the common denominator to define a so-called "cultural map" that has all the potentialities to rise from the local to a national and international context.

The whole project aims to value the territory from a high quality tourist viewpoint. Throughout the restoration of valuable earthen buildings it aims to insert it in specific cultural circuits.

One idea, for example, is to connect the external greenways to the Museo dei Campionissimi (Cycling-Champions Museum) and to the others territorial tourist areas (Alessandria and its hinterland, the Gavi hills, the "wine route", or the typical food paths) (Fig. 3).

Figure 3. The ecomuseum touristic path (graphics processing: R. Galuzzi, I. Parodi).

3 TRAINING AND AWARENESS ACTIONS

3.1 *The Regional law on earthen heritage preservation*

The recent Regional Law n. 02/2006 promotes specific educational training on earth construction, both for craftsmen and professionals, as well as for local schools and university students. The specific research on the field could be encouraged transforming, in accordance with private owners, the single restoration building yard into pilot and experimental yards. These could become occasions where private, research and school worlds meet each other to offer an innovative way to live a cultural, architectural, historical and territorial heritage.

On this subject the Municipality has already started such actions, organising short didactic internships, both with the pupils of the local schools and university students (Polytechnic of Turin), as well as several interesting actions to promote earthen architecture (for further information, please, see the web site www.comune.noviligure.al.it, choosing the link "Novi città della terra cruda") (Fig. 4).

3.2 *The COLORE project experience*

In 2007 Novi Ligure took part in the INTERREG III C ProgreSdec Project. The lead partner was the province of Rieti (Italy), while the others partners were the province of Ragusa (Italy), the Alto Jarama Mancomunidad (Comunidad de Madrid) and the Macedonia Region in Greece. The sub-project was called the COLORE Project (Countryside and Landscape: Opportunities for Renewable Energies). It aims to promote an active *ruralship*; this means to lead the rural areas to get an active, conscious and constructive role concerning the growth and development of their territory. After the first phase of the project, focused on the swot analysis, we recognized the best operative strategy to achieve the final goal of promoting a local active *ruralship* in the Ecomuseum.

The operating methodologies were:

- *Architectural heritage map*, that aims to mark the potential of "local capital" (work in progress);
- *Tangible and intangible assets map* (in cooperation with Distretto Novese, www.distrettonovese.it);
- *Data collection map* (work in progress);

After the COLORE experience, all the above methodologies remained as a reference for the Novi development policies.

3.3 *Earthen architecture census*

In accordance with the Regional Law n. 02/2006, the Public Administration planned a local earthen architectural heritage census.

The goal was to assess its state: existing buildings, deterioration, habitability and so on. The starting point was a participative approach and in this sense the analysis started with the collection of the expressions of interest of building owners, interested in being included in the census. The intention was to use the census not as simple heritage "reading tool", but as an instrument for its repossession. So it became:

- A pretext and an instrument to approach people and "to intrigue" them;
- A pretext to approach the owners of earthen buildings;
- A tool to give local earthen heritage its dignity back;
- An instrument to investigate and to mark out the rural capital potential in order to have an innovative and sustainable territory development;
- A push towards a correct technological and architectural restoration;
- A local acculturation tool.

Today we have about 130 listed earthen buildings, most of them situated in the rural and periurban area of Novi Ligure.

3.4 *Communication plan*

Different actions were carried out in this field: conferences, and exhibitions during the annual

Figure 4. Local workshops on earth building (photo: G. Bollini).

Figure 5. Events (graphics processing: I. Parodi).

European Heritage Days or during the Culture Week, thematic brochures, prizes for policies and programs of land management, press releases about the activities carried out etc. (for further information, please, see the web site www.comune.noviligure.al.it, choosing the link "Novi città della terra cruda") (Fig. 5).

4 OUTPUTS AND THE NEXT STEP

More generally the Terre di Terra program aims at a balance between urban, peri-urban and rural areas, through "a correct reading" of the territory. The main outputs were:

- A deeper knowledge of the territory, of its still living and active potential (represented by people who still live in rural areas). This is the real strength to be supported and stimulated through the valorisation of the immaterial and material heritage;
- The awareness of the importance of involving people as they are the first element of connection to implement active ruralship; the earthen architectural heritage is just the means;
- The consciousness that earthen heritage is a winning pretext for acting in the way of territorial sustainable development.

The expected result is to find a shared methodological approach for the definition of a leading instrument of territorial resources valorisation (in the sense of natural, local, social, cultural and economic ones), with respect of each local identity and inspired to environment supportability.

More generally the expected impacts are:

- Improvement of green tourism infrastructure;
- Creative revival of landscape, including measures for recultivation of traditional crops;
- A new awareness of local cultural and historical l values;
- The birth of an alternative and conscious way of tourism.

The focus of all these actions should be the earthen heritage restoration and revaluation so that it becomes the reference point of new defined tourist paths.

Later (or at the same time) a specific study should be carried out regarding the history and traditions, exploiting tourist paths through meaningful sites (urban, rural, and fluvial). This will help the final planning of the *ecomuseum*.

The final step is the creation of a *Documentation centre on the earthen architecture and the territory*. It should be the starting point (or the arrival) of the integrated touristic path called *Strade di Terra* (Earth Roads).

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The rammed earth walls in the watchtowers of the order of Santiago in Albacete province (Spain)

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ABSTRACT: The construction of rammed earth walls is usually found in vernacular architecture. The use of the same technique to build up walls in military buildings, with stones and mortar (roman concrete) is frequently confused with ordinary masonry walls. This paper aims to analyze the technique used in the construction of a selected group of military towers located in the south of Albacete province (Spain). A detailed study was made of the existing walls in order to achieve a characterization of the technique (formwork and associated tools). The methodology followed is based on similar studies proposed for other geographic areas of the Iberian Peninsula to allow a comparison and to date the construction. The results distinguish two variants of the same typology, which leads to the need of further historic research for a precise dating. A framework was also developed for the characterization of similar military constructions existing in the area.

1 INTRODUCTION

Las atalayas constituyen construcciones relativamente pequeñas cuya función era el contacto visual entre unas y otras, para poder servir de aviso sobre posibles invasiones o ataques. Estas torres están situadas en la Sierra de Segura, en un área geográfica delimitada físicamente por tres cursos fluviales (el río Tus, el Taibilla y, en el centro, el Segura) y tres sistemas montañosos (el Calar del Mundo, Sierras de Gontar, Lagos, los Morales y Juan Quílez y entre ambas la sierra del Ardal). Muchas de las aldeas donde se ubican las construcciones fueron asentamientos paleolíticos, con sucesivas presencias romana, visigoda y musulmana, siendo esta última época a la que deben pertenecer las atalayas, más concretamente hacia la segunda mitad del siglo XIII, en el ámbito de la denominada Encomienda Santiaguista de Yeste y Taibilla (lugar fronterizo con el reino Nazarí de Granada y el reino de Castilla). Es presumible que las torres se construyeran todas en un breve periodo tiempo de sólo cincuenta años. (Rodríguez Llopis 1982).

Se tiene constancia de que la línea fronteriza estaba compuesta por quince atalayas en el término de Yeste, tres en el de Molinicos y dos en el de Nerpio. De todas ellas, sólo quedan vestigios de Torre Pedro, Torre de Los Calderones y Torre Huertas en Molinicos; Llano de La Torre, Moropeche, Tus, Paules, la Graya, Vizcable y Gontar en Yeste y la de Pedro Andrés en Nerpio.

En la investigación que se presenta en este texto se realizó el estudio de las tres atalayas ubicadas en el término municipal de Molinicos para obtener conclusiones que, en una fase posterior del trabajo, se podrán contrastar con el estudio de las restantes torres. Estas tres atalayas se sitúan a diferente altura sobre el nivel del mar (Torrepedro a 1130 m., Huertas a 740 m. y los Calderones a 790 m) y presentan diferencias en el material de aportación para la construcción de la tapia, datos que parecen suficientes para considerarlas representativas del conjunto de todas las torres.

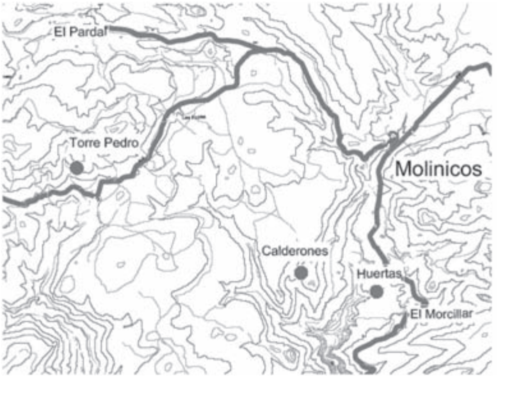


Figura 1. Plano de situación de las Atalayas de Molinicos.

Las tres atalayas presentan un mal estado de conservación, debido principalmente a que no tienen ni han tenido ningún tipo de mantenimiento ni reparación. Por ejemplo: la atalaya de Huertas (Figura 2) sólo conserva un lienzo de la torre y otro de menor espesor de la muralla; las de Torrepedro (Figura 3) y Calderones (Figura 4) son atalayas exentas que conservan los cuatro lienzos de su planta cuadrangular. En lo que atañe a la envergadura de los restos conservados, se pueden ordenar de menor a mayor altura: Los Calderones, Torrepedro y Huertas.

Figura 2. Atalaya de Huertas.

Figura 3. Atalaya de Torrepedro.

Figura 4. Atalaya de Calderones.

En la atalaya de Torrepedro, el lienzo de la cara norte presenta un importante nivel de erosión en el material aglomerante con la pérdida de aproximadamente la mitad del espesor del muro y el irreversible deterioro que, de no mediar con algún relleno, llevará a la ruina del mismo. Este fenómeno de erosión profunda, sin duda debido a la altura y exposición del lienzo a temperaturas extremas, se ha ido produciendo mediante ciclos de hielo-deshielo y por la acción del viento.

Debido a su esbeltez y grado de exposición, la integridad del lienzo de la torre Huertas, que se encuentra a escasos tres metros de un camino rural transitado por vehículos agrícolas, queda seriamente comprometida.

Por último, la torre Calderones, a excepción de parte de la última hilada, no presenta peligro inminente de ruina.

Las trazas de los muros demuestran que la técnica constructiva utilizada fue el procedimiento tradicional del tapial. No obstante existen muchas variantes y posibilidades para la puesta en obra que se pretenden plantear.

Para ello el estudio se centra en dos parámetros característicos de la tapia fácilmente identificables, la caracterización material de la fábrica y su modulación, y un tercer parámetro derivado de la interpretación de los anteriores: el proceso de ejecución. Asimismo, en relación a este último parámetro, varios autores ya han señalado hechos que resultan indicios elocuentes de cómo se ha desarrollado el proceso de ejecución y que permiten datarlo, además de interpretar los recursos y los medios materiales, humanos y económicos de los que disponían sus constructores (Graciani, 2009): 1. el tipo estructural; 2. las agujas o mechinales; 3. los contactos entre cajones e hilos; 4. las improntas en la argamasa, 5. los elementos de fábricas asociadas a la tapia de tierra, en su caso.

En los tres casos analizados, se trata de tapias monolíticas y homogéneas en su composición, a excepción del tamaño de los mampuestos, por lo que quedan claramente definidos los puntos 1 y 5 a partir del estudio del material y la modulación. Por esta razón, el análisis se centrará en los otros tres puntos.

2 MATERIALES

El estudio de los materiales de construcción de los muros y murallas construidos con tapial necesita de un estudio comparativo del área fuente de aprovisionamiento de material y de los constituyentes de la propia tapia (Ontiveros Ortega et al., 2008).

Por norma general, la materia prima para la realización del muro suele encontrase en zonas cercanas a las construcciones, y las atalayas de Molinicos no son una excepción. Están situadas sobre materiales mesozoicos de edad cretácica formados por depósitos margo-arcillosos, calizas y dolomías. Se encuentran asentadas sobre montículos naturales, sin que se aprecien grandes modificaciones del perfil natural del terreno, lo que no quiere decir que no la hubiere; pues en estos setecientos años se pueden haber difuminado o borrado las huellas de las intervenciones hechas para enrasar la primera línea de asiento del muro de tapia.

Los materiales que conforman el muro son cantos de caliza y dolomía, fragmentos de cerámica-alfarería, barro o margas arcillosas y mortero de cal. Se trata de una tapia de hormigón de cal con bolos o mampuestos de gran dimensión, una variante de la tapia tradicional de tierra donde el muro se realiza a base de hiladas de piedra de tamaño parejo sobre lechos de argamasa de cal y grava de granulometría más o menos constante. Este sistema constructivo está documentado en diversas fortificaciones de época islámica (Martín et al., 2008).

Para la determinación de la composición y descripción petrográfica de los materiales constituyentes, se realizó una observación en campo de los materiales y un análisis de éstos en laboratorio. La mayoría de los cantos de más de 2 cm de tamaño son de caliza y dolomía, diferenciándose entre ellos por su grado de efervescencia ante la presencia de ácido clorhídrico (HCl). Para la determinación del tipo de conglomerante utilizado y sus proporciones se siguió la metodología propuesta por Alejandre y Martín Río en 2004 que consistía en analizar la composición química de carbonatos y sulfatos de la fracción granulométrica inferior a 4 mm que se corresponde a la matriz cementante del mortero.

Para la determinación del porcentaje de carbonatos que presentaban las muestras se utilizó el calcímetro de Bernard según la norma UNE-103-200-93. Tal y como apuntan los autores (Alejandre y Martín Río, 2004). Esta metodología tiene validez para determinar el contenido de cal apagada original $Ca(OH)_2$ ya que ésta, con el paso del tiempo, se re-carbonata al entrar en contacto con el CO_2 de la atmósfera y se transforma en carbonato cálcico ($CaCO_3$). Para determinar la posible presencia de yeso en la tapia como conglomerante se determinó cualitativamente el contenido de sulfatos mediante la norma UNE-103-202-95.

Los resultados obtenidos muestran un contenido elevado de carbonato cálcico de entre el 32 y 35%. La no aparición de precipitado en la determinación de sulfatos indica la no existencia de estos en la matriz cementante del conglomerante.

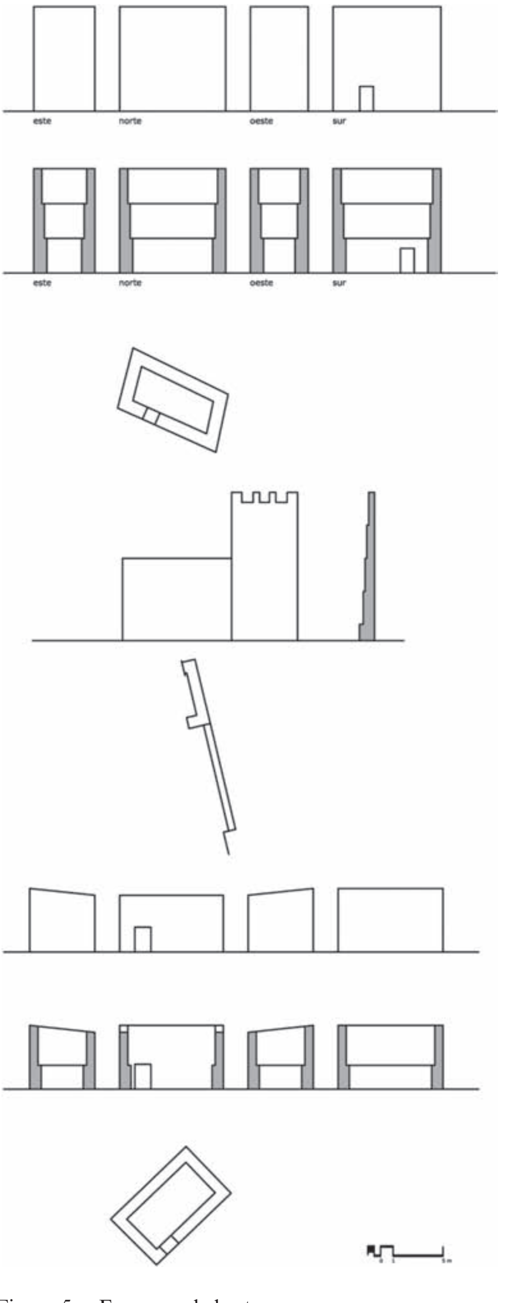


Figura 5. Esquema de las torres.

Con estos datos e independientemente de que el árido sea de composición calcárea se puede concluir que la tapia se realizó con importantes cantidades de cal. En un mortero de referencia cal-arena con proporción 1:1 el porcentaje en carbonatos es del 21%.

3 MODULACIÓN

El muro de tapia se construye mediante la repetición modular del conjunto, primeramente conformando un hilo horizontal, para posteriormente colocar otro hilo a mata-junta en su parte superior, y así sucesivamente hasta lograr la altura deseada. La repetición modular verticalmente (hilos de tapia) es de aproximadamente 0.90 m.

Los espesores de los muros disminuyen en Torrepedro en orden ascendente, comenzando con tres hilos de 1.05 m de espesor en la base, decreciendo de espesor en fracciones de 0.25 m cada tres hilos. En Huertas tenemos solo un lienzo con un espesor inicial de 0.90 m con cuatro retallos de 0.15 m. y tres hilaos cada uno y en Calderones un espesor inicial de 1.30 m y retallos de 0.30 m con tres hilos nuevamente por tramo. La altura total es de es de 9, 15 y 6 hilos respectivamente. El espesor se rellena mediante tres o cuatro filas en planta por tongada y 5 tongadas por cada hilo. Estos parámetros se resumen en la Tabla 1.

4 EJECUCIÓN

4.1 *Agujas y mechinales*

Las oquedades que presentan los muros responden en general a la impronta dejada por las agujas de sujeción de los tapiales, a excepción de las saeteras que se encuentran en las caras noreste y sureste de la atalaya de Torrepedro y en el lienzo de Huertas.

Por tanto, la distancia entre agujas (m) oscila entre 1.10 y 1.96 en el torreón de Torrepedro; 0.90 y 1.35 m en torre Huertas y 1.70 y 2.25 en la torre de Calderones. Si bien las medidas que más se repiten en los tramos centrales de los paramentos son las de 1.96 m. en el caso de Torrepedro, 2.25 m. en el caso de Calderones y 1.35 m. en el caso de Huertas, que presenta un ritmo de huecos claramente diferenciado de las anteriores (ver Tabla 1). Esta disposición viene a coincidir con dimensiones de tapiales de 2 codos de altura y entre 4 y 5 codos de largo, tal como se observa por ejemplo en torres de vigilancia de la misma época en alquerías valencianas (Rodríguez Navarro 2008).

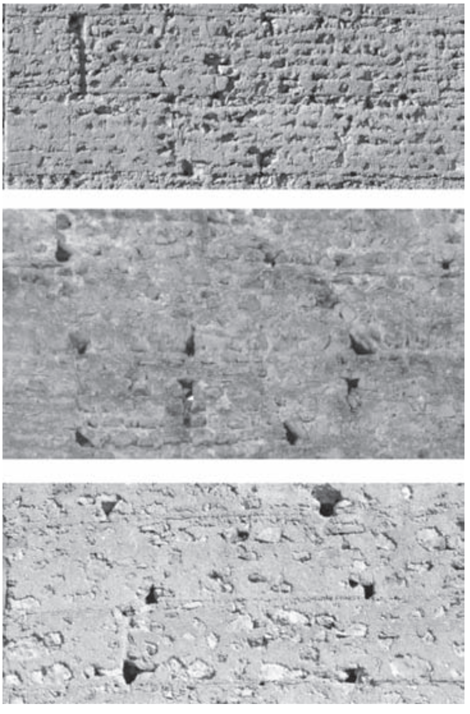
En casi todos los casos los orificios son pasantes, lo que implica la utilización de un sistema de sujeción mediante aros (cercos) compuestos por agujas, costeros, tensores (lías y garrotes) y codales, a excepción del primer tramo (primeros tres hilos) que sirve de basamento (con espesores superiores a 1 m), donde no se manifiestan los mechinales.

La distancia entre mechinales parece demasiado amplia para los dos primeros casos, ya que implicaría la existencia tan solo de dos cercos por tapial, considerando la longitud del mismo algo superior a la distancia que más se repite entre dos oquedades consecutivas. Numerosos estudios, tanto de los autores de este artículo (Castilla 2005), como muchos otros especializados, han constatado la habitual existencia de tres cercos para la ejecución en el caso de las tapias de tierra.

No obstante, esto puede justificarse dado que en el tipo de fábrica que nos ocupa, es muy poco probable que se produjera apisonado y, por tanto, los tapiales no sufrían un excesivo empuje lateral, a diferencia de lo que ocurre en el compactado enérgico de la tapia de tierra. La sección de la oquedad es muy irregular en casi todos los casos, debido a que se conforma por la superposición de algún mampuesto, siendo de 10 cm de dimensión aproximada, a excepción de Huertas donde es algo menor, por lo que resulta difícil precisar el tipo de aguja utilizada. Estudios realizados en Sevilla han constatado que, si bien fue con los almohades en la segunda mitad del siglo XII cuando se produjo la sustitución de las agujas de rollizo—más simples y menos evolucionadas—por las agujas de tabla plana, aquellas, por no precisar ser manipuladas, perdurarían en el tiempo en fábricas de tapiales menos cuidados y ejecutados con medios más rudimentarios (Graciani 2009).

Tabla 1. Medidas de los elementos.

	Dimensiones en planta (m)	Altura (m) de "retallos" Nº de hilos	Distancia entre mechinales	Composición: Ancho de muro Alzado Tamaño (m)
Huertas	5.30 × ¿? (sólo un lienzo)	13.5 5 ret 15 kilos	Entre 0.90 y 1.34	2–3 mampuestos y 5 tongadas Diam 0.15
Torrepedro	8.45 × 5.00	8.20 3 ret 9 hilos	1.96 (Entre 0.59 y 2.13 en extremos)	3–4 mampuestos 5 tongadas Diam 0.15
Calderones	8.40 × 5.00	5.40 2 ret 6 hilos	2.20 (Entre 1.70 y 1.10 en extremos)	3–4 mampuestos 5 tongadas Diam 0.15



Figuras 6, 7 y 8. Detalle de los paramentos de las Atalayas de Huertas, Torrepedro y Calderones respectivamente.

Por último, en los dos primeros casos (Torrepedro y Calderones) los mechinales se encuentran sobre la tabla de asiento del hilo superior, encajados en la primera hilada de mampuestos (que suele ser más estrecha y regular) y rematados superiormente por otro mampuesto. Esto contribuiría igualmente a facilitar una mejor sujeción de las agujas y por tanto a soportar tapiales de mayores dimensiones. En Huertas resulta más difícil determinar esta posición, ya que en algunos casos aparecen rebajados en los hilos y enrasados con la tabla de apoyo del hilo superior.

4.2 *Uniones entre cajones e hilos*

Las separaciones entre cajones resultan difíciles de distinguir, lo cual contradice la hipótesis del encofrado de un único módulo y desplazable. En cualquier caso esto suele ocurrir en fábricas donde se vierte mortero de algún tipo (como las tapias calicostradas) cuya plasticidad permite disimular dichas juntas. En la parte baja de Torrepedro se aprecia una clara junta con inclinación de 45º, en la cara interior, pero sin embargo no se puede confirmar su correspondencia con la posición de las agujas (debido a la inexistencia de mechinales). Por el contrario en las esquinas se puede distinguir con claridad los puntos en que una tapia atesta contra otra ya ejecutada en el paramento perpendicular, a través de las juntas verticales en la cara exterior, permitiendo además confirmar el sentido de avance de la ejecución alterna en cada hilo consecutivo.

4.3 *Improntas en los paramentos*

Las caras interiores y exteriores presentan un aspecto totalmente distinto, los mampuestos se pueden apreciar con mucha más claridad en el exterior, debido sin duda al progresivo deterioro de la argamasa, mientras que en la cara interior se pueden identificar con más claridad la diferencia entre tongadas.

Tan sólo en el caso de Huertas se aprecia con claridad la impronta de barzones en los extremos de algunos hilos que atestan contra otros, aunque sin apreciarse regularidad o solución de continuidad en dicha disposición. Si bien la conservación de un solo paramento dificulta la obtención de datos más concluyentes para su justificación.

5 CONCLUSIONES

De los estudios realizados hasta el momento se pueden obtener suficientes datos para definir el tipo de tapiales (modulación) que se utilizaban para la construcción de las torres, aunque se precisaría un estudio algo más profundo sobre la posición de algunos huecos de difícil acceso para definir más claramente del proceso de ejecución.

En lo referente a la adscripción temporal, los datos indican una clara diferencia en cuanto a los tapiales utilizados en Huertas, respecto a Torrepedro y Calderones (muy parecidos entre ellos), por lo que no resulta lógico que fueran construidas coetáneamente, dada la proximidad (escasos 500 m) entre estas dos últimas torres. Asimismo, esta proximidad no parece tampoco lógica si su función fuera la de vigilancia, ya que la distancia es muy escasa y en una zona con mucha visibilidad. Sería conveniente por tanto realizar estudios sobre la posible función de Huertas, quizás más defensiva, teniendo en cuenta el paramento de mayores dimensiones que se encuentra adosado a la torre y que, en consecuencia, sería de una época posterior a las anteriores.

NOTE

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y perspectivas" (ref. BIA 2010-18921) granted by the Spanish Ministry of Science and Innovation.

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Montroy Islamic Tower (Valencia, Spain)

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ABSTRACT: This paper presents the study done on the Tower of Montroy (Valencia, Spain). Precise measurements were taken that have permitted an assessment of the interesting details about the rammed earth construction techniques. The intention was to make a comparison of this tower with others of a similar construction of the same period. At the same time, a meticulous presentation of the tower's preservation was made. In order to achieve it, a diagnosis of the main pathologies or problems affecting the building together with the principal causes was completed.

1 HISTORIA

El emplazamiento de la Torre de Montroy está relacionado con el castillo de Montserrat y de los Alcalans, que se entrevén perfectamente entre ellos. Formaban los tres una estructura defensiva del valle donde se asentaban las alquerías de Montroy, Real y Montserrat. En cuanto la datación cronológica, fue construida alrededor de la segunda mitad del siglo XII, durante la época de almohade.

El acceso a la torre se producía mediante una escalera de ocho escalones, y una vez dentro estaba situada la prisión a un lado y en la otra parte una cámara con 6 pequeñas ventanas para albergar guardias y soldados. Subiendo otra escalera de 15 escalones se accedía al primer piso donde se ubicaba una antigua cocina. Junto a ésta había una ancha estancia con una ventana que servía como almacén. En la segunda planta se encontraban dos cámaras cubiertas por bóvedas de ladrillo y con tres ventanas para tener luz natural. Finalmente, subiendo por una larga escalera se accedía a la parte alta de la torre, cuya puerta de acceso a la azotea estaba cubierta de cañas, quedando el resto al descubierto.

El abandono de la Torre ha sido progresivo hasta la actualidad, presentando un mal estado de conservación.

Se trata de un edificio declarado Bien de Interés Cultural (BIC). Tiene una importancia en primer lugar histórica, por ser resto más significativo del origen de la población; en segundo lugar, arqueológica, por los datos que puede facilitar para conocer el primitivo asentamiento de Montroy y su relación con la población actual y, finalmente, paisajística, por constituir la imagen característica del municipio.

Figura 1. Emplazamiento.

2 EMPLAZAMIENTO

La Torre de Montroy se alza en lo alto de un estratégico cerro (216 m) del término de Montroy.

Es el icono representativo del municipio, teniendo un gran valor paisajístico y siendo un lugar privilegiado de observación, divisándose la totalidad del término municipal y buena parte del valle y de la comarca.

El cerro donde se ubica sufrió importantes desmontes de tierra con anterioridad y presenta un cierto riesgo de desprendimientos por los excesivos taludes.

Actualmente ha sido acondicionado aprovechando las obras de estabilización de las laderas, realizando algunos senderos y muretes de piedra siguiendo la topografía y colocando bancos, aunque llegar a la entrada de la torre sigue siendo difícil.

3 DESCRIPCIÓN

Se trata de un edificio de planta cuadrada conformada por cuatro gruesos muros perimetrales de carga, con un espesor de 1.5 metros (aproximadamente) que se reduce en cada tramo de altura. Los muros están construidos con la técnica árabe de tapia con mampuestos. La altura de la torre es de 21 metros y las dimensiones de los muros perimetrales son de 9.5 metros en las vertientes norte y sur mientras que en las orientaciones este y oeste mide 7.60 metros.

La torre dispone de 3 plantas y sótano. En el sótano encontramos un aljibe y un depósito de víveres y almacén. El aljibe se cubría mediante una bóveda y el almacén seguramente con un entramado de madera del que ya no quedan restos. En planta baja, está ubicada la puerta de acceso al interior. Antiguamente se accedía mediante una escalera de madera móvil. A día de hoy, se accede a unos 30 cm del nivel del suelo debido a la acumulación de derrumbes y restos de la barbacana adosada a la torre.

La estructura interior es de bóvedas que apoyan en cada planta. Éstas son de tapia, excepto las de la cubierta, que son de ladrillo debido a una reconstrucción posterior.

El uso en el interior de arcos de medio punto conforma dos estancias por planta. Por medio de una escalera de piedra encopetada, debido al desarrollo limitado del ancho de una bóveda, se accede a las otras plantas. Las otras 2 plantas se suceden con el mismo emplazamiento trazado. La azotea recogía el agua, desaguando por un conducto cerámico que atravesaba las bóvedas por un ángulo hasta llegar al aljibe.

4 FUNCIÓN

Del recinto del castillo, hoy en día solo queda la torre. Estas construcciones de carácter bélico fueron en la Edad Media un punto originario y neurálgico para la concentración de los asentamientos humanos en forma de alquería. Muchas torres formaban parte del circuito defensivo de la ciudad de Valencia, después de la ocupación islámica de la Península Ibérica. Esta red defensiva se creó en el siglo XI y constaba de dos cinturones defensivos, cuya función era de impedir la llegada del enemigo y proteger la zona agrícola de los alrededores de Valencia.

5 ESTADO ACTUAL

El deterioro del núcleo original de la alquería fortificada ha sido continuo.

En la actualidad la Torre presenta un estado de abandono total siendo patente un activo proceso de degradación.

En el exterior de ésta se pueden observar una serie de patologías debidas fundamentalmente a la acción de los agentes atmosféricos y la acción humana.

La parte superior de la torre ha sido afectada también por el crecimiento de vegetación sobre la antigua cubierta. En las fachadas opuestas este-oeste, existen grietas que afectan a todo el espesor del muro y recorren verticalmente la torre, partiéndola en dos. Estas grietas arrancan de la coronación y llegan hasta la base aproximadamente. En las esquinas, sobre todo la sureste, se advierte una antigua reparación hecha con sillares.

El interior de la torre está mejor conservado por su mejor protección frente a los agentes atmosféricos, aunque la acción humana ha sido más intensa (demoliciones, grafitis, escombros, etc.). Sin embargo, las estructuras abovedadas, menos estables que los gruesos muros, se hallan derruidas en gran parte debido a la acción del agua que ha entrado por la cubierta. Las estructuras interiores son de gran valor ya que son bien pocas las torres que aún las conservan.

Se ve claramente cómo la línea que siguen los mechinales está inclinada hacia abajo, dejando ver que la torre se ha inclinado ligeramente por la erosión a lo largo del tiempo.

Figura 2. Vista exterior.

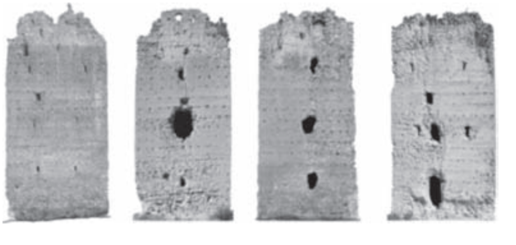

Figura 3. Alzados Norte, Este, Oeste y Sur.

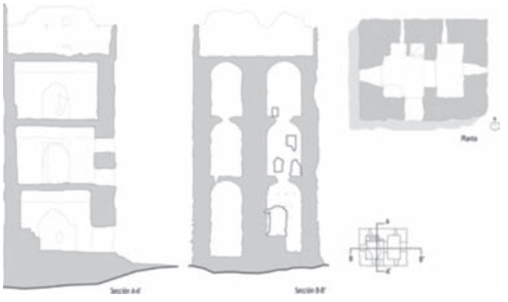

Figura 4. Planta y Secciones.

6 CONSTRUCCIÓN

6.1 *Muro tapial*

Se trata de un muro tapial con mampuesto entre areniscas y calizas de la zona de colores pardos rojizos y grises, de muy diferentes tamaños (hemos encontrado piedras de 50 cm en su lado mayor) y sin labrar, salvo en los sillarejos, el muro tiene un espesor medio de 1.00 m.

En el sillarejo las piedras son paralelepípedos de unos 20 cm de espesor y 50–60 cm de largo aproximadamente.

Sus materiales son la piedra arenisca, la piedra caliza, desengrasante, agua y arena o fibra.

La técnica constructiva que se utiliza es modular. Se coloca un encofrado llamado tapial, se vierte en su interior la tierra y los otros materiales y se apisona por tongadas. Una vez terminado el cajón, el tapial se desmonta para completar la hilada, así hasta la altura propuesta.

El encofrado consiste en un tablero de madera, compuesto de varias tablas, de unos centímetros de grosor dispuestas horizontalmente, unidas con la ayuda de unos listones o barrotes verticales, situados por el exterior y clavados por la cara interior del tablero. Las cabezas de los clavos originan, al estar sobre las tablas, improntas del tapial: una columna de oquedades grabadas sobre el paramento.

6.2 *Bóveda*

Es el elemento que conforma la cubierta de cada una de las plantas. Actualmente se encuentran derruidas pero se observa claramente cual era su lugar y se aprecia, a la vez, su construcción con el mismo material que los muros dando continuidad constructiva con el cerramiento.

Como en todas las estructuras basadas en el arco, el empuje tanto vertical como horizontal, se dirige hacia los muros que la sostienen. Estos empujes quedan contrarrestados, en este caso, gracias al grosor de los muros de tapia.

La cubierta original de la torre supuestamente era cubierta plana, como el resto de las torres de estas mismas características y de la misma época. Seguramente tendría un remate almenado en los muros que haría las veces de antepecho pero no se puede asegurar por estar completamente desmochado.

Por tanto, la cubierta actual de ladrillo y mortero es un añadido posterior que se ubica a principios del siglo XX por el tipo de ladrillo. Se presupone que se realizó con la finalidad de proteger la torre de inundaciones y un mayor desgaste causado por la lluvia.

6.3 *Arco*

Es el elemento constructivo lineal de forma curvada, que salva el espacio entre los dos muros y está construido por varios materiales como piedra arenisca, mortero, agua y arena o fibra.

Estructuralmente, el arco funciona como un conjunto que transmite las cargas, ya sean propias o provenientes de otros elementos, hasta los muros o pilares que lo soportan.

6.4 *Escalera*

Se trata de una escalera con descansillos, abovedada. Estas bóvedas toman la silueta de un arco de medio punto, que posee sus líneas de arranque a diferente altura.

Este sistema de bóvedas permite realizar los tramos de forma independiente, apoyándose en los forjados o paredes directamente; o por tramos sucesivos, apoyando el tramo superior sobre el inmediato inferior.

El primer tramo de la escalera es el único que se encuentra hoy en día parcialmente completo y por el que se puede llegar hasta una altura media. Aún faltaría un segundo tramo hasta llegar al siguiente forjado desde el que arranca el siguiente tramo de escalera.

Estos primeros tramos son más compactos, de piedra, e independientes del sistema abovedado de cubierta por lo que esta es la razón de que aún se conserven. Los tramos derruidos están construidos con materiales como piedra arenisca, mortero, agua y arena o fibra.

6.5 *Dintel*

Es el elemento superior que permite abrir los huecos en los muros para conformar la puerta y las ventanas.

Tras dejar el hueco en el muro de tapia, y mientras endurece en el cajón, se coloca el dintel que salvará el hueco, que en este caso se realiza de madera, y sobre el que descargará la parte superior del muro que se continúa ejecutando.

Estos elementos ya no se encuentran actualmente debido a la descomposición de la madera por la influencia de los agentes atmosféricos y a su contacto con el ambiente exterior.

6.6 *Solera*

El elemento de la solera en planta baja está apoyado en el terreno y encima de un aljibe. Deja un espacio vacío a un lado que se empleaba de calabozo cuando la torre cumplía su función militar y despensa cuando pasó a ser vivienda.

El aljibe cuenta con una bóveda de cañón de arco de medio punto realizada con piedra arenisca, mortero, agua y arena o fibra, que soporta la solera, hecha de la misma masa de tierra cruda que la tapia de los muros.

7 ESTRUCTURA

7.1 *Cuadro deformativo*

Una de las causas principales de los daños estructurales en la torre es la pérdida de material como consecuencia de los agentes atmosféricos y, en concreto, del agua. Estas pérdidas se aprecian mayoritariamente en la base de la construcción así como en la coronación. Esto podría haber provocado debilidad en la construcción así como un asiento en el terreno. Se aprecia claramente que las líneas de mechinales están inclinadas hacia la fachada Sur tanto en el alzado Este como en el Oeste. También se observa cómo en la parte baja de la torre los mechinales están mucho más inclinados que en la parte superior de la torre lo que nos lleva a pensar que el terreno asentó más durante el proceso de construcción en la parte Sur que en la Norte. Frente a este asiento diferencial la torre se siguió construyendo pero intentando conseguir la verticalidad que se buscaba en un principio. Por eso, las líneas de mechinales están en un principio inclinadas (debido al asiento diferencial primero) y luego horizontales debido a la continuación correcta de la construcción. En los alzados Este y Oeste, los mechinales están inclinados hacia el sur. Esto puede deberse al asentamiento diferencial del terreno durante el proceso de ejecución de la torre. El asiento de la torre se debe en gran medida a la pérdida de material. En su esquina Sureste la torre ha sufrido especialmente las consecuencias del desconchado y este hecho coincide con la inclinación de la torre. Respecto a la hipótesis de mecanismo tenemos dos afecciones principales que son las causantes de los principales daños y problemas que presenta. En primer lugar, tendremos las fisuras y grietas verticales que ocasionan la apertura de la fachada y una posible separación de estas y, por otro lado, veremos cómo el asentamiento del terreno ha acentuado la creación de estas grietas además de provocar una clara inclinación en los mechinales y la construcción de la tapia de la torre.

7.2 *Cuadro fisurativo*

En la fachada sur la fisuración vertical es evidente. La pérdida de material más importante es en la parte inferior de la torre. Podemos intuir que esta torre fue construida con encofrados en U más baratos que los encofrados completos y por lo tanto la torre sufre en la junta, justo en su parte central. Se da la casualidad de que en el interior de la torre también se producen grietas que dividen el edificio entre el Norte y el Sur.

8 PATOLOGÍAS

En el muro tapial aparece desprendimiento en la parte baja de la torre, de forma más acusada en las esquinas, también en su coronación.

Parte de las bóvedas del interior de la torre se han desprendido, imposibilitando el acceso a las dependencias.

Las posibles causas pueden ser las inclemencias meteorológicas, el paso del tiempo y el escaso mantenimiento de la torre.

Encontramos erosión en gran parte de la superficie de la torre, debido sobre todo a la exposición al viento y al agua de lluvia. En algunas zonas puntuales se produce erosión superficial, con una consecuente pérdida del color.

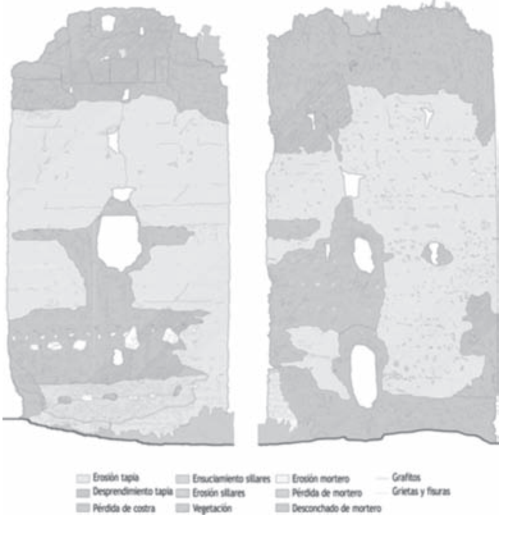

Figura 5. Mapeo de degradación de materiales.

También se observan fisuras y grietas en las piedras dispersas en las cuatro fachadas, debido a la carga que soportan y posibles movimientos.

Otra patología presente es la alveolización, que se da puntualmente en todas las fachadas. Ésta puede estar originada por disoluciones de determinados minerales, por la acción del viento o por la vegetación.

En la parte inferior de las fachadas oeste y este aparecen coqueras debido a la disgregación de la piedra por discontinuidad material. También se da la presencia de líquenes en las superficies exteriores expuestas a la humedad.

La costra de la tapia se ha perdido fundamentalmente en las fachadas sur, este y oeste en sus partes bajas y altas y también en el interior de la torre. Esto se produce tanto por las inclemencias atmosféricas como por la falta de mantenimiento.

9 CONCLUSIÓN Y PROPUESTA DE INTERVENCIÓN

Según el estudio realizado y en vista de los daños analizados, se plantea una intervención que asegure el posible uso de la torre pero sin llegar a una falsificación de la misma.

Así, el planteamiento general de intervención se basa en la consolidación de la estructura y la reparación de las patologías y daños para asegurar ese uso que se le quiere dar al monumento.

Todo ello marcando la diferenciación de lo nuevo y lo añadido, respecto a la preexistencia, mediante diferentes materiales, métodos constructivos, acabados o texturas.

Se plantea darle a la torre la función de mirador, debido a su enclave; así como de espacio expositivo e informativo acerca de la historia propia y del lugar. La propuesta plantea una reparación de las fachadas actuando sobre desconchados, grietas, mechinales, agujeros y boquetes.

El antepecho es reconstruido parcialmente pero dejando el perfil de la ruina existente pues no se quiere construir totalmente el perfil original de la torre. Aún así es necesaria una cierta consolidación para que la cubierta pueda ser accesible para el uso del mirador.

Respecto al interior, la intervención trata de darle una función al edificio tocando lo mínimo posible la prexistencia.

Para la subida a cubierta se mantienen los tramos de escalera de piedra que se encuentran en estado aceptable y aquellas partes que ya no existen debido a su desmoronamiento son reconstruidas con una escalera de madera (material utilizado en época islámica), junto con una pasarela también de madera que va dando acceso a los diferentes niveles.

Estas subestructuras son independientes del cerramiento original por lo que no lo alteran ni lo modifican.

Así, la intervención se lee como una sutura en la imagen exterior de la torre y una rehabilitación del interior dándole una nueva función al espacio para lo que se ha recurrido a la consolidación y reparación de sus partes.

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Sustainability lessons from the past: Rammed earth architecture in Vojvodina, Serbia

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ABSTRACT: Northern part of Republic of Serbia, autonomous province of Vojvodina, is located on Pannonia plain, a crossroad of multicultural influences over centuries. Researching the rammed earth architectural tradition of Vojvodina, the goal of this paper is to illuminate the relation between the concept of sustainable development and earthen architecture in the Vojvodina context, underlining the need for drawing sustainability lessons inherited from the past. The paper starts with an introduction on the necessity for researching sustainability issues, which is followed by the presentation of the local rammed earth building tradition. In addition, sustainable development in the Vojvodina context is discussed. The paper also presents an example of a local good practice, which finally leads to the conclusion that rammed earth building technique revival in Vojvodina could have the significant influence on the sustainable development of the region.

1 INTRODUCTION

Analyzing inherited building tradition in rammed earth in historical, social and cultural context, the goal of this paper is to emphasize the need for learning from the past in order to reveal principles of sustainability that is neglected during the shifts of historical periods in Vojvodina region. Conducted as a part of the project 'Science in society: multidisciplinary, educational and inter-generational perspectives', the true relevance of this research is the lack of interdisciplinary approach in science communication in national framework.

Specifically in the region of Vojvodina, traditional civil architecture attracted less attention of the researchers in the past than medieval sacral buildings that have been recognized as high artistic and national values. Even in the last several years, despite the increased interest of the researchers of cultural heritage of Balkan Peninsula, architecture in earth is still not profoundly examined and popularized. This is the reason why it is necessary to deepen the knowledge on building traditions and its implications on present-day practice. Therefore, the target of this paper is to illuminate the relation between the concept of sustainable development and architecture in earth in Vojvodina's context.

There is a significant body of knowledge on the subject of sustainability of the architecture and the built environment. In the first place, there is a consensus-based literature that consists of documents written after broad consultative processes. They usually address all the social, environmental and economic aspects of sustainable development and tend to give very broad goals and strategies for action while also explicitly taking into consideration the poor's needs (Sanya 2010). On a global level, such documents are: The Universal Declaration on Human Rights, Our common future, Agenda 21 … On a national level, in the last four years there have been many documents adopted: National Plan for Environmental Protection, Strategy for Spatial Planning Republic of Serbia, National Strategy for Sustainable Development, and so on. There is also a group of individual literature on: sustainability of building materials (Berge 2009, Spiegel & Meadows 1999, Lawson 1996), earth as building material (CRAterre publications, King 1996, Minke 2000, Oliver 2009), and local tradition in rammed architecture in Vojvodina (Kojic 1958, Nikolic 1958, Deroko 1968, Vukovic 1988, Djekic 1996). Nevertheless, scientific work on the subject of building heritage in Vojvodina is not thoroughly elaborated and most important, many of the researchers were not able to publish their work, so it is difficult to search.

On the other hand, the need for a multidisciplinary approach lies in the fact that earthen architecture is threatened by natural disasters, the advent of urbanism, and the inappropriate use of modern technologies, as well as by the disappearance of traditional conservation practices. Climate change, growing energy costs and the impact of human activities on the environment have all become key concerns for future development in recent years. As major sources of carbon dioxide and energy consumption, alternative methods are being explored in order to reduce the environmental impact of construction and infrastructure, and thus to comply with government targets to reduce carbon dioxide emissions. This is the reason why earthen construction is currently investigated as a low-carbon material (Becket 2011).

The following paper is organized in five main parts. After the introduction on the research necessity, rammed earth building tradition is presented from the historical point of view of urban and architectural development, followed by a review of local building technique and specific designed elements. Furthermore, sustainable development in Vojvodina is discussed, including current policies and strategies, stressing some of the development issues that could be significantly affected by the rammed earth building technique revival. The goal of this chapter is to explain current political position and prevailing opinion on the issue. In the fourth part of the paper, present-day activity is considered in order to emphasize good practice example and sketch the formal education in technical sciences. This finally leads to the summarizing of the paper and highlights that the rammed earth building technique revival in Vojvodina could have the significant influence on the sustainable development of the region.

2 RAMMED EARTH BUILDING TRADITION IN VOJVODINA

2.1 *Historical overview of urban and architectural development*

Vojvodina is an autonomous province of the Republic of Serbia, located in the northern part of the country. It is situated on the Pannonian Plain covering the area of 21.500 km^2. It is consisted of three smaller areas: Srem, Banat and Backa. Since the architecture is not only determined by geographical and topographical conditions, but also by cultural influences and ethnicity of the people. It is important to remember that Balkan is not only a habitat mosaic of people, but the meeting place of their wonderings as well (Krunic 1996). During turbulent history, ever since Slaves settled Balkan Peninsula in sixth century, many nations left their mark on this region and its architecture. According to the first results of the 2011 population census, households and dwellings in the Republic of Serbia, region of Vojvodina have 1.9 million inhabitants. Beside Serbs, which are majority, in Vojvodina also live Hungarians, Slovaks, Croats, Romanians, Romes, etc.

Since there are no preserved buildings from the period of Ottoman Empire, development of the traditional house in Vojvodina can be traced from the middle of 18th until the third decade of 20th century. According to Branislav Kojic, researcher of architectural heritage (Kojic 1949), development of traditional building has been influenced by two large groups of factors.

First, there is a group of natural factors, such as geological composition of the soil, vegetation, climate, configuration of the land, etc. All over Vojvodina these conditions do not vary much: the scarcity of rock and wood, lead to the domination of earth as local building material, usually used as rammed earth, and in recent history more as adobe and brick; also, numerous swamps and puddles gave the cane which traditionally used to be roof cover. On the other hand, moderate continental climate, with hot and often dry summers and very cold winters, forced traditional builders to have very massive walls with small openings and double windows.

The other large group is consisted of social and historical factors: the mode of economy, family structure, historical and political factors, migrations, etc. The division of Serbian land between Ottoman and Austrian Empire used to be along natural borders, Sava and Danube Rivers. At the end of seventeenth century the liberation of Vojvodina from Ottoman Empire domination started. Finally, in 1718 Austria got the governance of Srem and Banat. In that time, the majority of inhabitants of these regions were Serbs. Subsequently, there occurred a need to upgrade a level of economy and to strengthen the defense in this border area of the Empire. Thus began the systematic settlement of Serbs and colonization of Germans, Romanians, Slovaks, Hungarians, Russians, Spanish and French.

Following the colonization, the process of planned urbanization started in 1748, in order to protect houses from fire and flood: villages were shaped with orthogonal matrix of streets, houses had the same distance among each other, canals were dug, and embankments were built. One of the official documents which defined village regulation, ordered by Maria Teresa in 1772, emphasized that it was necessary to measure the land and see how many lots, halves and quarters it was possible to form. According to this instruction, one lot must be 75 to 100 klafters long and 12 to 15 klafters wide (1 klafter = 1896 m). A house must be on the street line of a lot with its narrow side and the distance between houses should be at least 17 meters as a fire precaution (Djekic 1994).

Consequently, under the Austrian government, various programs in architecture appeared. Building conceptions and the elements of western building schools are becoming more complicated as a result of the Austrian law implementation

(Folić-Kurtović: 2008). It is important to note, that during the colonization the Viennese court helped the development and sent experienced builders to build by legitimate plans, fast and cheap. Approximately, it took six to eight weeks to finish a rammed earth house. Nevertheless, development of a house typology is very dynamic.

The most widespread house type in Vojvodina was a longitudinal one. The narrow side of the house is positioned right on the street line and all the rooms are built in the row inside of the yard. The reason for this position on the lot could be the need to have an open wide view over the yard or to keep the possibility to build extensions in the future but at the same time not to violate the street view. The simplest variation of this type was a one room house with double doors, where cooking and sleeping took place together. In Serbian language, 'kuca'—a house was essentially a name for a room where people cook—a kitchen. In the next step of the development, there is a two-room house. The room is placed in front of the kitchen, next to the street. Further development continued to the three-room house: room-kitchen-room, which is the most common spatial distribution in Vojvodina, also called Pannonian house. The room next to the street used to be a guest room, a room for dead person, clean room, a parade room … Usually, the family lived in the back room.

Since the middle of 18th century, there could be found a porch along the yard side of the house in Vojvodina. Its function was to protect the longitudinal façade from the rain and snow. Today, the porch is usually closed with a wall and a window on the street line. It seems that the front room has three windows. In some cases, instead of a window there are richly decorated doors, opened only during celebrations. The people used to gather in front of them.

Since the economic conditions influenced the architectural development of the house in the second half of 19th century, there were so called long houses with three or four rooms and two kitchens. Besides the longitudinal type, there are also 'L' shaped and transversal house type. In the 'L' shaped house, economy space usually divide front from the back yard. It is also called a German house, characteristic of a richer social class. The transversal house type on the other hand, is still not thoroughly researched, so development of this type is not completely understood. Nevertheless, it is important to observe that it was always a one-story house (Djekic 1994).

2.2 *Rammed earth building technique*

The value of traditional building techniques lies in the long development period that determined spirituality and cultural identity of the region and its people. As a result, every building tradition is followed with local beliefs and myths. In Vojvodina, there are numerous examples of local beliefs related to the building process. For instance, in the Srem area there is a belief that the foundation of the old house should not be moved, because otherwise the host will die. In some villages, a live rooster or a bottle of local drink had to be built into the foundations, in order to bear the weight. People were also strict about children not coming close to foundations so 'their shadow would not be built into them'.

In Tavankut, it has been documented that it is not good to build in rammed earth before St. George's day, May 6th. The reason for this belief lies in the explanation that earth respires and therefore is not good as a building material. That is why people in Vojvodina usually build their rammed earth houses in May which leaves enough time for walls to dry completely before winter comes (Djekic 1994).

As a building material in Vojvodina, the widespread material is earth, used as rammed earth, adobe or fired brick. Specifically, architecture in earth is typical for rural house in Vojvodina and it has its roots in the 18th century when colonists popularized rammed earth. Even before that period, it is documented that Serbs, actually used cut turf in rectangle pieces, then tied down with grass and arranged one upon another before they learnt to build in rammed earth. According to Djekic's study (1994), for rammed earth architecture it is recommended to use a mixture of black and yellow earth or just yellow earth mixed with chaff. After defining the place to erect a house, it is also necessary to mark the place where earth is going to be dug out. Usually the upper layer of earth is putting aside and only the deeper layers are used for building. Afterwards, the created pit is usually used as a dump.

The building process is started with wetting the earth thoroughly and then mixing it with chaff by legs or hoe, until the moment it starts to separate from the hoe. In order to build a foundation for the house, it needs to be dug down to the 'healthy earth' and then put in 20 cm of prepared earth for building and rammed it with mallet. Accordingly, supporting walls are built next. In the formwork, a layer of earth is rammed, then branches or cane are put in to strengthen the wall and then another layer of rammed earth, and so on. In the following manner, where two supporting walls meet, it is correct to place branches vertically, which would tighten the construction.

Walls inside the house are used only to divide rooms from the kitchen. Consequently, they are usually thinner than supporting walls and sometimes even hand-knitted with willow birch.

At last, when walls are built, it is time to cut doors and windows. After it is all done, walls are usually plastered with mud inside and outside the house and then painted with lime. Before the roof erection starts, it is important to leave walls to dry thoroughly. Traditionally, the roof construction is made of wooden beams. In the middle of transversal walls is a central beam and it supports beams in other direction. These beams are also supported by the beam positioned upon the columns of the porch, in the case the house has one. On those, paired roof beams are erected and in that way, the gabled roof is built. Further, a chimney needs to be built in order to collect smoke from the hearth in the kitchen and furnaces in the rooms. In the back part of the kitchen, first the open area of the chimney is built up to the roof in the shape of a cone. Above the roof, the chimney is built straight up (Djekic 1994). Finally, it is time to cover the roof and plaster the attic with mud. Roofs covered with cane could be found in every part of Vojvodina (Kojic 1949), but there also could be found shingle and straw roofs.

The floor in the house used to be made in rammed earth, plastered in mud and painted. Layers of rammed earth are usually 20 to 40 cm with the final layer of diluted cow dung (Marjanovic 2010). In time, some rooms got wooden board flooring and the porch got brick and tiles.

Besides this rammed earth building technique, it was often a case to use nuggets of old rammed earth houses, as a solid material. Sometimes, adobe was also used and rarely "pleter"—structure made of thin sticks around the vertical stakes, wood and stone. The use of wood was common in Srem, where the Austrian emperor donated spacious woods to his privileged frontier soldiers so they could use it as a fuel or building material. This is also the reason why some villages had houses built in half-timber (Djekic 1994).

After the WWII, with the improvement in living conditions and the widespread use of more expensive building materials, earthen building techniques went out of use completely and were thus forgotten despite their cultural, historical and economic importance. This was partly due to the stigma of poverty and backwardness that was attached to these buildings (Conti 2009).

2.3 *Characteristic architectural design elements*

Characteristic design on rammed earth houses of Vojvodina is a gable, decorative triangular surface that closes the roof. The decoration depended on the period of building and the dominant style at the moment. So, the simplest gables used to be made of thin sticks twisted around vertical stakes or cane fastened in mud. Since this kind of wall is not resistant to rain, the roof overhangs the façade and that way protects the gable. Upgraded gables are made of vertically composed wooden boards. Variations in design of wooden gables influenced the innovation in decorative treatment of built gables that followed. Consequently, on built gables there could be seen the imprint of many styles, such as baroque, secession, eclecticism … Decoration in plaster is expressing the richness of traditional art, creating the unique impression and the identity of local buildings.

Beside the gables, special attention is also given to the porch decoration. In the areas where the Austrian emperor donated wood, richly carved wooden gables and porches occurred. Also, decoration included color. Hence, according to the color of the house in some parts of Vojvodina it was possible to differentiate to which people it belonged. For example, in some villages, Slovaks painted their whole houses in blue, or just some parts, carpentry or socle. Romanians painted their houses in white and the socle in yellow. Hungarians' houses were usually green and Serbians' were white (Djekic 1994).

3 SUSTAINABLE DEVELOPMENT AND THE REGION OF VOJVODINA

In order to sustain our global environment and improve the quality of living in our human settlements, we commit ourselves to sustainable patterns of production, consumption, transportation and settlements development; pollution prevention; respect for the carrying capacity of ecosystems; and the preservation of opportunities for future generations (…) We shall promote the conservation, rehabilitation and maintenance of buildings, monuments, open spaces, landscapes and settlement patterns of historical, cultural, architectural, natural, religious and spiritual value (Istanbul Declaration on human settlements 2006).

Sustainable development concept and comprehensive idea that people should live sustainably is generally accepted in environmental scientific discussions and media debates of nowadays. Certain scientific circles agree that sustainable development should be essentially considered as a concept, since it combines the idea of prescriptive action and knowledge based on scientific principles. That reference to scientific principles is actually a foundation of rational human activity (Milutinovic 2009). Essentially, sustainable development represents the idea of creating a better world in the way of balancing social, economical and environmental factors. In order to upgrade a human life quality, nature and the environment could be considered as a reflection of social and economical fluctuations. Therefore, it is important to have a broad multidisciplinary approach to this subject.

Following the EU instructions, in order to become a member state, the Republic of Serbia is considering sustainability issues in several important documents on development that was adopted in the past few years. Based on these documents, the following paragraphs are going to underline some of the development issues that could be significantly affected by the rethinking of the rammed earth traditional architecture.

From the perspective of rural architectural tradition, it is crucial to have in mind that 65% of Republic of Serbia is agricultural land and it is mostly in Vojvodina region. Agriculture is a very important lever in development of Republic of Serbia, which contributes to rural development and ecological balance. As a consequence of breakdown, internal conflicts and international isolation of SFR Yugoslavia, in the period 1990–2000, agricultural production was reduced, as well as building and other economic activities. The influx of refugees—between 700 and 800 thousands persons (Initial National Communication RS 2010) is also characteristic for this period, which was followed with the increased need for the expansion of building capacities.

Urbanization and spatial planning have a significant role in the system of environmental management and rational usage of natural resources, since it integrates environmental protection, economic and social development. Uncontrolled urbanization in the last few decades led to the extensive decrease of population in rural areas and excessive population growth in the largest cities (National Program for Environmental Protection 2010), which certainly have the influence in the natural and built environment as well. Namely, Strategy for Spatial Planning Republic of Serbia (2009) defined burning issues in rural development: depopulation of rural areas, low level of technical and social infrastructure, disorder in spatial structures, the lack of institutional, organizational and planning support in rural development. On the other hand, the Strategy recognizes cultural heritage as a non-renewable resource of great potential and one of the key points of sustainable development. Also, it emphasizes the problem that much more attention is concentrated on the conservation and research of sacral monuments than traditional architecture in rural areas. Arguing further the necessity of reevaluation of traditional building techniques in a holistic approach, it is important to notice that buildings are responsible for 40% of energy consumption and 36% of total EU CO_2 emissions. Reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions (Directive 2010/31/EU). Therefore, energy performance of buildings is crucial in order to achieve the EU climate and energy objectives, such as the reduction of 20% of the greenhouse gases emissions and 20% energy savings by 2020. In accordance with Directive 2010/31/EU the Republic of Serbia adopted the Regulations on energy efficiency in the building sector (2011), which proclaims that every new building must have an energy passport—a certificate of energy consumption in the building. However, rural houses are not specifically covered and it is underlined that if a house is seasonally used, it does not have to obey this Regulation.

Moreover, one of the key touristic products of Republic of Serbia is certainly rural tourism (National Program for Environmental Protection 2010). Thus, cultural tourism development demands and financially makes possible the higher quality of heritage conservation and scientific research, which could significantly contribute to public knowledge and governmental assistance as a feedback.

4 EDUCATION AND RESEARCH OF RAMMED EARTH IN VOJVODINA

Despite its rich and globe-spanning heritage, rammed earth construction went into decline during the 20th century due to the growing availability of modern building materials and a consequent reputation as an unreliable material (Conti 2009). Modern rammed earth construction suffers from a number of disadvantages, for example: a lack of a regulatory framework and national guidelines for design and construction, higher costs due to a labor-intensive construction process and the use of specially-designed formwork, and, perhaps the most damaging, a perceived reputation for poor quality and durability (Becket 2011).

Project 'Vojvodina—heritage in earth 2010–2014' was created to cope with this kind of problems and positively affect public knowledge. Coordinated by former CRATerre student, Dragana Marjanovic, the goal of this project is the sensitization of students and professors of Faculty of Technical Sciences in Novi Sad and, most significantly, public popularization of rammed earth tradition. The main idea is to influence and shape the future architecture by researching local practice in rammed earth and simultaneously educating local people to build in earth on their own. The project is supported by a web site, providing information on a regular basis and educating the broader public.

The project will be carried out in two phases. Currently, in the first phase, supported by the Ministry of culture and approved by the Provincial Institute for the heritage preservation, an interactive map of rammed earth architecture in Vojvodina will be created, followed by typologies and photographs. Information should also be gathered on local masters and traditional crafts, which would be available in the freshly organized Center where workshops and seminars could be held as well. The second phase should take place in the field and include material analysis, interviews with local inhabitants and masters, etc. in order to learn which earth properties should be corrected. As a practical part of the project, in the summer 2011 the first Mora—summer school of architecture in earth was carried out (www.kucacuvarkuca.com).

This was a unique example of good practice in the region of Vojvodina, initiated by a person with vision. Doubtless, initiatives would be numerous over time if Republic of Serbia and the region of Vojvodina specifically recognize its built heritage in earth as a resource for sustainable development and incorporate it in formal education. The Center for environmental policy and sustainable development University of Belgrade conducted a study on the technical and technological group of faculties on Belgrade University, a leading educational institution in the country. According to the study, subjects that consider sustainable development and environmental protection are mostly represented as a subject of student's choice. Low interest of students is understandable, since these kinds of issues are not properly popularized on the university level (Djordjevic 2011). Hence, in the Faculty of Architecture on a master level, traditional building techniques are thought insufficiently and superficially, without any practical exercise.

5 CONCLUSION

One may ignore traditional environments; one may acknowledge their existence but deny that they have any value, interest or lessons; or one may romanticize them and try to copy them. I argue that the only valid approach is to analyze them in terms of concepts, and derive lessons, which are applicable to research, theory in building or design (Rapoport 1989).

In an increasingly globalized society with many social, economic and environmental uncertainties, there are still lessons that can be drawn from local knowledge of building in rammed earth in Vojvodina, as a part of European patrimony. This paper portrayed a wide context, researching the interconnection between rammed earth building tradition and sustainable development as a dominant concept of our time, underlining the need for a further holistic approach.

It is crucial to notice that the human relation toward nature has drastically changed, so it seems they are not so mutually dependent. Rammed earth houses in Vojvodina used to be a ground floor house exclusively, developed usually along the courtyard, providing close contact with the natural environment. Moreover, present-day practice is to build in concrete and brick in rural areas, so houses are often not finished for many years and the life quality is remarkably decreased. We neglected the main building principles of our ancestors—the house should be designed to do most of the work on its own, such as illumination, ventilation, cooling, heating and the technology should only slightly upgrade nature. It seems rational that the availability and economic quality of the earth as a building material could significantly contribute to living standard, poverty alleviation and other sustainable development issues. For example, in the past a rammed earth house used to be finished in six to eight weeks. There comes to mind a relatively recent problem of giving shelter to 800,000 refugees of the war during nineties, when the effective solutions provided by the local knowledge adapted to the environment were put aside, and terrified people were often accommodated in low quality living conditions in urban areas.

Certainly, the importance of putting science in the center of sustainability is reflected in more integrated policy making. Thus, it is crucial to be aware that sustainable development requests multidisciplinary scientific approach. The key premise of an integrative approach is a strongly perceived need for systematic scholarly and public engagement with this issue, especially acute in Serbia since dramatic changes in social, political and intellectual identity is taking place.

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The monitoring of rammed earth experimental walls and characterization of rammed earth samples

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ABSTRACT: This article analyzes differences recorded in the construction and ageing of experimental rammed earth walls. After 10–12 years of exposure some superficial degradation was observed in some walls, pointing to the necessity of applying a compatible surface protection. The behavior of samples of the rammed earth similar to those used in the walls was also analyzed in terms of density, thermal conductivity, capillary absorption and drying. A different behavior was recorded between: different unstabilized soils, the same soil but with different grading, the same soil but stabilized with different hydraulic binders and different soils stabilized with the same binder.

1 INTRODUCTION

Earthen construction techniques are used since mankind learnt how to build shelters (Bruno et al., 2010). They were abandoned in Portugal in the 50's but in the last couple of decades (mainly since the 90's) regain interest and application. Fortunately the craftsmanship was not totally lost but those who used to build with earth are now elderly masons. Also since the 90's professional courses in the area have appeared.

In Southern Portugal almost every dwellings built prior to the 50's has earth-based walls. The exterior walls were made using rammed earth techniques and the interior walls with the same technique or alternatively using adobe masonry or framed earth. Portugal is a seismic area and many of these old buildings have already resisted to (weak) seismic activity.

The majority of Portuguese earth buildings are dwellings, but earthen techniques can also be found in many other types of constructions, and even in national monuments.

The problem of durability of rammed earth walls still raises questions, although there are very ancient buildings, hundreds of years old, all over the world, with satisfactory performance (Mileto et al., 2011). Problems are often about seismic action and water sensibility. Some researchers have considered that problems due to loss of strength when saturated with water, erosion due to wind and driving rain and lack of dimensional stability can be significantly reduced by stabilizing the soil with hydraulic binders.

Many new buildings have been constructed in Portugal (mainly in the Alentejo region) and across the world. In the case of new buildings, appropriate design—for instance the creation of a suitable roof covering, a basement for avoiding capillary rise from the soil and the use of compatible materials—may suffice to guarantee good behavior in terms of resistance to water and moisture drying.

Degradation mainly occurs when the buildings are left without maintenance, abandoned to natural ageing. Some old buildings have been the object of rehabilitation and/or conservation efforts. These interventions are often not well designed and succeeded mainly because of the use of cement based mortars to overcome earth walls degradation (Faria-Rodrigues 2006, Gomes & Faria 2011). Frequently the pathology caused by these wrong interventions is much worse than the original problem and often becomes irreversible.

Earthen constructions offer several advantages such as thermal and acoustic comfort, local employment creation, minimal impact on the environment (Morel et al., 2001, Venkatarama Reddy & Kumar 2010), the valorization of cultural and social techniques, workmanship and human traditions.

Allinson & Hall (2010) stated that stabilized rammed earth contributes to reduce the amplitude and fluctuation of relative humidity indoors and the frequency of high humidity periods at the wall surface. Hall & Allinson (2008) consider stabilized rammed earth a "high thermal mass fabric". In terms of passive cooling, peak indoor temperature is reduced when an excess heat gain is absorbed by the walls and cooled overnight.

The present article intends to approach the characterization and durability of rammed earth walls from complementary perspectives: the comparison in terms of rammed earth construction and visual analysis of the weathering of experimental rammed earth walls, especially prepared for observation over time with natural exposition, and the characterization of rammed earth samples in terms of density, thermal conductibility, water capillary and evaporation. Furthermore, other tests can also be made on the walls and on the rammed earth samples.

The construction of the walls was included in professional school courses, involving students of level 3 in Traditional Building Techniques degree of the Professional School of Serpa (Alentejo, Portugal) (Rocha & Faria 2005). Serpa is located at the interior of Alentejo region, Portugal, about 100 km to the Atlantic coast, close to the border with Spain. It is about 25 km from the national weather station of the city of Beja. Data collected between 1971 and 2000 indicates that the average temperature is 16.5ºC, with a minimum of −3.2ºC (February/March) and a maximum of 45.2ºC (July). The monthly precipitation average is 47.6 mm, with a daily maximum of 111.3 mm.

Besides the above mentioned fact of allowing to perform a continuous observation of the walls degradation over time, this method allowed the students to achieve other important skills while building it.

During the construction of the walls, plans were made to store some quantity of soils for further characterization. Rammed earth samples were also made with the same soils and similar additions, with a view to trying to reproduce the rammed earth walls.

Finally, now in the near future, the aged walls were planned to be used as substrate to allow the *in situ* application of consolidants, of repair mortars and of rendering mortars and to allow its evaluation on rammed earth walls conservation and repair.

But the inclusion of wall's construction procedures in the student courses made things a little more difficult than expected. This did not go exactly as planned because of different pedagogical aspects that had to be prioritized. Some deficiencies were identified: not all the different soils that were used were stored for characterization; the rammed earth samples that were made did not reproduce all the walls that were built; some rammed earth samples were made with binder additions but reference samples of the same soil and compaction without addition were not made. These deficiencies will be resolved in later campaigns.

The behavior of another set of experimental walls as well as its behavior with the application of different superficial protections were analyzed by Dayre (1993) and Bui et al. (2009).

Concerning rammed earth sample tests many standards exist, including test procedures (Jiménez-Delgado & Cañas-Guerrero 2007, Cid et al., 2011, Gomes et al., in press). It is common to find different versions for the same test. They should be unified so that comparison of results could be facilitated.

Hall & Djerbib (2004), Hall & Allinson (2008, 2009a, 2009b, 2010), Allinson & Hall (2010), Heathcote (2011) and Schroeder (2011) have analyzed rammed earth behavior in relation to water, liquid or vapor, through different methods and its relations to thermal comfort. Values of 0,56 W/m.K to 1,21 W/m.K for dry-state thermal conductivity, for stabilized rammed earth with Portland cement, with dry density from 1400 kg/m^3 to 2120 kg/m^3 are refered by these researchers.

Hall & Allinson (2009b) consider that for highly compacted stabilized rammed earth there is no correlation between thermal conductivity and dry density and that the main parameter affecting heat transfer, when comparing materials with the same mineralogy, appears to be the degree of inter-particle contact, determined by the particle-size distribution and degree of compaction. These authors consider that the thermal conductivity increases with saturation ratio because the material acts as if it possessed thermal bridges, augmenting inter-particle contact in partially saturated soils. Differences in grading induces pore-size distribution to change and, consequently, the capillary potential.

Schroeder (2011) monitored a rammed earth wall made with coarse aggregates and straw fibers 1,5 m long, 1,0 m high and 0,5 m thick, with 12–13% optimal moisture content (OMC), for 6 months at 12ºC temperature and 68% RH. The researcher states that the optimum moisture content from Proctor test was not generally the optimum level for the rapid drying of rammed earth and that an higher initial moisture content (>10%) can accelerate the drying process. He indicates 90 days of drying as the minimal period before testing rammed earth samples.

Hall & Djerbib (2004) observe that the total required energy input for rammed earth compaction is not a fixed value regardless of the type of soil. The researchers consider that the main factors controlling the dry density are particle-size distribution and the corresponding OMC, and that these parameters are indexed to the strength and durability of the rammed earth. When rammed earth is produced, if insufficient quantity of water is present, the soil cannot achieve an optimal level of compaction due to greater friction between soil particles; if the water is excessive, it will occupy porous space, reducing the level of achievable compaction and increasing the porosity when the wall is dry.

2 EXPERIMENTAL WALL SETS

2.1 *Construction and evaluation of horta do Chó walls*

The construction of the walls occurred during June and July 1999. In a rectangular area, 12 rammed earth walls were built separately at a distance of 1 meter, according to three alignments. The same orientation was used for every wall: the two major faces of the experimental walls were exposed to N and S and the two smaller faces to E and W. The walls' foundations were made of concrete, with 0.40 m and their basement was made of stone masonry, with 0.30 m height. The soil was prepared with the intended optimal amount of water, and it was placed inside the formwork and compacted in successive thin layers until the top of the traditional formwork. After the formwork was filled in, it was dismounted and installed in the upper level. Each wall was completed with the two higher formworks, with final rammed earth dimensions of 0.5 m thick, 1.0 m high and 1.0 m long. The top of each wall was covered with two strands of tile, for protecting from rainwater.

Three types of soil were used, from different places in the municipality of Serpa (soil I, II and III). Four walls were made using each soil (walls 1, 2, 3 and 4). On walls number 4, no stabilizer was added to the soils; on walls number 3, 15% volume of hydraulic lime was used as a stabilizer and on walls number 2, 8% volume of cement was used. All walls were manually rammed with a traditional wooden tamper. Wall number 1 was also made with each of the three soils, without stabilizer, but has been mechanically compressed with a pneumatic hammer.

The differences in the construction of the walls allowed for a comparison of the work and the different performance of the material, using different soils and compaction methods. The walls monitoring allowed for a comparison between their performance when exposed for years to natural climatic conditions.

Regarding the implementation of the walls it was observed that when ramming was manual, soil III allowed the compression of a greater amount of material in a shorter period of time compared to other soils, independently of whether or not a soil stabilizer was introduced. Concerning the differences between the two ways of ramming unstabilized soil, it was observed that the mechanical compaction led to the introduction of more raw materials in a much shorter period of time, resulting in a very compact wall in comparison to manual ramming. On the other hand, this implied "sacrificing" the formworks and required a greater pressure control of the air compressor, to avoid damaging the wood.

In terms of visual evaluation of the walls over time, it was observed, after 12 years of exposure to natural climatic conditions, that the different walls had different levels of surface degradation.

The most obvious consequence was that the walls constructed with soil stabilized with hydraulic lime revealed a lower degree of surface degradation. The walls rammed by mechanical means were in good condition. The loss of pieces of the top protection of the walls, which happened in most cases, greatly accelerated erosion not only on the surface but also in the mass of the blocks.

2.2 *Construction and evaluation of herdade da bemposta walls*

Like on the wall set made at *Horta do Chó*, the wall set built at *Herdade da Bemposta* consisted of 12 experimental walls. The first 6 walls were erected in the spring of 2000 and the other walls in the following spring.

The implantation was also made in a rectangular area, with one meter of distance between the walls.

The orientation given to these walls was that a N/S axis would be coincident with the diagonal line of its rectangular base, so that one longer side and one shorter side of each wall were exposed N and the others South. As in the previous case, all walls have protections at the bottom and at the top. At the bottom there is a small base of concrete, with a height of 0.25 m, to avoid direct contact with the ground. The top protection was made with a tiled capping.

Each wall consists of two overlapping rammed earth blocks, made according to the traditional method, like the above described set. Four different soils from the Serpa region were used in construction: soil A (from the western outskirts of the city—walls 1 to 4), soil B (from the northeastern outskirts of the city—wall 5), soil C (site soil—walls 10 to 12) and soil D (from Serpa's urban zone—walls 7 to 9); wall 6 was never made. For the walls 8 and 12, the soils were stabilized with one part of hydraulic lime to seven parts of soil (12% volume). The soils of walls 9 and 10 were sieved (with a mesh size of 1 cm), in order to separate and remove gravel. All the walls were manually rammed, except for wall 11 which has been mechanically rammed.

The differences between the walls were intended to allow for an evaluation of the ramming of different soils (through differences in mineralogy, in grading, the addition of hydraulic lime as stabilizer and the type of ramming—manual or mechanical) as well as of the different performance of the walls when exposed to weathering.

The most remarkable observation concerned the fact that walls made with sieved soil had needed a "heavier, harder" and longer ramming; apparently the drying time of these walls was also much longer.

Regarding the evaluation of the walls over time, it was observed that, after 10–11 years of weathering, the walls without superficial protection were in very good condition, with only some superficial erosion. However, some slightly unequal levels of surface degradation should be pointed out. It was observed that the walls using stabilized soils with hydraulic lime were the ones with a lower degree of surface degradation.

3 RAMMED EARTH SAMPLES

3.1 *Rammed earth sample production and curing*

Rammed earth samples were produced with soils used at the Bemposta experimental set of walls. Eight samples were made with soil A, four with soil A sieved (eliminating the coarser particles retained in 1 cm mesh), six with soil B, two with soil B with 10% volume of hydraulic lime, two with soil B with 10% volume of Portland cement, two with soil C with 10% volume of hydraulic lime, two with soil D with 10% volume of hydraulic lime and two with soil D with 5% volume of hydraulic lime and 5% volume of Portland cement. The samples were produced in a TESTARAM machine for BTC production. The material was placed and compressed all at once and samples resulted in an area of 14 cm by 12.5 cm height (average volume of 2425 cm^3).

The samples were executed in 2001 and kept in a controlled laboratorial environment of 20ºC and 65% RH until 2012. All tests were held in the same controlled environment.

3.2 *Testing campaign and results*

At the age of approximately 11 years all rammed earth prismatic samples were tested for thermal conductivity λ with an ISOMET Heat Transfer Analyzer 2104 and a 03–2.0 W/mK probe. The samples were placed over a thermal insulation plaque and λ was measured in two lateral faces of each sample. Average values of λ are presented in Table 1, as well as the average values of the density of the samples (at 65% RH). All values are in the range presented in chapter 1. With a traditional 0.5 m thick rammed earth wall and the measured λ, U values will range between 1.1–1.7 W/m^2 K, always lower than the maximum for Serpa exterior walls.

Two samples of each type of material were tested for capillary water absorption, based on EN 15801 (CEN 2009). The lateral faces of the samples were watertight to enable lateral evaporation and assure unidirectional rising; the base was covered by a fine cotton tissue to enable the loss of material. The samples were regularly weight and placed with the base immerged in 5 mm water, over an open grid. The difference between the distinct types of material could be directly evaluated during the test by the height of the water and the lateral touch of the samples—some needed to be held with particularly care because they became very tender—and the difference between distinct samples of the same type of material was minimal. The capillary coefficient (CC), determined by the initial slope of the capillary curve, reflects the capillary velocity

Table 1. Rammed earth materials and average values of thermal conductivity, density, capillary coefficient, capillary absorption after 6 h, water high and drying index.

Rammed earth	λ (W/m.K)	Density (kg/m^3)	Cap. Coef. ($kg/m^2.min^{0.5}$)	CA 6 h kg/m^2	WH (mm)	DI (–)
A	0.64	1905	6.39	33.1	125*	0.7
A sieved	1.21	2003	2.07	19.2	91	0.9
B	0.95	1942	2.30	27.0	125	0.8
B + hl	1.05	1950	0.90	13.2	70	1.0
B + c	0.81	1876	1.34	27.8	123	0.9
C + hl	0.80	1846	4.34	23.5	125**	0.7
D + hl	0.87	1874	2.15	27.8	125	0.8
D + hl + c	1.06	1990	1.26	18.6	96	0.9

Rammed earth: A, A sieved, B, C and D; binder stabilizers: hl—10% volume of hydraulic lime, c—10% volume of Portland cement, hl + c—5% volume of hydraulic lime and 5% volume of portland cement; *—in 60 min.; **—in 150 min.

and the weight gain per area of contact with water induces the total amount of water that the material is able to absorb (CA) in the period of time of the test. When the test was stopped, after 6 h of contact with the water, the capillary absorption of some types of materials were already stabilized whilst others were still absorbing capillary water and the asymptotic value had not yet been achieved. That can be observed by the high the water (WH) attained in the samples. CC, CA and WH are presented in Table 1 for each type of material. Minimal CC and minimal CA induce better behavior of the rammed earth.

After 6 h of contact with water the samples began the drying test, based on RILEM (1980) and Brito et al. (2011). The samples were placed over a plane impermeable base and the evaporation was unidirectional at the same controlled environment. The weight loss was measured regularly. Because of the schedule of articles deliverance, the results of the tests were analyzed on the 3th day, but the evaporation was still going on.

The difference between the distinct types of material could be directly evaluated during the test by the changes in color of the samples and the difference between distinct samples of the same type of material was minimal. The drying index (DI) is registered in Table 1, calculated through Eq. (1) from the drying curves of each type of material:

$$DI = \frac{\int_{t_0}^{t_i} f(W_i) \times dt}{W_0 \times t_i} \qquad (1)$$

where $f(w_i)$ reflects the variation over time of the water content w_i (%), w_0 (%) is the water content at the beginning of drying and t_i (h) is the total duration of the test.

4 DISCUSSION

The levels of erosion observed on the experimental walls over time had an inverse evolution, that is: the strongest degradation took place in the early years, and progressed very slowly afterwards—except when the protection at the top of the walls began to deteriorate at *Horta do Chó* walls. As referred to above, the binder stabilization seems to have increased rammed earth's superficial resistance. On the other hand some unstabilized rammed earth walls also presented very good superficial appearance and integrity. In other walls, the aggregates became more visible; traditionally this means that the wall surface is ready to be rendered (Faria-Rodrigues 2006).

The experimental rammed earth walls are not directly representative of common walls in earthen buildings because experimental walls have two outer surfaces, whereas in a dwelling the interior atmosphere (without rain, wind and with minor temperature gradient) to which the internal face of the walls are subject is different from the external, subject to weathering (Bui et al., 2009). Anyway, a correlation between the experimental walls and current rammed earth walls can be assumed.

The observation of the experimental walls confirms the durability of the traditional unstabilized and stabilized rammed earth walls from Serpa region, exposed to natural ageing without superficial protection for 10–12 years. It also confirms the durability of traditional building walls that have undergone multiple decades of natural weathering. In similar conditions, stabilization with hydraulic lime seems not to be essential because unstabilized rammed earth also behaves properly. Stabilization with hydraulic binders may disable the natural recycling of the material at the end of its life cycle. This is not a totally positive point in sustainable development. For this reason it should be implemented only when justified. Other types of stabilization (Vegas et al., 2009) with natural and local materials—more eco-friendly—were sometimes used and should be further tested.

Moreover, some care should be taken when comparing the characteristics of real walls *in situ* with experimental ones, and especially with small samples. The same compaction apparatus and compaction effort should be used, for test results to be meaningful and transposable. However, the level of energy input used for compaction can vary depending upon the soil type. Experimental results are directly conditioned by the dimensions, preparation and production of the sample (Hall & Djerbib 2004, Bui & Morel 2009, Ciancio & Gibbings 2012). In the present case, the comparison between the compaction of experimental walls and the compaction of the cubic sample cannot be guaranteed and this can also be a problem.

Hall & Allinson (2009b) consider that no correlation exists between λ and density for highly compacted stabilized rammed earth. However, from the analysis of Table 1 for the analyzed rammed earth, thermal conductivity λ is directly correlated with density. Differences obtained with the same type of soil are also to be remarked, when used directly or without the coarser particles (presenting A the best λ and A sieved the worst). The particle-size distribution of the earth is then critical in terms of density and thermal conductivity but also in what concerns the rate at which moisture ingresses due to capillary suction (Hall & Djerbib 2004). Through addition/subtraction of soil material (granular stabilization), the rate of capillary moisture ingress in rammed earth can be controlled. The thermal conductivity also depends on the water content.

For the analyzed samples, the B + hl rammed earth displays the best behavior in terms of capillary absorption, being the one with slower and less water absorption during the test. On the contrary, the A rammed earth shows the worst behavior, while the A sieved presents a median behavior. It is clear that granular differentiation has in fact great importance on capillary behavior. Comparing the behavior of B + hl rammed earth with C + hl rammed earth it can be remarked that a similar stabilization does not control equally the capillary behavior of distinct soils. Comparing B with B + c and B + hl rammed earth, one can see that the same soil, unstabilized or stabilized with the same amount of addition but with different types of binders, behaves quite differently in terms of capillary action.

Table 1 shows that there is an inverse relation between density and capillary absorption after 6h of contact with water. Drying is easier when the drying index is lower. It seems that rammed earth A and C + hl present the best behavior, while B + hl rammed earth shows more difficulty in drying. In terms of drying, the granular differentiation between rammed earth A and A sieved is also to be noted, as well as the different behavior between rammed earths with the same soil but unstabilized or stabilized with different binders. The best behavior is recorded for the unstabilized rammed earth.

Strength characteristics are not presented but tests ran with the action of water and corresponding handling of rammed earth samples has indicated that those characteristics can be differentiated according to the rammed earth moisture content. This study is still being carried out, with a view to further characterization of rammed earth walls and samples.

5 CONCLUSION

This paper has analyzed the differences obtained in the construction and evaluation of the ageing of experimental walls with 10–12 years of natural exposure. Good and expected behavior was observed in both unstabilized and stabilized rammed earth walls, showing that the binder stabilization of the soils is not always needed. In some cases, after more than 10 years of natural exposure, an exterior layer should be applied for protection.

The paper also presents some characterization of rammed earth samples, similar to part of the experimental walls. The behavior of the rammed earth samples, in terms of density, thermal conductivity, capillary absorption and drying, was very distinctive according to different soils, different particle-size distribution of the same soil, the same soil with different binder stabilization and different soils with the same binder stabilization. This reveals that considerable research should continue for understanding and optimizing the characteristics of rammed earth and, therefore, for rammed earth walls to be able to meet all necessary requirements.

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Earthen architecture in Galicia (Spain): Rammed earth in Terra de Lemos

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ABSTRACT: Even though stone construction was dominant in Galicia (Spain), earthen construction was developed from immemorial times in some sedimentary areas where stone ran short: in Alta Limia region, where *terróns* (*adobes* with a wetland herb framework) were used; and in Terra de Lemos region, where rammed earth was developed. In this area was prominent the city of Monforte de Lemos with more than 500 constructions made with rammed earth and *corres* (half timber with earth). Earthen construction in Galicia is unknown by population and professionals and forgotten by all monographs about peninsular and Galician traditional architecture. This document is a summary about the research work developed in these years about earthen construction in Galicia.

1 INTRODUCTION

1.1 *Sedimentary and large interior depressions areas in Galicia*

Galicia presents a granites and schists predominant geology. However there are some geological areas formed by tertiary and quaternary clayey deposits: mainly, in large interior depressions in Lugo and Ourense and also in the big rivers around. These are very singular areas in Galician geography because of its shortage: they occupy only 4% of territory; but they also made possible to arise several traditional crafts like pottery and tile work. The largest basins enabled population to erect earthen buildings.

1.2 *Earthen construction in monographs about galician traditional architecture*

References about earthen constructions in Galicia are not usual in traditional architecture monographs. There were only found mentions to not structural half timbers with earth. Techniques that implied structural earthen construction were not interesting enough for authors who opted to omit them stressing differences between another peninsular architectures instead of similarities; or maybe they consider them residuals.

We think this research will be interesting to increase Galician architecture heritage. Earthen architecture was another inhabitant's ability for environmental adaptation, using the nearest most available and economic material in that moment.

2 EARTHEN CONSTRUCTION TECHNOLOGY IN GALICIA

2.1 *Construction with earth material in Galicia*

Earth is going to be used in most part of traditional constructions in Galicia: on the one hand, it is used as mortar for erecting stone walls and to cover external and internal walls (with or without lime); on the other hand, it serves for several external and internal half timbers. Like in north

Figure 1. Alta Limia (AL) and Terra de Lemos (TM) position in Galicia.

Portugal, similar to Galician territory, structural earthen construction techniques are going to be developed only in places where to find a high quality construction stone is difficult. These places are Terra de Lemos, all around Cabe, Saa and Mao basins and Alta Limia depressions, all around Antela lake. In the remainder territory and basins these buildings were very little developed, finding only few examples of earth construction.

2.2 *Half timbers with earth. Geographical expanse and use classification*

Building half timbers interior and exterior with earth was widespread in all Galician geographical areas. Even though, it was more visible in flat areas and depressions of Ourense and southern Lugo, as well as in large areas of Pontevedra. They are similar to examples in northern Peninsular (Feduchi, L. 1977) and northern Portugal (AAP. 1988). We found two types of half timbers in relation to its function inside the house:

– Interior half timbers, that enable the division of large spaces of early Galician farmhouse in specialized spaces. Particulary they have been used to wean the bedrooms of the living area
– Exterior half timbers, specially used to close the facade wall that was protected in first floor's *solainas* and *corredores* (large balconies); they were used also to close the end of *corredores* and even to close them from the exterior.

2.3 *Half timber with earth as structural closure*

Sometimes there are found houses built entirely with half timbers with earth from the first or second floor. In this case, the walls have a principal structure made of diagonal and vertical beams that serve to connect the wall and to hold the half timber with earth. We find some examples in old urban homes of Monforte de Lemos and Ourense, (Gómez, A. 1998) and also in farmhouses like San Clodio, Rivadavia (Feduchi, L. 1977). This use can be attributed to economic and practical reasons—due to the higher price of stone.

2.4 *Types of half timbers with earth*

There are many names known to refer to these half timbers, denpending on the depending on the area, the authors and their configuration, differing by the type of filler, wood of the tree (willow, cherry, hazelnut, chestnut or oak) and the different ways of joining the timbers. It can be observed an evolution of the technique of building half timbers:

– *Tabique encestado* (Plainting half timber): it is the less common of the half timbers, probable due to being the most primitive; reason why it was disappearing and currently it is difficult to find. It is made with round rights sticks that go from floor to ceiling, on which are twisting the branches of willow or hazel until a tightly structure is woven. Then it starts to be covered with layers of clay to achieve a uniform surface that eventually will be chalked. We know of examples in the regions of *Terra Chá* (Álvarez, F. 1993) and *Terra de Lemos*, in the province of Lugo, by Castro Caldelas, Ourense, (Feduchi, L. 1977) and others in the Portuguese Tras-os-Montes (AAP 1988). Today there are some artisans in Galicia who recovered this technique for the construction of interior half timbers for biobuilding of houses.
– *Tabique de pallabarro* (Pallabarro half timber): it is the most referenced to. Sometimes it is confused and mixed with the *tabique de corres*. This construction built on a vertical wooden frame made out of tables of 10 to 20 centimeters wide and 3–4 centimeters thick called *fitoiras* or *cangos*. The fitoiras link together with thin, narrow boards, *bitoques*, that are assembled horizontally and obliquely. The spaces between *fitoiras* are filled with a twisted mud kneaded with straw, *lampreas*, which are intertwined between *bitoques* or by *mangados* of straw. The two sides of the wall is coated with lime or earthen mortar and whitewashed with lime. This timber is used mainly indoors (Lorenzo, X. 1936).
– The most common system used in the outside, more advanced than those described above, was the *tabique de corres* (Corres half timber), name used in *Terra de Lemos*, or *de barrotes* or *de barrotillo* (Bas, B. 2002). It consists of a series of narrow wooden strips, usually willow or new oak branches—the *barrotes*—of 4 × 3 cm, very regular and just spaced 1–2 cm, mounted on regular feet that connects from floor to ceiling and spaced about 10 cm. The barrotes are positioned horizontally. The space between them is filled with straw, pebbles or wood shaving, and coated the outside with white clay whitewashed. This timber is very common in Terra de Lemos and throughout the province of Ourense.

2.5 *Boulders walls*

Boulders walls are not an earth technique strictly, but in them earth has a fundamental role. Its extension is restricted to the banks of large rivers and near the mountain glaciers of Ourense, where stones are brought from their beds. As the settlement of these stones is not easy in dry surfaces, for their placement are required large amounts of mud mortar. The result is walls that sometimes, in appearance could be confused with a wall of mud with a large proportion of stones. But its construction technique has nothing to do. There are few examples (Monforte de Lemos, A Pobra do Brollón) and currently it is an extinct art.

2.6 *Earthen mortars*

Earthen mortats were habitual in building in Galicia, used on the walls of *cachotería*: wall made of small granite or schist stones without cut, with many joints, with the risk of moisture penetration that many times were rendered with clay and lime, leaving only in sight large pieces of carved stone present in openings and corners. In coastal areas this lime and mud coating covered the whole face on the walls more exposed to winds (de Llano, P. 1996).

2.7 *Terróns walls in Alta Limia region*

In the region of Alta Limia, south of the province of Ourense, there are still retained some constructions made with an only original technique of this area: the walls of *terróns*: earthen parallelepipeds that were extracted directly from the margins of the former Lagoa de Antela (Antela Lake). In it abounded a type of wetland herb: *beón or bíon* (*scirpus lacustris*), widely used in housing construction as an isolating material and closure and it still can be found in some constructions of the region (Gómez, A. 1998). The *beón* was cut at ground level in the less flooded areas. The roots were buried and served as the *terróns* armor that were carefully extracted in blocks and, once dry (at which moment they acquired a high hardness), served as if they were *adobes*, for lifting the walls of houses. The terróns do not received any type of cooking, they were used crude. Walls of *terróns* were made

Figure 2. Villages in Alta Limia with constructions made with terróns, all around the extinct Antela Lake.

with granite foundations sometimes reaching a height greater than one meter. The corners and the middle of the wall were reinforced also with pieces of granite which supported the roof. Stood on the granite *terróns* wall settled with earthen mortar. Some walls of terróns had a particular structure with granite foundations and a tree trunks structure that supported the roof (Trigo, A.B. 2004). The logs were spaced approximately a meter and they left directly from soil or from the foundation wall. The separation between trunks was coated with *terróns.* In both cases *terróns* did not have a structural function but only as closure. Auxiliary buildings like cowsheds, mainly, and homes, seldom, were made with terróns, particularly in the plain areas of the county.

The technique definitely stopped once the landscape of Limia was completely transformed because of the drying of the Lagoa Antela for new agricultural uses during the 70's. Developmental momentum of Franco's dictatorship wiped out an ecosystem of great natural value, making it impossible to continue the already declining *terróns* construction. Just like were lost a hundred and fifty palafitics buildings that stood on the big lake (Conde, F. 1959).

It should be noted that no other examples of *adobe* construction or other parts similar to *terróns* are known in other areas of Galicia.

2.8 *Rammed earth in Galicia*

Rammed earth technique was used for building in Galicia in plain inland areas of Ourense and Lugo mainly, but also there are examples in other areas of the territory. The importance of this technique in Galicia was, however, scarce.

Rammed earth construction in Galicia is not different from other peninsular rammed earth but has some peculiarities. Its origin is unknown and it may have been imported from Leon, Castilla or Portugal. This technique reached its highest development in the region of Terra de Lemos, where we focused our study.

3 RAMMED EARTH CONSTRUCTION IN THE REGION OF TERRA DE LEMOS

3.1 *Necessity and urgency of this research*

Rammed earth construction in Terra de Lemos was spread across the region until the early twentieth century. Today we can not find witnesses to inform us about the vicissitudes of its construction. This heritage in earth is unknown to most practitioners and general public. It does not possess any asset protection even though the old town of Monforte de Lemos was declared an historical-artistic set in 1973. Thus, earthen heritage is gradually disappearing. This research seeks to highlight the value of this heritage in the area, which also has added value to want to release the very existence of rammed earth in Galicia, a region with *a priori* unfavorable characteristics to its development.

3.2 *Approaching Terra de Lemos*

The depression of Monforte de Lemos—Pobra do Brollón—Bóveda-, shaped square, has an area of 320 km^2. It is cut half by a series of elevations in the direction SE-NW.

The area located at southwest of the median elevation is bounded by scarp mountains of 150 to 250 m of altitude, with a fill of pink or green clays reaching there a few hundred meters thick. There are also some schists and quartzite hills, like the ones that the old town of Monforte has at its feet. Except in the west, where the vineyard extends, the available space is very irregularly occupied by crops.

In the northeastern part (A Pobra do Brollón-Bóveda), the scarp mountains that delimit it by the margins are less high. The valleys of the rivers that run through (rivers Mao, Cabe and Saa) are spacious and well designed, leaving long platforms including watersheds gently sloping. The fields are much better distributed, but often separated by wide pieces of uncultivated land (Bohuier, A. 2006).

In depression, the dominant soil type is the pseudo-gley soil (Kubiena-Mückenhausen classification) and in the vicinity of major rivers, the plain brown allochthonous-gley soil. Also notable is the pelosol in the central part around the stream of Rioseco. There are likewise small portions of gley soil and brown land (Guitián, T. et al., 1982).

The seismic risk is generally very low in Galicia. Only in recent years it has been reported some low-intensity earthquakes with epicenter in eastern province of Lugo. But historically, there is no record of important earthquakes (Rueda, J. et al., 2001).

County of Lemos has a Mediterranean-mesomediterranean type of microclimate below 450 m above sea level—area where earthen constructions are built-, unlike the more common Atlantic climate prevailing in Galicia. Monforte de Lemos (300 m high) has a mean annual temperature of 13.4ºC and an annual rainfall of 823 mm. The summers are particularly dry (Martínez, A. et al., 1999).

Human settlement have a structure with a tendency to gather around the parish church throughout the depression. The structure of the village is compact with a size of 5–10 to 40–50 houses with a variety of formats.

The fields are in process of change towards more extensive farming, with more land for cereals per household (Bohuier, A. 2006).

3.3 *Ancient Travelers by Terras de Lemos*

Although today earthen heritage from the town of Monforte de Lemos is hidden and unknown, and most of the times it may go unnoticed by the traveler, it was not always like this. We reproduce two of the descriptions made by authors of the nineteenth and early twentieth centuries:

"The houses are made of ashlars, rammed earth walls, large antique wood balconies, replaced at the best houses with elegant and comfortable glass balconies, roof tile and slate, as we have seen from the Bierzo to here and cylindrical chimneys with slate roofs" (Becerro, R. 1883).

"Monforte, if I may give the impression got during a quick tour in town, it has an aspect that distinguishes it from any other town in Galicia. It looks more like the cities of Castilla. The streets are long and lined with poplar—trees that are not common in Galicia—and the houses are not made of granite if not earthen." (Hartley, G. 1911/1990).

3.4 *Methodology*

The aim of this study was, firstly, to identify rammed earth constructions of the region, limiting the area of extension of this technique and the main characteristics and dimensions of rammed earth found. It is also being made a selection and classification of buildings and rammed earth walls representative of the region. On the other hand, it has begun an inventory of earthen constructions (though it is not finished) in the town of Monforte de Lemos, identifying rammed earth and walls. Each building has an identification card with photographs and drawings. So far the number of items listed in the city amounts to 500.

3.5 *Geographical coverage of earthen construction. The town of Monforte de Lemos*

Rammed earth is spread over the bottom of the region, where soils are of sedimentary origin. When the land rises, the rammed earth disappears, being more present in the flatter areas. It is found in most towns of Monforte and Bóveda, and in parts of Sober, Pobra do Brollón and Panton.

In these areas, rammed earth is not the only construction technique. In some places it is majority, in others it is in a similar proportion of the *cachotería* walls, and other rammed earth is residual. Often are found mixed buildings with walls of stone and

Figure 3. Geographical coverage of rammed earth in Terra de Lemos: Freguesías (parish) with rammed earth contructions.

Figure 4. Rammed earth houses in Monforte de Lemos. Inventory of earthen constructions.

rammed earth and even later additions of brick, as a chronological sequence of the use of materials.

With rammed earth was erected most of the oldest buildings of the *lugares* where we have conducted our investigations. So it is possible that residual status in many of them were due to disappearing, as in the past 100 years we have almost no record of new buildings.

In interviews with local people none of them could confirm the date of construction of buildings made out of rammed earth, noting only that "the houses were always there". Only one of the oldest remembered having seen his own building rammed earth fences (when they were children), but not housing (Fernández P., A. 2010/2011/2010).

Of the rare earth rammed homes from which we have information on the date of construction (property register data from 1880), we found buildings constructed primarily from that year until 1911. We also found some constructions built in posterior years until the 40s (type 3 of urban housing, as discussed below). From there we have no data of new earthen homes.

Monforte de Lemos (20,000 inhabitants) was from the Middle Ages one of the main cities of Galicia and it is today the capital of an extensive area of historical significance. The city was born on a small hill, now dominated by a castle, where many buildings are built with *cachotería walls*, boulders walls, and earth. In the Middle Ages the settlement spread across the plains around the hill being rammed earth houses the most part. The various *arrabales* (extramural suburbs) emerged from the Middle Ages (Ramberde, Carude, Os Chaos, Abeledo, Morin) were raised entirely on earth and today it still can be observed.

The situation changed in the early twentieth century, stopping building first homes and then also fences because of the arrival of brick, which started production in the region in an industrialized way in 1909 and especially from 1926 (Carmona, X. & Nadal, X. 2005). (The Galaica began operating in 1909 in Sober manufacturing brick, in 1926 began Rubian Ceramics in Bóveda and García Rey in Canabal Factory).

3.6 *Types of rammed earth constructions*

From the selection of buildings that were found it was done a typological classification distinguishing urban homes, mainly located in Monforte but not only, from those relating to the field:

- Urban housing—Type 1, with ground floor, first floor with solaina (large balcony) and faiado (attic): It is the oldest type in the town of Monforte, present mainly in both hill and suburbs. It makes sets of long, narrow houses in a row, the rueiros. Rammed earth is used for dividing walls with spans of between 4 m and 6 m wide. The front and back part can be rammed earth, of corres half timber, or even sometimes cachotería on the ground floor, but foundations typically do not rise more than 70 cm.
- Urban housing—Type 2, with ground floor, stone on the front and two floors with gallery and *faiado* (attic): Present in public areas of the old city. These are homes between dividing walls of rammed earth with lights up to 8 m or 9 m divided into two *vans* (supporting space between two walls). The beams support in the middle, in

Figure 5. Rueiros structure in Abeledos suburb: Dividing walls in urban housing type1.

a wooden structure or other earthen wall parallel to the dividing walls. Normally the facade is made of stone, hiding the rammed earth. Incorporated into the floors there are galleries in front or behind, according to their orientation. May be an evolution of type 1, that it would take two units of this to make a bigger home.

– Urban Housing—Type 3, located next to road, it has ground floor, one or two floors and the *faiado* (attic): the latter type is more modern. Presents a typology very similar to Galician road homes, arising from the city growth around roads, probably in the late nineteenth and early twentieth century (they abound in Morin, in the vicinity of the railway station and in the streets out of town). These homes can have only ground floor or adding one or two floors, without *solaina* (large balcony) and galleries. Although sometimes they have small balconies. The walls are rammed earth with foundations of schist. In many of them the front was covered with a concrete structure and brick.
– Rural housing: In the plains there are round prismatic volumes and a wide Solaina (large balcony) facing south. They often have a courtyard, which is accessed through a big gate where the agricultural units are (Llano, P. de 1996). Rammed earth is used here in the exterior walls of the house and the closure walls of the courtyard. In other cases the houses are grouped in small blocks with rammed earth always present in the exterior walls. The courtyards here disappear and houses may seem at times to those of type 1.
– Support facilities and fences: as well as rural homes many of the auxiliary buildings, such as *palleiros* (haylofts) are made of rammed earth. Also in many enclosures for livestock farms got up rammed earth upto two or even three *tapialadas*.

Figure 6. Morin suburb. Urban housing type 3.

Figure 7. Palleiro (cow shed) in Rioseco, built with tapialadas 90 cm height.

3.7 *Composition and size of rammed earth*

The dimensions of rammed earth are highly variable:

In rammed earth walls range from 45 cm to 60 cm. In rammed earth of homes range from 55 cm to 75 cm.

For tapialadas is typical heights 90 cm, complemented by others of 50 cm in building houses. In these cases, the long may normally range between 210 cm and 230 cm. In other cases the tapialada has a height of 75 cm to 45 cm supplemented by others in the construction of houses. The long in these cases range between 160 cm and 195 cm.

The tapialadas often are separated by slates slabs, covering their rammed earth walls also with the same slates slabs or tiles. The rammed earth protects it from moisture by a schist wall that rises at least 30 cm and a maximum of 70 cm. In the case of housing the minimum starts in 70 cm reaching often the building in stone all the ground floor.

The composition of rammed earth is usually very schistose, with boulders up to 5–7 cm.

4 CONCLUSIONS

Much remains to be done in an attempt to preserve, disseminate and even resume earthen building techniques in Galicia, of which this research is intended as a first step: for Contribution to knowledge of their heritage and the impact it may have to make known the possibilities of an old material with low environmental impact in an *a priori* hostile environment.

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Rammed earth walls in Serón de Nágima castle (Soria, Spain): Constructive lecture

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ABSTRACT: The Raya or frontier between the kingdoms of Castile and Aragón was fortified with a system of castles and walled-cities that were useful during the several conflicts that took place in the Late Medieval Age. The Serón de Nágima castle defended the communication road between the axis of the Jalón river valley, which flows into the Ebro, and Duero valley. Its uniqueness stems from the fact that it is one of the few fortifications in the area where rammed earth is the only building system used. In this paper, the castle building fundaments are exposed mainly focusing on the techniques and building processes developed from the interpretation of the legible constructive signs in its walls.

1 INTRODUCTION

The Late Medieval strategy for delimitating and defending the frontier between Castile and Aragón was in its systematic fortification. Ancient castles and Muslim fortifications were repaired and new buildings for defense were erected. The aim of the author's Doctoral Thesis, which gathers from the present paper, is to know the construction techniques of a selection of these castles, so as to interpret the building activity of that historical moment and analyze the systematization of these construction techniques within the historical, geographical and architectural context. The research method consists of a fieldwork in which a series of castles are documented and surveyed; they are previously selected after analyzing the bibliographical works of the medieval Soria's castellology. An extensive table has been compiled with all fortified elements of the province, which includes basic historical, typological, building and bibliographical data. With the data collected on site, the analysis of the construction of each element is developed (about 30 have been selected and documented), supported by graphical and computer resources.

Many of these castles were built using the rammed earth, as the case of the castles of Serón de Nágima and Yanguas. In other occasions, there are only some walls of the castle which were built with this constructive technique. We can observe this item in the castles of Caracena and Berlanga de Duero. Finally, we have noticed that the rammed earth was used as filler in the walls with a masonry external layer, for example in the castles of La Raya, Arcos de Jalón or Ágreda. Through the constructive putlog holes left in the masonry by the scaffolding we can study the systems and processes of building. The architectonical lecture of these putlog holes reveals to us the auxiliary methods and the constructive processes.

This paper presents the study of the fortress of Serón de Nágima. This castle is, along with the castle of Yanguas, the only case in which rammed earth is the only technique used for building the walls in the province of Soria.

Figure 1. Situation map where are signed the places named in the paper: Ágreda (007), Almazán (038), Arcos de Jalón (048), Berlanga de Duero (075), Caracena (111), Ciria (140), Deza (165), Gómara (211), Medinaceli (265), Monteagudo de las Vicarías (279), Morón de Almazán (287), Osma (320), Peñalcázar (332), La Raya (279C), Serón de Nágima (412), Soria (415), Vozmediano (530) and Yanguas (531).

2 THE FRONTIER FORTIFICATION

The current provincial administrative boundaries, due to their arbitrariness and sometimes lack of consistency with the historical frontiers, are not usually suitable for historical researches. However, the strip of land that forms the geographical framework of the research has been a historical frontier in which there has been effort to define since the Reconquest. Furthermore, one of the Castilian monarchs' concerns was the definition and defense of the border with Aragón, because of the constant wars between the two Spanish Crowns throughout the Late Medieval.

The administrative territory which the current Soria occupies since 1833 has been a transit and border territory since antiquity. Celtiberian culture experienced its greatest development here. The desire of Rome to control this territory—for example, the famous and extensive siege of Numancia—responded to the need to control such an important way between the river Ebro and the river Duero Valleys.

However, the character of passage and communication road between these large geographic features—the Ebro, the Duero and the Tajo valley—turns into a border as the Reconquest takes place. The Reconquest of the Duero Valley develops along the 10th Century, when the western part of the current province is taken. The Islamic Marca Media—Middle Mark, an Islamic administrative territorial division—establish its frontier in the Duero, and for its surveillance they built up a complete network of *atalayas* or watchtowers. In 946 Abd al-Rahman III rebuilds and fortifies the town of Medinaceli, where he moves the capital of the Marca Media in reaction to the Christians advance and so as to control the Jalón River, an extremely important communication channel between the main cities as «sentry against Castile» (Rubio Semper 1990, 115–116). Castile advances through the south and in 1104 conquer Medinaceli.

Meanwhile, Alfonso I of Aragón conquered Zaragoza, the eastern of Soria in the early 12th Century. In 1124 he reaches the upper Jalón until Medinaceli. The concern of Alfonso I, named *Batallador*—the Battler—, after conquering these territories was to control them. His political plan was to repopulate and organize the new conquered lands. In order to achieve this, he kept the Muslims who were already in these lands and brought Mozarabic Levantine people. Alfonso I the Battler, King of Aragón, had married Lady Urraca, who succeeded to the throne of Castile his father Alfonso VI of Castile and León between 1109 and 1126. Under his reign, Aragón advanced from the Ebro's valley thanks to the conquest of Zaragoza in 1118. A year later he reaches Soria, seizing power of the eastern of the province. He repopulated Soria territories, the Vicarías, Morón, Almazán, Serón, Ciria and Ágreda. When he later divorces his wife, he kept the land under the government of Aragón. These lands are soon claimed by Alfonso VII, king of Castile and emperor of León who reigned from 1126 to 1157, Urraca's son and the stepson of the Aragonese king. He seized the *Regnum Caesaraugustanum* (Zaragoza, Tarazona, Calatayud and Daroca) and returned them after the Carrión's Treaty in 1140, to the recently formed Kingdom of Aragón, in exchange for the vassalage of Ramón Berenguer IV. Later, in 1296, Alfonso de la Cerda reaches Soria lands with Enrique de Aragón help and proclaims himself king of Castile, after taking possession of Serón, Soria, Osma, Almazán and Deza. With the Treaty of Tarazona and Huerta they are returned in 1328 (Zamora Lucas 1969, 30–31; Torres Fontes 1987).

With these border disputes and frictions among other reasons, a series of struggles begin between the two crowns which would not cease until the late Middle Age. The most important was the "Guerra de los Dos Pedros"—Two Peters War—in the 14th Century (Diago Hernando 1998, 125–156).

When Castile, halfway through the twelfth century, the Muslim population is expelled from Calatayud to Sigüenza, establishing Communities of *Villa y Tierra*—Town and Country—and repopulating with people brought from the Lara's *alfoz*: from Biscay and Burgos.

These communities of *Villa y Tierra* were transformed into lordship lands as a means of guarding the borderlands. The Crown must appoint *fronteros*—a kind of frontier knights—in villages near the borders so as to monitor these disputed regions, who were responsible for raising and reforming military fortresses and buildings, which are nowadays located in the east of the province of Soria, in the mentioned above regions, which constitute the scope of the investigation.

3 STATE OF THE ART

The historical elements that merge in the castle of Serón de Nágima were collected by Florentino Zamora Lucas, who was a Soria's castellology expert. In 1969 he publishes an article in the Journal *Castillos de España* (Bulletin of the Spanish Association of Castles Friends) in which he compiles the known historical facts known about this fortress and Vozmediano one. However, it offers no details about its construction. These same data are collected by the same author in the encyclopedic work *Corpus de los castillos medievales de Castilla* (Espinosa de los Monteros & Martin-Artajo

Saracho 1974, 456–461). There are several books about the castles of the province of Soria in which this castle appears (Casa Martinez et al., 1990, 66; Lorenzo Celorrio 2003, 197–200; Bernad Remón 1994, 50–51), although they don't show any further information besides the already given by Zamora Lucas. Finally, Fraile Delgado studies the construction material of the fortress of Serón in his doctoral thesis (Fraile Delgado 2005, ch. 5, 6–14, ch. 9, 19–23). This is the latest research—and, constructively, the most complete—about the castle of Serón de Nágima.

4 HISTORICAL ELEMENTS

In the river Nágima's valley, between Ariza and Gómara, over a hill near the intersection of the river Carraserón or Valdevelilla stream, lie the each time scanter rests of the Serón de Nágima's fortress.

Figure 2. Ortophotography of the village of Serón de Nágima. In the southern part, on a hill which dominates the houses, there are the ruins of the castle (IDECyL 2011).

Figure 3. General north-east view. The castle over the village.

Figure 4. Inner view of the castle.

There are no clear evidences about its foundation. Several authors date its construction during the Muslim domination (Zamora Lucas 1969, 30; Lorenzo Celorrio 2003, 197), maybe confused because of the construction materials: the rammed earth leads them to relate this fortress with the ones in Andalucía and even in southern Morocco.

News about the fortress are dated since 12th Century. It has already been reconquered, and the Episcopal frontiers between Osma and Sigüenza were being outlined. The Pope Inocencio II «gives to [the Bishop of Sigüenza] the tithes, salines, mills and the Serón fortress: "necnon Seronen castellum cum omnibus terminis suis"» (Zamora Lucas 1969, 30). From that moment on, mentions to the fortress are frequent but always related to disputes and lawsuits both administrative and ecclesiastic. However it is not known whether that «Seronen castellum» is the one we can see nowadays, or a previous construction. That information would only be revealed after an archaeological exploration. There are not building materials either that appear to have been used in a previous construction. Perhaps the stones from glacis were used for the construction of the houses of the village. In any case we cannot confirm that hypothesis.

This fortress is named many times during the late medieval confrontations between Castile and Aragón. That responds to the fact that it is located in one of the busiest routes between Jalón's and Duero´s valleys in the "Two Pedros War". The last historical event was the responsible of its downfall: May 10th 1811 French troops set fire to the fortress (Calama y Rosellón 2009, 218). From that moment on its downfall has been unstoppable. The last pull down took place in March 20th 2011 after an intense rain. Unfortunately the last wall was the only one that kept the upper lime mortar rubble finish.

5 CONSTRUCTIVE FUNDAMENTS OF SERÓN DE NÁGIMA'S FORTRESS

Nowadays only one out of the two towers of the castle and some of the boundary walls remain standing. It is not known how the interior layout was, however, based on the floor's shape; we can assume it perhaps had an internal courtyard with cistern. This can only be known after detailed archaeological study.

The main constructive characteristic of this fortress is the technique used to build its walls. They were built with rammed earth with a lime mortar coat. The preserved walls have 2.40 m width at the lower part: about eight Castilian feet. The difference between the lower and the upper parts of the wall, as well as the lack of covering in the former, leads us to think that a skirting board protected the lower part of the wall. It could be ashlars masonry. It could have had a 30 cm width, but we do not know whether it had glacis or not. As in many other cases those stones were probably used in nearby constructions, due to the fact that they were cut accurately.

The upper part of the wall has a 2.7 cm width, with the mortar external layer, equivalent to nine Castilian feet. It is built by rammed earth levels around 90 cm high. Batches of compacted earth can be observed. The average thickness is between six and seven centimeters.

The presence of the putlog holes of the wooden cross ties helps us to reconstruct the process of the walls construction. The distance between these putlog holes to each other is about 70 cm. They pass ever from one side of the wall to the other side. In some of them, the superficial sealing remains. This stopper is made with a fill of rubble, gravel, mud and lime. None of them shows any rest of the wooden cross ties. These signs are the negative of the wooden beams used both as wooden cross ties of the formwork as scaffolding to build the walls. Two wooden cross ties' sizes have been documented. The most common size is rectangular: 8 × 15 cm. The other dimension is square: 10 × 10. This difference of sections may result from use of different sized timber by different crews. Over these putlog holes, stones that form the roof of the putlog hole can be observed. These stones

Figure 5. North wall ruins. We can observe the difference of the thickness and the lack of external layer of clay. We can also observe the stones that form the putlog holes in which there were the wood cross ties.

separate the wood from rammed earth. Thus the adhesion between both materials is avoided, and the removal of the crossbar as the work progresses is facilitated. We conclude that the elements of wood were reused.

In addition to these elements of wood, of which only the trace remains, others have been found embedded inside the wall. They are wooden rough logs, about 8 to 10 cm of diameter. They appear mainly in the corners or in encounters between the castle walls. Perhaps, its role was to lock the joint between perpendicular walls. After March 2011 collapse, some rough logs have been found inside the ruins of the rammed earth and has been collected for laboratory analysis.

The wall has an outer layer of lime mortar coat about 10 cm thick, where we can see the lines of the rammed earth constructive levels. So, we can deduce that this coating was executed on the inner face of the planks forming the cast. The process of reinforcing the rammed earth batches with the successive addition of lime mortar layers at the edge will create an external harder lime crust, commonly known as *calicastrado*. Looking at the "section" of the wall which the ruin offers, the characteristic saw cross section of this type of *caliscastrado* coating in each batch—6 to 7 cm compacted earth level—is shown. After the removal of the formwork boards, it was leveled and putlog holes from the wooden cross tie were blocked.

The upper part of the walls was finished off with lime mortar rubble, constructed with the same technique of rammed earth formwork. This way, the head of the wall would be protected from impacts and erosion with a more resistant material.

In the walls preserved from the Serón de Nágima castle, we can see several voids. In the western wall there is a big high hole, which could have perhaps been the access to the site. However, the most exceptional holes are some *aspilleras* or *saeteras*—loopholes or arrowslit: defensive holes with vertical form—formed by a formwork inside the rammed earth.

To reproduce the building process, the graphical analysis method has been very helpful not only as a mere representation language, but also as a valid tool for the rational interpretation of the building, as reflected in the following figure. This graphical analysis of the construction is based on the traces of the construction processes which remain in its walls.

The encounter among the several phases of the building is done by a inclined joint. It is the result of the shortening of the length of each batch. In this manner ensures proper interlocking between the different phases of work. The elevation of the Figure 6 shows those that are visible outside the western wall. A vertical overlap is seen on the left side of the elevation. The inclinations of the different joints are parallel. This indicates that the wall was built from the right (south) to the left (north). On the north wall, inclined joints are also observed in the same direction: from the west to the east. We can know the process of the work by studying the graphic analysis of these joints.

Through the analysis of the constructive signs and joints, we can know the constructive process. Despite the advance state of collapse, inclined joints which mark the advance of the construction can be observed (elevation in Fig. 6 and axonometric view in Fig. 11). Construction started in the south-west tower and continued in the west wall and in the north one. From this tower, the south wall was built. However, between the tower and the south wall there is a vertical joint. There are some putlog holes in the tower which were occulted by the south wall: this indicates that the tower was

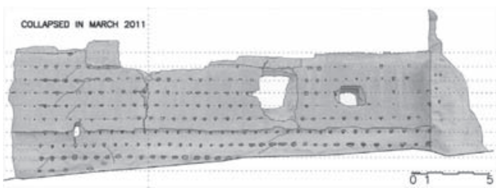

Figure 6. West elevation of the castle.

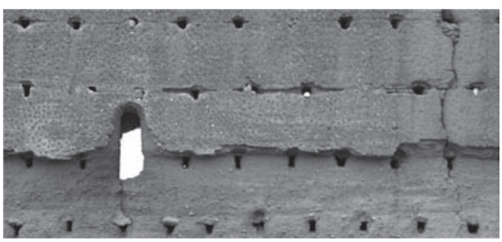

Figure 7. Constructive putlog holes in the west wall.

Figure 8. Arrowslit void in the north wall.

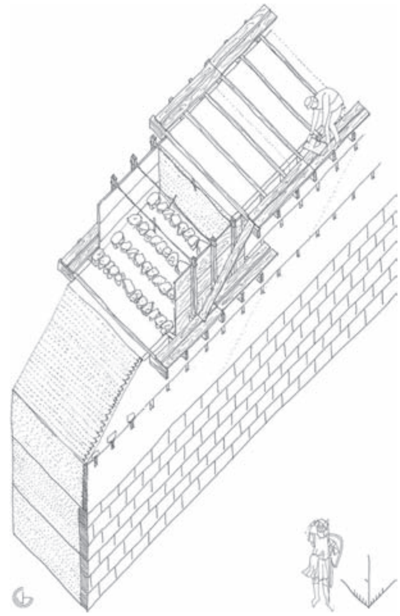

Figure 9. Graphical analysis of the constructive process for the rammed earth walls.

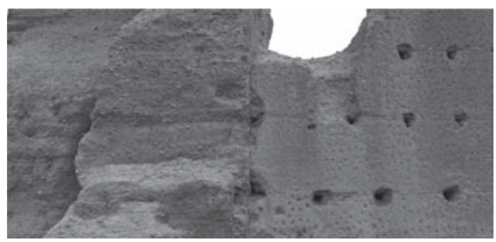

Figure 10. Detail of the joint between the south wall and the south-west tower.

built first and after was erected the south wall. The construction seems to continue towards the east, as the constructive joints show. In the east wall there is hardly any rest and we can not know its constructive process. This complete process is summarized in Figure 11.

The conserved walls have been drawn and a hypothetical reconstruction of Serón de Nágima Castle's complete volume has been designed.

6 CONCLUSIONS

The ruin of the fortress of Serón de Nágima is one of the two only complete constructions of rammed earth of the castles in the frontier between the Late Medieval Crowns of Castile and Aragón. The use

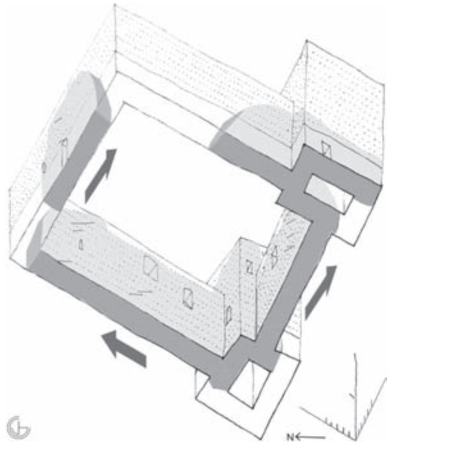

Figure 11. Axonometrical view of the ruins and the hypothetical reconstruction of the rammed earth walls of the castle. Constructive joints—viewed in the ruins—have been designed. The arrows mean the sense of the constructive process. The plan is based in the survey of Lorenzo Celorrio (2003, 347) and in author's data took on site.

of rammed earth as a building system in the castle of Serón is why in almost all publications it is referred to as a Muslim construction. It is often compared to those rammed earth fortresses in southern Morocco. However, the analysis of its building process does no state so. The hispano-muslim rammed earth techniques are different from those used in this castle. It is very likely that in the site now occupied by the Serón castle, a Muslim fortification were erected so as to protect the communication with the 10th Century capital city of Medinaceli. Nevertheless, the building we can still see today does not seem to be Islamic characteristics.

From this constructive analysis it is concluded that preserved walls were erected in the same time, with the same material and with the same construction system. The only noticeable difference lies in the two dimensions of the wooden cross ties observed through the sign left by the putlog holes which pass through the walls. The uniform distribution of the two types of beams may indicate the simultaneous work of two groups of workers: while one was building a wall, the other could be building another wall. Despite the ruin state, a constructive and volumetric hypothesis has been designed and graphically analyzed.

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Rammed earth—its use in new building and training as a building-school

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ABSTRACT: In the Litoral and Pampa region (Santa Fe, Argentina), earth was the most used material by native aboriginal, conquerors and immigrants. Churches and monumental sites can still be found in good condition. Nowadays, parts of the population, still build informal constructions with earth. From a provincial government initiative, through the interdisciplinary group La Terrada, an earthen sustainable construction was built. Serving as a structure for reception of tourists, it holds a strong cultural identity and is used for training. This synergy materializes through theoretical and practical workshops on sustainable construction. Several entities are involved in this initiative, such as, the University (UTN), provincial government, municipalities, cooperatives, entrepreneurs and professionals. The project is in *Tapia* (rammed earth) combined with a wooden structure and a green roof. The design adapts to *Tapia* requirements and the regional climate. Tests were undertaken for the local material correct use and the detection and correction of pathologies.

1 INTRODUCTION

Si bien tiene un espesor histórico similar al de Europa Occidental la construcción en tierra en Latinoamérica posee peculiaridades; ha pasado por una serie de circunstancias que hace que la forma de abordar las construcciones con tierra cruda (en este caso específicamente la técnica de la tapia). En lo referente a la restauración de monumentos históricos es reciente el interés despertado por las construcciones prehispánicas que han utilizado en diversas formas la tierra. Por otro lado, existe un importante patrimonio de 500 años a esta parte de construcciones que, de acuerdo a las características de la región en la que se sitúan, han utilizado la tapia como una tecnología no solo de construcciones militares o monumentales sino que también en construcciones domésticas.

Sin embargo, si bien hay acciones precisas destinadas a la conservación y recuperación de este patrimonio, las condiciones socioeconómicas de la región convierten al déficit habitacional en un tema prioritario donde últimamente las técnicas de construcción con tierra, si bien resemantizadas y tecnologizadas en algunos casos, vienen ocupando un espacio que se vislumbra como una real alternativa para determinados tipos de edificaciones. Es así que existen en varios países latinoamericanos normativas que legitiman el uso de técnicas como el adobe, la quincha y el más moderno Bloque de Tierra Comprimida (BTC). No ha sucedido lo mismo con la tapia que, a pesar de tener antecedentes históricos y buenos resultados en cuanto a prestaciones y durabilidad, no ha sido utilizado en construcciones contemporáneas al menos con la asiduidad de otras técnicas.

En la provincia de Santa Fe, con suelos aptos para este tipo de construcciones y referencias históricas muy fuertes (Figs. 1–5), no se tiene la costumbre de recurrir a la tapia como una alternativa válida para la construcción de viviendas, no solo de sectores populares sino también de sectores de niveles sociales y adquisitivos más elevados, dado las comprobadas ventajas de utilizarla tanto

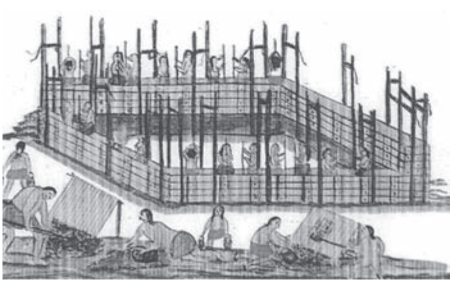

Figura 1. Florián Paucke—Arquitectura en tierra (Circa 1750) (*Hacia allá y para acá*. F. Paucke—E. Wernicke, 2010).

Figura 2. Ruinas Santa Fe “La Vieja” (1573).

Figura 3. Construcción contemporánea en tierra. Paraná.

Figura 4. Iglesia San Francisco. Santa Fe (1673).

desde el punto de vista de confort bioambiental, sustentabilidad y rapidez y economía.

En este escenario, el gobierno de la provincia de Santa Fe propuso realizar una serie de acciones entre las que se cuenta con una construcción a manera de prueba piloto para el rescate de este perdido saber hacer de los pobladores autoconstructores.

Figura 5. Construcción rural actual Vera. Santa Fe.

2 LA INTERVENCIÓN CONCRETA

Con fondos públicos provinciales y municipales, se generó en el Ministerio de la Producción un programa de construcción de receptores turísticos en puntos claves de acceso a la provincia con la utilización de tecnologías de tierra cruda, entre las que se cuenta en la localidad de Humberto Primo (Figs. 6–8), una edificación en donde se utilizan muros de tapia y techos verdes.

La gestión del proyecto por parte del grupo interdisciplinar de La Terrada fue lo suficientemente amplia como para incluir a: profesionales independientes capacitados en la temática; cooperativas de construcción sin experiencia en estas técnicas: y la Universidad Tecnológica Nacional que, a través de su Departamento de Ingeniería Civil, puso a disposición su experiencia y laboratorios para certificar la calidad del producto y para extender la capacitación de los cooperativistas que, asistiendo a charlas teóricas y con la metodología del Aprender—Haciendo, participaron en la construcción de la Obra—Escuela. De este modo se logró no solo el resultado tangible de la edificación sino también el intangible del interés de la población, al tener una muestra de que otra forma de construir es posible, y que están a mano los materiales y la mano de obra capacitada para replicar la experiencia.

3 EL RECEPTOR TURÍSTICO

El proyecto consta de una estructura de rollizos de Eucaliptos Grandis (especie maderable que se cultiva en la región), que sostienen un entramado de madera que recibe un entablonado que oficia de plano de apoyo de los elementos que componen el techo verde (Fig. 8). Entre los pies derechos (Fig. 9) de esta estructura se utilizó un encofrado de madera con un revestimiento fenólico, que fue el utilizado por los cooperativistas (en su mayoría mujeres) para realizar los muros (Fig. 10).

Figura 6. Ubicación de Humberto Primo.

Figura 7. Receptor turístico. Humberto primo.

Figura 8. Entramado de madera.

Figura 9. Pies derechos y encofrados.

Figura 10. Encofrados utilizados en muros.

Figura 11. Pisón metálico.

La tierra utilizada se eligió, tras los correspondientes ensayos de clasificación, entre tres locaciones posibles y provino de la apertura de un canal para riego en las inmediaciones. Se utilizó un pisón metálico (Fig. 11) y se ensayó la incorporación de óxidos metálicos (Ferrita) para colorear

Figura 12. Juntas constructivas coloreadas con ferrita.

Figura 13. Vista general de obra en construcción.

las juntas constructivas (Fig. 12). La dosificación empleada incorporó un 8% de cemento y un 2% de cal, especialmente en las juntas entre tongadas.

4 ALGUNAS REFLEXIONES

Cabe destacar el voto de confianza depositado por las autoridades en desarrollar un sistema constructivo que no tiene ninguna referencia actual, en cuanto a método constructivo. Los cooperativistas constructores de la obra no dieron su aprobación implícita hasta no haber probado tanto de la manera recomendada por la Universidad para realizar la ejecución, como de otras maneras para corroborar y comprender la tecnología.

De tres muestras de suelos clasificadas en laboratorio se eligió una que es la que mejor resultados dio en obra siendo las otras tierras, probadas por los cooperativistas para darse cuenta de su menor aptitud para su uso en esta técnica. Asimismo se eligió la cuestión estética de colorear las franjas de unión entre llenado y llenado.

5 CONCLUSIONES

Si bien la obra no ha podido ser terminada por problemas económicos derivado de cambios de autoridades políticas; el resultado se considera como exitoso en función de la rapidez y aceptación que tuvo la técnica por parte de los trabajadores y también por parte de los pobladores de la localidad y de localidades cercanas que ante la vista de los resultados obtenidos estiman posible la utilización de la tapia en otro tipo de obras como ser viviendas particulares y obras industriales.

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Patrimonial rammed earth structures at the Sierra Nevada, Mexico

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ABSTRACT: This paper demonstrates the progress achieved in the analysis of materials and construction systems of the rammed earth patrimonial structures located in the Eastern foothills of the Sierra Nevada, in the center of the Mexican Republic. The research includes typological information of the architecture, characteristics of composition and resistance of the raw material, patterns of damage and deterioration, as well as ethnographic information derived from interviews to artisans that built rammed earth walls until half a century ago. It is a relevant study for Mexico because there is very little information about the rammed earth architecture's development and geographical dissemination, which is essential for its conservation.

1 INTRODUCTION

Earthen architecture was widespread in Mexico during the pre-Hispanic era. From this period, the development of *bajareque* (wattle-and-daub), adobe, cob and rammed earth building systems may be highlighted. However, the latter technique was restricted to the construction of the nucleus of bases and platforms, as no rammed earth walls have been found in pre-Columbian cities.

Several authors (González, 1995:54; Gamboa, 2001:55; Cano, 2001:84) have stated that the remarkable architecture in the Sierra of Chihuahua, as well as in the archeological zone of Paquimé—both in the North of Mexico–, was made with rammed earth walls. Nevertheless, some elements suggest that the constructive system was based on the use of mud in plastic condition mixed with variously sized stones. This argument is supported by the absence of vertical joints between the building components, as well as, the cracking of the nucleus of the walls.

While, as a matter of fact, molds were used for the construction of walls, the level of soil moisture did not allow its compaction. For this reason, the technique does not correspond to rammed earth building logic, but it is related to the procedure which Doat et al. (1990:103) called "stabilized earth concrete". (Figure 1).

After the Spanish conquest, only earthen building systems of *bajareque* and adobe prevailed. Both were developed by the fusion of European constructive cultures and native civilizations' wisdom.

Rammed earth architecture in Mexico presents several questions about its technological development level and dissemination.

Figure 1. The cracking of the core of the walls suggests that the soil that was used for the construction was excessively moist. Pre-Hispanic houses at *El Embudo* Caves, Chihuahua, Mexico.

From the 16th century, the conquistadors probably introduced this building system, as happened in most of Latin America. However, for reasons not clarified until now, its evolution and expansion were limited both technically and geographically. (Guerrero, 2002:153).

Examples of historical rammed earth structures are only located in a territorial strip that goes from the Sierra Nevada to the *Pico de Orizaba*.

This area is in the center of the country, on the edge of the Royal Way (*Camino Real*) that linked Mexico City—capital of the New Spain Viceroyalty—with the Veracruz harbor, main point of connection with Europe.

In this region, rammed earth walls were built in chapels, parishes, convents, *haciendas*, graveyards and a large number of traditional houses. Fortunately, some of them survive despite the prevailing climatic and seismic conditions. However, although it is assumed that many of them correspond to the colonial era, there is not sufficient information for it's dating.

On the other hand, as it will be detailed in this text, the constructive processes that were developed show deficiencies in their sizing and structural performance in comparison with rammed earth buildings made in other Spanish domains. These "origin failures" limited the technological evolution of the system, and, in many cases, have preceded deterioration problems of the heritage buildings.

Thus, despite the obvious historical value of these structures, many have been abandoned, destroyed, or replaced by buildings made of industrialized materials. Local communities consider that earthen buildings are a symbol of poverty and underdevelopment, so they are being lost at a high speed.

This is why the study and documentation of the rammed earth building culture in this region is necessary and urgent, in order to identify their formal, functional and material characteristics as well as their potential vulnerability. With this information, it will be possible to propose solutions for their safeguarding and restoration.

Furthermore, the recovery of knowledge about rammed earth building and its implementation in contemporary architecture will contribute to generate sustainable solutions for the growing housing demand that prevails in this territory, as well as in many other rural areas of Mexico.

2 ENVERONMENT AND ARCHITECTURE

The study area is located on the eastern slopes of the *Iztaccíhuatl* volcano, in the central part of the Sierra Nevada of Mexico. In this place, there are various earthen constructive structures arising from multiple cultural influences throughout the history.

Among the evidence of the ancestral uses of raw soil, the Cacaxtla archaeological zone stands out by its dimension, and it is internationally recognized for its priceless murals. Another example is the pyramid of Cholula, one of the largest earthen buildings in Latin America, which was built with millions of adobes.

The *Iztaccíhuatl* volcano, with an elevation of 5286 m, it is the sixth highest mountain in North America and the third highest in the Mexican Republic, after the *Pico de Orizaba* and *Popocatépetl*.

Its name originates from the Náhuatl root *Iztac* that means, "white" and *cihuatl*, "woman". Its silhouette resembles the profile of a sleeping woman.

It is located 64 km from the city of Mexico and 48 km from the city of Puebla. It has an elongated shape with a longitudinal North-South profile, and it separates the Puebla and Mexico States in its slopes East and West respectively. (Figure 2).

The impact of the warm winds from the coast against the extensive length of the volcanic structure (about 15 km) has allowed the development of geographical conditions of remarkable diversity. Over 4000 meters above sea level, there is a landscape of high moorland vegetation Alpine style. Under these elevations a coniferous forest zone is located between the 2900 and 4000 meters of altitude. From this stage to 2400 meters above sea level is the location of the study area. (Sánchez-González, 2003).

The region lies in a high seismic zone and it is especially vulnerable because of its proximity to *Popocatépetl*. This volcano's activity is manifested in a cyclic form through intermittent explosions, exhalations of dense smoke of steam and ash, as well as vibrations, which despite their medium strength, are usually of a long duratio.

Although this is a pine, oak and cypress forests region, for millennia it has been occupied by human settlements engaged in agricultural activities, for which the native vegetation has been greatly disturbed.

The current subsistence of the inhabitants is based on the cultivation of fruit trees. In addition, agriculture of corn and beans is prevalent because, since pre-Hispanic times, it has remained as the basis of the peasants' diet in all the Mexican Republic.

Figure 2. Ruins of rammed earth walls on the slope of the Iztaccíhuatl.

The ice melting from volcanoes results in a hydrological network that covers the entire area. In the rainy season, the river flow significantly increases. This forms countless streams that for centuries have been channeled for agricultural irrigation.

Climate is sub-humid temperate. The average annual temperature is 14°C. January is the coldest month with 2.4°C on average, though sub-zero temperatures are recorded during several days between December and February. The warmest months are April and May with an average of 28°C.

The Wet season goes from May to October. The approximate annual rainfall is 935 mm. June, July and August are the rainiest months with up to 333 mm monthly average. On the other hand, December, January and February are the driest months with an average of just 6.7 mm. (Sánchez-González, 2003).

This information becomes relevant when it is linked with the material and morphological characteristics of the region's historical and vernacular housing. The need for climate protection has influenced the use of soil, the dimension of the walls, the occupation of the land, the shortage of windows and the roof slopes, among other typological features.

Even though during most of the year, and several hours of the day, environmental conditions are in hygrothermal comfort ranges, temperatures are sometimes extreme.

However, the use of soil as the construction material for walls and floors, has maintained stable temperature and humidity in interior spaces, despite external heat or cold. This process is supported by the massiveness and thermal retardation associated to the water vapor exchange through clay.

In addition, the single slope roofs covered with tiles protect the walls from the direct impact of the rain that can become quite heavy, and is almost always accompanied by hail.

Figure 3. Façade of a vernacular house. Calpan, Puebla.

Roofs slope towards the interior of the house, and possess eaves that generate shaded spaces of transition between the courtyards and rooms. Under those areas an important part of the daily activities take place, such as work and social relations of the inhabitants.

The regional architecture is essentially introverted and has a single level. The façades are extremely simple and rarely have windows that open to the street.

Lighting and ventilation of the habitable areas come from the interior of the premises in which the work courtyards, which are both orchard and farm, become the core of the urban blocks.

Housing habitable rooms are reduced and little illuminated because dwellers spend most of their life in open areas. For this reason, open spaces perform a very important role in the house. Living rooms, bedroom, kitchen, laundry, latrine, hen house, barn and roofed farmyards are generally located around the patio.

The few openings that prominent buildings possess are lined by stonework frames. Nevertheless, in most of the houses these elements are limited simply by lime and sand plaster decorated frames in relief, painted with geometric or plant motifs.

Almost no vernacular buildings have plastered walls or façades, but important houses, chapels and churches, have remains of lime and sand coatings that were placed on them decades ago, and have rarely received maintenance.

The remarkable quality of the soil in the region has allowed uncoated walls to resist the effects of the climate for decades.

Interiors of homes, public buildings and temples are regularly revoked and painted with light-colored limestone.

Internal divisions in the rooms are rarely found, but where they exist, the walls are made with adobes with a height that normally does not reach the underside of the roof. These walls do not get structural loads and the longitudinal rammed earth walls support the beams that bear the tile roofing.

3 THE CONSTRUCTION OF RAMMED EARTH WALLS

As mentioned above, there are many doubts about the chronotopical development of this technique in the region (Guerrero, 2009a:17) as well as, the reasons why some locations have abundant examples of historical and traditional rammed earth architecture, while in neighboring towns, there is not a single example and the predominant architecture was made of adobe.

There are some colonial religious buildings that have rammed earth walls, but there are no documents detailing the date in which they were introduced, so they might well be subsequent modifications.

The fact is that by the end of the 19th century this technique was fully spread and reached a high development in several agricultural and cattle ranches where it was used until the mid-20th century, as informed by some elderly artisans who participated in its construction.

The walls of the homes only have two overlapped rows. In the lower row, blocks are longer than the upper one. The first blocks are 2.4 m length by 1.45 m tall, while the upper ones are 1.65 m in length by 1.8 of approximate height.

It is worth mentioning that the blocks of the second row have an unusual proportion for any masonry structure. Their height is slightly superior to their length, which makes them potentially unstable. (Figure 4).

The thickness of the walls is fairly regular, ranging from 55 to 60 cm, although in some prominent buildings they are 80 cm wide.

In the constructive system of the chapels, public buildings and *haciendas* the walls are confined

Figura 4. Rammed earth wall with buttress made of volcanic stone and boulders. Chapel of Santa Ana. Calpan, Puebla.

with buttress or "*rafas*", a name given by Marcos y Bausá (1879: 170), but without horizontal reinforcements (*verdugadas*). These vertical reinforcements were built with volcanic stone masonry and boulders, settled with mortar of lime and sand. In these cases, the walls' height raises between three and four rows.

The sideboards of the traditional formworks were made with several planks reinforced with transversal battens. The side gates were simple planks.

Nevertheless, unlike the rammed earth building tradition in most of the world—which is characterized by the use of clamps to join the base of the formworks—in the study area, the control of the pressure exerted by the soil to be compacted was resolved from its outer face.

In the first row, the blocks were confined by posts tacked on the ground and pressed with wooden wedges to keep them verticality. The top of the posts were tied with a rope to maintain their separation.

Upper rows were supported using vertical wooden struts and diagonal studs with the same purpose, so that it did not require the use of clamps. As a result of this complex procedure, the walls do not have the characteristic holes usually called *putlog* holes (Jaquin, 2008:3) that are left when the horizontal timbers that join the boards are removed from the wall.

The building method consisted in filling the formworks in layers of soil, 15 cm deep. These were packed with heavy rammers that had been hand-carved in one piece of the hard wood of *capulín* tree (*Prunus virginiana*).

Soil was extracted from areas close to the workplace and it was used in its natural moisture condition without any stabilization process (Hernández, 2007:137). It was transported in large baskets known as "*chiquihuites*" that workers loaded on their heads.

At the Universidad Autónoma Metropolitana Xochimilco, resistance studies of the remains of rammed earth walls that were demolished as a result of urban development have been performed. In sections that were cut and carved to form 20 × 20 × 10 cm prisms, simple compressive strength average of 12 to 14 kg/cm^2 was measured. Values varied ± 1.5 kg/cm^2 depending on the height from which the section samples came.

4 MAIN DAMAGES AND DETERIORATION

As in most constructive systems, the main causes of deterioration of the structures derive from the conjunction between problems in the original design, the execution of works, the effect of environmental agents and the lack of regular maintenance.

In the study area, the unusual geometry of the blocks stands out. They are almost square or may even be higher than their length. This irregularity reduces the stability of the blocks by their slenderness ratio and it also affects the appropriate bond of the blocks. Many walls presented shearing faults as a consequence of the proximity between vertical joints of the walls.

The problem becomes critical in the corners of the buildings, which almost always present separation of the blocks by the short overlap of their components.

Another problem in the local building technology derives from the fact that the lower row was built directly in a trench or on the ground, without any kind of foundation or plinths. This is a very serious fault because almost all the walls are undermined in their bases as a result of the capillary absorption of groundwater. This, in extreme cases, has led to their swing by differential subsidence or earthquakes.

Another deterioration that was often found in the walls of the region is the presence of multiple perforations caused by colonies of insects known locally as "*tlapipilloles*". It is a striking phenomenon that they are mainly located in the East wall surfaces and with less intensity in the South walls. On the other hand, the North walls—which are in contact with the prevailing cold wind's impact and do not receive sunlight-, are not damaged. (Figure 5).

Local producers keep the ancestral belief that these insects are introduced in the walls when the soil that was used for its construction is not worked

Figure 5. The South façade, to the left of the picture, does not present insects' boreholes, while the East is crammed with them. Also to be noted is the weathering on the base of the walls by the lack of foundations and plinths.

during the period which they call "strong Moon", i.e., the days between the waxing and waning of the lunar cycle. It is considered that in this period soil has "greater force". This tradition is applied in many other activities related with agriculture and animal husbandry, and even the social relations of communities.

Although deterioration caused by these colonies of insects have a superficial effect, its impact is noticeable and produces collateral damage, such as, the entry of rainwater, and it's freezing at night and the final disintegration of the earthen surface.

5 CONCLUSIONS

Earthen building in Mexico is at a crucial stage. On one hand, government institutions in charge of heritage safeguard make outstanding efforts to preserve prominent historical sites in which the wisdom of native societies to adapt themselves to the environment is present. On the other hand, the communities—heirs of this constructive culture—struggle to destroy it.

Although they usually recognize the habitability qualities of earthen architecture, traditional societies consider it a burden of the past that reminds them of their poverty and feel it as a symbol of underdevelopment. The few construction craftsmen who survive, do not value the work they did years ago and do not worry about repairing their homes to extend their duration and generate conditions of health and safety. Despite the remarkable quality of the soil in the study area—which has permitted the subsistence of rammed earth walls with severe constructive faults and without any maintenance–, local residents destroy and replace them with buildings made of more prestigious materials and systems, such as cement blocks and reinforced concrete structures.

These processes irreversibly affect both the built heritage, by deleting traces of the passage of time forever, and the intangible heritage, constituted by an ancient building wisdom that is about to be lost.

Fortunately, in recent times initiatives have been generated to face this problem. Some non-governmental organizations have started promoting the development of bioarchitecture and permaculture, and they have included building with rammed earth in their technology transfer processes. Although still in a somewhat incipient way, they have built homes, schools and tourist facilities, guided by the principles of sustainable architecture, in which the soil takes a central role.

At the same time, in some universities undergraduate and postgraduate research is being carried out, focusing on the documentation and assessment of earthen architecture heritage in general and historic rammed earth in particular. This is a significant step forward because up to this moment, there is not even an inventory of this heritage available.

Finally, certain international institutions such as ICOMOS and the UNESCO World Heritage Committee have organized and sponsored meetings on vernacular heritage. In April 2007, the first meeting of traditional earthen builders in Latin America and the Caribbean took place. This was in order to promote the exchange of experiences between them, and to document their way to work as a form of cultural safeguard in the heritage. This colloquium was in the World Heritage Site of *Coro y La Vela*, Venezuela, and in September 2009 a second meeting took place in the city of Tlaxcala, Mexico, very close to the study area, source of this text.

The two symposia were very successful because they brought together academics, architects, personnel responsible for the protection of heritage, masons and traditional builders. Prior to the development of both meetings, artisans were interviewed and video recorded in their communities, in order to document their constructive practices. The presentation and explanation of these videos was the axis of the events.

Both meetings enabled the edition of two books (Chavarri, 2007 and Guerrero, 2009b) that include part of the interviews, studies on earthen architecture in Latin America, and concluded by a series of reflections and proposals generated from the working roundtables.

Rammed earth architecture conservation and restoration has unique constraints as a consequence of its materiality and constructive processes. Unlike other earthen building systems in which the raw material is used in high humidity conditions that facilitate its handling and reintegration, rammed earth structures depend of compaction processes where knowledge about materials, building technology and capacity of the labor force is essential.

This gives a key role to the constructive tradition because it is the depository of the proper functioning of the system in each locality where it unfolds.

Although there are valuable books and treaties in which for centuries the bases for the construction of rammed earth walls have been preserved and transmitted, their application is restricted by their level of abstraction and generality.

As it happens with any procedure with vernacular origin, its development never required these kinds of texts, simply because construction was part of everyday life in traditional societies. Vernacular builders knew the way to characterize the raw material, the favorable dates for its transformation, the labor organization, the manufacture of the tools and the methods of ramming. For this reason, it is so important to develop actions to preserve both the material evidence of the architecture, and the integrity of all the links that bond the chain of tradition.

It should be clarified that we are not speaking from a romantic point of view that seeks for a return to the past on the belief that it was better than the present time. We are talking about the necessity of a genuine interest in the full knowledge of constructive wisdom as a fundamental tool to make the preservation of ancient structures for future generations possible.

Arrogant architectural actions, influenced from the rationalist thought of the Modern Movement which forgot the historical architecture, have led to the development of restoration works or new rammed earth buildings, which have overlooked the constructive principles of this system. These transgressions—sometimes intentional but almost always derived from ignorance—have promoted the implementation of unfortunate interventions that do not last long and, in more severe cases, affect the integrity of the built heritage.

Earthen building techniques are not the result of simple pragmatism of societies that used it because “they had no other choice”. It is a highly refined technology whose efficiency has been tested by centuries of experience.

Contributions to building technology must emerge from the traditional “know-how”, evolving as a consequence of errors committed in the past. Capricious modifications or technological hybridization resulting from incompatible building logics can make traditions slip and become lost forever.

Hence, the urgent need to carry out research about earthen architectural heritage in order to know the *raison d’être* of all its components, their interrelationship and, above all, the motives why their builders executed them in the way they did.

This is the safest form to carry out real technological contributions to be applied both in heritage restoration and in the generation of new architectural solutions to raise the society’s quality of life from the perspective of sustainable development.

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Characterization of compressed earth blocks built with natural low-cost energy stabilizers

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ABSTRACT: This research was done as a self-production of compressed earth blocks, in which some natural stabilizers, such as lactic casein and corn gluten meal, traditionally used in earth-based plaster, were tested. After a time of maturation and drying, the blocks were put to some laboratory tests: capillary absorption, surface erosion and mechanical resistance to buckling. The same tests were also carried out on blocks compressed with a hydraulic press, in order to be able to compare their performance over the manually pressed blocks. The results showed that the gluten gives some improvement to the blocks but when they are used together with lime, it leads to some worsening of the properties; also that the casein is more ameliorative than gluten, especially when dissolved in ammonia; and finally that for mechanically pressed blocks, the highest increase in performance, compared with the manually pressed ones, is the surface resistance.

1 INTRODUCTION

The research is focused on the usage of earth as a low environmental impact material. The main aim was to test a product without high ecological cost but that is characterized by good mechanical and physical properties with the help of natural stabilizers. The idea was to make an entirely natural and sustainable product, regarding the lifecycle (LCA) of blocks from production to disposal; so all additives used must be natural and, for the same reason, the lime was chosen as a base stabilizer, in place of cement. The research was based in the territory of Piemonte, Italy, but another main aim was to make a product which was easily available also in many other places. This objective brought to the decision of using byproduct materials of agricultural industries that were rather common: corn gluten and lactic casein, which are traditionally used in earth-based plaster.

For these reasons, and since it is possible to self-produce the specimens, these blocks could be of interest in cases of self-construction for sustainability-conscious consumers, or in places where there is economic hardship and low technology.

2 STATE OF ART AND LITERATURE REVIEW

In recent literature there have been other studies that have focused on investigating the strength improving characteristics and limiting water absorption of compressed blocks. In these researches natural stabilizers are used to produce a composite, sustainable, non-toxic and locally sourced building material. To cite some examples the effect of molasses, cow-dung, sawdust were investigated, Vilane (2010), and some attempts have been made with waste phosphogypsum and natural gypsum, Degirmenci (2008), or with natural polymers, the Alginate (a natural polymer from the cell walls of brown algae), and Sheep's wool, Galán-Marín, Rivera-Gómez & Petric (2010). Or even, about natural stabilizers, many researchers have been done on the use of fibers, Binici, Aksogan, Bodur, Akca & Kapur (2007). In particular about the topic of this research, there is some study on the use of casein and gluten grains for the conservation and protection of surfaces and for earthen plasters Tosco (2005), Amisano (2010).

3 SPECIMEN CONSTRUCTION

3.1 *Used materials*

The materials used to prepare the specimens where: Earth that comes from Piossasco, Pinerolo (To) and which contains, as a preliminary analysis showed, 60% of sand, 13–14% of silt and 26–27% of clay, so a "sandy-clay-loam" composition, which is good for building. The earth also has a Plastic limit of 15.8, Liquid limit of 33.1 and Plasticity index of 18.35 (plastic earth) with a pH of 5.5, so it needed an addition of sand because of the high quantity of clay and that it can be stabilized with lime.

Lactic Casein from "Chimica Strola Snc", which is composed by 85% protein of milk, produced by acid precipitation and drying.

Corn Gluten Meal from "Roquette Italia SPA", which is produced by wet extraction process from corn, as byproduct, usually commercialized as animal meal. It has got a volume mass of 0.5 kg/L, 11.3% of humidity, and 59.9% of protein. Hydrated Lime from "Unicalce SPA" for building with a carbonated component of less than 1.5%.

3.2 *Mixtures*

The doses used where based on the known dose used for plaster, progressively increasing the quantity of the additives. Sample test blocks which were used as comparison specimens were prepared, some were made without additional components, and others with only some percentages of lime and sand. Also some mixtures were prepared with 3–5% of gluten, and others with 2–5 and 10% of casein in dry mixture, but soon it was clear that percentages equal to or over 5% were too high, because it can generate a mold on the block's surface, this due to excessive amount of organic matter, and also it can produce a consequent decrease in its performance. That is why the other specimens were prepared with 1 and 2% of casein, but in that case with an ammonia solution in hot water to help the casein dissolve, generating ammonium caseinate.

Table 1. All kinds of mixtures produced.

Code	Specimen	Gluten (%)	Casein (%)	Ammonia (%)	Sand (%)	Lime (%)
P	EARTH					
13	NS2				20	
14	NS2C5				20	5
15	NS2C10				20	10
2	G5S2C5	5			20	5
3	G3S2C5	3			20	5
4	G3S2C10	3			20	10
5	G5S2	5			20	
6	G5S2C10	5			20	10
7	G3C5	3				5
8	C5S2C5		5		20	5
9	(C2A) S2C5		2	0.75	20	5
10	(C1A) S2C5		1	0.37	20	5
11	(C1A) S2C10		1	0.37	20	10
12	C10S2C5		10		20	5
16	C2S2C5		2		20	5
17	(C2A) S2C10		2	0.75	20	10

These mixtures were mixed with water and pressed with a manual press, and then, each of the specimens were left to dry for a month in a dry and dark place without any wind of drafts. Table 1 describes the components and the percentage of the different mixtures used in the research.

4 ANALYSIS

4.1 *Research methodology*

The research was structured as a comparative one, that is, it was decided to compare the characteristics of control blocks with those with additives. Some specimens were made with the same amount of sand, or sand and lime, but without casein or gluten. One type was made only of earth to understand the differences in performance features between these specimens and the stabilized ones, so that it was possible to observe which reactions in the blocks were due to the stabilizers. Six specimens for all type of mixtures were made to be able to execute all laboratory tests more times.

4.2 *Mechanical strength*

The mechanical resistance of the blocks was tested with a yard equipment design done by CRATerre (Fig. 1). With it the block is loaded until the crushing limit is reached, afterwards it is possible to calculate the shear strength through the Navier Bresse formula (Equation 1):

$$\sigma_{fi} = 1.5\left(\frac{P_{fi}d}{lh^2}\right) \tag{1}$$

where P_{fi} = tensile strength; d = distance between supports; l = length of block; h = height of block.

The obtained value is converted in the compressive strength by multiplying it by a

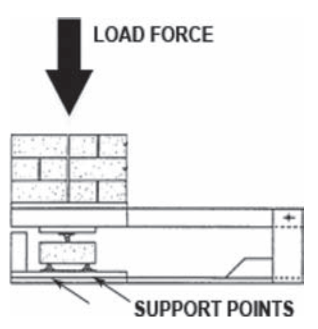

Figure 1. CRATerre equipment for calculating mechanical strength. Author: Arzachena, Cirillo, Mocci & Sanna (2008).

coefficient k = 8 (decreed by Ecole National des Travaux Publics de l'Etat de Lyon). Figure (Fig. 2) shows the compression strength values.

The test showed that mixtures with casein have an improvement in the compression strength value, especially those with ammonia caseinate. For the dry mixture there is the same improvement for the blocks with a high quantity of casein with the exception of the specimen with 10%; in fact, it is very fragile for the high quantity of organic matter. Instead, all the specimens that contain gluten have a lower performance value, only the mixture with 5% of gluten and 20% of sand without lime has an improvement with respect to its comparison specimens.

4.3 *Superficial erosion resistance*

To analyze the surface resistance, a test from the Standard New Zeland-NZD4298 was done: the Pressure Spray Method, where the block is directly sprayed with a water hose at a constant pressure of 0.5 bar for one hour, with a standardized dispenser. During this time, measures of the erosion are taken every fifteen minutes. The tests were done to all the different specimens. In the following figures it is possible to see the depth of erosion during the time of test (Figs. 3–5).

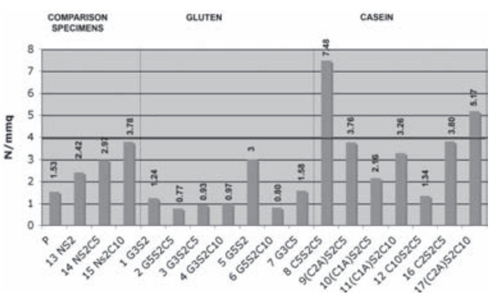

Figure 2. Compression strength values. Author: Guerrieri (2011).

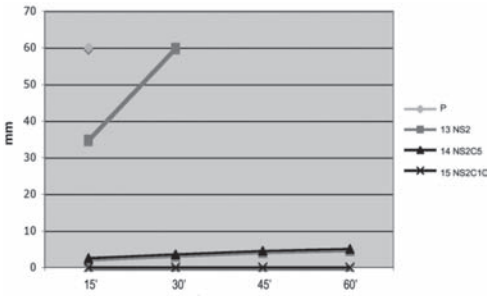

Figure 3. Erosion value of comparison specimens. Author: Guerrieri (2011).

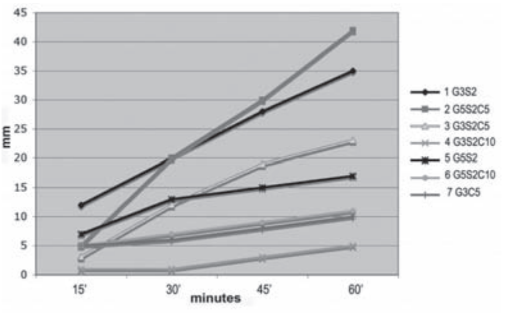

Figure 4. Erosion value of gluten specimens. Author: Guerrieri (2011).

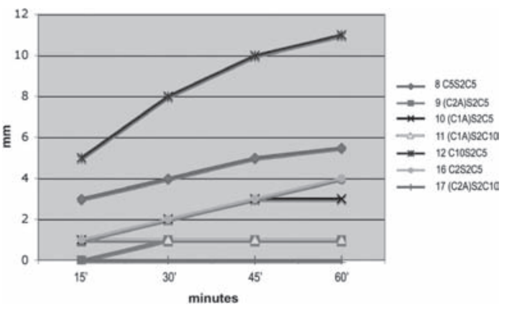

Figure 5. Erosion value of casein specimens. Author: Guerrieri (2011).

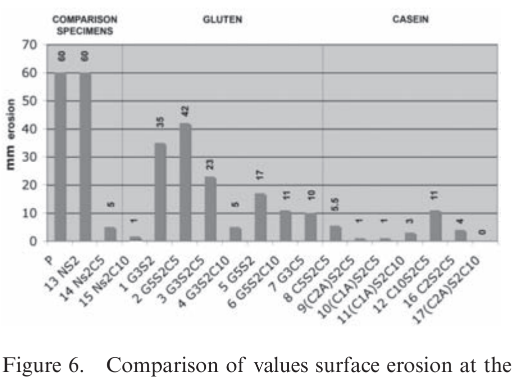

Figure 6. Comparison of values surface erosion at the end of the test. Autohor: Guerrieri (2011).

After this, the values of erosion that were obtained at the end of the test were put together in a single graphic to better compare the erosion resistance of the blocks (Fig. 6).

Observing the results, it was possible to determine that the specimens with only gluten and sand have a higher erosion resistance, while all the samples that contain lime have a lower resistance. With respect to the casein specimens, the ones with ammonia solution are more resistant than the ones with dry mixture. Generally for all the mixtures, except for those with a lime percentage of 10%, there is a better performance compared to the comparison ones.

4.4 *Capillary absorption of water*

The test is executed with a Karsten tube, following the Rilem (International Union of Laboratories and Experts of Construction Materials System and structures) Test Method No. 11.4.

The Rilem tube has a 92 mm long graduated column that containing 4 mL of water, that applies a pressure equal to a wind of 157 km/h on the surface of the brick. Every minute, for a maximum of fifteen minutes, a measure of the quantity of absorbed water is taken. The data collected can be seen in the following figures (Figs. 7–9).

With the obtained values it was possible to calculate the values of the absorption coefficients of the samples (Fig. 10) and compare the results between themselves.

The results show that there is a general increase in performance for the casein specimens, especially for the ones with ammonia solution, but not for

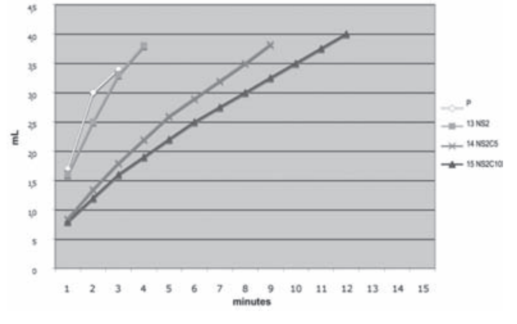

Figure 7. Absorption values of comparison specimens. Autohor: Guerrieri (2011).

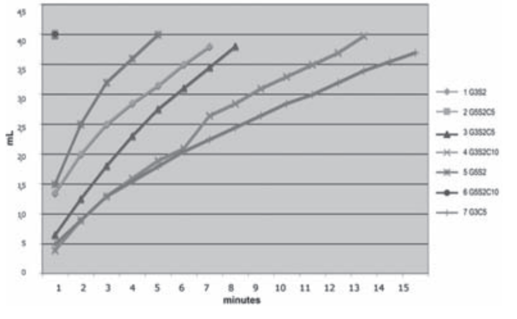

Figure 8. Absorption values of gluten specimens. Author: Guerrieri (2011).

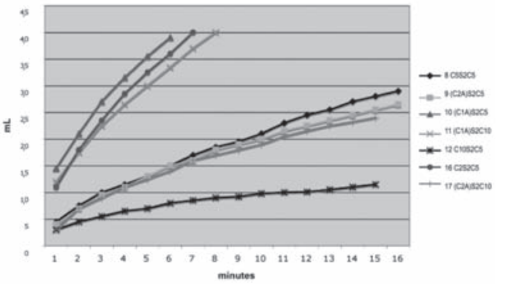

Figure 9. Absorption values of casein specimens. Author: Guerrieri (2011).

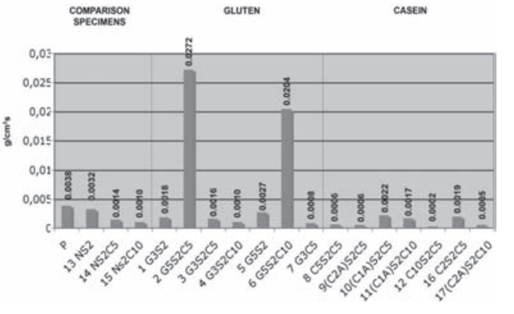

Figure 10. Absorption coefficient values. Author: Guerrieri (2011).

the ones with 1% of casein. Whereas for the gluten blocks there is an improvement for the mixture without lime and a sharp deterioration for the ones with it, and the same kind of results are obtained for all the tests as it was previously described. The reason for this could be an interaction of lime with the corn gluten, which makes the block fragile, especially for high percentages of gluten. Some studies (Imam & Gordon 2002) have shown that neutral pH, high humidity and hot temperature can favor the process of degradation of corn gluten meal. In fact, after doing pH analysis on the specimens, it was able to see that after the drying period, the pH of the compost fell down from 11 to 7.5 (from alkaline to neutral value).

5 COMPARISON BETWEEN MECHANICAL AND MANUAL PRESSING

To compare the differences in behavior of mechanically and manually pressed block, the same tests described before, were applied to a single sample chosen amongst of the different mixtures that were made. This is because it is more relevant to compare the results obtained when having the same block pressed in two different methods. The chosen mixture was 14-NSC5.

After applying the compression strength test, the results show that for the mechanically pressed block there was an improvement of almost 16% (Fig. 11).

Also the erosion test is done, and it showed that the resistance of the mechanically pressed block is five times higher than the manually pressed one, as it is possible to see in the Figure 12.

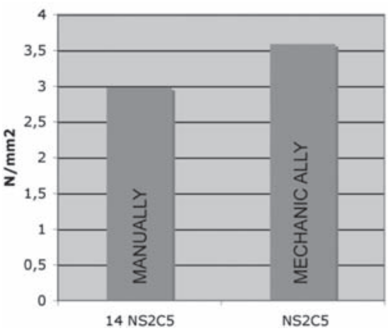

Figure 11. Values of compression strength. Author: Guerrieri (2011).

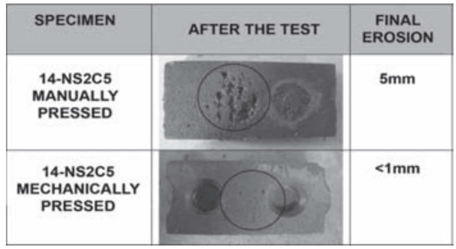

Figure 12. Value of surface erosion at the end of the test. Author: Guerrieri (2011).

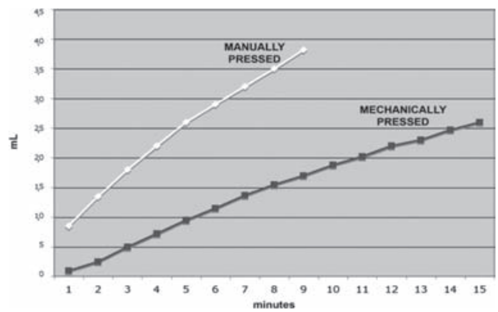

Figure 13. Absorption value. Author: Guerrieri (2011).

days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Excavation	x																											
drying period / stirring earth					x				x				x															
breaking big parts																x	x	x										
sifting																			x	x	x	x						
mechanical grinding																							x	x	x			
mixing																										x		
pressing																											x	x

Figure 14. Graphic of time work analysis Author: Guerrieri (2011).

		GLUTEN %	CASEIN %	WEIGHT kg	COST euro	SAND %	WEIGHT kg	COST euro	LIME %	WEIGHT kg	COST euro	$COST_{tot}$ euro
14	NS2C5			0	0	0,2	0,5	0,06	0,05	0,125	0,018	0,08
15	NS2C10			0	0	0,2	0,5	0,06	0,1	0,25	0,035	0,1
1	G3S2	0,03		0,075	0,04	0,2	0,5	0,06		0	0	0,1
2	G5S2C5	0,05		0,125	0,06	0,2	0,5	0,06	0,05	0,125	0,018	0,14
3	G3S2C5	0,03		0,075	0,04	0,2	0,5	0,06	0,05	0,125	0,018	0,11
4	G3S2C10	0,03		0,075	0,04	0,2	0,5	0,06	0,1	0,25	0,035	0,13
5	G5S2	0,05		0,125	0,06	0,2	0,5	0,06		0	0	0,12
6	G5S2C10	0,05		0,125	0,06	0,2	0,5	0,06	0,1	0,25	0,035	0,16
7	G3C5	0,03		0,075	0,04		0	0	0,05	0,125	0,018	0,05
8	C5S2C5		0,05	0,125	1,25	0,2	0,5	0,06	0,05	0,125	0,018	1,3
9	(C2A)S2C5		0,02	0,05	0,5	0,2	0,5	0,06	0,05	0,125	0,018	0,58
10	(C1A)S2C5		0,01	0,025	0,25	0,2	0,5	0,06	0,05	0,125	0,018	0,33
11	(C1A)S2C10		0,01	0,025	0,25	0,2	0,5	0,06	0,1	0,25	0,035	0,34
12	C10S2C5		0,1	0,25	2,5	0,2	0,5	0,06	0,05	0,125	0,018	2,6
16	C2S2C5		0,02	0,05	0,5	0,2	0,5	0,06	0,05	0,125	0,018	0,58
17	(C2A)S2C10		0,02	0,05	0,5	0,2	0,5	0,06	0,1	0,25	0,035	0,59

Figure 15. Data of cost analysis (without cost of earth) Author: Guerrieri (2011).

The last test that was done was the RILEM absorption test. The results shown in the Figure 13, prove that a mechanical pressing improves in about 57% the water absorption resistance, and decreases the absorption coefficient from 0.0014 to 0.0006 g/cm^2 s.

6 COST ANALYSIS

Since the blocks were self-produced, it has been possible to draw up a cost analysis (Fig. 15) and an analysis of the production time (Fig. 14) to give an idea of the economical sustainability of the product.

7 CONCLUSION

By comparing the blocks with their corresponding comparison block it has been possible to determine that by stabilizing the mixture with gluten there was a significant improvement with respect to specimens without lime, and that this improvement increases proportionally with the quantity of gluten. Instead, mixtures with gluten and lime have a net lower performance when compared with the specimens that contain only lime and sand. On the other side, for casein specimens there is always an improvement for percentages of casein higher than 1%, proportionally increasing with the quantity of it, up to a maximum: in fact percentages from 5 to 10% have proved excessive, not only decreasing the blocks performance but also rising the economical cost.

Generally the best results were obtained with mixtures containing lactic casein, especially those mixtures with ammonium caseinate. But for what concerns the cost analysis the casein is more expensive, but it is possible to produce it with sour milk. With respect to the differences between mechanically and manually pressed blocks, the improvement of shear strength is not so significant, but instead, there was a considerable increase in the water resistance and the superficial erosion behavior. Based on the results, it would be interesting to further do research on testing mixtures compositions with more than 5% of gluten without lime; and also on the ones with a percentage of casein around 2% or more, with a higher percentage of lime than 5%, taking advantages of mechanical pressing.

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Rammed earth architecture in the middle course of the river Júcar, Spain

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ABSTRACT: This work deals with the research of rammed earth architecture for defence, built on the banks along the middle course of river Jucar, Spain. From the study of the most representative examples of Islamic fortifications found in this geographical area, several results and hypotheses can be concluded. They will be very useful tools in the research related to typology and constructive aspects of this architecture.

La orografía de las tierras valencianas se caracteriza por la existencia de una red de barrancos, ramblas y ríos que relacionan transversalmente el territorio. Por tanto, es lógico pensar que el mayor número de castillos y estructuras defensivas se encuentren siempre en torno a los ejes formados por estas vías fluviales.

Centraremos nuestro estudio en el ámbito del curso medio del río Júcar a su paso por la provincia de Valencia, zona abrupta y montañosa, donde el río discurre encajonado en la mayor parte del recorrido, y que constituye una de las áreas con mayor densidad de fortificaciones de la región oriental de Al-Andalus (Sharq Al-Andalus).

Durante el período de dominación islámica el Júcar desempeñó un papel de frontera en cuanto que fue, en ocasiones, límite meridional de la taifa de Valencia (López Elum 2002, Vol. I, 143). Al mismo tiempo, este río era una importante vía de comunicación y de transporte, adquiriendo gran relevancia el transporte de madera desde la serranía de Cuenca hasta los astilleros de Denia, destacado centro naval de la época (Azuar 1988, 172). Por todo ello, la importancia geoestratégica del Júcar debía quedar asegurada por una red de fortificaciones que tenía como objetivo controlar las vías de comunicación y los pasos obligados, así como defender a la población que habitaba el entorno sirviendo de refugio en los momentos de conflicto o peligro. Estas construcciones de carácter defensivo, construidas durante un período histórico concreto en un ámbito bien definido geográficamente, presentan una serie de características comunes que son analizadas en este estudio, que quiere contribuir de este modo al conocimiento de la arquitectura defensiva de tapia de origen islámico en Sharq Al-Andalus, a través de su análisis histórico, geográfico, tipológico y constructivo.

1 ANÁLISIS TIPOLÓGICO

En primer lugar habrá que distinguir entre los diferentes tipos de fortalezas que nos encontramos en este ámbito, ya que no todas las estructuras fortificadas tienen las mismas características morfológicas y funcionales. En este sentido, Bazzana, Guichard y Segura definen el *hisn*, término árabe que designa un lugar fortificado de ciertas dimensiones, diferenciándolo de la ciudadela urbana (*al-qasaba*) y de la simple torre (*burdj*). Así el *hisn* primitivo se podría definir como un albacar constituido esencialmente por un recinto amurallado destinado a acoger en tiempo de inseguridad a la población rural del territorio que quedaría bajo su influencia. En general estos albacares no parecen haber comportado instalación de jefes militares o administrativos, idea que queda reforzada por la inexistencia de torre del homenaje en los ejemplos estudiados. Se instalaban sobre cerros más o menos bien defendidos naturalmente y no demasiado alejados de los terrenos de cultivo y las alquerías, constituyendo el centro político o militar de un territorio que controlaba y protegía, también denominado *hisn*, formado por un conjunto de hábitats, agrupados o dispersos, que se repartían sobre él y que estaban en relación de dependencia con la fortaleza (Bazzana, 1983, 161–175). En la mayoría de ocasiones los restos que han llegado hasta nosotros nos demuestran que estas fortalezas estaban constituidas por espacios abiertos simples o con construcciones muy sencillas de carácter funcional para el almacén de provisiones, como silos para el grano o aljibes para acumulación de agua.

En una categoría inferior nos encontramos una serie de torres (*burdj*) con recinto amurallado de pequeñas dimensiones, que cumplían al mismo tiempo una función de acogida y vigilancia, o únicamente de vigilancia. En cualquier caso, estas torres presentan una serie de características comunes tanto a nivel morfológico y formal, como constructivo y funcional. En primer lugar son de planta cuadrangular, tienen una considerable altura como lo demuestran aquellas torres que todavía hoy mantienen en pie alguna de las almenas del remate superior, y cuentan todas ellas con un pequeño recinto amurallado, que integra normalmente una de las caras de la torre. Los elementos defensivos se repiten, aspilleras en las plantas intermedias y almenas en la terraza superior.

2 ANÁLISIS CONSTRUCTIVO

En el estudio de la arquitectura de tapia existen tres parámetros básicos que facilitan su comprensión y constituyen el eje vertebrador de cuantos análisis e hipótesis se han formulado al respecto: el material de construcción, los elementos del tapial, y su módulo y dimensionado.

2.1 *El material de construcción*

En cuanto al material de construcción de la tapia distinguiremos entre la tapia conformada con tierra y las que están construidas con otros materiales. Prácticamente la totalidad de las construcciones estudiadas están ejecutadas con tapia de argamasa de cal con mampuestos. Por lógica constructiva la argamasa se debía verter con una consistencia blanda para que pudiera envolver los mampuestos y rellenar los huecos dejados por las piedras más grandes (Font e Hidalgo 2009, 70). Sin embargo la dosificación de los distintos elementos variaba, lo que influía en su grado de cohesión. Cuando se requería mayor resistencia en los muros se ejecutaban una especie de hojas exteriores con mampuestos, cuyo objetivo era fortalecer los paramentos (castillo de Tous). En otras ocasiones los mampuestos se situaban atestados al tablero del tapial, dando lugar a un plano de acabado en el que éstos se manifestaban parcialmente (Castillo de Abajo y torre Este del Castillo de la Pileta); en los demás casos es la costra de mortero de cal la que se manifiesta en la superficie de la tapia, ofreciendo un acabado homogéneo y regular. El castillo de Ruaya, como una de las excepciones, está construido con tapia calicostrada de tierra, apareciendo las esquinas reforzadas mediante la adición de mampuestos a la tapia.

2.2 *Elementos del tapial*

El tapial, como elemento indispensable para la ejecución de la fábrica de tapia, presenta multitud de variantes morfológicas en función de su grado evolutivo, del ámbito geográfico o del material al que va a dar forma. A continuación analizaremos los elementos de los tapiales que suponemos se utilizaron en la construcción de las fortificaciones estudiadas.

Para sostener los tableros que conformaban los encofrados o tapiales, en los que se vertía la argamasa y los mampuestos, se disponían en su parte inferior unas barras de madera llamadas agujas, en las que se apoyaban los tableros del tapial, formados por tablas de madera unidas entre sí por los cantos. Encajados de forma vertical, en estas agujas se colocaban los costales a modo de estribos, abarcando toda la altura del tablero del encofrado y manteniendo la distancia entre los dos tableros opuestos al tiempo que dotaban de rigidez al conjunto. La frontera, compuesta de tablas de la misma forma que los tableros del encofrado, cerraba transversalmente el tapial, por lo que determinaba el ancho de muro de tapia a realizar de una sola vez (tapiada). Normalmente sólo se utilizaba la frontera en uno de los extremos, ya que el opuesto quedaba definido por la tapiada anteriormente ejecutada. Los costales eran arriostrados en la parte superior normalmente por cuerdas de esparto (lías) bien tensadas a modo de tirantes que evitaban que se abriera el encofrado con el vertido, y en ocasiones compactado, de la masa. Para esta misma función también podían utilizarse barras de madera a las que se les practicaba un hueco en los extremos donde se encajaban los costales, rigidizando el conjunto mediante el empleo de cuñas de madera, del mismo modo que se hacía con las agujas. Las tablas que formaban los tableros eran mantenidas firmemente en su posición mediante unos elementos rígidos denominados barzones o costillas.

Cuando una nueva tapiada se ejecutaba contra un muro existente, como ocurría en las esquinas, la frontera perdía su función y era suprimida, quedando por tanto los barzones que la sujetaban, y que estaban colocados en el interior de los tableros, embebidos en el muro. En estas ocasiones, como hemos podido observar en los castillos de Abajo o de Cavas, aparece la impronta de estos barzones en la superficie de la tapia. Para que el espesor del muro fuera siempre el mismo era necesario mantener constante la separación transversal de los tableros y evitar que se cerraran durante el montaje del tapial y el vertido de la argamasa y los mampuestos, por ello se colocaba una pieza de madera llamada codal entre ambos tableros que mantenía la distancia entre ellos constante, ésta podía tener la misma sección y disposición que las agujas utilizadas en la parte inferior y de esta forma facilitar el montaje de las nuevas agujas, por simple sustitución de los codales, en las tongadas superiores. Son varios los elementos del tapial que dejan huellas legibles en los muros, como los tableros y en menor medida los barzones, pero indudablemente son las agujas los elementos cuya impronta permite la lectura de un mayor número de parámetros de la tapia. Del estudio de los mechinales de las agujas que encontramos en las fortificaciones que componen nuestro ámbito de estudio podemos conocer, entre otros aspectos, el grado de especialización y desarrollo de la técnica empleada en el momento de su construcción. Las agujas se utilizaban para sostener el cajón, para favorecer la traslación del tapial en el avance de la construcción de la tapia y a su vez para arriostrar la base del cajón. El material utilizado en las agujas de todos los castillos estudiados es la madera, si bien existen variaciones en cuanto a la morfología y dimensiones. La sección más generalizada es la rectangular con los cantos redondeados, encontrándose variaciones dimensionales desde los 6 × 4.5 cm. en el castillo de la Madrona, hasta los 8 × 3 cm. en el caso del castillo del Corral de Antón. La mayoría de las agujas que todavía podemos encontrar embebidas en la fábrica son listones de madera, elemento que indica un cierto grado de especialización tecnológica, frente al uso de rollizos de sección circular, solución más simple y menos evolucionada (Fig. 1). En varios de los ejemplos estudiados hemos podido encontrar en un mismo muro agujas de sección circular combinadas con otros tipos, lo que evidencia que el uso de la aguja de rollizo perduró en el tiempo, incluso combinándose con la de tabla plana (Graciani 2009, 685–686).

2.3 *Módulo y dimensionado*

La disposición y dimensiones de los elementos que componen el tapial definen las características constructivas y dimensionales de la fábrica de tapia. Así pues, tenemos que la longitud de una tapiada está íntimamente relacionada con el número de agujas empleadas en el tapial y con la separación entre ellas; la altura de la tapiada equivaldrá a la suma de la altura de cada una de las tablas del tablero que define las dos caras del cajón; el espesor del muro coincidirá con la longitud de los codales empleados.

Si bien estos parámetros dimensionales pueden ser objeto de múltiples variaciones por diversas causas, siempre respetan unos valores límite definidos por el propio proceso constructivo, como

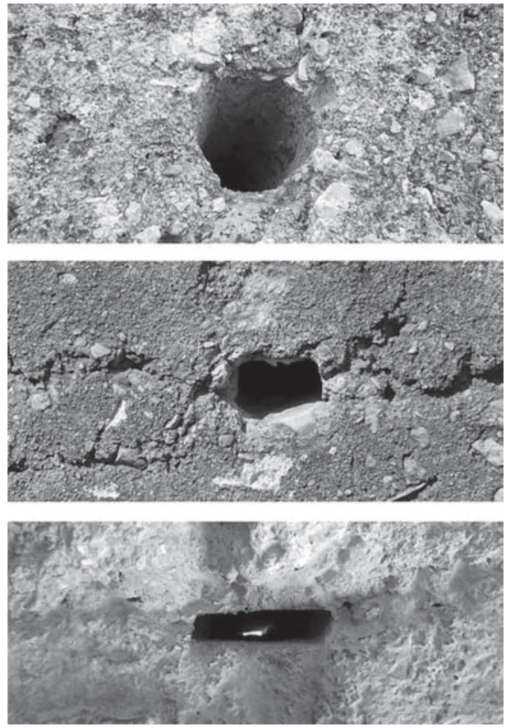

Figura 1. Mechinales de agujas en el ámbito de estudio.

por ejemplo el hecho de que el peso del conjunto no debe sobrepasar ciertos valores que dificulten su traslado (Cuchí 1996, 159–160). En los ejemplos de nuestro ámbito de estudio, que por sus condiciones de conservación nos permiten realizar un mínimo análisis arquitectónico y constructivo de las fábricas, se comprueba que el número de agujas por tapiada varía de unos casos a otros. Por ejemplo, en el caso del castillo de la Pileta se encuentran tres agujas por tapiada mientras que en el de Abajo son cuatro, sin embargo su disposición dentro del módulo se repite, quedando la última aguja de la tapiada enrasada interiormente con la junta determinada por la frontera, consiguiendo con ello el solape del tapial necesario para alinear los paramentos de la tapiada posterior.

La altura de tapiada es la dimensión que menos dispersión ofrece, según se desprende de la toma de datos realizada, quedando en valores próximos a los 85 cm., repitiéndose el número de cuatro tableros por tapiada en los casos en que ha sido posible su identificación. En cuanto al espesor nos encontramos con tapias que por su carácter defensivo alcanzan valores notables, sobrepasando en numerosas ocasiones el metro de anchura. En las torres se efectuaba una reducción progresiva del espesor de los muros, lo que suponía un ahorro de material a la vez que la formación de unas repisas que permitían situar el arranque de las bóvedas o realizar el apoyo de forjados.

3 LAS FORTIFICACIONES

3.1 *Castillo de Tous*

El Castillo de Tous se alza sobre un cerro alargado que se erigía en la margen izquierda del río Júcar y que en la actualidad ha quedado rodeado por el agua del embalse de Tous. Entre los escasos restos del castillo se conservan aljibes y almacenes, apareciendo numerosos restos cerámicos que evidencian la existencia de una ocupación humana significativa. Los restos de la muralla que todavía perviven son de tapia de argamasa con mampuestos, presentando éstos un cierto orden en su colocación al disponerse en hiladas horizontales que se alternan con otras de argamasa.

En el lado opuesto de la cumbre del cerro, en su extremo norte, a unos 200 metros de los restos del castillo, sobre un peñasco que condiciona su morfología, se encuentra la torre, de planta aparentemente triangular pese a estar formada por cuatro lados, forma que poco tiene que ver con el resto de este tipo de torres, por lo general de planta cuadrada o rectangular. Construida con gruesos muros de tapia de argamasa con mampuestos, está formada por dos niveles comunicados por una escalera de planta semicircular. El primer nivel se cubre con una bóveda de cañón que se conserva completa. La escalera estaría cubierta por una superficie abovedada de la que todavía se puede apreciar el arranque. Los peldaños mantienen su geometría original, pudiéndose observar todavía hoy las marcas de las agujas utilizadas para su construcción. La torre ha perdido elementos de valor como su remate, probablemente almenado, no obstante se pueden observar otros elementos de interés como las incisiones oblicuas practicadas en el enlucido de cal del paramento de la escalera, elemento decorativo que también hemos podido observar en el castillo de Cavas o en el de La Pileta.

3.2 *Castillo de Abajo*

El castillo de Abajo está situado a los pies del pueblo de Millares, sobre un promontorio rocoso alzado directamente sobre el curso del río dominando una extensa zona de cultivo (Fig. 2).

Es una de las escasas fortalezas de esta zona que conserva completo su recinto amurallado, emergiendo en su punto más elevado una robusta torre de planta cuadrada en la que aún se conservan parte de los forjados, formados por bóvedas de

Figura 2. Castillo de Abajo.

cañón construidas con lajas de piedra tomadas con mortero de cal, técnica constructiva que también podemos encontrar en el castillo de La Pileta. Las bóvedas apoyan sobre las repisas horizontales que se generan en el cambio de sección de los muros de tapia y en los muros diafragma intermedios. Tanto las murallas como la torre del castillo de Abajo están construidos con la técnica de la tapia de argamasa con mampuestos, elevada bien sobre una fábrica de mampostería ordinaria construida a modo de zócalo que horizontaliza el arranque de los muros, o bien directamente sobre la roca natural. Los mampuestos se disponen de forma irregular, colocados sin un orden concreto, manifestándose parcialmente en el paramento.

Las tapias aparecen trabadas, disponiéndose las juntas verticales de forma alterna, con el objetivo de lograr el necesario monolitismo de la fábrica. En las esquinas, colocados en el interior de la tapia, podemos encontrar rollizos de madera dispuestos para mejorar la traba entre los dos muros enfrentados.

3.3 *Castillo del Corral de Antón*

El castillo del Corral de Antón se emplaza sobre un cerro que domina la población de Millares. Los escasos restos que se conservan en la actualidad nos remiten a una construcción de planta muy irregular, condicionada por las características orográficas del emplazamiento. Podemos observar parte de las murallas, la base de dos de sus torres y los restos de lo que parece ser un aljibe. La técnica constructiva empleada es la tapia de argamasa con mampuestos, conservándose todavía un importante zócalo de mampostería del que arrancaban los muros de la muralla. Los mampuestos de la tapia presentan una disposición ordenada en hiladas horizontales.

3.4 *Castillo de Cavas*

El castillo de Cavas es una torre de vigilancia y control que se asoma a las gargantas del Júcar, en la parte del término de Millares que linda con el vecino Cortes de Pallás. Se trata de una de las fortificaciones islámicas mejor conservadas de la zona; la torre, de planta sensiblemente cuadrada, pese a haber perdido los forjados mantiene su estructura muraria completa. Se enclava sobre un peñasco rocoso, del que emergen los lienzos de la muralla que abraza la torre, los cuales todavía conservan alguna de sus almenas. Está construido con muros de tapia de argamasa con mampuestos, elevada sobre muro de mampostería o directamente sobre la roca. En este caso encontramos dos tipos de acabado de los paramentos; en la torre y en la muralla Este, de ejecución más cuidada, los mampuestos quedan ocultos en la masa de hormigón, existiendo además una continuidad constructiva entre las tapiadas de ambos elementos. Por el contrario, en la muralla Oeste los mampuestos se manifiestan parcialmente en el paramento, evidenciándose que este lienzo de muralla se ejecutó en una etapa posterior y de forma menos cuidada.

En esta torre todavía persisten distintos elementos decorativos característicos de la arquitectura defensiva islámica. Por un lado tenemos la decoración de los revestimientos de cal en forma de incisiones oblicuas (Fig. 3), y por otro un motivo decorativo que se realizaba coincidiendo con las líneas de las tapiadas, una especie de franjas paralelas horizontales que se unían entre sí a través de otras verticales alternas, formando una decoración a base de rectángulos. Estas franjas servían para cerrar todas las marcas de las agujas del tapial, consiguiendo al mismo tiempo un interesante efecto visual. También hemos podido encontrar este motivo decorativo en la torre Este del castillo de La Pileta (López Elum 2002, vol. II, 160; Azuar, Lozano, Llopis y Menéndez 1998, 481–502).

3.5 *Castillo de Vilaragut*

El castillo o torre de Vilaragut se encuentra en el pueblo de Dos Aguas, totalmente rodeado por viviendas en la parte más alta del casco urbano, quedando accesible desde la vía pública únicamente uno de sus paramentos.

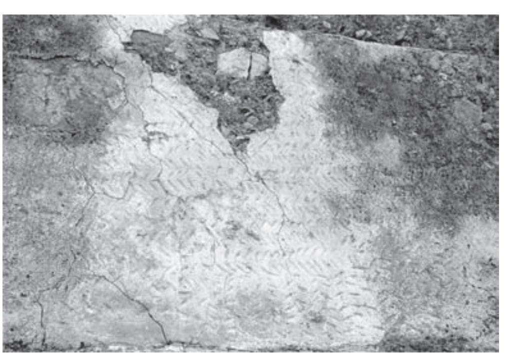

Figura 3. Motivo decorativo en el castillo de Cavas.

Los restos que han llegado hasta nosotros consisten en una pequeña torre de planta regular, sensiblemente cuadrada, de la que arranca un tramo de muralla que conserva una de sus almenas y parte del adarve. La fábrica es de tapia de argamasa con mampuesto, presentando en este caso una diferencia respecto a los otros ejemplos estudiados, al ser la distancia entre los mechinales de las agujas considerablemente menor que en el resto de casos. Esto puede ser debido a que nos encontramos en una fase menos evolucionada de la técnica de la tapia, con una distancia entre agujas de unos 50 cm. e incluso menor, distancia que iría aumentando progresivamente conforme se perfecciona la técnica y evolucionan los encofrados (Graciani 2009, 687).

3.6 *Castillo de la Madrona*

El castillo de Madrona está situado en la cumbre de una escarpada montaña junto al actual Embalse del Naranjero, dentro del término municipal de Dos Aguas. Tuvo relativa importancia en las décadas posteriores a la conquista cristiana, apareciendo citado muchas veces en los Registros de Real Cancillería, donde queda constancia de que se ordenaron hacer en él obras de reparación en el año 1292 y en el 1341. (López Elum 2002, Vol. I, 143). Por la gran cantidad de cerámica visible en superficie se deduce que existió cierta actividad humana en este emplazamiento, pese al carácter inaccesible de su ubicación. Se dispone de forma alargada, con dirección Este-Oeste, adaptándose a la topografía del terreno. Se conservan muy pocos restos, entre ellos parte de un aljibe de pequeñas dimensiones que todavía conserva el revestimiento de mortero hidráulico, así como la base de lo que parece una torre y algunos restos de lienzos de muralla en un estado de degradación muy avanzado. Los muros son de tapia de argamasa con mampuestos, colocándose éstos en hiladas horizontales que se alternan con otras de argamasa, siguiendo un cierto orden.

3.7 *Castillo de Otonel*

El castillo de Otonel se encuentra en la aldea del mismo nombre, dentro del término de Cortes de Pallás. Está situado en la coronación de una montaña que domina el barranco de Otonel. Este castillo servía de refugio a una alquería cuya población cultivaba las numerosas terrazas que todavía hoy pueden observarse en las faldas de las montañas cercanas.

El conjunto defensivo está muy degradado en la actualidad, quedando únicamente la traza de la muralla, que permite conocer las dimensiones del recinto que servía de refugio a la población, el acceso al mismo y uno de los paramentos de la torre que se mantiene milagrosamente en pie arriostrado por los restos de los muros perpendiculares al mismo. Los muros son de tapia de argamasa con mampuestos, destacando el uso, poco común en esta zona, de agujas de sección circular.

3.8 *Castillo de la Pileta*

El castillo de la Pileta se alza sobre un promontorio que se recorta verticalmente sobre el río Júcar, cuyo desnivel original queda hoy reducido por el agua embalsada por la presa de Cortes de Pallás.

La torre, de altura considerable, contaba con cinco plantas, estando el forjado de la última de ellas resuelto con bóveda de cañón, de la que todavía se aprecian los arranques, similar a la que queda en pie en la torre de Tous. Está rematada con almenas, de las que aun hoy quedan cuatro, y cuenta con sendas líneas de aspilleras en el tercer y cuarto nivel. En su parte inferior existe un paso transversal construido con bóveda de cañón de directriz recta resuelta con lajas de piedra, técnica que aparece en otros casos ya comentados. La torre está construida con muros de tapia de argamasa con mampuestos, de ejecución muy cuidada, apareciendo en su superficie la técnica decorativa a base de líneas horizontales y verticales que ya se ha descrito en Cavas, torre con la que guarda muchas similitudes (Fig. 4).

Dentro del mismo conjunto fortificado encontramos otra torre, de la que sólo queda la cimentación de mampostería y el arranque de los muros de tapia. En este elemento encontramos restos de revestimiento de cal decorado con incisiones oblicuas, como en Tous y Cavas.

3.9 *Castillo de Ruaya*

El castillo de Ruaya está situado en la falda de una montaña al suroeste de la población de Cortés de Pallás. El conjunto fortificado, del que queda parte de la torre y los restos de la muralla que define un recinto trapezoidal, controlaba una amplísima zona de cultivo en una posición de dominio sobre el barranco que recoge las aguas de la muela de Cortes de Pallás.

Figura 4. Técnica decorativa en la torre de la Pileta.

Esta fortaleza constituye el único ejemplo encontrado en nuestro ámbito de estudio donde se ha constatado el uso de la tapia de tierra calicostrada, técnica con la que están construidos la mayor parte de los muros de la torre, exceptuando las esquinas y las murallas, donde nos encontramos muros de tapia de argamasa de cal con mampuestos.

4 CONCLUSIONES

Entre las fortificaciones estudiadas, desde un punto de vista tipológico, destacan por su mayor entidad y dimensión las que hemos denominado *hisn* o de tipo albacar, entre las que encontramos el castillo de Tous, el de Corral de Antón y el de Abajo, en Millares o el de la Madrona en Dos Aguas. Entre las fortalezas de menor entidad que cumplían una función de refugio y vigilancia, y cuya área de afección se limitaba a una población menor formada por una o varias alquerías, encontramos Vilaragut en Dos Aguas, y La Pileta, Otonel y Ruaya en Cortes de Pallás. Existen otras fortalezas como el castillo de Cavas, de menor tamaño, que cumplían una función exclusiva de vigilancia y control del río.

En cuanto a las técnicas constructivas, podemos afirmar que la práctica totalidad de fortificaciones de origen islámico presentes en este ámbito han sido parcial o totalmente construidas con la técnica de la tapia de argamasa con mampuestos. Es importante destacar que no se ha detectado la existencia de tapia simple de tierra, muy común en otras zonas de la Comunidad Valenciana. Sin embargo sí se ha constatado la existencia de tapia de tierra calicostrada en algunos paramentos del castillo de Ruaya, en Cortes de Pallás. Por otro lado, en la tapia de argamasa con mampuestos, éstos aparecen distribuidos de distintas formas. Así encontramos algunos casos donde aparecen dispuestos de forma irregular sin seguir un orden concreto, como ocurre en el castillo de Abajo, y otros casos más numerosos donde aparecen colocados con un cierto orden, consecuencia del relleno por tongadas de los tapiales, lo que suele producir una cierta regularidad en la distribución de los mampuestos, como observamos en el castillo de Tous o en el de la Madrona.

Hay que destacar también que en numerosos casos se da la existencia en un mismo muro de dos técnicas constructivas distintas, apareciendo la fábrica de mampostería ordinaria en combinación con la fábrica de tapia. En estos casos la mampostería aparece creando un zócalo inferior que, arrancando directamente desde la roca, genera una superficie horizontal sobre la que se asienta el muro de tapia. En cuanto a las reparaciones, reconstrucciones y ampliaciones de época cristiana era común que se realizaran con fábrica de mampostería o sillarejo, utilizando elementos puntuales o de refuerzo en sillería, principalmente en las esquinas. En otros casos estas reparaciones se hacían empleando la misma técnica de la tapia de mampuesto con argamasa con la que habían sido construidos en la época islámica, debido a que la mano de obra empleada era la formada por los propios moriscos de la zona.

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About the rediscovery of the *tapia valenciana*

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ABSTRACT: The so-called *tapia valenciana* is a particular type of brick-reinforced rammed earth wall used in the area of Valencia between the 14th and 17th centuries. Replaced by brick or rubblework walls in the 18th and 19th centuries, the technique was forgotten until the 1980s. The text addresses pioneer contributions in this field with professionals like Manuel Galarza, Fermín Font and Pere Hidalgo, as well as some early approaches to the restoration of rammed earth.

1 FOREWORD

1.1 *Tapia valenciana technique*

The technique known as *tapia valenciana* is a variant of rammed earth wall reinforced with courses of bricks, visible from the outside. It was particularly successful in the Valencia area, and it is likely that the invention arose in these lands during the Middle Ages. Its origins can be traced back to the mid 14th century and it continued to be the main building system until the early 17th century, when brick or rubble gradually began to replace it (Cristini & Ruiz Checa 2009). After that, it fell into disuse in urban areas, and we can assume it was virtually extinct at the time of the construction boom in the 18th century.

The *tapia valenciana* wall has resistant qualities far superior to a conventional rammed earth wall. Fray Lorenzo de San Nicolas, in his *Arte y uso de Arquitectura* (1639) described it as a "very strong structure" and constructions of this type that have survived to the present day are evidence of this. However, its main problem is deterioration caused by water infiltration, as in conventional lime-washed rammed earth walls.

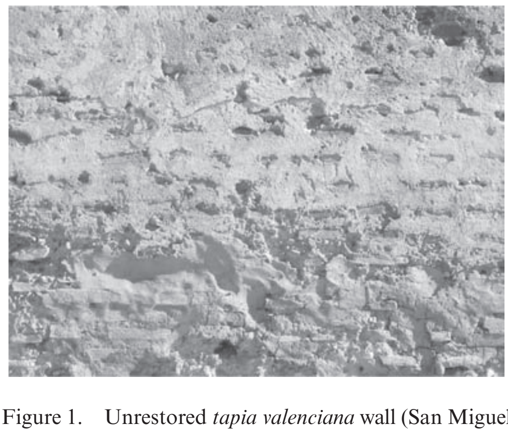

Figure 1. Unrestored *tapia valenciana* wall (San Miguel de los Reyes, Valencia).

The purpose of this paper is not to discuss the particularities of this technique or the process of its replacement by brickwork, a subject on which Professor Valentina Cristini has been working for many years. Our aim is to reflect about its disappearance and recovery in the last decades of the 20th century.

1.2 *Abandonment and mistrust*

As we mentioned above, it was in the late 16th and early 17th century that the first brick structures were built in the city of Valencia. A remarkable example is the old church of San Andrés in Valencia, now San Juan de la Cruz, built in the first decade of the 17th century. There, the main façade is made of brick and the side walls are made of reinforced rammed earth. Mid-century residential buildings are executed entirely with brick walls.

This process was already fully developed in the 18th century, when an important first stage of replacement of buildings took place in Valencia.

The agricultural revolution and especially the prosperity of the silk industry led the city to a process of growth and improvement, in which many of the old medieval buildings were rebuilt. The change in architectural tastes in the 19th century would continue with the demolition of the old rammed earth architectures, or hiding them under mortar coatings. Urban renewal and change of alignment to widen streets contributed to the renewal of many façades, with only party walls surviving. Monumental and residential in small towns fared better.

1.3 *Oblivion and recovery*

Loss of traditional skills in the second half of the 20th century and the new training provided by Schools of Architecture focused on new materials led to complete neglect of a technique that was still known by some old master builders, especially in peripheral areas. It is true that, when acting on historic centres, "earthen" party walls repeatedly appeared, usually very patchy and prone to collapse if the site had been long exposed to rain. These walls, spurned for their apparent weakness, were covered with new walls in framed structures or, when possible, demolished to gain a few inches for the plot.

More complex was the subject of the intervention on heritage buildings. In the 18th and 19th centuries there had been many interventions focused on renovating the exterior of the buildings in which the original structures remained hidden under plaster and other claddings. The modern approach to restoration, based on the principles of the French tradition, was primarily intended for monumental architecture, characterised by the use of stone.

A typical example was the intervention of what is known as the Palace of the Generalidad, initiated in the twenties by Vicente Rodriguez. The building, with stone façades, was preserved almost intact in the tower, although it had been greatly altered at its side elevations. Restoration, which lasted for several decades, recovered -or rather reinterpreted- the old-style doorways, windows and galleries, restoring the medieval appearance lost centuries before. The courtyard was better preserved, but as it was a minor space the walls were made of rammed earth and not stone, which led to its demolition and reconstruction in brickwork. This interesting fact was brought to light during the preparation of the Master Plan and, although it was not documented, there are some urban photographs where you can see the partial demolition.

Without going to such extremes, mistrust of the bearing capacity of the *tapia valenciana* has continued to exist until relatively recently. For the work of Scala Palace restored in the 1980s, a metal structure was embedded in the original walls. It is true that the MV standards (later NBE) already required a particular structural behaviour and load bearing capacity in public buildings, but the thick walls of the building would probably have been able to support the required weight without problems. This distrust of rammed earth walls would have much more serious consequences when deciding to perform complete or partial demolition, as in Cervellón Palace or the House of Cerveró, which probably would not have taken place if the walls had been made of brick or stonework.

We must recognise the weakness of the walls of buildings without a roof or simply in areas seriously exposed to moisture. Furthermore, the reduced bearing capacity, measured by Proctor compaction tests in a new wall, is virtually impossible to assess in an old wall affected by water leaks. Uncertainty makes it easy to understand the fear or lack of security of the architects responsible for its restoration. In that sense, we appreciate even more a series of contributions that have helped to see this type of construction in a different light.

2 SOME NAMES IN THE RECENT HISTORY OF THE *TAPIA VALENCIANA*

2.1 *The previous Spanish situation*

Recovery of the *tapia valenciana* technique occurs within a broader context of valorisation of vernacular building traditions that took place from the nineteen seventies and especially the eighties.

The beginning of this change can be located in 1973 and the Oil Crisis, which could be linked to the

Figure 2. Collapsed *tapia valenciana* walls in a 16th century building ("El Relpá" in Alquerías del Niño Perdido, Castellón).

criticism of Modernism, which began several years before. In this line we can trace the valorisation of the Spanish vernacular architecture, represented by Carlos Flores (*Arquitectura Popular Española*, Madrid, Aguilar 1973) and Luis Feduchi (*Itinerarios de la arquitectura popular española*, Blume 1974). Both of them briefly discussed the technique of the rammed earth wall.

The Oil Crisis of 1973 would also mean the beginning of interest in what we now know as bioclimatic architecture. The pioneering book in this line would be *The Autonomous House*, by Brenda Vale, published in 1975 and translated into Spanish in 1977 by Gustavo Gili. Several books related to this alternative new view of architecture were brought out by this publishing house, and especially Blume, greatly concerned with these issues, in the following years.

In 1979 Blume brought out *Shelter* (translated as *Cobijo*) a compilation of texts written by several authors under the supervision of Lloyd Kahn, describing vernacular construction in different regions of the world. Spain was represented by the rammed earth technique. The book was first released in 1973, making it perhaps the first work concerned with self-construction. On that date, the primary bibliography available was an old article by Gustavo Fernández Balbuena, published in the 38th issue of the journal *Architecture* in 1922, and entitled: *La arquitectura humilde de un pueblo del Páramo Leonés.*

It was in France that research on earthen architectures had the widest readership. The work of Patrick Bardou and Varoujan Arzoumanian, titled *Archi de terre* and translated as *Arquitecturas de adobe*, should moreover be noted. Originally issued in 1978 by the prestigious French publishing company Parenthéses, it was translated in 1979 by Gustavo Gili in the collection *Arquitectura y Tecnología*, directed by Ignacio Paricio. This book contained a large repertoire of vernacular building techniques in earth, both in Africa and America, as well as proposals for its use in climatically efficient new buildings. Two anecdotes from the Spanish edition: first, there is nothing about European vernacular architecture, although in some regions of France rammed earth is used; second, the translator used widely the Gallicism *pisé-de-terre* to refer to the work know in Spain as *tapia*.

At the same line another important referent, at least in the Valencian area, was the exhibition *Arquitecturas de tierra* organised by Jean Dethier, from the Centre George Pompidou, held in the Lonja in 1983 and sponsored by the City Council and the Ministry of Construction and Urban Development. This exhibition, which was widely visited by the public, presented such important issues as the strength of these structures, their wide geographical diffusion and problems for their conservation.

In the Spanish area the creation of the *Centro de Investigación de Técnicas y Materiales Autóctonos* in Navapalos (Soria) the following year should be noted. It has since organised courses and meetings in an attempt to spread the use of vernacular techniques, and experimentation in the search for a sustainable, low-cost architecture. Attendance of young architects and architectural technicians at these activities gave rise to a new awareness nationwide.

In parallel with this revision of popular architectures it became necessary to know the techniques for their restoration. At university level, the pioneer work of EUATV (Escuela Universitaria de Arquitectura Técnica de Valencia) professor Fernando Benavent, should be noted; since the academic year 1977–78 he has imparted a subject focused on architectural intervention techniques, awakening the sensitivity of several generations of architectural technicians Not so in the case of the architects, whose training was entirely focused on new construction.

It was from the eighties onwards, with the organisation of regional governments, that multiple institutions were created for the preservation of historical heritage, understood in a broader sense than the traditional concept of the monument. In the Valencian area, the need to rehabilitate buildings for local government management and the work of the Dirección General de Patrimonio led to the multiplication of all kinds of restoration works, directed by young architects who had no specific training in academically underestimated historic architecture.

In these circumstances, the presence of veterans and experienced builders is crucial. Some of these young architects, now recognised as experts in historic construction, still remember some singular characters whose judgment and experience they could trust. A prominent example was Tirso Ávila, from the Minguet Company, who was one of the few persons with experience in rammed earth walls at that time, thanks to his training in a town of *La Mancha*. However, this knowledge acquired on site had almost no diffusion.

We must conclude that in the previous cases, when speaking of the rammed earth wall or *tapia*, we have referred to the most widely used techniques, but not the local variety called *tapia valenciana*, which is the subject on which we are now focusing.

2.2 *Manuel Galarza and the rediscovery of the tapia valenciana*

If you were to write a history of the restoration of *tapia valenciana*, one name that should not be missing is that of Manuel Galarza. Galarza is one of those rare examples of a person who has managed to combine professional practice as architectural technician with scholarly research in archives, which also has allowed him to interpret documents from a construction point of view. He has made many contributions, among which the most important has perhaps been the rediscovery of the *tapia valenciana* and its value.

As he himself states (Galarza 1996) the origin of this research dates back to 1983, when he was commissioned to restore the Capuchin Monastery in Ollería. Looking for the building's original documentary sources, he decided to explore the Archives of Notarial Protocols of the Corpus Christi College, where he found information about the arrival of the Capuchins in the Kingdom of Valencia. The Ollería contract did not appear, but he found information on other buildings, with references to *tapia valenciana*.

Contracts for the construction of the church of the Jesuit Monastery (1595) and the Capuchin Monastery in Valencia (1597), signed by the master builder Francisco Antón, made explicit reference to the fact that the walls should be made of *tapia valenciana*, detailing its thickness as well as some details for its execution.

Both works have been demolished, so that there was no way of verifying directly in the specifications of the contracts. However, Galarza's training and his great building experience enabled him to identify documentary references with what he had found in Ollería and restore the technical execution process, similar to the common rammed earth wall, but adding a reinforcement of layers of bricks facing the quarter-deck board.

Although his research dates back to the eighties, it had a rather limited diffusion until the submission in 1996 of a paper on the subject at the *Primer Congreso Nacional de Historia de la Construcción*, a text that at present is an indispensable part of the literature on *tapia valenciana*.

2.3 *Fermín Font and Pere Hidalgo: The recovery of the technique*

If Manuel Galarza had the merit of recuperating the *tapia valenciana* from a documentary and restoration standpoint, we must thank Fermín Font and Pere Hidalgo for the recuperation of the building tradition, which they reflected in a book.

Fermín Font, also an architectural technician, became interested in traditional rammed earth construction in the mid-eighties. He was a member of the Navapalos Research Centre in 1985 and later, between 1987 and 1991, he combined his professional activity with collaboration in a workshop for the restoration of the Real Santuario de la Fuente de la Salud in Traiguera, and Vall de Uxó. During this time he took the opportunity to learn and perfect the craft of building *tapia* through contact with an elderly Forcall builder. In the nineties he cooperated with the Ministry of Foreign Affairs and various NGOs to carry out works in developing countries.

In 1990 Fermín Font and Pere Hidalgo published *El tapial—una técnica constructiva milenaria.* The book, published by the Colegio de Aparejadores y Arquitectos Técnicos de Castellón, may not have had all publicity it deserved, but it is the first monographic work published in Spain on this issue. Recently, in 2009, the same authors brought out another book called *Arquitecturas de tapia*. The pragmatic component of both works is evident if we note that the former was accompanied by a video and the latter by a CD.

The current study is not limited to the *tapia valenciana*, but obviously this technique of widespread local importance has a prominent place in his work.

3 THE AESTHETIC VINDICATION

3.1 *The case of the Almudín in valencia*

In the mid nineties, after the above mentioned contributions and the experience of many restoration works, the *tapia valenciana* was beginning to be a recognised technique. However, from the point of view of Galarza, interventions realised during these years had been quite unsuccessful, due to ignorance about the technique, inadequate training of the workers or an excessive mimetic-decorative intention:

"Perhaps the most blatant case, fairly recent, is the restoration of the façades of the *Almudín* in Valencia [...] where, after restoration, the wall has become, a merely decorative surface of poor construction value. Concentrating the entire restoration of the execution on a simple surface finish, ignoring all the rules of good construction with brick, and not retrieving the hard-to-recover rammed earth technique not only distorts the essence of the building technique but also annihilates all the cultural value of the monument itself" (Galarza 1996).

The work carried out on the *Almudín* (a former grain warehouse) in Valencia between 1992 and 1996 by a prestigious team of architects is a good example of the widespread rehabilitation criteria put into practice in Spain during the last decades of the 20th century. This is a very correct work from the point of view of project design, even though some bold decisions were made that might be questionable from a conservational approach to the discipline of restoration.

The works on the building were focused on the restoration of its medieval image after recovering openings and eliminating added elements: a roof in poor condition, the 18th century rendering and other non-original parts, such as a gallery of arches and a stone pavement, possibly made in the late 16th or early 17th century. After replacing the wooden structure, only the primitive walls remained, combined with stone elements and wall paintings dating from the 17th century.

The "discovery" of the technique of *tapia valenciana* when drafting the architectural project became the leitmotiv of the intervention. The interest aroused by the aesthetic value of the wall is clear, for example, in the manner in which the authors report the technique of the *tapia valenciana*:

"After compaction and curing, demoulding produces a textural effect due to the abundance of mortar on the bricks in the wall, which causes a plastic quality characteristic of the surface material, with random effects of unquestionable aesthetic value" (Llopis 1996).

The restoration of the rammed earth wall included different interventions, depending on the degree of deterioration of the material:

"[...] And finally repairing the slightly damaged crusts, or the resulting surface after pitting the walls, covered with a widespread gypsum, lime and sand rendering, which may have been applied at the end of the 17th century on walls that may already have had localised damage and, as a general criteria, on the façades, since large parts of the interior has preserved to this day the original specific texture *tapia* intact, above all, and served from the time of drafting to identify the performance criterion for the recuperation of the characteristic textures "(Llopis 1996).

Again we note the architects' concern about the shades of the materials used in the entire building.

Figure 3. *Tapia valenciana* wall restored with a protective coating (*Almudín*, Valencia). Here two walls from different periods can be perceived.

In the case of the rammed earth wall, furthermore, a protective coating was selected.

"On the finished surface, depending on the texture as a result of the building procedure, it was decided to apply a protective coating to ensure the textural quality obtained, waterproofing compatibility with optimal levels of water vapour diffusion, protection against the aggressive effects of the atmosphere and carbonation and, finally, durability and adequate maintenance" (Llopis 1996).

The idea of protecting the wall was not new. Traditionally, it was fairly common to apply a protective whitewash on brick or even stone walls.

The idea of protecting the wall was not new. Traditionally, it was fairly common to apply a protective whitewash on brick or even stone walls.

Galarza's criticisms are now more understandable. The recovery of the external image and the closure of some openings had led to the restoration of the texture of the wall with repairing mortar, even faking its characteristic finish. It is common practice even in the restoration of stone, especially in severely damaged areas. But it is true that it somehow a betrayal of the traditional technique. The second point concerns the homogenisation of the facing and sealing of joints between different construction phases, which now prevents a clear stratigraphic reading. Also in this sense we can understand it as a decision aimed at obtaining a unitary, unfragmented aspect, more architectural than archaeological.

3.2 *Fake tapia valenciana*

The consequences of the restoration of the *Almudín* were important. From that moment onwards, people began to take an interest in *tapia valenciana* and its value as a typical feature of the historic architecture of Valencia. Many rammed earth walls have since been restored, more or less successfully. We will not go into these issues, but we think it is worth mentioning some singular cases where image has prevailed over materiality.

The most striking and paradigmatic example is probably the rehabilitation of the headquarters of the *Gremio de Carpinteros* (Carpenters' Guild) in Valencia, whose design dates from 1996 precisely. It was a delicate operation, because the main hall was divided into two floors and part of the building was converted into dwellings in the 19th century. Inside, the retrieval of the old guild chapel space is remarkable, preserving the original gallery but removing the posterior framework. However, the most daring feature is the work on the façade. Apart from the curious voids, forced by joining the upper balconies with the lower windows, or the peculiar high front ends, the strangest thing about this building is precisely the surface treatment.

From a certain distance, a *tapia valenciana* wall in a brown tone, similar to that of *Almudín*, is visible. In any case, the excessive separation between the rows of brick and the shade are unusual. However, when we come, we realise that the effect is caused by a rendering on which a false finish of bricks has been applied. The building dates from the 16th century and its walls are really made of *tapia valenciana*, as we can see in some areas. However, it is clear that in this case it was decided to keep the original material, probably in very poor condition, hidden and to simulate it on the surface as described above.

We suppose that the intention of the designer was to evoke the original wall without deceit, with a modern technique fully recognisable, according to the tenets of critical restoration. The result, in any case, is unique and is definitely a factor that contributes to the success of the works on the *Almudín*.

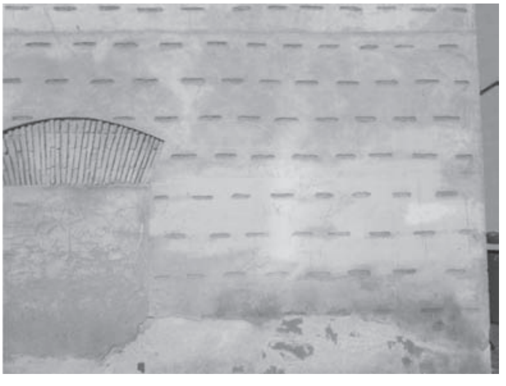

Figure 4. Fake *tapia valenciana* wall: an old wall coated with a textured rendering (*Gremio de Carpinteros*, Valencia).

Figure 5. Fake *tapia valenciana* wall: new wall coated with a rendering into which the bricks are inserted (Alquería de Pinohermoso, Burjassot, near Valencia).

In an intermediate line, we might consider the ingenious recuperation of the image of *tapia valenciana* in the Alquería de Pinohermoso, in the town of Burjassot. The building, one of the medieval farmhouses in the Valencian countryside, had suffered a progressive decline throughout the 20th century, and had ended up in a state of ruin. Besides the loss of floor and roof, in recent decades the walls of the main façade had collapsed. Recently acquired by a new owner, its rehabilitation was undertaken to be used as a second residence. In this case, the walls were rebuilt with new material and then "transformed" into *tapia valenciana* with a layer of mortar and bricks -or fragments of brick- embedded afterwards. It would have been preferable to build the wall in the traditional way, but even so, the recovery of the farm, a landmark that was destined to disappear, must be celebrated.

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Clay in architecture: Slovenia and beyond

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ABSTRACT: Earthen architecture is more or less architecture in clay, but the boundaries between earth, clay, gypsum, lime and stone are not very clear. Earth, soil and turf can be used in construction in a number of selected environments with constant moisture and with limited construction possibilities. Clay and concepts of construction with all the associated problems are a matter of bearing strength, resistance to external circumstances and execution. A healthy relation between man and the clay construction is essential for the natural material. Modern clay can be used as a veneer, as insulation and as hard surfaces: insulation tiles in space capsules, in brakes, as hard, sharp knives. Use of clay in architecture: current maintenance means to live with the material; it is not a sterile relation. Clay cannot only be used in construction, it depends on the circumstances—protection and feelings, as a real human material.

1 INTRODUCTION

Earthen architecture is more or less architecture in clay, but the boundaries between turf, earth, clay, gypsum, lime and stone are not very clear. Stone, from magmatic origins to soft stone, can be a perfect constructional material—with several properties and uses. Not all these materials can be used everywhere and they cannot all be found everywhere.

Differences between soft stone and clay cannot be defined but architecture in these materials can be. Earthen architecture can be traced for thousands of years (Correia, 2007:32). Tombs in Sardinia in a single piece of stone are quite common (from the first millennium BC), houses in classical Greece (from the same time or earlier) are not. Current architecture in soft, sawn stone in Malta has simple constructional principles, as with bricks, but there is no constructional system with cut or sawn 'repnice' in Slovenia (or 'bodegas' in Spain), only the use of a bright mind (Juvanec, 2011:146).

There is an interesting question concerning the stone in Malta (Juvanec, 2006). Are the 'cart ruts' (tracks carved in hard stone, as for a train) cut into hard stone or into soft stone? The stone was definitely hard for carving, though not for use. On the other hand, turf, as an extremely soft and decomposed material, can be used with highly developed knowledge and experience: in layers. Both hot and dry and moist conditions are very difficult for raw clay. Firing changes the properties to create a better building material but wood at least is needed for the fire (and even charcoal is made of wood). The difference between soft stone and hard clay is not defined.

2 EARTH, SOIL AND TURF

Earth, soil and turf can be used for construction in many selected environments, with constant moisture and with limited construction (span). Earth cannot be used because of its organic material, which decays—and changes the volume.

Turf is the most problematic material and least in use. It can be only found in Iceland, where there is high moisture and low temperature (Juvanec, 2010:38). The turf is dug with specially designed tools, which ensures a constant width of the building material. Layers are set alternately, one against another: this creates interesting patterns on the vertical walls. The vegetal roof, made of living grass, covers the walls as an important accent in this type of architecture (comp. Vegas, 2011:163). Another possibility is a dug-in house, whereby most of the building sits in the ground and only the roof is visible. Insulation is perfect, excellent for field crops. The roof is interesting: the bearing construction in

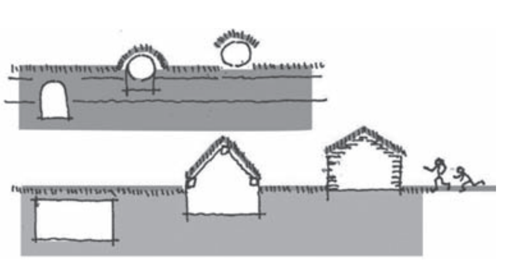

Figure 1. Three crucial locations of architecture: underground, in the ground and on the ground. The most natural and the oldest roofing material is turf.

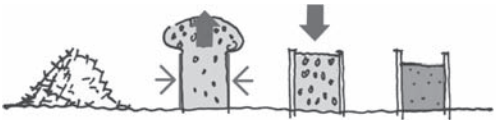

Figure 2. Clay in chips has to be squeezed to expel the air. Density of the clay is so higher, and material becomes more constructive.

wood is massive, covered with earth, and the turf flourishes well on the top surface. In addition to having good insulation, the house is hidden in the landscape; this is result of historical experience; enemies could not see the objects to destroy them.

3 CLAY AND CONCEPTS OF CONSTRUCTION

Clay and concepts of construction give rise to questions of the bearing strength, resistance to external conditions and all the techniques of execution (Zbašnik. 2005:40).

Clay in nature can be found in layers: industrial use is possible in broad layers only. Thin layers cannot provide material with the same properties—clay layers can be found alternating with sand and harder strata.

Two elements are important: compression and strengthening.

Reinforcing with compression: 'Reinforcing' the strength by removing possible sources of splitting is the first step. Air bubbles or clusters lead to possible cracks in the material and cracks lead to decay of the whole composition, decomposition. The density of the material is an important thing. Reinforcement can be achieved with the use of straw (Zbašnik. 2005:43).

The straw has to be dried and sufficiently long. The length can be at least several cm (up to seven). Over-long straws have too big an expansion potential, caused by humidity. If the expansion of the straw is different from the clay itself, the straw can be shortened—but the hole (for the straw) in the clay cannot. If this happens, the clay becomes brittle and its bearing capacity is unpredictable.

4 RAW CLAY AND USE IN SLOVENIA

Raw clay can be used in four techniques: cob, rammed clay, adobe and compact bricks, and it can also be used as a filling and sealing material between wooden beams. A non-constructional use is as outer or inner cladding, or as coloring. Vernacular architecture in Slovenia can be found in stone, in wood and in clay. Stone objects normally

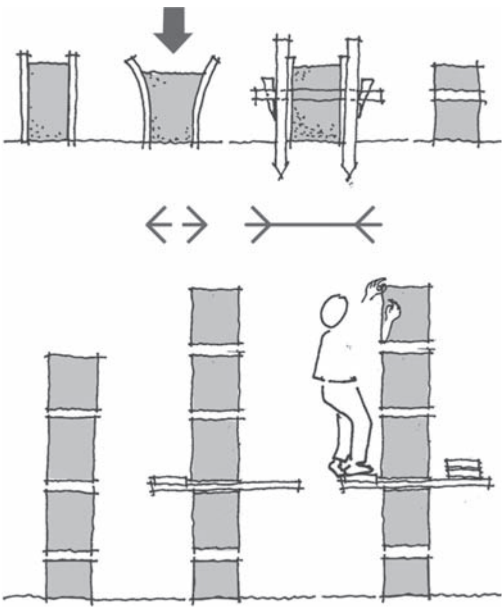

Figure 3. Principle of ramming: pouring in, and squeezing. Construction elements (the holes) are used later for maintaining and repairing.

have wooden constructional elements: lintels and ceiling and roof structures—even if there is stone roofing material (Juvanec. 2010).

In the Alps and in Karst regions, the architecture is mostly in stone, in central Slovenia it is composed of stone, wood and fired bricks, in the eastern part—from Pomurje through Kozjansko down to Dolenjska and Bela krajina, clay can be found as an essential material.

Clay is often used in the northern part of Pomurje, in particular, with influences from Hungary. There are houses in cob, in rammed clay and in the adobe system; in the south, the wooden architecture is plastered and sealed with clay, in some places only decorated.

Pomurje (the north-eastern part of Slovenia), as part of the Hungarian-Austrian monarchy, had a particular historical development. There were no landlords—except those in the castles—and after colonization in the 15th century, all the people had the same area of land: slim and long, from the road to the woods.

The architecture is the same: the houses are at least four metres wide and up to 24 metres long. They are mostly made of wood, and sealed and covered with a clay daub (Juvanec. 2010). On the main façade and in the inner part (toward the inner yard) they are white, the back is coloured red or brown.

Figure 4. Slovenia and use of clay: in the Karst region it enables the ponds, in the central region it is cut for storing rooms, in the Eastern part it is used in cob and rammed houses, in the South it serves as filling in the wooden constructions.

Figure 5. Kal or sort of a pond, used for drinking water over the summer, and for making the ice from December to April.

Figure 6. The main façade is white, the back one is darker, brown or red.

Figure 7. Repnice in Slovenia, artificial caves are cut into the hard, compressed clay. Or is it actually soft stone. photo: Domen Zupančič.

The basement is normally stone, because of the humidity and for stability, but where there is lack of stone, it can be composed of fired bricks, or simply cut into the ground (where the clay is hard enough). The basement is the lower part and to accentuate the stability of the building, it rises out of the ground by approximately 50 to 60 cm.

When chickens see white lime, which is vital for eggshells, they eat it. The wall is, of course, thus damaged and an unmaintained wall can easily decay. Our forebears introduced a fine idea for solving this problem: they painted a belt at ground level in dark colour (Juvanec. 2010: 49). The oldest surviving houses are made of wooden logs, covered with clay cladding. Even the wooden beams of the roof construction in the façade are coloured white.

Houses about two hundred years old (made in the years after colonization) are constructed in the rammed system but functional buildings in vineyards are mostly in cob. The latter buildings have cellars cut into the ground, a living room above and some have stables. Stables need daily visits: and this is a perfect excuse for men to leave the house and evade the wife's control. Even today, houses in clay are well maintained and they have painted, in some places designed, edging stones—to emphasize the construction values. There are many houses in clay in Slovenia; the problem is that is not visible. Their construction can only be understood after decay.

Cob architecture can be found on all continents. In areas with less rain, cob walls are all a vertical construction, with horizontal wooden roofs, coated with clay against leakage. Horizontal roofs are normally covered with branches against severe rain and destruction. In stony countries, stones are used as filling and for 'reinforcing' the walls.

Cob architecture in Slovenia: This is a rare construction, not used for the most valuable buildings. The houses are made for temporary use: wine cellars or outbuildings mostly. The name for this type of building is 'blatnjača' (mud-house, 'blato' means dirt, also dug, certainly with a derogative connotation, Juvanec. 2010: 45).

Rammed clay compositions are very frequent in vernacular architecture where the material is near to hand, and the technology enables good results. Ridged roofs are normal in Europe, usually thatched with straw.

The wall itself is normally covered with a clay daub and the appearance gives no hint of its construction (wooden carpentry, adobe, cob or rammed earthen walls, coated can appear the same).

Rammed architecture is mostly used for a single storey house, although several storey houses can also be found: in Yemen even up to seven or eight.

Rammed architecture in Slovenia: It is hard to see their construction but houses made in rammed clay appeared in the sixties of the last century (Juvanec, 2010:43). Whole villages in this system can be found, where clay is available in the near vicinity. This is very ecological architecture.

The basement can be cut into the ground or can be made of stone, occasionally in fired bricks. The roof construction is always wood, thatched with straw (in Hungary reed is mainly used, and sometimes in Slovenia, too—as a cheaper material). The adobe system is a more advanced construction than rammed clay: it is theoretically pre-fabricated and then constructed in modules: using longitudinal and transverse elements in its construction (Juvanec, 2009:66). The wall can show constructional elements or can be daubed with the same material, clay.

Figure 8. Blatnjaca, a cob house, as vine cellar.

Figure 9. Butanca, rammed construction.

Figure 10. The vintage vine cellar: the windows are somewhere only some cm big.

All clay walls need regular maintenance: every year. While building is mainly man's work, maintenance is hand-work (literally done with the hands, with no tools) and it is a woman's job, even in European countries.

Adobe in Slovenia: It is rare architecture here, because rammed clay is more in use. Adobe is a matter for craftsmen and needs organization and a place for semi-industrial production (the rammed system can be done with the help of the family in a shorter time). It is hard to distinguish between adobe and rammed architecture when the house is finished. Some adobe constructions can be found, in dwelling houses and in outbuildings. It is also interesting that constructional elements, like columns, can also be found in adobe. Clay as sealing and filling: Where a wall is composed of wooden logs, the imprecise joins have to be filled. The problem with hand trimmed logs is that the surfaces are not level. All old houses are made of hand trimmed timber.

Some wooden constructions are daubed with a four to five cm thick plaster, with a finish of white lime.

Some are only filled with clay reinforced with straw and only these visible ribbons are whitewashed. Some poorer houses are sealed with straw and moss, mixed with clay.

The commonest corner connection in wooden constructions is with overlapping beams: half sawn joints are hidden in the corner and overlapping parts project beyond the walls.

Figure 11. A wooden construction, sealed with clay is useful, successful and decorative. The final decoration in lime is the crosses around the window, made with the fingers.

Figure 12. The tomb Campu Lontanu near Florinas, Sardinia is an object in a single piece of stone. Even the internal house fitting is in this stone: the bed for the dead. This is hard to 'build', hard to achieve appropriate material. This is very rare architecture.

Wooden constructions with clay daub in Slovenia: The commonest construction in the south—eastern part of Slovenia is a wooden construction, covered and sealed with clay. This is visible as a full cladding or sealing only. The construction itself can be seen at the corners, where the projecting ends ensure the solidity of the construction itself (in Portugal with stones, Correia, 2007:136).

5 RELATION OF LENGTHS

Modular coordination depends on the construction. The use of a system of proportion ensures exactness and avoids mistakes. The first and the most successful system was modular brick, with lengths increasing by a factor of two. The unit 'one' is the first, the second is 'one times two' = two, two times two equals four. Bricks also create dimensions—in the selected system. In Slovenia, we now use bricks with the primary unit equal to 6 cm. In the former Austro-Hungarian monarchy, the unit was shorter, with the use of the foot. It was the same in Roman times, with thicker tiles, but the longer side was a 'pous' or 'pes', nearly 30 cm (Kurent. 1960). The dimensions are as follows: $6 \times 12 \times 24$ cm, with the use of a whole brick, its half and three thirds, in a 6×6 cm net.

Proportion systems can be used in bearing walls, partition walls (Vegas, 2011:118), corbelling and arches, false domes and domes. There is of course a difference between a construction and a frame, in which the bricks or tiles represent the outer surface only. There, a net or grid is normally used.

6 HUMANITY OF THE MATERIAL

A healthy relation between man and clay is not in the construction. It is a matter of feeling: man's direct touch on a clay surface. Some feelings cannot be explained: for instance—why is the warmth of a clay stove in a room 'more human' and 'warmer', more desirable. Other typical aspects are clearer; they are matter of conduction, convection, insulation, and radiation (Zbašnik, 2005:45). Clay is an excellent insulator, with a warm touch to the human skin, because of conduction. Convection can be achieved by design: the 'tiles' on a 'pumpkin stove' are curved to increase the outer surface. The problem of clay is its surface: raw clay is soft and can be scratched; fired clay is harder but cannot be

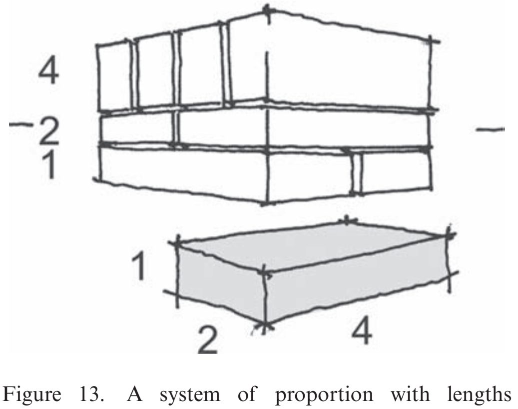

Figure 13. A system of proportion with lengths increasing by a factor of two enable partition walls (with width '2'), bearing walls '4', and insulation walls of '6' units. This principle can be used in adobe as well as for the bricks.

washed for reasons of hygiene; glazed tiles, with all the technical properties of raw clay are hygienic, can be washed, are extremely hard, but cold to the touch. Nobody is perfect.

7 MODERN USE

There is no modern or non-modern material in architecture. Raw clay is no longer in use today but fired bricks are very common, because of all their characteristics. Clay is used in capsules, sent into space, as insulators. Clay is a useful material for heating devices, as automobile brakes, clay knives can be used in the kitchen and so on.

8 CLAY IN ARCHITECTURE, THE FUTURE

Clay cannot only be used in construction, it depends on the circumstances—it can be used as protection outside but for the feeling inside, as a real human material. Glazed clay tiles have long been used in great architecture: Ishtar's door in the Near East has been famous for thousands of years, glazed tiles are in use throughout the Mediterranean area. The most important are in Portugal (Juvanec. 2010:41). Even the first written texts to have been found are clay, and the first passport was in this material. Today, we can use fired clay tiles as the external surface of architecture and the use of clay in architecture means using all the properties of the material, to live with the material, to appreciate it. It is not a sterile relation. The transfer of knowledge shift may be achieved by the function of identifying living environment values by using the methods of architectural analysis of space and the function of spatial structures (Zupančič. 2011:15).

Today, we must use in architecture all the high tech facilities, techniques and technologies, together with the thousands years of experience. The years of use have changed the techniques and technologies; they have not changed the material or human beings. The human relation between clay and man remains forever.

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From the ground up: Building the Dirt Works Studio

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ABSTRACT: In most regions of the United States, rammed earth architecture will remain marginal so long as we fail to remedy a significant lack of knowledge and awareness. The mission of the Dirt Works Studio—a material and tectonics undergraduate studio dedicated to the study of earthen architecture—is two-fold; to teach the next generation of architects the knowledge and skills necessary to design contemporary rammed earth structures and to raise awareness through projects serving the public realm. This paper provides the context in which the studio began as well as the early stages of its inaugural work, the Roth Trailhead. In support of this project, soil mapping, compressive testing, and particle size analysis are employed to understand the limitations and the potential of local soils. Although a work in progress, the Dirt Works Studio is poised to contribute to lifting the shroud of mystery surrounding rammed earth in the Midwest.

1 INTRODUCTION

In the American Midwest, communities are intimately bound to the land. This dedication—revealed in agricultural cultivation and the heritage and stewardship of the largest remaining intact tallgrass prairie in North America—is inexplicably lacking in considerations of the built environment. Despite a growing awareness of the consequences of human activity on the natural environment, these communities continue to build from materials that deplete the limited nutrients of the topsoil. With topsoil being an often-overlooked endangered resource, we need to turn to alternatives—such as rammed earth—that bypass this organic layer of soil to access the abundant inorganic layers beneath and sidestep the industrialized processes that are major contributors to heavy carbon footprints.

Rammed earth construction, especially in America's heartland, has been relegated to the margins of the built environment due to factors including the prevalence of standardized industrial materials, misconceptions regarding structural capacity and moisture resistance, and a general lack of awareness and historical precedent.

Most detrimental to its widespread use is a shroud of mystery that conceals the process of selecting and transforming the soil.

As founder of the Dirt Works Studio at the University of Kansas and in conjunction with the Kansas Biological Survey Field Station, I am leading a group of architecture students in the design and construction of a public rammed earth trailhead and entry portal to the Field Station's nature reserve.

2 (UN)BOUND TO THE LAND

Kansas does not possess a fertile history of rammed earth architecture. While a number of factors likely contributed to this historical lack, there remain significant barriers preventing its current use. These barriers range from perceptual—many Kansans are unfamiliar with rammed earth or harbor misconceptions as to its suitability—to local soils, which tend to be quite high in clay content. On the other hand, Kansas has robust mineral resources, from large shale deposits to the 'flinty' limestone that made farming impossible over a wide swath of land, resulting in the Flint Hills tallgrass prairie.

According to the Kansas Geological Survey, sand and gravel operations are some of the most abundant mineral production facilities in the state; and most of these are located along its eastern edge (Kansas Geological Survey 1999). The challenge with locating appropriate soil for rammed earth construction in eastern Kansas is finding a relatively low-clay soil. The most suitable soils appear to be those located near rivers or streams,

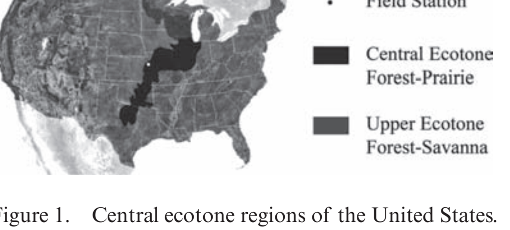

Figure 1. Central ecotone regions of the United States.

or areas receiving wind-blown sandy deposits from nearby watercourses, thus freeing sandy soils from their clayey matrix.

3 AN ECOTONE REGION

The Kansas Biological Survey, in conjunction with the University of Kansas, administers a 3400-acre Field Station in northeastern Douglas County. As an environmental research and education facility, the Field Station is unique for its diversity of biomes. Located in the ecotone region separating the eastern deciduous forests from the tallgrass prairie to the west, the Field Station serves as a natural laboratory. (Kettle 2000).

Although the soils of the Field Station are diverse, these soils possess little gravel content with the exception of occasional areas of limestone outcroppings. Figures 2–3 reveal that the vast majority of the Field Station soils contain high amounts of clay while sand content varies widely. There are two areas that emerge as potential sources of rammed earth material; a small area of Sibleyville loam located on the western portion of the McColl Reserve (bottom of rotated 'U'), and the northern half of the Robinson tract, located south of the main land area. The soils at the Robinson tract are fairly unique; comprised of a Fallleaf-Grinter, these soils were blown-in from the river and deposited atop a terrace, subsequently covered long ago. These sand dunes have relatively low amounts of clay and are somewhat diverse in their particle size distribution.

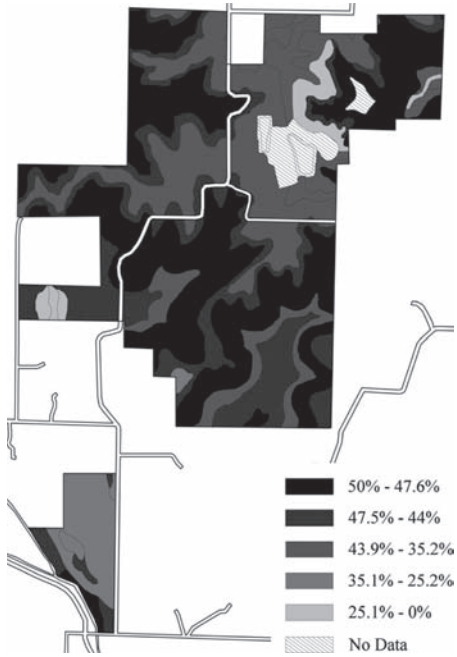

Figure 3. Percent clay content at the Field Station; from 10"–48" beneath surface; based on USDA Web Soil Survey data.

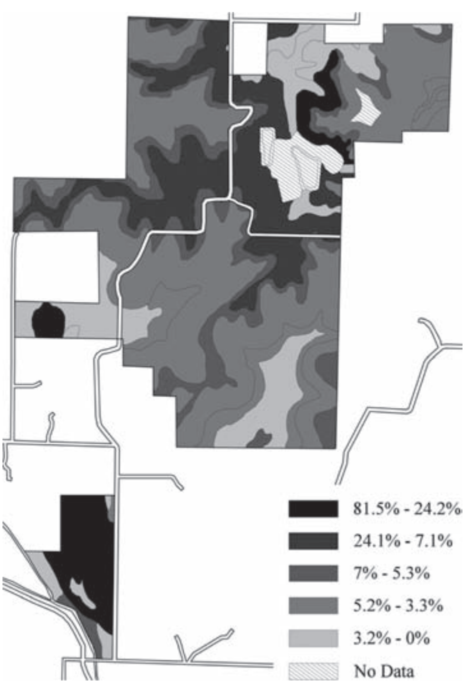

Figure 2. Percent sand content at the Field Station; from 10"–48" beneath surface; based on USDA Web Soil Survey data.

After further study, the Robinson soils seem to hold more promise; however, they still lack the course sand and gravel needed to make a strong rammed earth wall.

Located a few miles west of the Field Station is a quarry that extracts limestone and gravel. Initial tests using only material for the quarry reached adequate compressive strengths but lacked sufficient surface integrity and desired aesthetic appearance.

Utilizing a spreadsheet developed to aid with blending two or more source materials—based on particle size distribution criteria drawn from the North American Rammed Earth Builders Association specification—it was determined that a minimum blend of 75% 1" screened material from the quarry combined with 25% Robinson soils, came closest to meeting these requirements. A blend of 90/10 appeared better suited to higher compressive strength while retaining the dense surface and coloration of the 75/25 blend.

Figure 4. The Mud Hut, Marvin Studios, University of Kansas; built primarily of compressed earth blocks. Photo by author.

4 CONCEIVING DIRT WORKS STUDIO

4.1 *The Mud Hut, a forgotten legacy*

In 1941, W.C. McNown, professor of civil engineering at the University of Kansas, set out to build a single story 7000 square foot compressed earth block building for the, then, School of Engineering and Architecture (McNown 1945). Utilizing the labor of teen-aged boys from the National Youth Administration in its construction, Professor McNown successfully built, on a shoestring budget, a building of understated beauty (Alvy 1946). The building still stands today, in near perfect condition, as a testament to the durability of earthen architecture, and as the seeds of a legacy begun at the University of Kansas, albeit one that has largely been forgotten.

The Dirt Works Studio, a materials and tectonics studio in the School of Architecture, Design, and Planning was founded with the belief that earthen architecture holds great promise for a more sustainable future. The Dirt Works Studio wishes to resuscitate the legacy began by Professor McNown 71 years ago, with the Roth Trailhead a rammed earth design/build structure at the KU Field Station.

4.2 *East Hills Construction Lab, an uncommon incubator*

The Dirt Works Studio is fortunate to be able to call the East Hills Construction Lab its home. This 65,000 square foot facility contains a large studio space, a conference room, an office, and a large fabrication shop. This type of facility is rare among architecture schools in the United States, providing the space to conduct research on a large scale, test prototypes, and fabricate building assemblies.

4.3 *The Field Station, the ideal client*

If the old adage, 'great architecture requires great clients' is correct, then the Dirt Works Studio is well situated. The third ingredient making this ambitious project possible is the Field Station as client. Their knowledge of this unique natural environment, their vision for public engagement, and their commitment to sustainability is echoed in the principles of the studio atmosphere. Furthermore, they have the land, the need, and in several instances, the infrastructure to pull off such a project.

5 PREPARING DIRT WORKS STUDIO

5.1 *Hikaru dorodango, a hands-on experience*

To overcome students' initial disbelief regarding the transformative properties of soil, they were asked to create hikaru dorodango, an ancient Japanese craft of transforming moistened soil into a sphere of near-perfection with no tools save one's hands and an ample quantity of patience. William Gibson describes the dorodango as "an artifact of such utter simplicity and perfection that it seems it must be either the first object or the last" (Gibson 2002).

The essence of the art is in the patient process of continually smoothing the hardening surface with fine grains of soil, resulting in a particular type of luster that evokes the light-capturing qualities of jade. After several days of coaxing forth the desired properties, students discovered that they had made a remarkable artifact where only dirt had existed before.

5.2 *Terra firma bench, a chaise study*

Emboldened by this three-inch victory, students received their first lessons on rammed earth in the design and construction of rammed earth benches meant to serve as case studies for the ultimate project. The process of making the 'terra firma' benches allowed them to explore structural properties, material characteristics, soil blends, lift patterns, and the integral relationship between formwork and final work.

This case study provided a laboratory in which risks and experimentation were encouraged and failure was an acceptable outcome. The studio developed three unique designs; a prism with a curvilinear void, a faceted double cantilever, and a multi-height pair of blocks linked by a tapered backrest.

5.3 *Dirt Work Lab, understanding the architecture of soil*

Once potential soils for the Roth Trailhead were identified and applied in the terra firma benches,

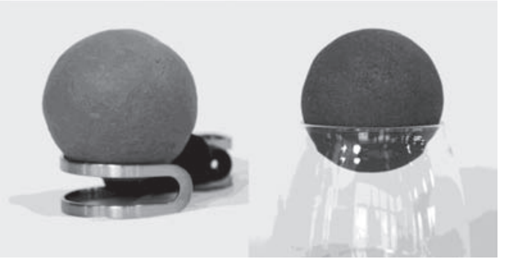

Figure 5. Hikaru dorodango; shiny balls of mud fashioned by students of the Dirt Works Studio (Gieseke and Chen).

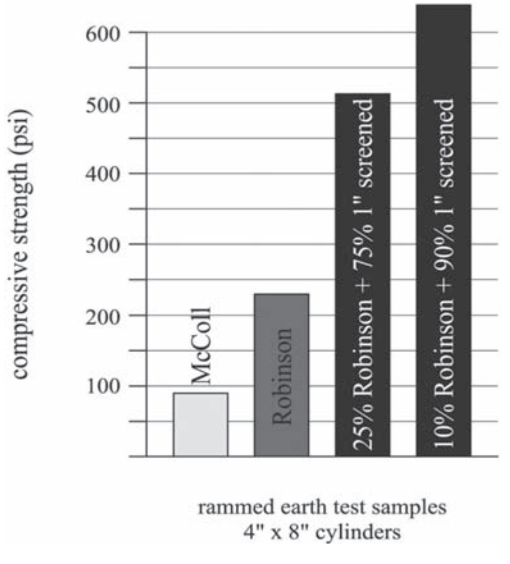

Figure 6. Compressive strength test results.

the studio began to experiment with different amendments, including Portland cement, lime, and fly ash. Differing soil blends were also examined.

While testing is ongoing, early compressive strength test results show promise. Figure 6 shows a variety of soil tests, from the poorly performing clayey soils extracted in the McColl region of the Field Station to the slightly better performing sandy soils of the Robinson. Soils blended with quarry material show significant improvement in compressive strength while maintaining the aesthetic quality of the site soils rather than adopt the less attractive aesthetic of the quarry material. This is due to the tendency for fine silt and clay particles to migrate to the surface of the forms and largely determine color and texture.

In comparing particle size distribution of the soils, a benchmark line was established based on criteria drawn from the North American Rammed Earth Builders Association specifications. In relation to this line, each soil or soil blend was charted. In theory, relationships between charted lines can loosely predict the compressive strength of future soils. The challenge with blending Robinson soils with 1" screened material from the quarry, for example, is that in order to increase gravel content, clay content is inadvertently increased as well. In order to address this, lime will be used in subsequent tests, since lime is better able to mix with the blocky structure of the clay rich soil. Further experiments will examine the effects of fly ash, bottom ash, and a combination of lime and fly ash.

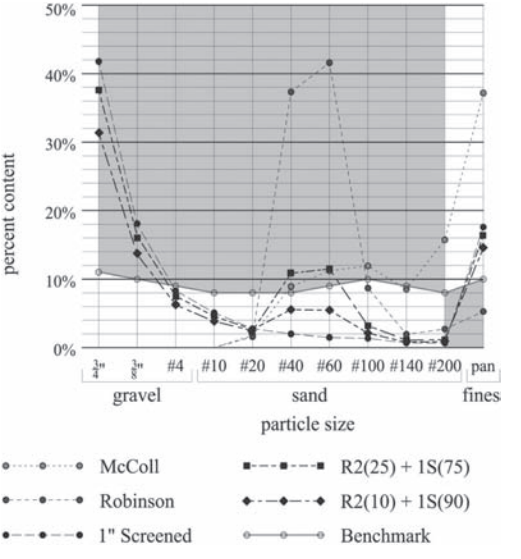

Figure 7. Particle size analysis on soils and soil blends.

6 THE ROTH TRAILHEAD

The Roth Trailhead will serve as a gateway into a new trail system, a gathering place, a source of information about the land, and a central element of a more robust public outreach effort. The design of the project concentrates on a few basic tectonic elements, including a punctuated rammed earth wall proportioned on the Fibonacci sequence; a gravel path guiding visitors along the wall; a sun-shading canopy hovering atop the wall; and a rainwater runoff collector that doubles as a water feature.

The studio's focus is on the details. According to architect Louis Kahn, "Design consults Nature to give presence to the elements … In the elements the joint inspires ornament, its celebration. The detail is the adoration of Nature." (Accademia 1974).

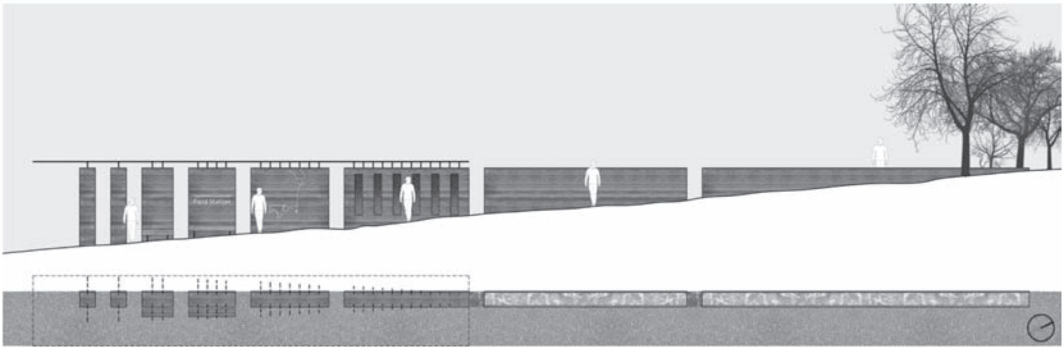

Figure 8. Concept for the Roth Trailhead. Drawings by author.

Figure 9. An early concept rendering for the Roth Trailhead. Rendering by William Yankey.

With these words reverberating in our minds, the Dirt Works Studio began the design of the Roth Trailhead with a series of schematic charrettes based on an initial concept. Simultaneously, members studied several rammed earth precedents. Questions of formwork design, soil mix, lift patterns, material and tectonic joints, corner details, and coloration were addressed.

In the studio, decision-making is done collectively, through a series of loosely structured debates in which each proposal receives a champion, with the remaining members positioned in the studio in closest proximity to the scheme they currently support. Through a series of points, rebuttals, and counterpoints, members stand their ground, shift toward a new champion, or else devise an alternate scheme for which they must defend. This form of 'messy' democracy continues until consensus is reached. If consensus proves elusive, I, as studio instructor, become the arbiter.

With design development under way, the studio is working toward breaking ground in early spring, with the ribbon cutting presentation scheduled for late spring.

7 CONCLUSION

In our reawakened recognition of the pressing need for a sustainable architecture, it is no longer enough to be "less bad" to paraphrase William McDonough (McDonough 2002). Instead, we must re-envision our built environment with building materials and methods that strive to be healthy for the planet and for their inhabitants.

Although I do not claim that rammed earth is the complete answer, I do believe it can play an important contributing role in this thoughtful new world.

The dearth of rammed earth construction in the American Midwest is a reflection of its absence in the institutions of higher learning throughout the region. Although there are a number of organizations advancing the cause of earth architecture, few focus on educating the next generation of architects and builders. The obstacle preventing wider acceptance of earth architecture is primarily a lack of public awareness and professional education. With the Dirt Works Studio, I aim to address both obstacles by educating architecture students in the design and construction of publically accessible rammed earth structures for all to experience.

ACKNOWLEDGEMENTS

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On perceptions of rammed earth

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ABSTRACT: Although building with soil is arguably the most ancient and abundant method of construction on earth, in most regions of the United States, you will not find a fertile tradition of earth architecture. Significant misconceptions regarding the potential of rammed earth architecture exist even among architects, with frequent perceptual barriers preventing its widespread adoption. The most common misconceptions, based on anecdotal evidence, can be grouped into three broad fallacies—the hot/arid fallacy, the antiquated fallacy, and the weak fallacy. This project seeks to lift a shroud of mystery concealing rammed earth architecture by probing the perceptions of professional architects and architecture students through a pilot survey assessing general attitudes, questions, and misconceptions surrounding rammed earth architecture. Survey data is used to sort these anecdotal observations from the perceptions of survey respondents. Although material performance and constructability are concerns for some respondents, the most significant barriers appear to lie elsewhere.

1 INTRODUCTION

In Kansas, rammed earth remains enigmatic. When interjected into a conversation, the term often invites a combination of curiosity, bewilderment, and disbelief. Significant misconceptions regarding rammed earth are commonplace outside of architecture, engineering, and construction disciplines. Even among architects, frequent perceptual barriers appear to prevent its widespread adoption. Although building with soil is arguably the most ancient and abundant method of construction on the planet, in many regions of the United States, you will not find a fertile tradition of earthen architecture.

This project seeks to lift this shroud of mystery by probing the perceptions of professional architects and architecture students through a pilot survey designed to assess general attitudes toward earthen architecture. It is hoped that by understanding these attitudes, we will be better positioned to educate the architecture profession and the public on the virtues and limitations of rammed earth at a time when knowledge of this ancient tradition has much to contribute to today's most significant challenges.

2 A PILOT SURVEY

The pilot survey was originally aimed at four unique audiences—architecture students in Kansas and New Mexico, and professional architects in Kansas City and Albuquerque. These audiences where chosen to measure differing attitudes between students and professionals; and differing attitudes between a region without a history of rammed earth (Kansas) and the only region in the United States with a rammed earth building code (New Mexico). Due to unequal response rates, the data presented here is an aggregation of the target audiences into one data set, with a particular concentration on Kansas and on students.

3 BARRIERS TO WIDESPREAD ADOPTION

It is evident when observing the built environment in the American Midwest that significant barriers have prevented or discouraged the adoption of rammed earth architecture. An investigation into these root causes reveals several possible barriers, such as the lack of a rammed earth building code. Yet, these types of barriers appear to be a symptom rather than a cause. Lack of an ice building code is hardly adequate in explaining why we do not build with ice (at least south of Quebec!).

Prior anecdotal evidence suggested that the root cause might have more to do with a variety of misconceptions regarding the potential of rammed earth architecture. It appears few architects possess much to address these assumptions through the preliminary findings of the pilot survey.

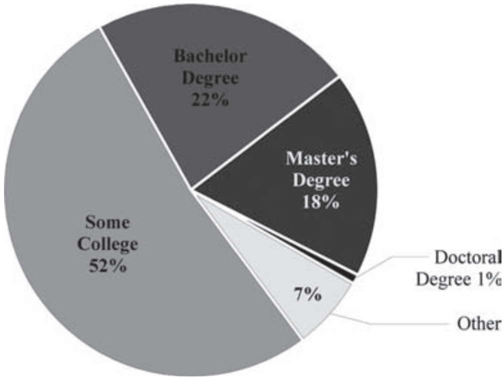

Figure 1. Highest level of education completed.

4 MISCONCEPTIONS OF RAMMED EARTH IN KANSAS

In Kansas, the public appears unfamiliar with the term 'rammed earth'. When familiarity is professed, rammed earth is usually characterized as one or more of three broad statements: 'rammed earth is only suitable for hot/arid climates, such as the Southwest; 'rammed earth is antiquated, surpassed by industrialized materials, and suitable only for developing nations'; and rammed earth sounds unstable, temporary, and prone to erosion or failure'.

Despite a lack of awareness and general misgivings, rammed earth is often perceived positively. When asked to associate words with rammed earth, respondents frequently used positive words, such as sustainable, natural, beautiful, and warm (Table 1).

4.1 *The hot/arid fallacy*

It is a common misconception that the viability of rammed earth construction is limited to hot, arid climates, despite a fertile genealogy occurring in almost every region of the planet. The climate of the Midwest is characterized by temperature extremes on both poles of the thermometer, well below freezing temperatures in winter months contrasted with hot humid conditions throughout summer months. Well known for its thermal mass, rammed earth is an ideal material for balancing large diurnal temperature fluctuations like those experienced in the American Southwest—hot days and cool nights. When temperatures fail to rise above the desired indoor temperature during any portion of the day, diurnal temperature swings and the flywheel effect of thermal mass have little to offer. Cold climates rely on high thermal resistance.

Table 1. Most commonly associated words with rammed earth.

Words	No.	Common variations
Sustainable	13	Sustainability, environmental, low-embodied energy, green
Dirt	10	Dirty, dusty, clay, soil
Mass	8	Thermal, poche, density, thick
Compressed	7	Compression, packed
Natural	7	Nature
Hot/Arid	6	Southwest, desert, regional
Beauty	5	Beautiful
Strength	5	Solid, load-bearing
Brown	4	Brownish
Warm	4	–
Layers	3	Patterns
Loose	3	Unstable, temporary
Primitive	3	Old world, ancestral

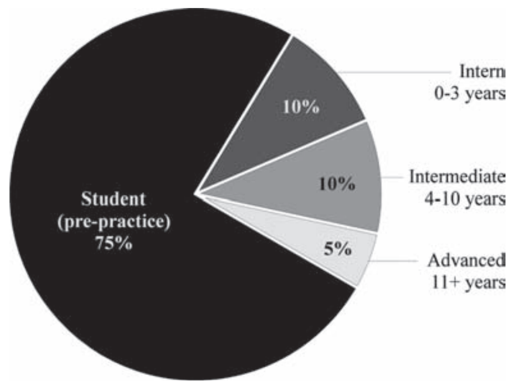

Figure 2. Architectural experience.

Rammed earth—like all dense materials such as concrete, stone, and brick—has an R-value roughly equivalent to .25 per inch (2.54 cm), or 4.5 for an 18″ (45.72 cm) thick wall, rather low by any standards. On the other hand, low R-value is a misleading indication of performance due to its inability to factor in dynamic influences such as solar radiation (Easton, 2007).

According to the US Department of Energy, Kansas falls within Climate Zone 4, a designation adopted by the International Code Council for use in its building codes. By this designation and according to ASHRAE Standard 90.1. the minimum R-value for walls in a commercial application in Kansas is R-20 (ASHRAE, 2010). Since building codes rely on the R-value index, criticism of the R-value remains a moot point. It is clear when measured against the R-value index that rammed earth cannot meet minimum energy standards alone. This would seem to justify the hot/arid statement.

However, a composite envelope built of rammed earth and rigid insulation takes advantage of both the thermal mass of the rammed earth and the thermal resistance of the rigid insulation. In fact, the performance of the thermal mass of the rammed earth wall is increased with the addition of rigid insulation They conclude that this type of composite construction is "highly applicable in all climate zones, including the cold Canadian Prairie climate" (Fix, 2009). According to rammed earth specialist Meror Krayenhoff, the founder of SIREWALL, when properly built, an insulated rammed earth wall can achieve R-29 or higher (Sirewall, 2012).

4.2 *The antiquated fallacy*

Another common misconception is that rammed earth is suitable for developing nations but no longer holds benefits over more advanced post-industrial construction methods; we no longer built monolithically; or concrete is a superior material. While concrete does possess several significant advantages, including higher compressive strength, higher levels of standardization and predictability, and better moisture resistance, rammed earth has its own set of advantages, which include lower embodied energy, locally available materials (in many locations), and better indoor air quality.

In the 1930s and 1940s, research and interest in rammed earth surged in the United States. In one instance, the South Dakota State College conducted research over a period of thirty years with a series of demonstration walls composed of a variety of soil and amendment compositions. The US Army Corps of Engineers explored rammed earth in a variety of projects from foundations to canals. The US Department of Agriculture built a community of rammed earth buildings near Gardendale, Alabama (McHenry, 1989). In each of these cases, rammed earth was determined to hold great promise; it was long-lasting, stable, inexpensive, and comfortable. During the late 1940s and 1950s, advances in industrial manufacturing made rammed earth appear less attractive.

The last sixty years have been witness to a culture of building largely out of sync with the environment. Today, we are beginning to understand the wisdom of the Native American proverb, "We do not inherit the earth from our ancestors, we borrow it from our children." Rammed earth is unique in that it is one of the few building materials that originates from the subsoil rather than draw nutrients from the limited layer of topsoil, is locally available, free of dangerous chemicals such as formaldehyde and benzene, emits negatively charged ions which research shows contributes to good health, and naturally regulates indoor humidity levels, to list but a few of its many positive attributes. More than ever a growing chorus of voices is calling for a healthier, more responsible way of building.

4.3 *The weak fallacy*

The third broad misconception often encountered is that rammed earth is a weak, unstable, temporary material; best used for projects of short duration or lesser importance, i.e. garden walls, pavilions, and storage sheds. Highly susceptible to moisture degradation, surface erosion, and freeze/thaw cycles, a project built of rammed earth is like a foundation born on sand, or so the fallacy goes. In the two thousand year history of rammed earth, we have witnessed many structures survive for several hundred years. Given the contemporary propensity for building materials with short life expectancies, the historical record of rammed earth ought to speak for itself.

Truth lies in all fallacies. Traditional—i.e. non-stabilized—rammed earth construction can indeed be highly susceptible to various kinds of degradation. To equate modern rammed earth practice to traditional one is to assume no standard of construction as well as discount significant advances in materials research. If we were to hold other building materials to this same standard, we would have to conclude that concrete is also highly unpredictable and susceptible to failure. However, ever since the pioneering work of François Hennebique, concrete has undergone a series of incredible advances.

Rammed earth is only recently beginning to receive this kind of attention, with advances in lime/cement stabilization, hydrophobic amendments, and insulated compositions. According to the New Mexico rammed earth building code in order to be considered qualified rammed earth, compressive design strengths must meet or exceed 300 psi [2 MPa] (New Mexico, 2006). In the specifications of the North American Rammed Earth Builders Association, expectations for stabilized rammed earth construction have been raised to 900 psi [6 MPa] design strength. Still lower than most concrete applications, this reveals substantial increases in rammed earth strength. SIREWALL has claimed to achieve compressive strengths of up to 6000 psi [41 MPa], far exceeding the strength of most common concrete applications.

5 COMPARING RAMMED EARTH

Despite professing little familiarity, survey respondents seem to intuitively understand the attributes of rammed earth, with the marked exception of

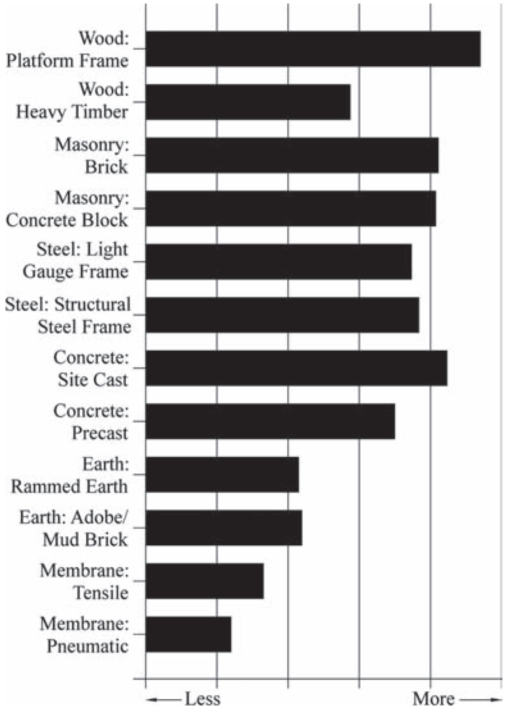

Figure 3. Familiarity with various construction types.

thermal resistance (Figures 3 & 4). Curiously, respondents viewed the thermal resistance of rammed earth highest, suggesting that rammed earth's relatively low thermal resistance—prior to being insulated as described above—is not perceived as a significant barrier to wide spread adoption. If anything, the respondents appear to have an over-inflated view of the material attributes of rammed earth.

While these comparisons revealed a generally positive outlook on rammed earth, specific questions addressing its most and least favorable attributes uncover additional layers of the narrative.

6 PERCEPTIONS OF RAMMED EARTH

When aggregating the most favorable attributes of rammed earth, the seven most common answers are (in descending order): thermal mass, aesthetics, life-cycle costs, thermal resistance, embodied energy, durability, and compressive strength. With the exception of thermal resistance and durability, these findings are of no surprise. Once again, thermal resistance is cited as a positive attribute of rammed earth, revealing that our respondents do not necessarily share the apprehension outlined

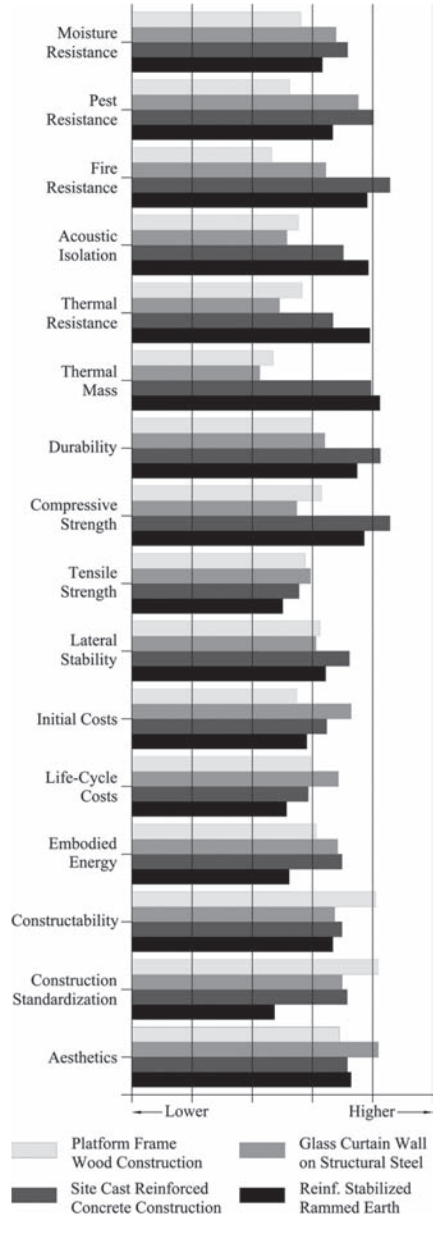

Figure 4. Comparing attributes across four building types.

earlier. The fact that durability was also cited tends to resist another common misconception.

The seven attributes considered to be least favorable are (in descending order): standardization, tensile strength, constructability, initial costs, moisture resistance, aesthetics, and durability. From these two lists, two attributes—aesthetics and durability—fall under both, suggesting a polarization of beliefs. Although fascinating, the fact that aesthetics is commonly considered to be a most favorable and least favorable attribute is readily explained by its inherently subjectivity. The question of rammed earth's durability, on the other hand, reveals significant confusion.

In comparing rammed earth to concrete, the perceived benefits of rammed earth are multi-faceted; lower costs (both initial and life-cycle), lesser embodied energy, and greater beauty. On the other hand, the perceived drawbacks of rammed earth are concentrated on lesser standardization and harder constructability.

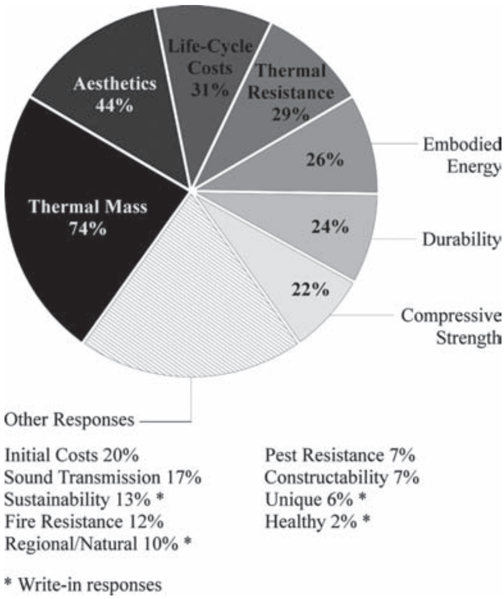

Figure 5. Most favorable attributes of rammed earth.

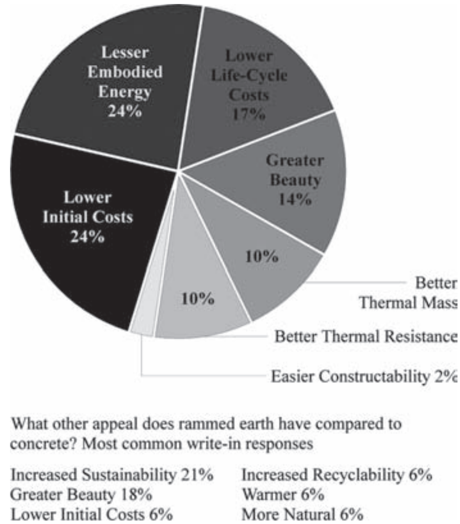

Figure 7. Advantages of rammed earth compared to concrete.

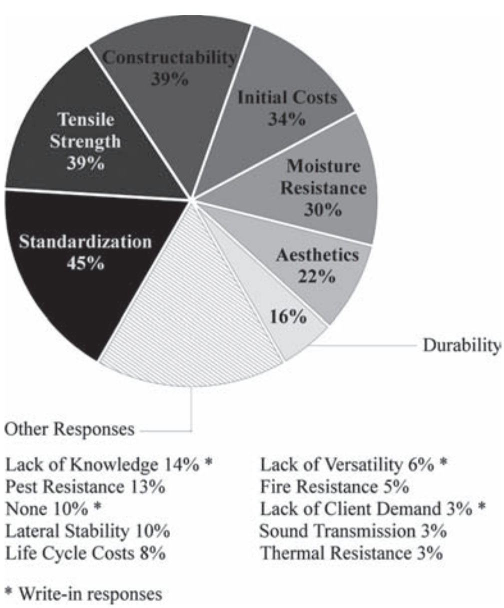

Figure 6. Least favorable attributes of rammed earth.

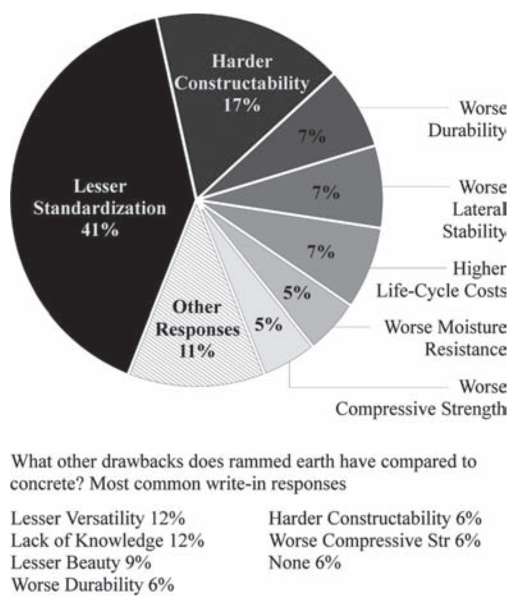

Figure 8. Disadvantage of rammed earth compared to concrete.

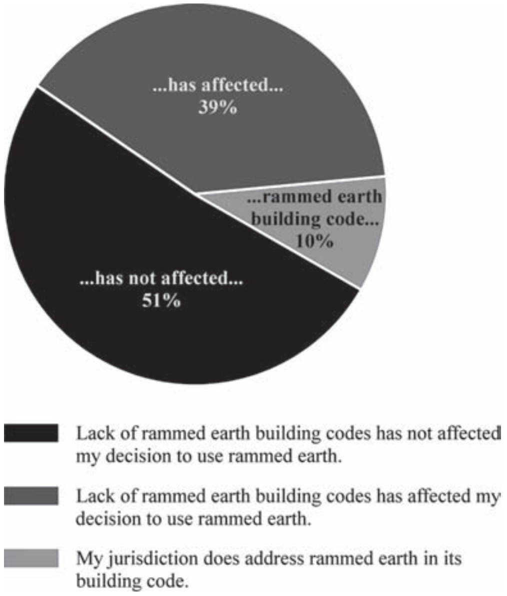

Figure 9. Influence of a rammed earth building.

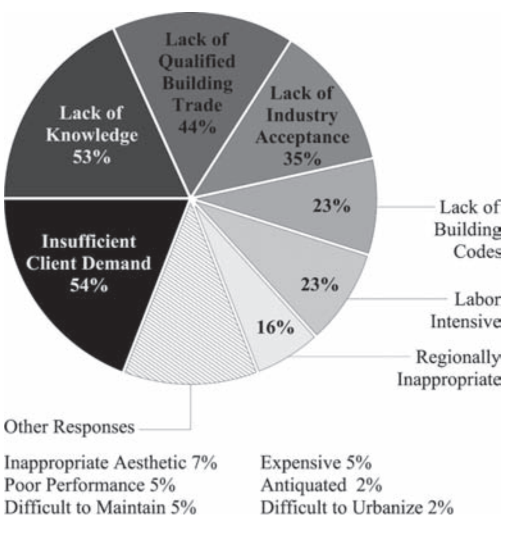

Figure 10. Barriers preventing the adoption of rammed earth.

7 CONCLUSION

It seems reasonable to conclude—based on findings represented by Figures 1–10—that architects and architecture students participating in this survey hold a positive view of rammed earth. Lack of appeal does not seem to be the underlying cause of rammed earth's marginal status in the American Midwest.

As with any material, rammed earth has its strengths and weaknesses, its potentials and its limitations. Yet, these physical attributes do not appear to contribute to this marginalization either. These findings suggest that what all of the barriers to widespread adoption have in common is a lack of education across the board; from public officials (lack of building codes) to the general public (insufficient client demand); from the architecture profession (lack of knowledge) to the construction industry (lack of qualification).

The central challenge to rammed earth architecture in the American Midwest is one of education. Since it is more difficult to re-educate the profession, researchers ought to turn to the academies and the profession's future; and since it is difficult to teach the general public from within the ivory walls of academia, educators ought to reach out through community design centers and design/build projects and through partnerships with industry; and since building officials are rarely proactive, the design community must call for a building code that addresses one of the most promising solutions for a more sustainable world.

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The construction of the Valencian rammed earth walls in the Corpus Christi College-Seminary in Valencia (Spain)

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ABSTRACT: The Corpus Christi College-Seminary in Valencia is a building whose construction is set in the historical period of the Renaissance; therefore it has over four hundred years of history. The building is of great magnitude, as it occupies an entire block of the old Jewish quarter of the city. It rests upon a stone plinth from which the walls, constructed with Valencian rammed earth, are raised. All its architectonic and constructive aspects elucidating its constructive process have been studied in depth. The study has been based on the graphical analysis of the costs produced during its construction, between the years of 1586 and 1610, as well as on the use of thermographic technology. This data has been synthesized into a 3D hypothesis of the constructive sequence. Our work proposes a methodology that can be extended to other similar studies for the analysis of the constructive process based on the original conserved documentation.

1 INTRODUCTION

In the Renaissance, many religious buildings were constructed inside and outside of the cities' walled enclosures. In the decade of 1570, in the Spanish city of Valencia, eighteen churches of different religious congregations were built. It is in this period that the Patriarch decided to construct its own religious institution, a College-Seminary next to the University. This new building followed the principles from the 1577 publication of Carlos Borromeo *"Instructionum Fabricaeet Suppellectilis Ecclesiasticae"*, on which other authors would later base their works, such as Aliaga (1631). An architectonic Renaissance was fully developed in Valencia, in line with the rest of the Peninsula, although with some differences (Llopis 2002).

There are few studies carried out by architects dealing with the entire building. In the Archive of the Corpus Christi College-Seminary there is a book called the Book of Construction and Manufacture or Book of Costs—*Libro de Construcción y Fábrica o Libro de los Gastos* (Anonymous 1892). This book gathers the costs that the construction of this unique building generated between its start in 1586 and finish in 1610.

The information gathered by this book are the costs derived from the building's construction, dated and grouped in months and years, following a not very strict chronological order. It attempts to state the master who charged them and the amount is indicated. We have copied the information contained in the book and computed it in such a way as to allow us to chronologically order all the items, add up the amounts and filter the results with the aim of obtaining written or graphical results that assist us in the development of our work. In total there are near to 10.000 items between the years 1586 and 1610 whose value reaches 165,500.70 pounds (Lerma 2010). As an example, the first costs ordered chronologically are shown in Table 1.

This data has been represented in figures 1 and 2, with which we can get a good idea of how the construction process of the College-Seminary was produced. Figure 1 shows the monthly costs from 1586 until 1610. Figure 2 shows the percentage of the annual costs organized by material (stone, ceramics, conglomerates, paint, metal, wood, textile, etc.).

From the start, the process of houses' acquisition is inclusive, so the overall area of the building was known (Anonymous ca. 1600). At the moment in which the first stone is laid, 30th October 1586, the Patriarch had still not finished acquiring all the lots of the block.

Being documented with the corresponding contracts, we know that the Church (Anonymous 1590), the chapel, the cloister, the cells and the library were constructed from 1590 onwards. The reason this service area is so irregularly shaped

Table 1. First registers of the book of construction of the college-seminary in the spreadsheet.

Year	Material	Pounds	Observations
1586	Wages	14.40	Stone. Master Damian
1586	Stone	0.00	First stone
1586	Wages	21.60	Receipt and wages. Master Loret
1586	Lime	6.40	Receipt for stone and lime to Jeronimo
1586	Plaster	4.50	Receipt for stone for this day, for plaster to Master Joaquin Jillol
1587	Sand	3.85	To Juan Sarcia sand supplier
1587	Wood	8.70	To Vicente Sanchez carpenter

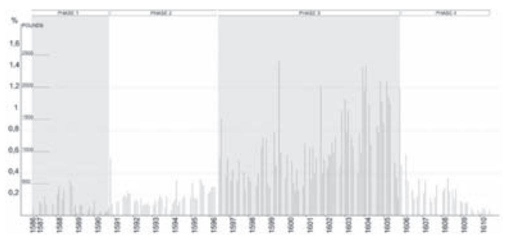

Figure 1. Annual costs ordered chronologically.

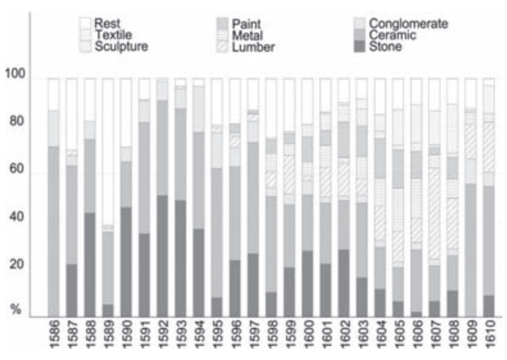

Figure 2. Annual costs according to groups.

in comparison with the church, the cloister, the chapel, etc., could be because the service area was considered residual and an addition to the important spaces. Neither its shape nor its layout was paid attention to.

The building has not been restored since it was built four centuries ago. This allows us to observe the materials' current state and the construction techniques used.

2 THE PERIMETER WALLS OF THE BUILDING

From the year 1586 in which the first stone was laid, the project of the College-Seminary would start. We know that the building's most important elements were constructed from 1590 onwards. Regarding the service area of the College-Seminary, we have found no document that explicitly sanctions its construction, nor the Master to which the project was assigned. However, between 1586 and 1589, there are project records that must correspond to this service area, although it is not stated as such. In any case, in this period of time, there is the execution of the "fundamentals" or foundations of the block's perimeter walls.

The constructive process in the first years is conditioned by the acquisition of the plots that were situated in the area that the building occupies today. The Ribera Patriarch did not buy all the properties at the same time. In fact, it is done progressively, even after the works started. In 1586, the year in which the project starts, the majority of the plots in the north, west and south had been acquired, but not the central and eastern areas. This fact clearly influenced the constructive process of the building (Lerma 2011).

Therefore, they must have started the construction of the foundation of the north face and of its two corners (between the first and second trimester of the year 1587). In the documentation, it is recorded that master stoneworker Pedro Bertomeu carried out the first corner. Later, the masters Leonardo and Juan de Ambrosio undertook the second corner. Juan de Ambrosio would continue with the third corner, named the "slender corner" that must make reference to the north-eastern corner, which is concaved (in February 1588). In March and June of 1588, the corners referring to the Cruz Nueva Street (west) are cited, again on behalf of the stoneworkers Leonardo and Juan de Ambrosio. Finally, in October 1588, Leonardo carried out the "last corner" of the College-Seminary, A summary of the constructive process is represented in 6 steps in Figure 3.

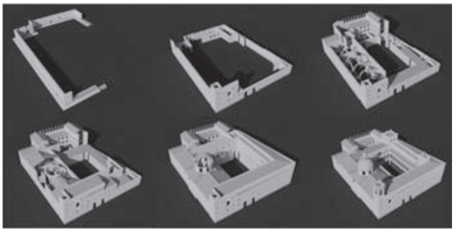

Figure 3. Evolution of the works of the College-Seminary.

3 IDENTIFICATION OF THE MODULATION OF THE VALENCIAN RAMMED EARTH WALLS

As it can be seen, the foundation of the perimeter of the building was executed in two years; a stone plinth from which the walls were raised. The walls made with Valencian rammed earth are characterized because into the tamped down earth, different courses of bricks are interspersed, with the aim of stiffening the wall. In the case of the walls of the College-Seminary, the proportion is quite high, so that the thickness of the course of earth and that of the bricks is practically equal.

The earth used in the construction of the rammed earth wall was obtained from the excavations and movement of earth generated by the works of the College-Seminary. We believe that the earth extracted from the foundation was sufficient in volume to be used in the construction of the rammed earth wall. In the consulted documentation, there are no entries of earth being brought to the Seminary. However, there are project entries to remove or eliminate earth. On the other hand, the bricks that were used in the rammed earth wall were brought from the Moncada kiln that the Ribera Patriarch hired exclusively.

With the help of thermography, getting to know the temperature of the material has not been of so much interest to us, as has using the small changes in temperature of the material, to identify the existing modulation. Figure 4 shows two thermography images, where the rammed earth walls can be seen, as well as the gaps for the crossbeams.

In Figure 5, the different courses of the rammed earth wall can be clearly recognized, because in each horizontal joint a discontinuity of temperature is produced. We have superimposed fine white lines to clarify this aspect.

In Figure 6 we can observe a general view of all the elevations of the building and the distribution of the rammed earth wall courses. The height of each rammed earth wall course is 5 Valencian spans (1.13 m) and the thickness is 3.5 spans (0.79 m).

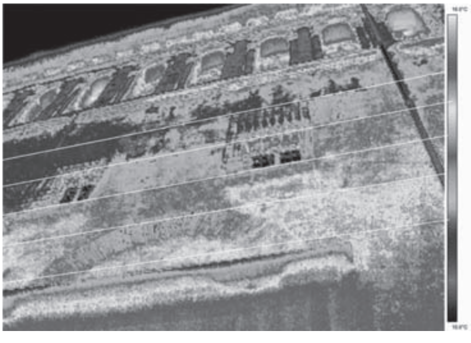

Figure 5. Superimposition of the rammed earth wall courses over a thermographic image.

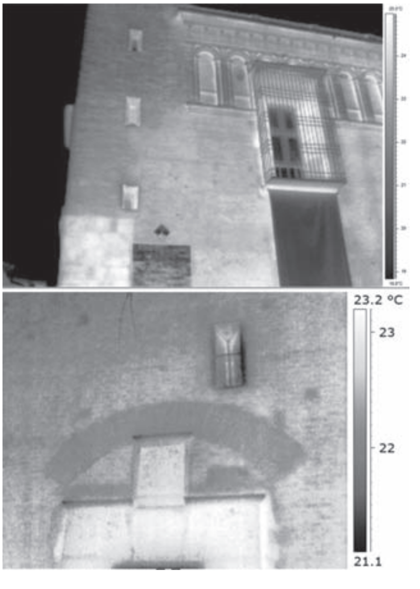

Figure 4. Thermography images of the rammed earth walls.

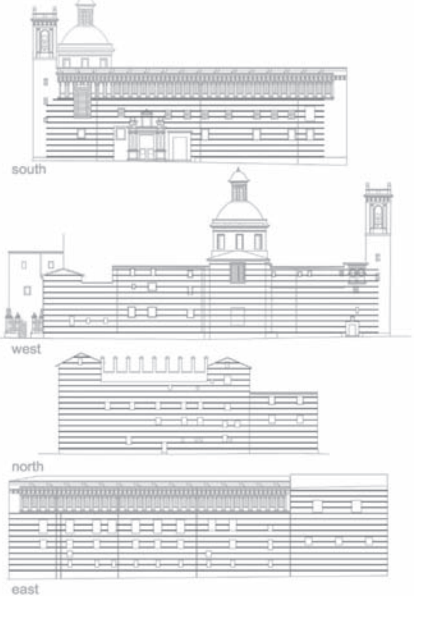

Figure 6. Elevations of the building with rammed earth walls.

Figure 7. Detail of W and S façades.

On the main southern façade, there are a total of 10 rammed earth wall courses (Fig. 7). On the western façade there are up to 12 courses and on the north-eastern corner, there is a height of 15 courses.

Seen from afar, the horizontal joints are appreciated more easily in regards to the vertical joints of the rammed earth walls in all the elevations.

In Figure 7, we have a detail of the western and southern elevations. We have been able to add some vertical joints of the rammed earth walls from the observation of real photographs and those taken with the thermography camera. It is feasible to think that the module would have a proportion of 1 to 3 and as such, the length of the rammed earth wall would be 15 spans (3.40 m). It can be considered that as there are multiple gaps, changes of material, etc., the distribution of the rammed earth walls is not perfectly modulated.

In those areas, where the temperature does not influence and the response of the material is more homogenous, it is more difficult to identify the vertical joints of the rammed earth walls.

In Figure 7 we have included the most relevant fissures, because these are generally produced in the weakest areas. Two large fissures appear to cut the building from the base of the wall to the roof. Also, it is produced approximately at the same distance (15 m) in regards to the SW corner. In both cases, the course of the fissures seeks the vertical joints of the rammed earth walls or the gaps left by the wooden needles, apart from gaps and areas where the inertia of the façade changes.

The southern façade of the College-Seminary has the peculiarity that it was built in various phases. From the contract (Boronat 1904) for the execution of the southern and eastern façades, by the masters Miguel Rodrigo and Antonio Marona, we can extract some interesting texts. For example, it indicates that part of the façade had to be demolished and the rammed earth wall courses later re-done (in the text they are called threads), in order to adjust to the new level imposed by the choir, and in this way, to make the beam fills (of the structural slab) fit in the rammed earth wall. Then, in another item, it specifies that a rammed earth wall would have to be constructed up to the second roof, leaving its "links" for the remaining work. Links or ligatures are understood to be the toothing work, necessary to continue with the project.

In the contract it is stated that the contractor was obliged to re-use the earth of the demolished rammed earth walls or that was available to them within the College-Seminary:

"… and in this way they have to prepare the earth to make the rammed earth wall as required so to be of benefit and as is required remove and dig the earth necessary from that which is within the area of the College-Seminary".

The rammed earth wall constructors were sought and paid by the College-Seminary, but the laborers and the work utensils (excluding the boards which the said institution also supplied) were responsibility of who was doing the job:

"Item XXVII. Both parties have agreed that the rammed earth wall constructors should not have to enter into this work because they have to be provided and paid by the College-Seminary, but that the laborers and the other necessary items such as buckets (as well as the planks and boards that the Seminary has to give) have to be on the account of who does this job".

In the item XXV the masters are obliged to reuse the earth from the demolished wall:

"… when the room is finished they have to demolish the street wall and place the earth and other work utensils within the College-Seminary, in the place that is indicated to them and use the earth in the same works. It will be paid in three thirds as is customary in the works …"

In the Book of Costs of the College-Seminary, between the years 1593 and 1595, there is a great production in the kiln that worked for the project. So, from the detailed entries, it can be established

Figure 8. Superimposition of the rammed earth wall courses over a photograph of the southern façade.

that more than 342,300 thick bricks, 18,300 boards, 34,900 tiles, 30,250 adobe elements and more than 280 pounds in firewood were manufactured. Here are some items:

"1300 large bricks, 1200 bricks, 2150 adobe elements with wood for the portals that there are next to the stairway, 1000 thick bricks" (1593/07/19).

"13,000 thick bricks, 1000small tiles and 1000 boards" (1594/09/21).

"10,000 thick bricks y 4300slim bricks and 300 adobe elements with costs without the firewood" (1595/07/2).

As already mentioned, the execution of the walls that were not brick face was carried out using the rammed earth wall technique. From the receipts of the year 1594 that we have been able to consult in the Archive of the College-Seminary, we have extracted the following information:

The rammed earth wall is 3 and half spans thick (80 cm approximately) and composed from tamped down earth and prismatic ceramic pieces, which could be thick bricks or adobe elements. (Mass of prismatic mud employed in the construction of walls). The constructive process could be:

1. Formwork;
2. Cook;
3. Throw in the earth;
4. Uncover and tamp down;
5. Remove formwork;
6. Make masonry wall;
7. Make crust;
8. Remove the ashes.

In the agreement, in item XXI it establishes:

"… that the buyers make at their cost the crust and mortar of little and great thickness for said project they have to remove the earth to make the rammed earth wall as required for it to be adequate and as required remove and dig the earth that was necessary from that which is within the area of the College-Seminary".

Galarza Tortajada (1996) contributes that the way of manufacturing the Valencian rammed earth wall was identical to that of a masonry wall, with the only difference that, after having tamped down the earth of each layer, whole or half bricks were placed, stretchers and headers, with sufficient separation between them so that on pouring the lime paste and the following layer of earth, they were completely contained within. On compacting the earth they would slide slightly towards the interior of the wall, remaining recessed in regards to the exterior plane.

In regards to the constructive process, the contract stipulates what the masters have to do or who provides the material:

"… give the masters Miguel Rodriguez and Antonio Marona the tools and materials on site, such as lime, sand, bricks, gypsum and wood for the scaffolding, which they have to put up and take down at their cost, leaving the wood for the Seminary and all the carved wood for the beam fills, beams, doors, windows and nails".

"… said constructors will have to put at their cost, ropes, buckets, barrels, carriers … for said project, with all the equipment needed for said project".

For this, the Patriarch promised to pay them 850 pounds, 566 pounds 13 *sueldos* and 4 *dineros* in weekly or monthly payments and the remainder on finishing the project. However, and even though it is not registered in the Book of Costs, Boronat (1904:278) comments that the factory was priced at 921 pounds and 5 *sueldos* although the Patriarch finally rewarded the masters with 1750 pounds an 6 *sueldos*.

4 DISCUSSION

In the work carried out, it has proved relatively easy to obtain the position and height of the different rammed earth wall courses. However, the vertical joints between the two formworks of one same course have been more difficult to determine. In the more heterogeneous areas, with gaps for windows and doors we have located some joints. The same occurs with the gaps of the crossbeams, which have not been able to be observed in all the elevations with the same ease. For a better observation, it is recommended that thermographic images be taken when there are adequate meteorological conditions. With rain, at dusk or at dawn, we can see small temperature differences in the materials.

5 CONCLUSIONS

There is abundant documentation on the Corpus Christi College-Seminary. However, the building's perimeter walls made with rammed earth were constructed in the first years or together with important elements.

First, we have undertaken a constructive analysis based on the cited documentation. The data has been treated in an objective manner and as such we have generated different graphics that have helped us to better understand the constructive process.

We have then analyzed a large number of images taken with the thermography camera, observing subtle horizontal lines and some vertical ones. These lines correspond to the different courses of the rammed earth wall, with its horizontal and vertical joints. In this way, we have been able to determine the dimensions of the module that was used in the building's construction, 5 feet in height, 15 in length and 3.5 thick.

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Rammed-earth construction in Southern Morocco: A reappraisal of the technology

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ABSTRACT: Rammed-earth or pisé wall construction is the most common technique used in constructing load-bearing walls in the vernacular architecture of Southern Morocco. The technique is alive in many rural constructions in the High Atlas and the Pre-Saharan valleys, where a number of other traditional construction systems exist as well, contemporary technologies included. This paper is a part of the scientific research project: *Paisaje y patrimonio en el Sur de Marruecos: Propuesta para el desarrollo de modelos de turismo responsable* (AP/050921/11), granted by the Spanish Agency for International Cooperation and Development, and describes in detail how a rammed-earth wall is built in the Mgoun Valley (Southern slope of the High Atlas, Morocco). Raw materials, tools and the components of the formwork are identified. The number of workmen participating in the construction process and their specific tasks are described, and the time needed from the installation of the formwork to the finishing of the wall is recorded. Finally, the cost of constructing a rammed-earth building is compared to that of constructing with reinforced concrete.

1 INTRODUCTION

A perusal of the literature on the architecture of Southern Morocco must start with the works of Montagne (1930), Laoust (1934) and Terrasse (1938), a scholarly tradition from the first half of the XX Century that may be extended to the research carried out by Jacques Meunié (1962).

These studies, produced in the context of the French Protectorate, contain a wealth of knowledge on vernacular architecture. As far as we know, however, a detailed, step by step description of the rammed-earth construction technique was never made. In the late XX and early XXI Centuries research conducted by a number of scholars focused also on the technique from different venues. The works of Hensens (1986), Huet & Lamazov (1988), Mimó (1996), Rauzier (1998), Naji (2001) and Soriano (2006) offer accurate descriptions of the construction process and its technical elements.

The construction of a rammed-earth wall from start to finish will be described here, as carried out on September 24th, 2011 in Douar Issoumar, a village located 24 Km North of the town of Qal'at Mgouna (Mgoun Valley, Southern slope of the High Atlas). Rammed-earth walls are common in the area: a description of the technique as applied by a local *maalmin* (sing. *maalem*, specialized building worker) is presented here with an emphasis in the description of the materials, tools and tasks of the workmen involved. The components of the formwork, often taken for granted in the literature, are described in detail. The procedures described are still in use in many areas of the High Atlas and Pre-Saharan valleys of Southern Morocco.

2 TERMS, FORMWORK COMPONENTS AND TOOLS

The Arabic word for the rammed-earth technique is *luh* (Arabic for wood plank). In Tamazight, the Berber dialect spoken in the Mgoun Valley, the word *tabut* (also from Arabic) is used for the procedure; a section of *tabut* wall is called *amtay* (*pl. imtayen*). Tamazight terms as reported by the work team observed are given. Mr. Youssef Alami, a local Geological Sciences graduate, was helpful with translation. Transcriptions have been simplified for clarity.

In order to hold the forms in place during ramming a number of auxiliary elements are necessary: a full gear is shown in Figure 1 and described in the following pages. All drawings, descriptions and measurements reported here were documented on site.

2.1 *The components of the formwork*

Rammed-earth or pisé walls are constructed by ramming earth between two parallel forms that

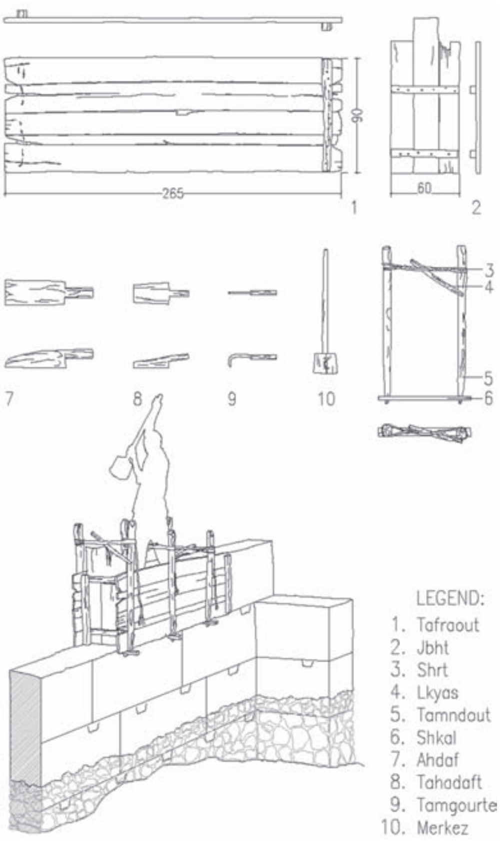

Figure 1. Terms, formwork components and tools.

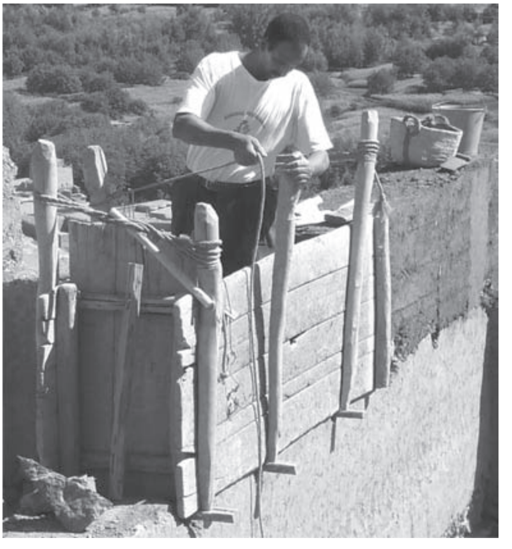

Figure 2. Mr. Ourohou, the *maalem*, installing the formwork.

are subsequently removed, revealing a completed section of hard earth wall. Section, or wall section, is that portion of the wall formed in any one completely filled form which has been rammed to capacity, and the form removed.

Form (panel, board) (*tafraout*, pl. *tifraouine*): Wooden board of the formwork. It is made up of four or five planks of poplar wood (the same wood, abundant in the Mgoun Valley, is used for the rest of the components). Planks are ca. 4 cm thick and 8 to 22 cm in height; they are horizontally placed and held together by two bonding strips (*ighil n' tfraout*) placed one on each side of the panel, 8 to 11 cm from the ends. Each form has thus only one bonding strip on each face, which allows turning them over during the construction process in order to avoid warping by repeated use. Bonding strips, 6 × 7 cm in section, are the same height as the forms. They are nailed to the planks with metallic nails. Planks are deliberately placed a few millimeters apart from one another in order to facilitate a slight swelling and moving from being in contact with moist earth.

Forms have a small, 10 × 4 cm opening located roughly at their center that is used as a grip: a single worker can thus handle it. Additionally, a few beveled cuts are made at both ends of some of the planks to allow two workers to handle the form, one on each end, and also to allow the use of ropes to shift the form, as explained bellow (section 2.3.). Forms measure 265 × 90 cm. Due to the horizontal and vertical overlapping necessary during the ramming process, wall sections of ca. 170 × 85 cm can be built at a time.

End stop or bulkhead (*jbht*, pl. *jbahis*): The end stop or bulkhead is made up by three wooden planks 4 cm thick, vertically arranged and hold together by horizontal bonding strips 5 × 7 cm in section. These bonding strips are as long as the width of three planks they hold together. The bulkhead is 120 cm high and 60 cm wide. Its central plank protrudes over the other two to facilitate handling during installation and removal. The width of the bulkhead sets the thickness of the walls that can be built with it. Walls can be of varying thickness: fortified farms (*tighremt*) may be four-storeys high and have walls of well over 1 m. thick. One full gear consists of two bulkheads, since the execution of the first section of a wall in a given course necessarily involves closing the two ends of the framework.

Stiffback (*tamndout*, pl. *timndouine*): Wooden rib used to hold the forms in place during the process of ramming to ensure that they do not open outwards. A stiffback is 132 to 159 cm high and has a circular section 4 to 6 cm in diameter. It is shaped with a sharp end that fits into a temporary stay and one of its sides is flattened for better contact with the form.

Stiffbacks are bigger than the forms because opposite stiffbacks must be tied to one another, a slot made at the top of each one facilitating this operation. Three pairs of stiffbacks are necessary to hold in place forms during ramming.

Temporary stays (*shkal*, pl. *lashkal*): Wooden stakes, placed on the bottom wall previously built, serve as temporary stays to support the forms during ramming.

Fig-tree wood is used at times for them instead of poplar because it is easy to drill. Stays are ca. 95 cm long (the appropriate length for the 60 cm depth wall considered here) and have a rectangular section of 8 × 4 cm. On both ends, 4 × 6 cm openings allow the stiffbacks to fit into them. Stays are extracted once ramming is finished and re-used.

Spacer (*lkyas*, pl. *lkyassat*, ar.): A wooden spacer is placed between the two opposite panels of the formwork during ramming in order to avoid their falling inwards under the pressure exerted by the stiffbacks. They have a circular section of 3 to 4 cm and are slightly longer than the end stop or bulkhead to facilitate a tight adjustment.

Rope (*shrt*, pl. *shrati*): Its role is to tie in place each pair of stiffbacks.

Chock (*lkyas*, pl. *lkyassat*, ar.): A chock is used to tighten the rope that ties each pair of stiffbacks. Being very similar in length and shape to the spacer, both are eventually interchangeable.

The set of stiffbacks, stays, spacers, ropes and chocks just described make up the frame that embraces and sets the forms in place.

2.2 *Specific tools*

A number of tools are specific to ramming and finishing pisé walls:

Rammer (*merkez*): Tool to ram the mixture. The head, 18 cm long and 20 cm in diameter, is attached to a 90 cm long arm.

Hand-rammer (*ahdaf*, pl. *ihadafine*): Tool with a semi-circular shape, provided with a handle, used for tapping the top surface of the wall, once the formwork has been removed.

Small hand-rammer (*tahadaft*, pl. *tihadafine*): Tool similar to the hand-ram but smaller, used for tapping the side surfaces of the wall, once the formwork removed.

Scraper (*tamgourte*, pl. *timgrine*): Metallic tool provided with a wooden handle used to brush and smooth the walls, eliminating imperfections, once the formwork has been removed.

Basket (*takfift*, pl. *tikfaf*): A basket is used to haul the earth mixture. It had a double rope sewn to its outer surface that formed the handles and lent it some rigidity.

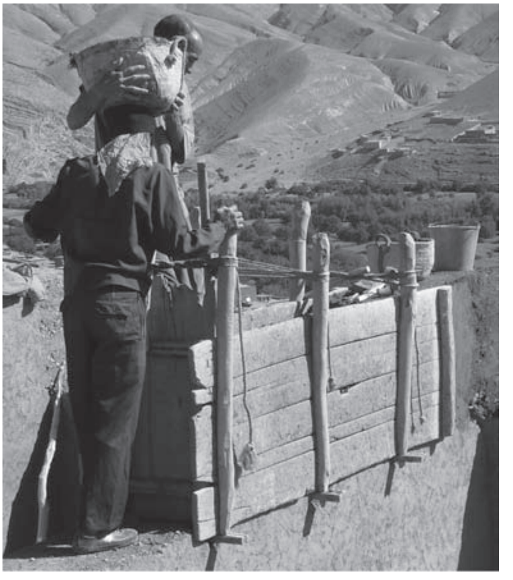

Figure 3. Hauling and pouring the earth.

3 THE CONSTRUCTION PROCESS

The construction process that follows, shown in Figure 4, was documented at the end of the summer of 2011. It was a sunny, mild day. The soil was dry.

The first step in building a rammed-earth wall is setting the foundations. The case documented was located on a rocky slope. The first operation was excavating a foundation trench that reached the bedrock, on which a stone basement was built. The basement had the thickness of the wall and was carefully leveled.

The formwork was installed on this basement to build the first course of wall sections. It was filled up to a third of its capacity with stones and earth mortar, the rest was filled with earth poured by layers and then compacted. Both the stone basement and the first layer of stones are intended to protect the walls against humidity by capillarity coming from the substrate as well as from surface running water.

The building of the first course of wall sections starts at one of the corners and requires the use of a formwork with two bulkheads. Occasionally one of the ends of the first wall section is placed protruding outside the limit of the building, both to protect the corner and as a support for an eventual outer wall.

The second course is built two or three days later, once the first one has dried to satisfaction of the *maalem*. Construction starts also at the

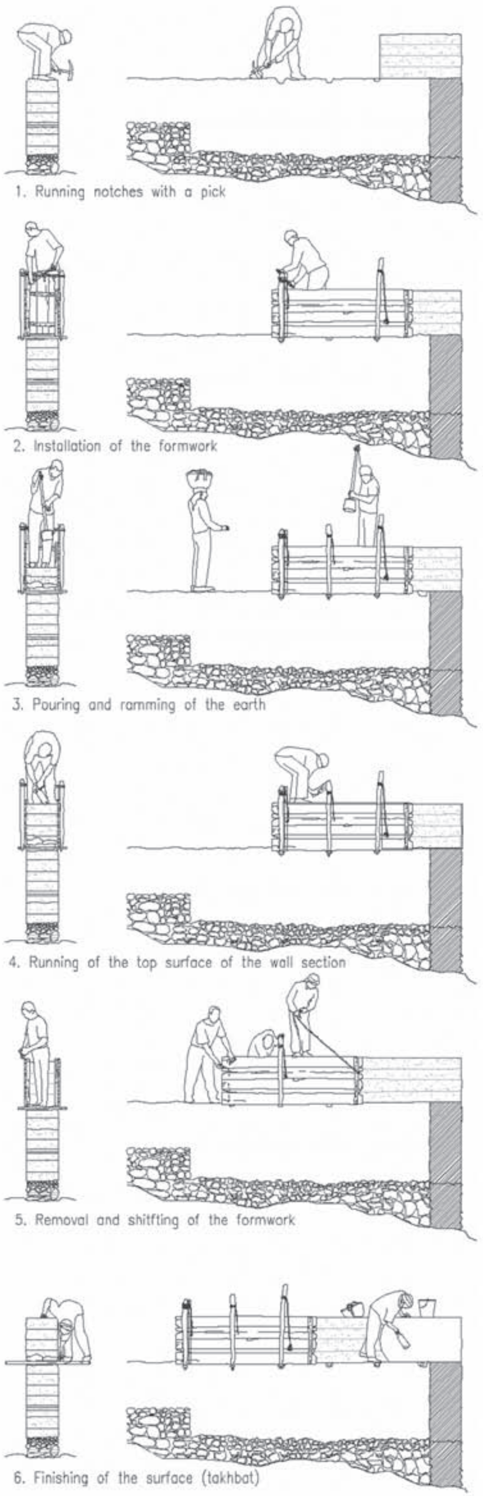

Figure 4. Construction process.

corner of the building. When the first wall section is finished the formwork is overlapped on it up to a third of the length of the form.

3.1 *Installation of the formwork*

Installation of the formwork starts by running a transversal notch on the top surface of the underlaying wall section to place the temporary stays that will support the forms. This operation is performed by the team master (*maalem*) who runs notches spaced ca. 90 cm with a pick. Two or three temporary stays are placed in them. In the case observed, the first one was placed in the hole left by the temporary stay used to build the previous, adjoining wall section; a second one was placed at the other end, the third would be placed later. Stays are placed some 5 cm below the top surface of the wall section on which they rest to allow the vertical overlapping of the form on the wall section previously built. Lateral overlapping of the forms with the built sections may reach 75 cm.

Two pairs of stiffbacks are put in place now, one embracing the adjoining finished section, another embracing the bulkhead of the section being built. They are tied up with ropes tightened by a chock (Fig. 2).

The forms are cursorily leveled with a plummet placed at the inner joint of the forms and the bulkhead. It is now that the third temporary stay is put in place, underneath the forms, and a third pair of stiffbacks inserted in its ends. Three spacers are placed to get a consistent separation of the forms. A final adjustment and leveling and the formwork is installed. This operation is carried out with the help of a plummet, no other measuring or leveling tool is used along the process. Two flat stones are placed on the temporary stays to facilitate their removal once ramming is finished.

3.2 *Preparation, transportation, pouring and ramming of the earth*

Preparation of the earth mixture started three days prior to ramming by digging a ditch (*aghji*), about 1 m. in diameter and 30 cm deep. The ditch is usually on site, located at a higher location in order to facilitate the hauling of the earth. Water lifted from nearby water-channels is transported in metallic containers and added to the earth. The earth mixture should not contain organic matter and its clay content should not be too high, otherwise retraction cracks may appear. When earth has an undesirable content of clay sand or gravel is added to the mixture.

When the work team is ready for ramming, one of the workmen (the *bou aghji* or "the one of the ditch") opens a little trench on the side of the hole with the help of a pickax and starts loading, with a hoe, the mixture in a basket (*takfift*) that another workman (the *bou takfift* or "the one of the basket") will haul to the construction site (Fig. 3). The moist mixture is then poured into the formwork in layers ca. 20 cm thick and rammer. Ramming is done rhythmically and is particularly heavy in those areas close to the forms (Fig. 5a).

When in the process of ramming the presence of stiffbacks and ropes make the task difficult, stiffbacks are twisted and inclined towards one of the sides. This motion is not accidental, but made possible by design: the sharp, pointy end of a round stiffback is inserted in the rectangular hole of the stay, which allows the motion of the former. As ramming progresses the inner spacers are removed since they are unnecessary once the formwork starts to fill-up.

Hauling, pouring and ramming in layers as described are repeated until the filling reaches the top of the formwork. The top surface of the wall section thus built is then hand-rammed, or rather tapped, with the help of a hand-rammer (Fig. 5b).

3.3 *Removal and shifting of the formwork*

Before the forms of a rammed section are removed, the first temporary stay of the next section is put in place, at the farthest end. The two pairs of stiffbacks located at the ends of the section are then removed, the forms are now loose and they are shifted until they are supported by the stay previously installed. The removal and shifting of the forms is carried out with the help of the ropes also used to tighten the stiffbacks. Ropes are inserted in beveled cuts located at the end of the forms (see above section 1.1.). Once the forms are in the intended position, the process of setting up the formwork is repeated and another section of wall is rammed.

3.4 *Finishing of the surface (takhbat)*

As the team master (*maalem*) rams a section, usually another specialized workman (the *bou takhbat* or "the one of the *takhbat*") undertakes the finishing of the sides of the previous section (Fig. 5c).

The first step is moisturizing the surface with a brush, just before applying by hand on selected areas a thin layer of earth partially moist that will cover the holes of the stays and other imperfections. A scraper is used to prepare the surface. A wet, small hand-rammer is used to finish the wall, which means tapping and making circular movements on the surface until it is perfectly smooth, with no evidence of the planks of the form or the joints with the two neighboring sections (one at the bottom, another one on a side). Finishing hides the traces of the modular nature of the building process and produces a continuous surface that protects the wall from erosion, improving its visual aspect as well.

The process described is carried out without scaffolding: the workman supports himself on small poplar beams that he inserts in the holes of the stays once they have been removed.

Figure 5. Ramming and finishing a wall section. a. ramming b. hand-ramming c. finishing (*takhbat*).

4 MANPOWER, EXECUTION TIME AND COST

The execution of the rammed wall documented was carried out by four workmen, each one with a specific task. The *maalem* or master of the team in charge of leading the construction process was Mr. Ahmed Ourohou. Mr. Said Ait Akka (the *bou takhbat*) was in charge of finishing the walls. Mr. Brahim Oukhom (the *bou takfift*) was in charge of hauling the earth from a nearby ditch (Fig. 6). A third workman (the *bou aghji*) was in charge of extracting the earth from the ditch. On occasion some member of the owner's family joined the team.

Construction of a wall section took 35 minutes. This included installation and removal of the formwork (10 minutes), pouring and ramming the mixture (20 minutes), and tapping the top surface of the wall (5 minutes). The time needed to smooth and tap the side faces of a finished wall is not included, since this operation was performed by one of the workers on a completed wall section as a new one was rammed. In a working day, workers may finish anything between eight and twelve sections, depending on the height of its location. Rammed-earth construction takes place between march and november; work stops before the rainy season.

Building costs of one rammed-earth wall section in the Mgoun Valley in september 2011 is estimated at 70 DH/7 €. The cost of materials (stone, earth mixture and water) is not significant since all of them were procured on site, as is the usual practice. Manpower makes up the bulk of the building costs: a team master (*maalem*) earns ca. 80 DH/8 € per day, a workman rarely makes more than 60 DH/6 €. In the Mgoun Valley, a two storey, 200 square meters rammed-earth building on a masonry basement with poplar and reed ceilings has a building cost (finishing, carpentry and installations included) of 150,000 Dh/15,000 €. A building that size built on a reinforced concrete structure with concrete block walls would cost four times that amount.

Figure 6. Forefront: Mr. Oukhom hauling the earth in a basket. Bottom: workman in the ditch.

Rammed-earth, as practiced in the cultural context discussed here, is an in situ construction method that demands a small amount of site and logistics planning. Materials are usually procured on site. The materials necessary to build a reinforced concrete building (concrete and steel) involve instead high environmental and economic costs since they must be transported over long distances in this region.

5 CONCLUSIONS

The exercise of researching and describing rammed-earth technology in the Mgoun Valley was not intended to be an exercise in looking at the past, but rather a way of evaluating the fitness of a vernacular technology for the purposes of contemporary building. The widespread use of reinforced concrete endangers the survival of a technique tested for generations and perfectly adapted to a set of climatic and social constraints. The more precise and comprehensive the knowledge we have on it, the bigger the chances of identifying its strengths and potential. Local communities know its advantages and limitations. In use for centuries, preserved virtually without changes, rammed-earth building is still in use in contemporary lodging in the Mgoun Valley. For how long is not easy to say: new roads have been built in the area in the past few years, making easier the transportation of industrially produced building materials. Still, from the environmental, social, technical and economic points of view rammed-earth has proved to be an un-expensive, flexible building procedure when compared to reinforced concrete technology.

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Analysis parameters for systematization of rammed earth walls in Granada and Almería (Andalucía, Spain)

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ABSTRACT: The latest research about building techniques in the provinces of Granada and Almería (Spain) have allowed, not only to propose some typologies and chronologies, but also to systematize some parameters for their study. These parameters are related to the different types of shuttering and also with the several kinds of documented rammed earth, depending on its materials or its distribution inside the shuttering. The studied elements have been mostly medieval fortifications, but gradually, modern civil buildings have also been added. The aim of the research is to use these parameter and criteria to study deeply the knowledge of building techniques, giving them a historical significance and contributing at the same time to a better protection and preservation of heritage.

1 PREMISA

En los últimos años se han generalizado estudios sobre fábricas antiguas de edificios históricos (Quirós Castillo 2002, 2008a, b, Azuar Ruiz 1995, 2005). El desarrollo del análisis de estas construcciones, especialmente a partir de la Arqueología de la Arquitectura, ha permitido mejorar nuestro conocimiento de los inmuebles, garantizando no solo unas mejores condiciones y criterios de intervención cuando el proceso ha sido correcto, sino también generando información científica de carácter histórico y técnico (Tabales Rodríguez 2000, Graciani García 2008, 2009a, b, Gurriarán Daza. 2002, 2008). Este conocimiento tiene una importante traslación en el ámbito de la interpretación social y económica y permite a su vez trascender el edificio para entender mejor las sociedades que construyeron, usaron y transformaron esas estructuras.

El presente trabajo se inserta dentro de una trayectoria común de los dos autores, a caballo entre la Arqueología y la Historia de la Construcción, una visión interdisciplinar y complementaria que está resultando especialmente fructífera y que esperamos nos permita llegar a nuevos e interesantes resultados. De forma conjunta o por separado hemos realizado un intento de sistematización y datación de las técnicas constructivas (especialmente las andalusíes) de las provincias de Granada y Almería y hemos llevado a cabo un inventariado y descripción de muchas de las estructuras construidas, fundamentalmente las fortificaciones (*vid*. Martín García, Martín Civantos). La abundante información y experiencia acumulada en los últimos años, permiten realizar una primera aproximación en este sentido de cara al establecimiento de una seriación tipológica y a la obtención de cronologías relativas y absolutas, esenciales para el conocimiento histórico de los yacimientos y de los propios edificios.

La metodología de estudio, enmarcada fundamentalmente dentro de la Arqueología de la Arquitectura, ha sufrido un importante desarrollo que permite en la actualidad la realización de análisis comparativos de carácter regional capaces de ofrecer nuevas perspectivas. Ya en su momento avanzamos una propuesta teórica y metodológica para llevar a cabo este estudio aprovechando el potencial histórico de la construcción como fuente de información (Martin Civantos 2009a). Asumimos, además las propuestas de G.P. Brogiolo (2007) respecto a la necesidad de pasar de una Arqueología de la Arquitectura pegada al monumento a una visión más amplia y compleja de la disciplina y de la noción del registro. Pero para poder analizar este potencial es necesario a su vez conocer bien los aspectos puramente formales o técnicos.

No es esta una tarea fácil y requiere además de una recogida sistemática de datos que posteriormente han de ponerse en común, confrontándolos a través del uso de parámetros diversos.

El volumen construido conservado es enorme. Es cierto que una buena parte de esos restos se encuentran enterrados y que carecen de un carácter monumental.

Es evidente que los edificios son elementos cuatridimensionales, es decir, ocupan un lugar en el espacio, pero igualmente perduran en el tiempo, con la misma o con otra funcionalidad, o incluso tras su abandono; sufren, por tanto, modificaciones en su diseño original en razón de muy distintas circunstancias. Pueden ser dañados intencionadamente o no y, en consecuencia, deben ser restaurados o parcialmente reconstruidos; puede igualmente cambiar su uso o la formación social que los ocupa y deberán entonces ser adaptados o rehabilitados. No obstante, en cualquier caso, desde su planteamiento original hasta la última de sus modificaciones o su destrucción o abandono, el edificio responde siempre a una lógica; es, por tanto, comprensible a través de las huellas dejadas en sus distintas fases. En este sentido es fundamental la aplicación del método estratigráfico, sobre el que no vamos a insistir, pero también el estudio en horizontal de las plantas de los edificios para intentar comprender su lógica y su funcionalidad.

Así pues, hay dos elementos fundamentales dentro del estudio arqueológico de la construcción: uno la cronología, otro su significación social en tanto en cuanto que forma parte esencial de la cultura material que puede, por tanto, proporcionarnos información de tipo histórico. Para cualquiera de los dos es necesario, como paso previo, conocer bien las técnicas, materiales y tipologías constructivas, pero también de las plantas y tipos constructivos, así como de los aspectos formales o simbólicos. Es más, es necesario comprender el contexto histórico y territorial en el sentido complejo al que se refería GP. Brogiolo (2007).

Como ya hemos dicho, tradicionalmente las técnicas constructivas en al-Andalus han despertado un cierto interés. Sin embargo, demasiado a menudo se ha dado por supuesto a qué nos estábamos refiriendo cuando hablábamos de mamposterías o tapiales o simplemente no se ha precisado más sobre el tipo de tapial o aparejo. La falta de sistematización y de unidad de criterios dificulta en muchas ocasiones saber a qué aludimos cuando describimos una determinada técnica e impide las más de las veces poder establecer comparaciones.

Nuestra propuesta pasa, primero, por la unificación de los criterios de análisis de estas técnicas. Más allá de la metodología y las técnicas propias de la Arqueología de la Arquitectura, especialmente la aplicación del método estratigráfico al estudio de los edificios históricos, deberíamos fijar, por ejemplo, aquellos elementos que son comunes a la construcción en tapial o en mampostería para identificar posteriormente las diferencias tipológicas y agruparlas según categorías que nos permitan establecer una clasificación más o menos general, al igual que se hace en otros ámbitos de la investigación arqueológica como, por ejemplo, los estudios cerámicos.

Para ello es necesario también unificar la nomenclatura de las técnicas constructivas documentadas en al-Andalus, de manera que podamos hacer análisis comparativos de amplio radio y comprender así la lógica que rige la construcción en este espacio histórico.

2 PROPUESTA METODOLÓGICA Y DE INTERVENCIÓN

Ya en su momento propusimos una primera clasificación tipológica que sigue siendo válida para el ámbito granadino y almeriense (Martín Civantos 2004, 2009a, b, c), aunque ha de ir ampliándose con nuevas variantes, sobre todo desde el momento en el que ampliamos el arco cronológico a la época moderna. Recientemente se han podido identificar interesantes ejemplos de tapia valenciana en la ciudad de Guadix, construidas con toda seguridad en el s. XVII (Bravo del Fresno & Sánchez Toro 2011). Respecto al tapial, la clasificación a partir de la elaborada en su momento es la siguiente:

1. Tapial de tierra.
2. Tapial hormigonado.
3. Tapial de cal y cantos o de calicantos.
4. Tapial calicastrado o de cal y costra.
5. Tapial calicastrado de cal y cantos.
6. Tapia real.
7. Tapia valenciana.

Como ya enunciamos, las distintas variantes se producen a partir de los materiales empleados en la ejecución de las tapias y la distribución dentro de ellas. Estas variantes pueden ser muchas en teoría, pero pueden agruparse para generar tipologías como categorías generales en las que poder encuadrar variantes locales o con un significado temporal. En la provincia de Granada, por ejemplo, tapiales de cal y cantos con piedras grandes y otros con piezas más pequeñas que lo asemejan a un hormigón. Los hay con cantos de río y con piedras con aristas vivas o con lajas de esquistos. Lo mismo sucede en el caso de los tapiales calicastrados, donde encontramos diferencias entre el grosor de las tongadas o de la costra, la presencia en algunos casos de una proporción variable de cal en el núcleo, la inclusión de algunas piedras de mediano tamaño o las diferencias en el mortero.

En esta casuística, es necesario tener en cuenta obviamente el contexto geológico en el que nos encontremos, para determinar si las diferencias entre unas fábricas u otras se corresponden simplemente a cambios a nivel litológico o edafológico local o si, por el contrario, se trata de opciones conscientes y, por tanto, responden a técnicas y saberes específicos de un área o un periodo determinado o incluso a estrategias constructivas concretas como, por ejemplo, las emanadas del poder.

Sin embargo, no son estas las únicas variantes posibles. También hay que tener en cuenta otras que son fundamentales como las formas de encofrar. Existen diferencias en el módulo, tanto en altura como en longitud. Hay encofrados corridos y en cajones. Hay igualmente otras variables interesantes, como la sección de las agujas o la forma de sujeción al cajón inferior o a los tableros, o la presencia de otro tipo de elementos como los costales interiores para alternar la posición de los tableros u otras formas de sujeción como las cruces de San Andrés (Martín García 2005).

Del mismo modo, es importante observar las formas de cimentación, especialmente los zócalos sobre los que en muchas ocasiones se levanta el tapial. En este caso, las mamposterías y sus distintas variantes nos ayudarán a discriminar y completar las observaciones sobre el propio tapial.

Estos serían, en líneas generales, los principales puntos a tener en cuenta en el estudio de los tapiales desde el punto de vista de las técnicas y los materiales (además de las analíticas de laboratorio). Pero además, es necesario tener en cuenta el contexto constructivo, estratigráfico, en incluso territorial en el que se sitúan las fábricas que estudiamos. Esto complica el estudio, saliendo de la propia fábrica para, por una parte, reconocer en planta su distribución espacial dentro del yacimiento/edificio, pero también la secuencia constructiva y las superposiciones en el proceso constructivo a lo largo de su historia. Es más, se hace necesario salir del propio yacimiento/edificio para observar el contexto constructivo a nivel local y regional, estableciendo las tipologías y las tendencias generales en cada ámbito en función de las variables históricas, geográficas o culturales.

En nuestro caso, una vez establecidas de manera general las tipologías y hecha la propuesta de sistematización y seriación tipológica (Martín Civantos 2004, 2009a,b,c), comenzamos un doble camino: Por una parte la realización de análisis comparativos entre técnicas y materiales constructivos de conjuntos homogéneos de fortificaciones medievales o de otra tipología de edificaciones históricas (Martín Civantos 2001, Martín García & Martín Civantos 2009, 2011). Por otra, el análisis de casos particulares en detalle a partir de la intervención en yacimientos o edificios particulares, en muchos casos aún inéditos o en fase de desarrollo como la alcazaba de Guadix o el castillo de Íllora (Bolado Castaño ined., Bravo del Fresno ined, Gómez Bachiller ined, Pozo Vilá ined, Sánchez Barbero ined). En éstos es posible desarrollar una metodología más precisa y meticulosa para la recogida de datos sistemáticos sobre los materiales, su distribución y proporción, técnicas de encofrado, cimentaciones, etc. Estos datos pueden ir siendo elaborados y comparados a su vez a una menor escala y, al mismo tiempo, una vez que sean suficientes, a escala regional.

Para ello es necesario recurrir a sistemas de información que permitan no solo gestionar los datos alfanuméricos, sino también los espaciales. El concurso de las nuevas tecnologías puede ser especialmente útil, tanto Sistemas de Gestión de Bases de Datos y Sistemas de Información Geográfica, como las técnicas de documentación gráfica de alta precisión actuales (fotogrametría digital y escáner 3D). En cualquier caso, la utilización de estas nuevas herramientas ha de adaptarse siempre a las necesidades y posibilidades de cada caso, pero siempre dentro de una estrategia de investigación coherente y con perspectivas a medio plazo.

Ese es nuestro objetivo y nuestro planteamiento desde hace algunos años. Para tal fin hemos diseñado una base de datos compleja que pone en relación las técnicas constructivas (también el tapial), con el resto del registro arqueológico, incluidas las secuencias estratigráficas, catalogación de edificios históricos y elementos urbanos, contextualización del yacimiento, relación con el entorno.

Estos campos representan los principales parámetros de análisis a tener en cuenta en el estudio de los tapiales, partiendo siempre de las consideraciones previas ya expresadas y, sobre todo, el contexto en el que se ubican las fábricas (constructivo, estratigráfico y territorial).

El siguiente listado reproduce de manera sintética el conjunto de tablas y campos correspondientes al registro y documentación del tapial:

En los casos de Granada y Almería los resultados comienzan a ser visibles en la sistematización y propuesta cronotipológica de las técnicas constructivas ya mencionada. Así, por ejemplo, la identificación del programa constructivo en tapial de cal y cantos en época zirí (s. XI) parece cada vez más confirmada. Sin embargo, es seguro que esta fábrica no se emplea exclusivamente en este momento, sino que tiene al menos algunas pervivencias con variantes en la composición o los encofrados. Para poder detectarlas es necesario

Tabla 1. Técnica constructiva.

Campos
id_técnica_constructiva
yacimiento_id_yacimiento
unidad_estratigrafica_id_unidadestratigráfica
nombre
anterior_a_técnica
posterior_a_técnica
primera_fase_constatada
ultima_fase_constatada

Tabla 2. Posición_estratigráfica_técnicas_ constructivas.

Campos
id_posición_estratigráfica
técnica_constructiva_id_técnica_constructiva
yacimiento_id_yacimiento
posición_estratigráfica

Tabla 3. Tapial.

Campos
Id_tapial
yacimiento_id_yacimiento
unidad_estratigráfica_id_unidad_estratigráfica
nombre
técnica_constructiva_id_técnica_constructiva
homogéneo
núcleo
costra
número_mampuestos_por_metro_cúbico
dimensiones_regulares_mampuestos
altura_media_mampuestos
longitud_media_mampuestos
presencia_de_tongadas
tongadas_regulares
altura_media_tongadas
disposición_en_tongadas_de_mampuestos
tipo_de_encofrado
altura_cajón
longitud_cajón
anchura_cajón
costales_interiores
material_agujas
altura_agujas
anchura_agujas
longitud_agujas
formaagujas
numero_agujas_por_cajón
atraviesan_todo_el_cajón
sujeción
junta_de_los_cajones
acabado_de_agujas_y_mechinales
acabado_de_costales_interiores
cruces_de_San_Andrés
otros_elementos_de_sujeción
encadenado
técnica_encadenado(técnica_constructiva_ id_técnica_constructiva)
enlucido_id_enlucido
tipo_cimentación
mamposteria_id_mamposteria
andamiaje_id_andamiaje
descripcion/observaciones

llevar a cabo una recogida de datos que tenga en cuenta estas características y que sea lo suficientemente representativa y precisa como para poder afinar en las variantes constructivas de una misma tipología. Lo mismo podríamos decir del tapial calicastrado, cuya datación no parece en ningún caso anterior al s. XII, pero que posteriormente tiene una larga pervivencia no solo en época andalusí, sino en la arquitectura mudéjar hasta una fecha difícil de determinar pero que alcanzaría, al menos, el s. XVIII. En este caso,

Tabla 4. De relación con mortero: tapial_has_mortero.

Campos
tapial_id_tapial
mortero_id_mortero

Tabla 5. De relación con sillería: tapial_has_silleria/sillarejo.

Campos
tapial_id_tapial
silleria/sillarejo_id_silleria/sillarejo

Tabla 6. De relación con acabado superficial: tapial_has_acabado superficial.

Campos
tapial_id_tapial
acabado_superficial_id_acabado_superficial

Tabla 7. De relación con bibliografía: tapial_has_bibliografia.

Campos
tapial_id_tapial
bibliografia_id_bibliografia

Tabla 8. De relación con persona responsable: tapial_has_persona.

Campos
tapial_id_tapial
persona_id_persona

Tabla 9. De relación con proyecto: tapial_has_proyecto.

Campos
tapial_id_tapial
proyecto_id_proyecto

las variantes locales o temporales son igualmente importantes y no siempre fácilmente reconocibles. Hemos podido apreciar, por ejemplo, diferencias en el grosor de las tongadas, incluso dentro de un mismo edificio, que indicarían la presencia de fábricas diferentes correspondientes a momentos constructivos distintos. Lo mismo podría decirse de las formas de encofrado, que cambian visiblemente también con un sentido cronológico. En este sentido, el estudio de la cerca exterior del Albayzín ha supuesto un avance en cuanto el conocimiento de las técnicas de sujeción de las agujas y los tableros a través del uso de cuerdas y cuñas, que parece testimoniado solamente a partir de época nazarí.

A partir de aquí proponemos la recogida de datos de campo, a los que se pueden añadir otros elementos procedentes de los análisis de laboratorio. En cualquier caso, pensamos que es esencial no perder de vista el sentido de la superposición y evolución del edificio, los aspectos estructurales y funcionales y, sobre todo, la significación histórica de las técnicas y materiales constructivos en su contexto, como parte de la cultura material de las sociedades del pasado.

En forma de fortificaciones, casas, lugares de trabajo, etc., la construcción es imprescindible. Como tal, ocupa un lugar esencial en la Historia social y económica. Como parte de nuestro patrimonio, tenemos una responsabilidad en el proceso de conocimiento, en el rigor científico en la teoría, la metodología y las técnicas aplicadas para ello y en los procesos de intervención, recuperación y protección del mismo.

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Rammed earth construction in El Rincón de Ademuz (Spain)

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ABSTRACT: Among the most interesting manifestations of vernacular architecture in the parish of El Rincón de Ademuz (Valencia, Spain), we often find rammed earth walls with gypsum supplements like reinforced joints, brencas (undulated reinforcement), rafas (embedded pilasters), very skillfully built in this parish, among other interesting construction variants. Of special interest is the fact that rammed earth and gypsum walls are not usually employed in the area as structural walls for bearing frameworks and roofs but only as outer walls placed between structural gypsum pillars, built into the wall. This article will analyze the presence, built substance and variants of rammed earth walls found in the parish, and their general state of conservation, their most common pathologies and alternatives for rebuilding and repairing them, taking into account the technical and aesthetic difficulties arising from the presence of the gypsum reinforcement.

1 FOREWORD

El Rincón de Ademuz is a parish in the province of Valencia (Spain) that constitutes an enclave isolated from the rest of the province, situated between the provinces of Cuenca and Teruel, that is, between the autonomous communities of Castilla La Mancha and Aragón. It has been historically linked to Valencia since the time of the Reconquista, in 1238, although from a geographic, geological, social and other points of view it could be associated with the parish of Bajo Aragón in the province of Teruel.

This parish, surrounded by mountains and quite isolated from contact with the outside world until recent times, has a peculiar architecture based on the use of gypsum as the main binder to make walls, pillars, frameworks, roofs, built-in furniture, etc. (Mileto & Vegas 2008, 174) The terrible depopulation of the parish due to mass emigration in the 20th century has led, in compensation, to the conservation of a great deal of its original vernacular architecture intact.

2 TYPES OF RAMMED EARTH CONSTRUCTION IN THE PARISH

Rammed earth seems to have been one of the oldest techniques used in the area, according to the testimony of the local people and its presence in the oldest buildings in the area. It can be found in different places in the parish, both in the settlements near the fertile plains around the Rivers Turia and Ebrón (Torrebaja, Torrealta, Val de la Sabina, etc.), and in higher or more mountainous areas, like the towns of Ademuz and Castielfabib, and the hamlets of Val de la Sabina, Sesga, and others). Below, there follows a description of the variants that exist in the parish and their peculiarities.

2.1 *The rammed earth wall*

Like in most of the walls in the area, it stands on a masonry socle between two structural gypsum buttresses that bear a coping girder on which the roof is laid, both at the ridgepole and the lower part of the hip. The inevitable presence of the structural buttresses (Vegas et al., 2012) leaving the rammed earth wall free from any structural function is characteristic of the area in most cases. Usually about 25 cm thick, the only function the wall fulfils is to encompass or circumscribe the building.

In these cases, the side walls are built on the same masonry socle and the rammed earth wall is tiered to follow the slope of the roof, but the coping acquires its sloping shape by completing the wall with masonry fabric. It is not commonly found except in outhouses in the area of Los Pajares in the town of Torrebaja, which runs parallel to the River Turia valley. The plasticity of the clay in this area is ideal for building rammed earth walls without needing to mix it with mineral degreasing agents of any kind.

2.2 *The rammed earth wall with reinforced joints*

This is a wall with identical characteristics to the above, with the horizontal and vertical joints

Figure 1. Simple rammed earth wall at Torrebaja standing on a masonry socle between two structural gypsum buttresses that bear a coping girder on which the roof is laid. The presence of the structural buttresses leaves the rammed earth wall free from any structural function (Vegas & Mileto).

reinforced with gypsum, mainly to protect the joints between the modules of the wall, which tend to be the weakest points, from atmospheric agents.

The works comprise the application of a 1- or 2-cm layer of gypsum at the bottom of the formwork, on the top of the course below and another layer of the same thickness on the side of the adjacent already built module of the wall. The modules are built in this fashion to make a wall with mortar joints that looks like a fabric of large mud ashlars. The L-shaped gypsum corners are usually slightly bevelled with a thicker coat of gypsum. It is commonly found in places in the valley of the River Turia, such as Torrebaja, Torrealta and Mas de Jacinto, and numerous examples can be found in the neighbouring province of Teruel.

2.3 *The rammed earth wall with brencas or undulated reinforcement*

We find the rammed earth wall with *brencas* when the horizontal reinforcement joints are thicker and have a characteristic curved shape. This is the commonest kind of wall in the whole area, more common than any other similar sort of construction. The *brencas*, made of gypsum, which is the main binder in almost all the building elements in the parish, are indeed reinforcements with an undulating shape at the base of the modules of the wall. They are added at the bottom of the formwork better to protect the joints, the consistency and the distribution of the weight and acquire their characteristic zigzag shape as a result of the compaction of the earth above. In the simplest cases, the reinforced earth walls are built without vertical reinforcement joints.

It is also found between structural gypsum buttresses that bear the girders of the framework and roof. In all these cases, these buttresses play an

Figure 2. Rammed earth wall with gypsum-reinforced joints in order to protect these weaker points from atmospheric agents (Cristini).

Figure 3. Detail of a rammed earth wall with brencas or undulated gypsum reinforcement (Vegas & Mileto).

important role at the same time, that is, they form the shape of the corner preventing the rammed earth modules from forming corners with a continuous formwork, etc. The rammed earth wall with undulated reinforcement can be found in the same riverside places as the rammed earth walls with reinforced joints mentioned above. But they can also be found in other places on mountain slopes, such as Ademuz, Castielfabib, Val de la Sabina and Sesga, usually in the upper stories of buildings known by the local people to be very old, which leads us to believe that this technique in the area dates from several centuries ago.

2.4 *The rammed earth wall with rafas or embedded pilasters*

This is actually a variant of the previous type, where the vertical joints are thickened to form little pilasters embedded in the wall, both systematically and by chance, along a course of rammed earth sections, particularly at the ends and corners.

The *rafas* are inserted in the rammed earth wall at the same time as it is built, as part of the forming mass. The combination of these little pilasters with the crescent shape of the undulated reinforcements gives rise to peculiar curved shapes. When the wall is very long, these little gypsum pilasters can be found inserted along the wall every 4 or 5 metres at most.

Rafas are different from the structural gypsum corner buttresses described above for several reasons: they are built in rows at the same time as the walls, adjusting them to the curves of the *brencas*, as opposed to the corner buttresses, which are erected beforehand, separately from the rammed earth wall so that the gypsum does not mix with the *brencas* in the wall; they form part of the rammed earth wall unlike the structural corner buttresses that merely circumscribe it; they have the same thickness as the wall, unlike the buttresses (25 cm on average for the wall and the embedded pilasters as opposed to 40 cm on average for the structural buttresses). As a variant of the wall with undulated reinforcement, the wall with embedded pilasters appears in the parish in the same places as the latter, but in much smaller numbers, given the higher price of gypsum for building the wall.

2.5 *The Valencian rammed earth wall with stone filling*

The Valencian rammed earth wall is a wall made out of earth and a larger or smaller amount of lime, bonded in mass and reinforced on the outside with bricks or stones, visible on the finished surface. The commonest Valencian wall is often improved with recycled bricks or fragments of brick and was typical in important cities like Valencia or

Figure 4. Rammed earth wall with *rafas* or embedded pilasters at the corner (Vegas & Mileto).

Figure 5. The tower at Torrealta, a typical case of Valencian rammed earth wall bonded in mass and reinforced on the outside with stones, visible on the finished surface (Vegas & Mileto).

Xàtiva between the 14th and 17th centuries, when it began to disappear little by little (Cristini 2012, 152–154). The Valencian rammed earth wall reinforced with stone is much less common. It can be found above all in rural areas like the parish we are dealing with here.

In the parish of El Rincón de Ademuz, only one example of a Valencian rammed earth wall with stone filling is conserved. It is Torrealta watchtower, a magnificent military construction that conserves all its projecting defensive machicolations and whose framework may date from the 16th century. The dating of these frameworks by chronotypology makes it possible to date the rammed earth walls at the same time, since the girders and joists are from the same period.

2.6 *The rammed earth wall with brencas and rafas with a stone filling*

This wall is a complex combination of the rammed earth wall with brencas and rafas and the Valencian wall with a stone filling. It is a peculiar construction, typical in the area, that seems to have doubted the resistance capacity of the solid Valencian wall and insisted on reinforcing it with *brencas* and *rafas* made of gypsum, a material used in all the architecture in the area. We only know two examples of this sort of technique in the parish and they are both in luxurious houses: the priest's house in Castielfabib and the house of the Señor de Torrealta (Vegas et al., 2001, 132). The scarcity of examples confirms the fact that this construction was costly, not only because of the use of gypsum but also because it was difficult to put into practice.

Strangely enough, the chemical analysis made by two of the authors of this article on the walls of the priest's house at Castielfabib confirmed the fact that the mass of the wall is made of lime mortar with a lime/sand proportion of 1:2,5; while the *brencas* and *rafas* are made of gypsum paste without any added gravel, merely the impurities attached to the mineral until it was fired (Vegas et al., 2009, 104–105).

This implies that even in a rammed earth wall with a large proportion of lime reinforced with a large number of stones visible on the outside surfaces, gypsum was still chosen as the main bonding agent for reinforcement.

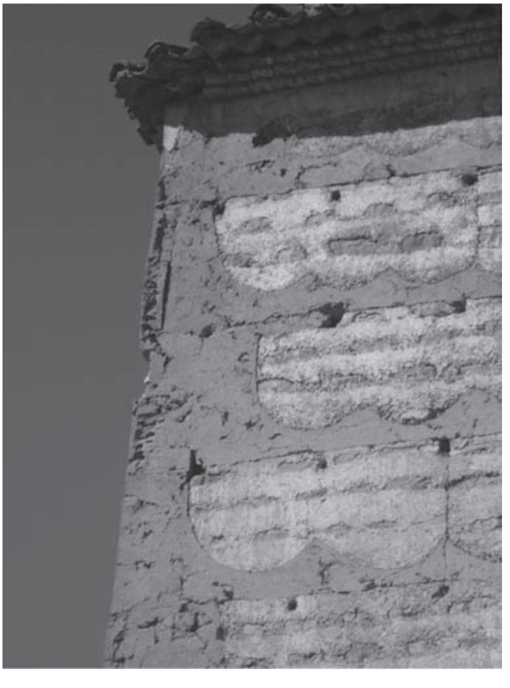

Figure 6. Valencian rammed earth wall bonded in mass and reinforced on the outside with stones with added brencas and rafas, all of them visible on the finished surface (Vegas & Mileto).

2.7 *The gypsum wall built with formwork*

The gypsum wall built with formwork is an extreme case on this list, since it shares the plank moulding system with the other techniques but differs from them in the way it is made, which is not by means of compacting, as gypsum does not need to be compacted in order to set and acquire its resistance capacity (Sanz 2009). The gypsum earth wall is very common in the domestic architecture of the parish for the outer walls of the upper stories. They can be planked on one side, reinforced with slabs of stone at the back with a total thickness of about 8–10 cm, or planked on both sides, with a majority of gypsum and a filling small stones and scraps

Figure 7. Gypsum thin wall built with formwork between two structural gypsum buttresses in a common auxiliary building (Vegas & Mileto).

and have a thickness of about 12–15 cm (Vegas et al., 2010).

On the borders of Aragón there have been and still are fortresses and towers built with very thick rammed earth walls that have survived over five centuries until the present day in a fairly acceptable state of conservation. This type of mass gypsum constructions cannot fail to remind us of the funeral towers in the city of Zenobia in Syria, also built with large amounts of plank-formed gypsum with funeral chambers inside.

The gypsum earth wall can be found all over the Rincón de Ademuz parish and the province of Teruel and the areas bordering the Maestrazgo in the province of Castellón. It is often studded with timber transoms that endow it with stability and at the same time help fix the planks of the formwork.

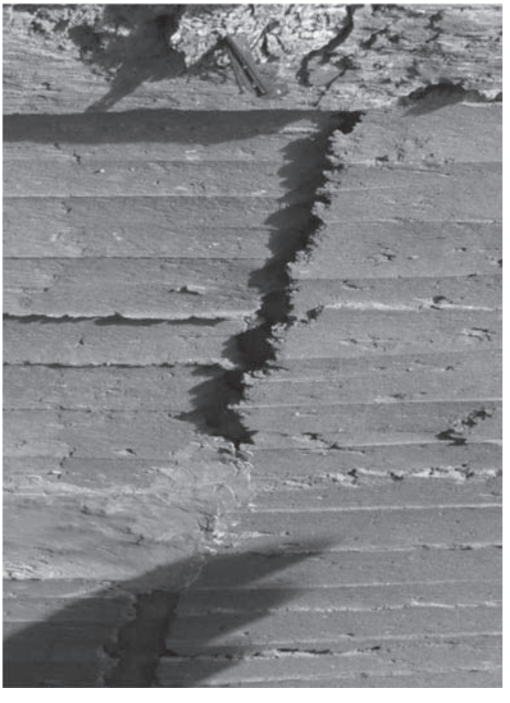

Figure 8. Detail of a gypsum thin wall built with formwork in a common house (Vegas & Mileto).

Figure 9. Massive gypsum wall built with formwork for defensive purposes (Vegas & Mileto).

3 PATHOLOGIES AND RESTORATION METHODS

The most common pathologies in this type of wall are not usually connected with the gypsum present in almost all the variants, but rather with the earth. In any case, these walls are seldom found to be in a poor state if periodical maintenance works are performed on them. Problems usually stem from damages in the roof and progressive leaks that seriously harm the wall and even destroy it completely if something is not done about it. If the stone socle is not sufficient, the pathologies can be caused by the dampness of the ground. The surfaces of the walls can also be damaged by weathering in a gradual

Figure 10. Example of a Valencian rammed earth wall with brencas and rafas damaged by weathering in a gradual process of erosion and loss of material (Vegas & Mileto).

process of erosion and loss of material, especially if the protective crust is missing (Fig. 10). Other damage that can be found in the area is caused by man, due to direct attacks on the materiality of the wall (perforations, holes, etc.) or because of an unsuitable use of building materials (for example, a parge coat with cement mortar on a traditional wall, which prevents it from transpiring).

The restoration of traditional rammed earth walls in the area requires the elimination of unsuitable materials, such as cement mortar, not only for aesthetic reasons but because they are often the cause of the progressive degradation of the wall. In the same way, any type of intervention requires the use of building materials compatible with the existing rammed earth wall, mainly earth, lime, gypsum and, if necessary, timber (Vegas & Mileto 2007, 56–57).

The authors of this article have performed several restoration works on rammed earth walls in the area, in different states of conservation. In most cases, the degradation consisted in the crumbling of the wall, with a loss of volume in different degrees. In order to replace the volume where it was necessary for structural reasons, multiple connection pieces of wattle were inserted and also wooden splinters whose ends were shaped with a knife to form a clasp or a hook to facilitate adhesion. Then the wall was completed merely by using earth or, in other cases, earth enriched with lime. The final finish was left rough so that it would harmonise better with appearance of the historic wall. In general the added parts blended in perfectly well in the rammed earth wall as long as they constituted no more than 20% of the total surface (Vegas & Mileto 2011, 252–253).

In the case of partly eroded or missing reinforced joints or gypsum *brencas*, they were not obsessively or systematically replaced, but their loss was assumed in the reintegration of the mass of earth, so that people looking at it would accept the gaps quite naturally and use their imagination to fill them in. Only in the cases of very large *brencas* were the missing parts replaced and a patina applied to them, because their absence would have involved not only a structural loss but a serious alteration in the pictorial rhythm of the crescent shapes, a factor to be taken into account in the built cultural landscape of the parish.

NOTE

This paper is a part of the scientific research project "La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas" (The restoration of rammed earth architecture in the Iberian Peninsula. Criteria, techniques, results and perspectives, ref. BIA 2010–18921) granted by the Spanish Ministry of Science and Innovation under the National Grant Scheme for the year 2010.

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 ISBN 978-0-415-62125-0

Building rammed earth walls in the municipal swimming pool in Toro (Zamora, Spain)

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ABSTRACT: This communication endeavors to convey the experience gained through the construction of the rammed earth walls of the new municipal indoor swimming pool in Toro (Zamora—Spain). The text focuses on the construction of the walls, particularly in their placing, and finally, proposes some measures that could be used in similar constructions. This communication is not intended as a scientific text, but tries to complement the technical investigations about rammed earth, from an architectural perspective.

1 THE BUILDING

The Municipal Indoor Swimming Pool has its origin in the proposal submitted to an architectural competition organized in 2004 by the city of Toro (Zamora, Spain), where Vier Arquitectos got the first prize.

The fascination with the landscape and traditional methods of construction in Castile and Leon are in the conceptual origin of the project. Through a series of load-bearing exterior walls made of rammed earth, the building is conceived, practically, as a closed space, focusing on the texture and the geometrical arrangement and composition of the walls, the expressive conditions considered suitable for urban environment where it is located.

Thus, it was designed a sober building, without sacrificing the language of contemporary architecture, trying to link, in a natural way, with the building tradition of the area (Fig. 1).

Figure 1. Autor: H. Fernández Santos-Díaz.

The swimming pool is set in an enclosure of rammed earth 60 cm thick, which determines its exterior and interior space (Figs. 2–3). The pool protects itself from external climatology and non-desirable views through its rammed earth perimeter walls, adapted to the available plot, folds forming the access area. Over their edges, the roofs of the changing rooms emerge.

The closed and severe aspect of the building contrasts with the image that appears as soon as one crosses the threshold The light enters the building through the skylights and courtyards which divide the rooms, but it is in the volume which contains the swimming pool basin where plays the prominent role, generating, at certain times of day, an intense play of light and shadows on the rammed earth walls (Fig. 4).

Figure 2. Autor: H. Fernández Santos-Díaz.

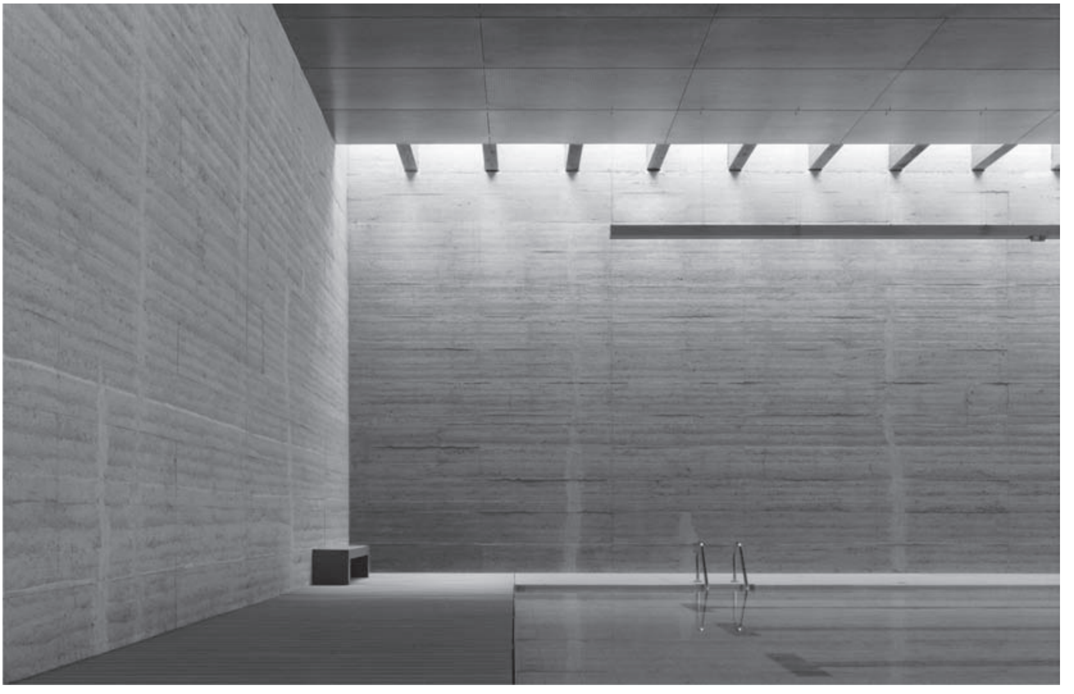

Figure 3. Autor: H. Fernández Santos-Díaz.

Figure 4. Light and shadows on the rammed earth wall. Autor: H. Fernández Santos-Díaz.

2 RAMMED EARTH WALL

The initial intention of solving the main walls in rammed earth has led us to intensive research of traditional techniques and the newly developed and improved ones in countries like Germany, Austria or the United States over the last decade.

From the outset, it was decided not to apply traditional methods, seeking to update the skills of construction in rammed earth in order to situate them amongst the levels of quality and control that currently required for the conventional construction processes.

From this position, the research was raised, from the confidence in the formal-architectural aspects of rammed earth, and concern about the new technical aspects unrelated to the traditional building practice.

2.1 *Wall construction*

The executive project, developed through the available technical information at that time, established a series of criteria for the composition and characteristics of the earth used to build the walls: a density value among 1.6–1.8 kg/m^3, a calculation compression resistance fixed in 3 kg/cm^2, a certain grading diagram, and an estimated rupture stress for the samples > 20 kg/cm^2, etc.

Furthermore, many tests were prescribed in the project in order to prepare and correct the soil samples, to define its texture and color, and even the specific processes of its construction were detailed.

Once the soil collected from the excavation was prepared, following the criteria established beforehand, and after the battery of tests designed to select the dosage that would match with both the mechanical requirements and the visual texture foreseen in the project, the final composition of the wall was as follows:

- 0.5 m^3 of sand, in a continuous granulometry between 1–2 mm.
- 0.85 m^3 of round grain, in a continuous granulometry between 2–20 mm.
- Conglomerates: 4% white cement type II/B-LL 42.5R and 2% slaked lime.
- Additives: a sealant liquid, Sika 1 (dosage 1:14 additive: water), in the kneading water.

For this final dosage, the obtained resistance to compression was greater than the 20 kg/cm^2 initially prescribed.

The test values of shrinkage obtained at the laboratory by using large samples yielded no significant results after 28 days. Subsequently, it was found that the measurement should have been more accurate if made on samples of at least 150 cm length, dried at open air for six months while protecting the tops with a plastic wrapping. To limit retraction processes in the last phase of the works, the mass of the wall was reinforced with polypropylene fibers (type SikaCim Fibres-6), obtaining satisfactory results.

2.1.1 *Placing of the walls*

The construction of the wall was developed through the following steps:

A. The rammed earth wall was built over reinforced concrete foundations with galvanized steel connectors, above the ground level and the levels of runoff. In all cases, an impermeable barrier consisting on a specific mortar was applied (Fig. 5).
B. The shuttering panels, with their associated connectors, were placed. The laying and texture of the formwork were carefully chosen in order to fix the appearance of the wall.
C. The tiers were poured in layers of 10–12 cm thick for a better compaction (Fig. 6). The first tiers were richer in cement and a sealant was added to prevent absorption of water. Each five tiers (50–75 cm), one, rich in lime, was poured as reinforcement.
D. Compaction. Mechanical manual compactors were used (Fig. 7).
E. Protection. During the construction, all surfaces of the wall were protected with plastic sheets, particularly the heads (Fig. 8).
F. Post-tensioning the wall. The most critical zone, in terms of structural requirements and stability, was focused in the hall of the pool basin, due to the significant height (6.40 m), the low permanent load of the roof and the large separation between the shear walls (35.00 m).

Figure 5. Reinforced concrete foundations with metallic connectors. Autor: Vier arquitectos SLP.

Figure 6. Pouring the earth once placed of the formwork. Autor: Vier arquitectos SLP.

Figure 7. Mechanical manual compactor. Autor: Vier arquitectos SLP.

Figure 8. Protection of the wall with plastic sheeting. Autor: Vier arquitectos SLP.

Figure 9. Galvanized steel tube with elastic joint inside the wall. Autor: Vier arquitectos SLP.

The structural solution proposed was based on stiffening the deck and post-tensioning the rammed earth walls to balance the possible lateral thrust, ensuring the stability of the whole enclosure. A concrete beam was placed over the wall to provide the tensioning load. The post-tensioning sheaths embedded in the walls should not transmit undesired loads to them when tightened –steel galvanized columns, embedded in the walls, equipped with an elastic perimeter joint to avoid movements, were chosen to convey solely the effort of tensioning (Fig. 9).

G. The wall surfaces were cleaned and repaired, after the application of two layers of a hydrophobic (water repellent) and fungicide impregnation but water vapor permeable, which did not affect their final appearance (Fig. 10). In the process of fissure repairs, injection techniques of pure mud were employed with uneven results, finally opting for the opening of the crevasses, filling and finishing them with clay slurry (Fig. 11).

Figure 10. Application of a hydrophobic and fungicide impregnation. Autor: Vier arquitectos SLP.

Figure 11. Reparation of small voids and defects. Autor: Vier arquitectos SLP.

3 CONCLUSIONS

In this final section, a series of recommendations and conclusions related to the laying of the rammed earth walls are proposed in order to be used in similar constructions.

The *post-tensioning* of the walls has enabled to balance the mechanical efforts appearing on the walls without compromising the compositional approaches of the architectural design.

The control of *shrinkage*, well-known and widely collected in the literature about the subject, is revealed as the Achilles heel of this specific kind of construction. Besides, the rhythm of the measurements and the results at the laboratory are too slow compared with the rhythm of construction. In this case, maximum shrinkage occurred six months after the completion of the building, and then stabilized. To mitigate this problem of shrinkage, it would be advisable to undertake the following precautions:

– Arming with polypropylene fibers, combining additional binders with a certain percentage of clay, as it was done in the final phase of this works with satisfactory results.
– The traditional way of laying of the walls (3–5 meters long), was proved as a good solution, decreasing the effects of shrinkage due to the formation of working joints.

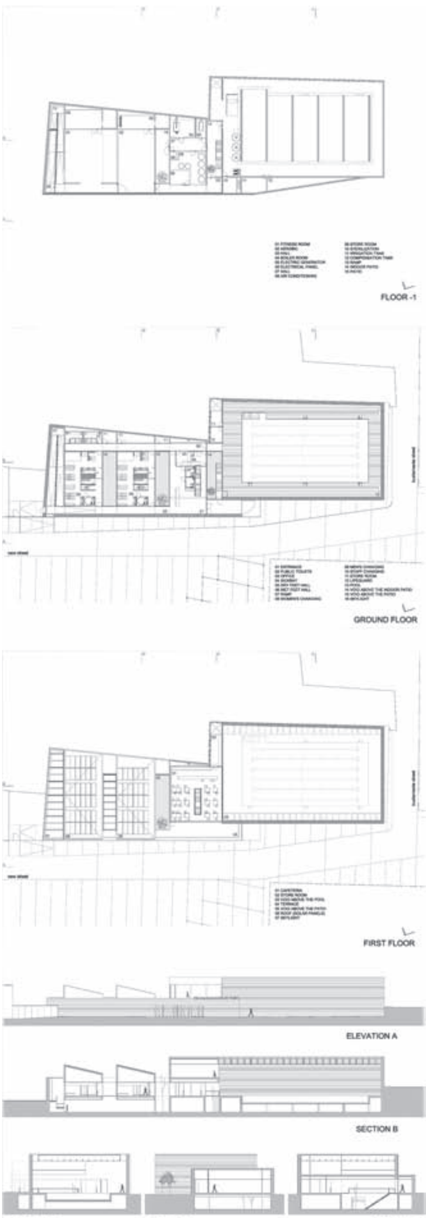

Figure 12. Drawings.

Figure 13. Exterior view. Autor: H. Fernández Santos-Díaz.

Figure 14. Entrance. Autor: H. Fernández Santos-Díaz.

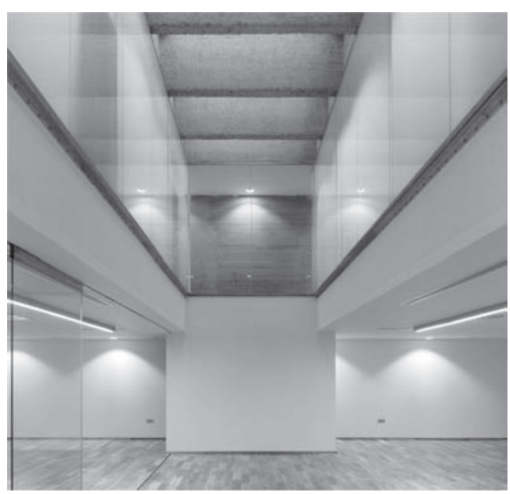

Figure 15. Changing rooms from floor—1. Autor: H. Fernández Santos-Díaz.

Figure 16. Pool. Autor: H. Fernández Santos-Díaz.

Figure 17. Fitness room (Floor—1). Autor: H. Fernández Santos-Díaz.

– Checking in construction the degree of compaction by nuclear density tests (density and moisture).

The wall heads must be *protected* during their construction and in its final state.

The executive project must provide *repair operations* of the surface (impact damage, covering and reparation of fissures and crevasses, etc.).

The water repellent and fungicide impregnation applied on the wall surface (interior and exterior) got a great result.

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DATA SHEET AND DRAWINGS

Project: Indoor swimming pool in Toro (Zamora, Spain).

Client: Toro City Council.

Location: Bustamante Street, Toro (Zamora).

Dates: September 2004, competition. December 2005, project. October 2006-august 2010, construction.

Architects and Construction managers: VIER arquitectos SLP (Raya, Crespo, Sánchez and Antelo).

Collaborators: Pablo Vilares, Cristina de Vera and Ruth Varela, architects. José Mª Sastre, rigger.

Contractor: Valsan SL (until march 2009, partial structure). Ferrovial SA (from september 2009).

Area: 2441.00 m^2.

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Introduction to traditional rammed-earth building in the Aragonian valley of Jiloca (Spain)

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ABSTRACT: In southwestern Aragon (Spain), the Jiloca River flows through a large interior valley from its source in Cella to where it joins the Jalón River near Calatayud. In the southern two-thirds of this valley a strong tradition in building rammed earth walls or 'tapias' for houses, and other buildings was kept alive until the mid-twentieth century. Through a series of interviews held with retired masons, which were contrasted with the analysis of samples of compacted earth along the valley, relevant information has been compiled about the last decades in which this traditional technique was typically used. Several findings of this study are highlighted for their interest: the uneven geographical distribution and historical use of rammed earth, the preferred time of the year for doing so, the earth preparation, the wooden formwork components (*tapial*), the assembling and earth-filling techniques, the procedure for moving formwork, and the survival of a rich vocabulary.

1 INTRODUCCIÓN

El presente texto es resultado de un estudio, financiado por el Servicio de Investigación y Difusión del Patrimonio Cultural del Gobierno de Aragón, cuyo trabajo de campo se desarrolló entre los meses de noviembre de 2005 y febrero de 2006. Esta investigación se basó en la realización de entrevistas etnográficas a albañiles jubilados (Fig. 1) y nacidos entre los años 1917 y 1947, por lo que será necesario encuadrar la mayor parte de la información expuesta en la última fase de construcción tradicional en tapia en la zona, aproximadamente entre 1930 y 1960.

El marco geográfico de referencia se corresponde con el valle del Jiloca, situado en la franja sudoccidental de la comunidad autónoma de Aragón y hacia el centro del cuadrante noreste de la Península Ibérica. Se trata de un extenso valle interior de unos 140 km de longitud que, desde su nacimiento en Cella a 1.020 m de altitud, describe un recorrido de sur a norte hasta su desembocadura en el río Jalón (afluente a su vez del río Ebro) junto a la ciudad de Calatayud a 530 m de altitud.

Aunque es posible constatar la presencia de construcciones de tapia en la totalidad de los pueblos situados a orillas del río Jiloca, resulta llamativa su mayor abundancia en los situados al sur de Daroca frente a su presencia más minoritaria respecto a los de mampostería o adobes entre los ubicados al norte de esta población. Esta distribución desigual puede ponerse en relación con una visión diacrónica de la construcción en tapia basada en el hecho comprobado de que mientras al

Figura 1. Pascual Allueva, albañil jubilado. Monreal del Campo (Foto: Félix A. Rivas).

norte de Daroca ninguna persona mayor recuerda haber visto construir con este material, al sur de Daroca esta técnica constructiva permaneció viva hasta hace escasas décadas. Tal como se ha descrito en relación a otras zonas aragonesas como el Somontano del Alto Aragón (Naval, 1988) y Los Monegros (Rivas, 2002), parece que en algún momento del siglo XIX se abandonó completamente la construcción en tapia al verse sustituida al menos en buena parte por el uso de *adobas* (adobes).

Todos los testimonios orales recopilados señalan que las personas que realizaban construcción en tapia eran albañiles profesionales y que muchas veces habían heredado y aprendido el oficio de su propio padre. También coinciden en que no existían albañiles que solo construyesen en tapia sino que lo generalizado era "hacer y saber de todo".

Los edificios que se construyeron de manera habitual en tapia fueron pajares, casas, "parideras" o corrales para el ganado, palomares, cementerios, y paredes de delimitación en huertos, fincas cerradas o recintos anexos a la vivienda.

Además, teniendo en cuenta las limitaciones de la temperatura ambiente para el acondicionamiento de la tierra necesaria, y el carácter extremo del clima local con sus habituales heladas invernales, resulta comprensible que la construcción en tapia se viera restringida al período del año comprendido entre los meses de abril hasta octubre o noviembre. Por eso, tal y como recuerdan en Monreal del Campo, se decía que "pa san Andrés, las tapias al revés" en el sentido de que los finales del mes de noviembre (san Andrés se celebraba el 30 de noviembre) marcaban el abandono estacional de la construcción en tapia.

2 LA TIERRA PARA TAPIAR

La materia prima fundamental para la construcción en tapia era tierra extraída del propio entorno en el que iba a hacer la obra y que requería un mínimo proceso de preparación. No valía cualquier tierra, sobre todo en el caso de que resultase demasiado arcillosa o arenosa, aunque lo habitual era que se emplease la del mismo solar de la obra y en ese caso no era problema que tuviese bastantes piedras o cantos.

La preparación a que se sometía la tierra consistía en proporcionarle el nivel de humedad adecuado para su trabajo en el tapial lo que se conseguía añadiendo agua a la tierra y mezclándola para conseguir una pasta lo más uniforme posible. Para mezclar tierra y agua había dos procedimientos conocidos. Uno consistía en cavar un hoyo o hacer una balseta en el suelo y arrojar en su interior agua para que la tierra se fuera "amerando". En este caso podía realizarse con antelación un año antes de comenzar la obra para que la tierra quedara "más hecha" y se dejaba "dándole los aires", unas dos semanas para que la tierra "se posara", o solamente desde la noche anterior y tras la que había que revolver bien la mezcla. El otro procedimiento era hacer un montón de tierra sobre el suelo, echarle agua e ir revolviendo con la "legona" o azada. A veces podía ser suficiente con el grado de humedad de la tierra si había llovido recientemente.

3 LAS PIEZAS Y EL MONTAJE DEL TAPIAL

A la técnica y a las paredes construidas con tierra compactada se les conoce en el valle del Jiloca como "tapia" de manera genérica. El "tapial" es el conjunto de piezas que una vez montadas hacían de encofrado que se rellenaba de tierra húmeda para ser compactada, aunque también recibía ese mismo nombre el principal de sus elementos. Casi todas sus piezas estaban fabricadas en madera y era por tanto el carpintero del lugar el encargado de su elaboración.

Como podrá comprobarse a continuación, las dimensiones y peso del tapial y de todas sus piezas responden con precisión tanto a las condiciones óptimas de realización propias de la tapia como a los límites y posibilidades de manejo manual de las piezas por parte de la unidad básica de trabajo en el tapial compuesta por dos personas.

Un juego completo de tapial constaba de las siguientes piezas cuyas medidas si no se indica lo contrario corresponden a las de un ejemplo conservado en Villafranca del Campo:

- 2 "tapiales" o "tableros" rectangulares (de 191,5 cm de anchura, 79,5 cm de altura y 2,5 cm de grosor). Están formados por varias tablas de canto unidas entre si con gran solidez. En cada cara tienen un listón rematado en media caña en uno de sus lados cortos (de modo alterno en cada una de sus caras), a 14 cm del borde lateral y separado de sus extremos inferior y superior por unos 3 cm. Este listón, denominado "reblón", tiene sus extremos acabados de manera oblicua y todo él está encajado en las tablas mediante un corte en cola de milano. En los extremos superior e inferior de sus lados cortos (a 6 cm de los lados largos) tienen sendas ranuras o "entras" (de 3,5 cm de altura) para facilitar el traslado manual del tapial desde la tapia finalizada a la siguiente por hacer. También para facilitar su manejo presenta un orificio de forma ovalada (de 11 cm en su eje horizontal y 4 cm en su eje vertical) en su posición central.
- 2 "frontales" en forma de T (de 54 y 38 cm de anchura, 92 cm de altura y 2 cm de grosor). Están formados por dos tablas verticales, con su cara lisa hacia delante, unidas mediante dos listones

traseros (de 7 cm de anchura) y rematadas en altura por un pequeño rollizo de extremos rebajados (de 3 cm de diámetro) y que sobresale en anchura para servir de tope.

– 5 “aujas” (de 67 cm de longitud, 3 cm de lado en un extremo y 5 cm en el contrario). Son listones ligeramente curvados y de sección casi cuadrangular con dos extremos diferenciados: el más delgado tiene uno o dos agujeros (de 1 cm de diámetro, a 5,5 y 8 cm del borde) y el grueso presenta una cabeza (de 6,5 cm de longitud) que sobresale ligeramente por dos de sus caras.
– 6 “costillas” o “trabas” verticales, de las que 4 son laterales (de 123 cm de longitud, 7 cm de anchura y 6 de grosor) y 2 centrales (de 141 cm de longitud, 7,5 cm de anchura y 7 cm de grosor). Son listones de madera de sección casi cuadrangular y con dos extremos diferenciados: el inferior es de corte oblicuo en forma de “uña de cabra” (de 7,5 cm de longitud) con una hendidura central (de 3 cm de anchura), y el superior (de 19,5 cm de longitud) es más delgado y de sección rectangular (de 2,5 cm de grosor).
– 3 “trabas” horizontales o “cruceras”, de las que 2 son laterales (de 99,5 cm de longitud, 8 cm de anchura y 7 cm de grosor) y 1 central (de 108,5 cm de longitud, 10 cm de anchura y 7,5 cm de grosor). Son listones de madera rectos, de sección rectangular y con parejas de hendiduras (de 14 por 3,5 cm), teniendo la traba central un extremo algo más largo que las otras dos y un gancho doblado clavado en ese extremo, llamado “gonce”, a modo de ojo en el que colgar la polea.
– 6 “cuñas” de madera con forma de rectángulo al que se le dado un corte desigual en una de sus esquinas (de 14 y 6,5 cm en los extremos de sus lados largos, 8,5 y 3 cm en los de sus lados cortos, y 3 cm de grosor).
– 3 “codales” troncocónicos de madera (de 35 cm de longitud, 4,5 cm de diámetro en su extremo grueso y 3,5 cm de diámetro en su extremo delgado).
– 3 ganchos de metal, formados por un extremo largo y curvado y otro en forma de anilla mediante en que quedan unidos por una cuerda.

En el momento de comenzar la obra en tapia, directamente sobre el zócalo, la primera operación era colocar las tres aujas de manera trasversal al muro, con su lado convexo hacia arriba, sobresaliendo por sus dos extremos, y separadas entre si de manera que las dos laterales quedaran en los extremo del tapial y la central en su punto medio. Sobre ellas se ponían los dos tapiales en ambas caras del muro, apoyados sobre sus lados largos, con los reblones de un extremo de ambos tapiales hacia dentro y los otros dos hacia fuera. Por último en los laterales de los tapiales se ponían los dos frontales para cerrar el cajón por sus costados, con su cara lisa hacia dentro y el extremo de la T en lo alto.

Para asegurar la estructura e impedir su apertura hacia fuera se colocaban ahora a ambos lados de los tapiales 3 trabas verticales con sus extremos hendidos encajados en los extremos de las aujas y, en el caso de las trabas laterales, con sus extremos superiores haciendo tope a los extremos de la T de los frontales. Respecto al extremo de cada una de las aujas que cuenta con una cabeza, ésta hace tope a la traba vertical, y respecto al otro lo hace el gancho de metal que se introduce por uno de los agujeros de la auja.

En su parte superior las costillas se sujetan insertando sus extremos en las hendiduras de las tres trabas horizontales que quedan perpendiculares al sentido de la pared y la central algo por encima de las otras dos. Para darle mayor seguridad a estos engarces se les añadía una cuña o falca a presión. Otra opción muy difundida era la de utilizar “soguetas” o cuerdas en lugar de las trabas horizontales, que se retorcían y se aseguraban mediante un fragmento de rama o “estampidor” trabado en el centro para que no cedieran.

Por el interior del encofrado, coincidiendo con los tres puntos correspondientes a las aujas y a las trabas verticales, y en el extremo superior del cajón, se colocaban entonces los tres codales que impedían que el borde superior de los dos tapiales se inclinase hacia dentro. Estos codillos se colocaban siempre cuidando de situar hacia al interior su extremo más grueso, “cara dentro”, para facilitar su extracción una vez se había rellenado el cajón y quedaban cubiertos por una capa de unos 5 cm de tierra.

La estructura total del tapial montado (Fig. 2) daba lugar a un volumen interior correspondiente

Figura 2. Tapial (con uno de los tableros puesto del revés). Villafranca del Campo (Foto: Félix A. Rivas).

al módulo básico de tapia y cuyas dimensiones podían variar ligeramente. A partir de las medidas aportadas por los informantes y de las tomadas en muestras concretas de paramentos de tapia en la zona pueden establecerse sus dimensiones más habituales y más extremas en 70 cm de altura (entre 60 y 76 cm habitualmente), 1,5 m de anchura (entre 1,3 y 1,7 m) y 40 cm de grosor (desde 37,5 a 50 cm).

Una vez montado el tapial completo se introducían en su interior tanto el albañil como el peón, uno a cada lado de la traba horizontal central y ocupándose por tanto de una de las dos mitades en que quedaba dividido de manera imaginaria el interior del tapial.

4 EL APISONADO DE LA TIERRA

Toda construcción en tapia conllevaba el levantamiento previo de un zócalo de mampostería asentada con mortero de barro para dificultar la ascensión de humedades desde el suelo hasta la tierra cruda de la tapia. Este zócalo, era denominado en Monreal y Villafranca del Campo "alizaz" o "alisaz", del árabe *al'isas* 'los cimientos'.

Antes de comenzar a introducir tierra en el tapial para su compactación, era necesario cubrir las aujas con una delgada capa de piedras conocida como la "piedrauja" para impedir que la tierra que iba echarse a continuación quedase directamente sobre ellas y pudiera impedir su extracción una vez terminada aquella tapia.

A la altura del suelo, la tierra ya preparada se echaba dentro de unas "cestas terreras" de "bimbre" de forma circular y provistas de dos "ansas". En el primer "hilo" o "tramada" (nombre con el que se conocen cada uno de los pisos o hiladas de tapias), los ayudantes les pasaban a los tapiadores directamente las cestas para que las descargasen en el interior. Pero conforme se subía había que arrojar al aire las cestas, lo que conllevaba cierta habilidad. A partir de cierta altura la solución era ayudarse de una "carrucha" que colgaba del gonce del extremo exterior de la crucera central.

Desde el interior del encofrado, los dos tapiadores arrojaban cierta cantidad de tierra cada vez y la iban apisonando. El pisón (Fig. 3) era una herramienta de madera compuesta por un mango redondo y largo, lo suficiente para que la persona que lo manejara lo pudiera hacer desde una postura erguida, y rematado por una "cabeza" en forma más o menos cúbica aunque algo apuntada hacia su extremo inferior y, frecuentemente debido a su desgaste debido al uso, un poco redondeada en su parte final. Su longitud total podía oscilar entre 1,13 y 1,40 m, y su cabeza tenía entre 10 y 12 cm de anchura y entre 12 y 15 cm de altura.

Figura 3. Pisón. Villafranca del Campo (Foto: Félix A. Rivas).

La cabeza, además, solía ser de madera de carrasca o sabina para que se desgastara lo menos posible a pesar de su uso. La acción, denominada de manera general "pretar", consistía en golpear la tierra con el pisón hasta que alcanzaba un aspecto compacto que se juzgaba suficiente.

Un poco antes de llegar al límite superior del tapial, unos 5 cm por debajo de él, la tierra comenzaba a cubrir los codales, situados en la misma posición que las aujas. Estas piezas dejaban ya fabricado el agujero en el que se insertarían posteriormente las aujas de las tapias inmediatamente superiores. Una vez finalizada la tapia, se retiraban (al menos los dos más alejados de la nueva tapia por fabricar) golpeándolos con el martillo o la maceta en su extremo más delgado para que salieran con facilidad por la otra cara de la tapia.

El procedimiento para rellenar el tapial que ha sido descrito hasta el momento se corresponde con lo que en Cella llaman la "tapia seca", es decir, aquella que no recibe ninguna capa de refuerzo ni entre sus juntas ni en su cara frontal. No es raro sin embargo que las juntas, tanto verticales como horizontales, que quedan entre tapia y tapia aparezcan selladas por una "cinta" o "lista" de yeso de entre 2 y 4 cm de espesor y de un llamativo color

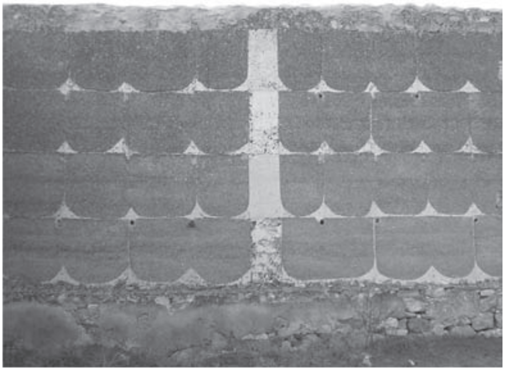

Figura 4. Tapia de cintas onduladas. Torremocha de Jiloca. (Foto: Félix A. Rivas).

blanquecino, anaranjado o rosáceo. La diferente disposición y forma de estas cintas ha dado lugar a lo que se han calificado de diferentes tipologías de tapias especialmente en relación a la producción de tramas visuales de gran potencia plástica en su aspecto exterior (Fig. 4).

Otro tipo de tapia, el que recibe una capa de refuerzo a base de mortero de cal en su cara frontal, es conocido genéricamente como tapia calicostrada y resulta de igual modo muy abundante en la zona aunque supusiera una mayor complejidad y trabajo para el propio albañil.

5 LA PROGRESIÓN DE LAS PAREDES

Lo más común era comenzar cada hilo de tapia utilizando dos frontales en el tapial para poder disponer de tope en ambos costados del cajón pero otra opción era levantar antes la altura correspondiente de una esquina y comenzar a partir de ella con un solo frontal en el lado opuesto del tapial. Otra práctica habitual era la de comenzar cada hilo de tapia desde el mismo punto pero alternando el sentido del avance de manera consecutiva en cada tramada, de modo que las juntas verticales entre tapias tendiesen a no coincidir en altura.

En el hilo inferior, una vez relleno y compactado el cajón, la operación siguiente era colocar dos aujas sobre el fragmento contiguo de zócalo hacia el que iba a avanzar la obra. Entonces se retiraban las cuñas, las trabas horizontales y las costillas de las dos sujeciones del tapial más alejadas de la nueva tapia por hacer. También, con la ayuda de la cuerda y los ganchos que se habían metido en sus agujeros, se retiraban las dos aujas correspondientes puesto que la última sujeción que quedaba más próxima, con su correspondiente auja, no se retiraba sino que ya se dejaba para que formara parte del sustento del nuevo tapial. Por último se extraía el frontal del lado de la nueva tapia (y si era la primera tapia de todas y no había comenzado en esquina también el frontal opuesto) y se aflojaba el sistema de trabas que había quedado montado para poder desplazar ambos tapiales que, a su vez, se deslizaban hasta quedar sobre las nuevas aujas. Esto puede explicar el hecho de que las aujas fueran el único componente del tapial del que era necesario disponer al menos de dos piezas además de las que formaban el juego básico.

Para su desplazamiento, los tableros eran cogidos por sus "entras" superiores y se corrían hasta dejarlos apoyados en las nuevas tres aujas (dos de ellas recién colocadas). Se tenía cuidado también en colocar los tapiales de manera que el reblón que quedaba hacia dentro estuviese en el lado de la tapia por hacer, ya que si fuera al contrario pegaría con la tapia ya elaborada e impediría la estanqueidad completa del cajón. Además, de esta manera, el reblón de la cara contraria de cada tapial, al estar hacia fuera y del lado de la tapia ya fabricada, una vez corridos los tableros, quedaba justo haciendo tope con las costillas de la sujeción de la tapia anterior que no había llegado a desmontarse.

A partir de aquí se reproducía el sistema de montaje ya descrito con la colocación de las costillas, las trabas horizontales con sus cuñas, y los codales. Solo que antes de continuar con el proceso de colocar la pedrauja e introducir y compactar la tierra, si se estaba elaborando una tapia sin cintas verticales de yeso, se tenía la precaución de picar un poco con una picoleta la pared de la anterior tapia que quedaba a la vista desde el interior del tapial, con el objetivo de mejorar el agarre de la tapia siguiente.

En los hilos superiores la operación era la misma solo que ya no era necesaria la colocación

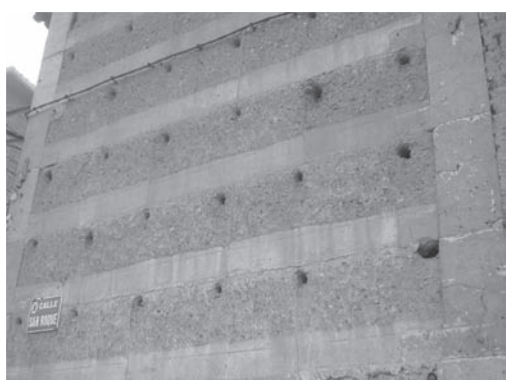

Figura 5. Pared de tapia con agujeros sin tapar. Monreal del Campo (Foto: Félix A. Rivas).

de la pedrauja porque las aujas se introducían directamente en los agujeros dejados por los codales retirados.

Al finalizar la obra, estos característicos agujeros podían o no taparse con un poco de yeso que en ocasiones ponía el albañil (sobre todo en la cara interior de la pared si se trataba de una vivienda) o el propio encargante de la obra. Caso de que quedasen abiertos, muchas veces solo por ahorrar un poco de material, solían servir después como lugares de nidificación para pequeños pájaros.

6 CONCLUSIONES

Ha tenido que pasar más de medio siglo desde el abandono de la construcción en tapia en el valle del Jiloca para que salga a la luz una primera intención de recuperar y actualizar esta técnica en la restauración de obras históricas (Sanz y Sopeséns, 2009) y en la autoconstrucción de pequeños edificios para el ocio rural (Centro de Estudios del Jiloca, 2011). En un ámbito más general, también se está comenzando a tener en cuenta a la hora de diseñar y construir con criterios de sostenibilidad e integración en el entorno.

Para todo ello resulta necesario contar con información rigurosa acerca de la forma particular en que la tapia fue elaborada en cada una de las zonas y comarcas en las que se mantuvo viva hasta hace bien pocas décadas. Y por ello tiene una singular importancia el rescate del testimonio de aquellos albañiles jubilados que fueron auténticos protagonistas de esta valiosa técnica constructiva que parece estar haciéndose con un merecido hueco en la arquitectura actual.

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The citadel of Reina (Badajoz, Spain)—10 years of interventions on its walls

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ABSTRACT: The citadel of Reina is located in the southwest of Spain. It's an Almohad building, from the 12th century, but nowadays in an advanced state of decay. In 2002, initiated by the City Council, a process began intended to rescue this monument from the state of ruin that was impending. Commissioned by the Junta de Extremadura, the project was drawn up, being the construction work assigned to the company Antaño Restauración. Since then they have carried out six work phases. Interventions in monuments built with earth are usually above the knowledge and technical capabilities of most construction companies, which involves us in the duty to disclose the work carried out and approaches and actions that made it possible. Ten years have passed and we are therefore able to make the review of action taken, in this case from the point of view of the building restoration firm.

1 THE CITADEL

1.1 *Location and overview*

The citadel of Reina is located in Extremadura, in the southwest of Spain, near the route between Badajoz and Córdoba. Positioned on a height in the foothills of Sierra Morena, dominates the countryside region called Campiña Sur. Sited in Reina's municipality, is owned by the City Council. Its shape is polygonal, nearly trapezoidal, with fourteen towers. Inside it, we find the remains of the old fortress, from which only the debris draw its south walls. In the citadel there are also the small church of Nuestra Señora de las Nieves and the remains of what was the Casa de la Encomienda (house of the Knights).

1.2 *Construction date and building techniques*

The configuration shown in early 21st century was a castle wall built up to the 12th century, with various subsequent interventions, among which those carried out in the 15th century by the Order of Santiago, and others at the beginning and at the end of the 16th century. This building is a big wall of earth, rammed inside reusable wooden forms, mounted *in situ* in tiers of about 0.85 m high and 2.10 m wide. We haven't detected a regular horizontal metric along the tiers. These walls have been erected on a stone base foundation with variable height depending on the ground's shape, almost in the entire perimeter, except in some cases where it has been built directly on the natural rock.

1.3 *Conservation state*

Despite some localized intervention that we have detected and we know it was made about 1970 (from which it was not yet possible to collect more detailed information) in the late twentieth century the citadel of Reina was in a eminent state of ruin due to neglect. The whole complex was filled with remains of stone, bricks and tiles, which undoubtless correspond to the old village inside the walls, with different kinds of constructions and reconstructions that have been made along centuries, only barely perceptible by the bases of some walls.

The remains of what was the house of the Knights were also in state of ruin and did not allowed to identify the original quarters which are reported in the literature describing visits to the citadel. Eroded by the action of wind and water, some parts of the so-called Almohade Ring had

Figure 1. Southwest walls and towers, before work.

already disappeared. Moreover, the image of the entire citadel was visually almost imperceptible.

2 THE PROJECT

2.1 *Background and project commissioning*

In the year of 2002, initiated by the City Council, begins a process that was intended to rescue this monument from the state of ruin that was impending. By request of the Culture Counselling from Junta de Extremadura, architect Gonzalo Diaz Recasens designs a plan for its consolidation and subsequent reconstruction, which was divided into six phases. The project for the first phase of intervention was drawn immediately.

2.2 *The walls of the citadel*

The project includes a description about the different types of walls of the citadel, discusses the causes of progressive destruction and describes the changes and pathologies in general. Also, lists the basic materials used in construction: carved and unworked stones, lime, earth, sand, clay bricks and ceramic pieces of all kinds. Furthermore, remarks that all the edifications in the citadel were built with these materials and highlights the rammed earth walls of the Almohade Ring.

2.3 *Rammed earth walls*

In these walls there are two types of material used for the overlapping rows. The first type is located in the lower rows, in some cases very deteriorated. The mass is rich in ceramic but has a low cohesion, due to the small presence of lime as a binder in its core. Mainly presents a high proportion of clay, silt, sand and gravel, along with pieces of pottery and large stones. The soil that becomes part of its composition was probably caught in the same area of construction. Thus, the wall has the same colour as the ground on which it is built.

In the upper rows we find a second type of material, of greater wealth. In areas where it remains it can be seen the high cohesion and resistance, mainly due to a better selection of materials. Among them there is high percentage of calcium hydroxide, slaked lime, which is intimately joined with the other raw materials. This reaction, in the presence of water along the time, carbonated and resulted in a material of high durability (Recasens, unpubl.). This second type of rammed earth, for its strength and consistency has worked, in some areas, like a tie beam at the top of the walls, which prevented further erosion and probably the ruin of the bottom rows, weaker by its nature.

2.4 *Causes of deterioration and pathologies*

As for the causes of progressive destruction and general diseases, it was identified, as the most important reasons, the weakness due to structural instability, loss of bonding material and alterations due to loss of mass. Also, we could see colour changes, crusts and deposits.

Most of the earth walls barely had lime in its constitution, reason that jointly with the lack of surface protection and lack of maintenance led to an easy deterioration, mainly produced by contact with water. The rain water flushed the surface, which has fallen apart dragging the components of the mass. In the upper rows of numerous parts of the walls there was a total loss of mass. In the lower rows, being made without lime, water erosion generated a significant reduction of thickness of the wall.

Because of the large loss of mass, there was a great instability of the whole set of the Almohade Ring. Such instability was producing the fall and continuing loss of the elements that configured the spaces, and the progressive loss of the original remains that make entirely recognizable the place values (Recasens, unpubl.).

The symptoms of structural instability could be seen in all building elements. The manifestations of these symptoms were translated into cracks, micro cracks, crashes, spins, distortions, tilting horizontal structural elements, and could reach the limit state of collapse or total overthrow.

2.5 *Proposal for actions*

The intervention in the walls of the citadel was established by two levels: consolidation and restitution. Considering the pathologies in the

Figure 2. Erosion in rammed earth walls. Here we can see the difference between the two types of raw material used in lower rows and in the upper rows.

walls, the project posed first to stabilize them structurally, in order to curb its further deterioration and to prevent the loss of the remaining parts and avoid possible accidents. Moreover, not only to consolidate but to restore them with all the richness of their authenticity, as an historical document, as a significant architectural element, referring to the message itself from the memory of the past and the meaning of the present (Recasens, unpubl.).

3 THE RECONSTRUCTION WORK

3.1 *Adjudication process*

Once designed and approved the project, open a public competition for adjudication of the work. However, after the contest deadline no company had submitted a proposal. Of course this fact was indicative of a number of problems found when work is needed in heritage buildings erected with earth, a construction technique that is almost always above the knowledge and technical capabilities of most construction or restoration companies. In order to solve this question, Culture Counselling has decided to assign the reconstruction work by direct invitation, being finally adjudicated to the new company Antaño Restauración. It is important to note that this decision was based, among others, in the fact that the now owner and manager of this company, had previously worked in the restoration of another castle wall built with earth, as construction manager. The proposals and actions in that historical heritage building had resulted in a successful intervention.

Each one of the next phases of intervention in the walls of the citadel had its corresponding project and all of them were drawn by the same architect. In the end, all the reconstruction works have also been in charge of the same company, which obtained the necessary qualifications to be submitted to the public competitions that have been opened for each one of the phases that have been followed.

3.2 *Main difficulties at start*

In late 2002, Antaño Restauración starts with the first activities to prepare the commissioned works. For the company, in addition to study the project is essential to examine in detail the initial conditions in each site, with the objective of developing a good plan towards an efficient performance of all tasks. Particularly important is to identify what will be the main difficulties of the work in each situation. We highlight some of the most significant ones present in this case.

3.2.1 *Access to the citadel*

To access the citadel, vehicles had to cross the urban zone of Reina, with narrow streets and hairpin turns, some with angle lower than 90 degrees, and then ascend in earth track over 700 m, with a steep slope, a scarce width and poorly consolidated slopes at its edges. All this posed a problem for the transport of mechanical media and supplies. To solve this problem, we had to do all transports in small trucks and vans, taking much longer than desirable. The prevision in project was to make use of concrete trucks and tower cranes, among other heavy machinery, that could not be used, for that reason.

3.2.2 *The steepness of the ground surrounding the citadel*

Apart from a small area in the southeast zone, all the ground bordering the wall had a big slope, making hard enough or impossible the movement and putting in place of machinery and auxiliary equipment. In some areas it was possible to flatten out the way for the movement of small machinery. In others, only to set up scaffolding and in this case all the work was made from the inside of the fortress, moving down the materials rather than raise them up. Besides this, it was necessary to place two protective mesh lines on the side and along the entire work area, to sustain any stone that could break off and roll downhill and eventually cause damage to persons or property.

3.2.3 *The implementation schedule of the work*

The deadline for execution of the work was six months, coinciding most of this time with the winter and rainy spring. In this, there was no alternative. Although at the end of each day, the freshly made wall was covered and protected, that did not prevent being necessary to demolish some cubic meters of it, because the mass had frozen.

Figure 3. Working zone on southwest wall. Notice the lack of space for scaffolding mount and for machinery work. See the small crane, working from the interior of the wall.

3.2.4 *Lack of technical expertise in rammed earth*

Although the company already had some technical knowledge and personnel experienced in rammed earth techniques result of previous work, it was not enough to meet this new challenge, because of its magnitude and complexity. This has been fixed by hiring a specialized technician in rammed earth, as a construction manager on site all the time, and doing continuous specific training for workers.

3.2.5 *Lack of archaeological investigations prior to the commencement of the works*

Although a small archaeological excavation that had been previously done, this was not conclusive as to the foundation and limits of the walls and towers. The original trace was not available before the commencement of the reconstruction works.

3.2.6 *Working only on one side of the wall*

Most of the wall to restore was only on one side of its width, which means we had to ram the earth in a different way than usual, which is assembling the formwork to form the two faces of the wall at a time, holding opposing boards each other. In this case we would have to mount the formwork only with the board of the outer face of the wall, since what would be the other board here was the existing wall.

3.2.7 *The point of contact between the top of the new rammed earth with the bottom of the existing wall*

Another difficult issue to resolve was the situation in which the top of the new rammed earth reached the bottom of the existing wall, since in this case there would be no space for tamping.

3.3 *Tasks prior to the work on the wall*

The project clearly posed an intervention of consolidation and restitution. However, some approaches for the implementation of the works posed in the project would not be feasible at all. So, before undertaking work tasks, the company pored over the particular characteristics of this wall, regarding to techniques, materials and construction procedures used in the original construction works. In this way, new solutions were studied and decisions were taken, together with the architect, about how to make the work accessible to the human and technical means available at the moment, but always respecting the old elements and genuine parts. Furthermore, taking the necessary security conditions and making every effort to reach high quality standards. To this end, we also define a set of tasks prior to the reconstruction work, essential to ensure a proper development of the whole intervention process: investigation of the raw materials and the most suitable one, study of the ancient formworks and the best way to upgrade them and analysis of the most efficient ways to tamp the earth.

3.3.1 *Raw material*

With the aim on making the new rammed earth with an appropriate material and compatible with the original wall, we began by requesting to a laboratory some tests of the site's soils. Accordingly with the results, we have prepared a set of samples to determine the mix best suited to the purpose. So, we produced a set of 28 samples of rammed earth, varying in the proportions of soil (from some different sites), lime, sand and gravel in order to choose one, regarding to its colour, texture and strength. The soil of the sample selected by the architect was collected in the base of the hill where the citadel stands, so we had to move it up under the conditions mentioned in Section 3.2.1.

3.3.2 *Formwork*

Making a review in the rammed earth on the wall, we found areas where we could still see the negative of the original formwork. Based on these data, it was possible to know that the original moulds were made of five wooden planks overlapping in vertical position, reaching the height of 85 cm. Using these same dimensions we have made new boards, therefore perfectly adjusted to the metric of the original construction. It was also possible to collect some original rods that were used to hold the boards. From these we have produced, with the same wood species, *quercus ilex*, new rods identical to the original, and we used them to mount the new formwork. Originally, the rods were set in place with some pieces of wood, small wedges

Figure 4. Rammed earth samples, made on site.

with a notch. We also tried to do the same, but we failed to put it into practice efficiently. So the option was to use for that purpose small galvanized iron pieces. This did not alter the traditional construction system as we had also found, in holes in the wall, evidences of the use of iron nails for holding the wood rods, from the time of original construction.

3.3.3 *Tamping*

It was also very important for us to define the most efficient way to tamp the soil. To achieve this purpose we also used the making of the samples, to test different forms of ramming the earth. We tested manual and mechanical means, electric and compressed air systems, also trying to simulate all possible situations of the work on the wall. Finally, it was decided to do a mechanical compaction with an electric hammer adapted for tamping. However, as some parts of the wall would have to be done with manual compaction, we had to draw and make some wooden rammers adapted to the circumstances that we knew we would have.

Figure 5. On centre of this photo, it can be seen in a corner of the rammed earth wall, the negative of the five wooden overlapping planks from the original formwork.

Figure 6. Newly produced formwork and rammers.

3.4 *The works over the past 10 years*

The intervention, developed in 6 phases of project and reconstruction work over the past ten years, included diverse units, such as archaeological investigations, study of the materials, elements and construction systems, search of the original design of the base lines of the walls, stabilization of the ground on the access zones and working areas bordering towers and walls, cleaning the surface of the earth walls and removing disintegrated material and invasive plants, consolidation of areas with structural instability by volumetric restoration of the mass of the towers and walls and protection of its top. All the phases had the same work units.

Phase 1 (12/2002 to 06/2003)—Facing southwest. Consolidation of four towers and four stretches of wall. This phase was completed the following year, 2004, with the restoration of a fifth tower, which closes this section of wall.

Phase 2 (12/2005 to 10/2006)—Facing Southeast. Consolidation of three stretches of wall and two towers. In addition, it was rescued the trace of one stretch of wall, which was imperceptible.

Phase 3 (06/2007 to 11/2008)—Facing northwest. Consolidation of three towers and four stretches of wall, saving them from the state of eminent ruin in which they were late in the twentieth century. Furthermore, the trace has been rescued along all this stretch, putting the walls visually perceptible, as they were under ground.

Phase 4 (11/2008 to 06/2009)—Facing northeast. Four towers, four stretches of wall and one door, have been consolidated.

Phase 5 (04/2009 to 04/2010)—Facing northeast. Consolidation and restoration of the Casa de la Encomienda, two stretches of wall, a tower and a monumental door. Furthermore, the trace has been rescued along all this area, making it visually perceptible. It was also enabled an area in the Casa de la Encomienda as a viewpoint of the landscape.

Complementary phase (06/2010 to 12/2010)—Northeast and northwest areas. Conditioning and soil drainage. Ground has been released from dragged and accumulated dirt in the interior face of the northeast and northwest walls. A drainage system was created in these two areas, so that the rainwater can be properly conducted to the outside of the wall, with the aim to protect it from further deterioration that could be caused by the harmful action of water on the earth walls.

In addition to the intervention we have been presenting, it is important to mention that between April 2007 and September 2008, in this same site took place and experimental program for local employment,

Figure 7. Result of archaeological excavations in *Casa de la Encomienda*. See on left wall the level of deposits before excavations.

Figure 8. Completion of works on northeast walls and towers.

called "Heritage Creates Jobs", resulting from a collaboration agreement between the Economy and Labour Counselling, through the Public Employment Service of Extremadura, and the regional commonwealth of Llerena. The development of this project, drafted by the same architect of the intervention on the walls of the citadel, allowed to rehabilitate and to give a new value to the surroundings of this monument and part of its interior.

The main work units were: improvement of the access road from the town to the citadel, creation of a zone for parking, construction of toilets and bar, creation of inner and outer perimetral paths, reforestation with native low growing species, conditioning of an area in the interior of the citadel to be used as public square, cleaning and restoration of five wells, restoration of coatings and pavements of the chapel, and important archaeological works. This intervention has been a complementary action to the consolidation of the citadel wall, clearly contributing to the enhancement of this unique building of historical heritage, recovered for new uses and converted in an important touristic resource.

4 CONCLUSIONS

When drafting a consolidation or restoration project of any rammed earth building it is very important to consider the particular circumstances of the site and the monument, overlooking the actual execution of the work.

Although companies must address and answer these questions, a number of issues related to the reconstruction works, commonly result in added costs, sometimes high, which had not been budgeted. Apart from this, the databases of construction prices used to prepare the budgets of the projects barely provide valuable information for the specific circumstances of rammed earth walls restoration, with all its variants. On the other hand, public administration authorities usually require terms and conditions of execution of works often not compatible with the real needs of the progress of earth walls restoration tasks. Also, the archaeological works tend to be incomplete and the time needed to effectively carry out their activities is often not compatible with the rhythms of a construction company. Therefore, in works on large-scale monuments, such as this, archaeology should go in advance of the reconstruction work, since their results may lead to introduce significant changes in the execution of the work.

If we do not take care to study the particularities of each situation and accordingly design and plan the execution of work, there is the danger of losing efficiency and quality in the execution of tasks, with the risk that this entails in the proper preservation of historical heritage buildings that are to be preserved, not only as a witness of the past, as well as a projection for the future.

Any intervention in historical heritage buildings should be, above all, respectful with the monument and with the environment, and this applies not only to the work of the architect but also the performance of companies, which involves us in the duty to disclose and bring to discussion the works carried out and the approaches and actions that have made it possible.

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Rammed earth architecture in La Hacienda de Santa Teresa Ixtafiayuca, Mexico

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ABSTRACT: In the state of Tlaxcala remain a significant number of estates built between the XVI and XIX century, which mainly used adobe and rammed earth techniques for their construction. The hacienda, Santa Teresa de Ixtafiayuca, dates from nineteenth century, and stands out as one of the most important examples of mud architecture in the region. It was well-known for the production of *pulque* (an alcoholic drink made from cactus) and agriculture crops of corn, barley and wheat. This structure demonstrates the permanence of earthen construction systems and their vulnerability and protective actions.

1 ASENTAMIENTO DE LAS HACIENDAS

Las haciendas fueron un importante modelo productivo en México durante el periodo del siglo XVI al XIX; la mayoría de ellas asentadas en sitios con existencia y abundancia de recursos naturales, mismos que fueron explotados de manera fructífera; de igual manera se emplearon en muchos de los casos como materiales constructivos para este tipo de espacios en los que prevalece el empleo de materiales pétreos en su composición.

Lo imprescindible para los asentamientos de las haciendas fue el poderío sobre los recursos naturales, la explotación de la mano de obra y la fuerza de trabajo de los habitantes del territorio o aledaños, así como la existencia de mercado local y regional para el consumo de los productos obtenidos.

Las haciendas fueron de vital importancia para el equilibrio económico durante el virreinato en la Nueva España; tanto en el estado de Tlaxcala como en todo el territorio de la República Mexicana, la finalidad de las haciendas durante su periodo de asentamiento y auge fue la obtención de recursos naturales, mismos que sirvieron como materia prima para la producción o para la edificación de las mismas, por lo que era imprescindible la extracción de lo existente para la generación de estas unidades productivas; la abundancia de determinados recursos estableció el tipo de producción, así como el sistema constructivo a emplear, optimizando lo existente en la región, aunque cabe mencionar que en algunas haciendas, los materiales de construcción fueron extraídos de otros sitios; la siguiente tabla muestra la optimización de las recursos naturales existentes.

1.1 *Haciendas en el estado de Tlaxcala*

El asentamiento de las haciendas en la región de Tlaxcala estuvo ligado a los privilegios que la Corona Española les otorgó a destacados soldados como estímulo a su lealtad y por las proezas que pasaron al aliarse en la conquista de Tenochtitlán y algunos otros territorios; sin embargo, los indígenas tlaxcaltecas fungieron como peones en los primeros siglos de asentamiento de estos sitios. Las haciendas edificadas en Tlaxcala durante el virreinato fueron unidades productivas destinadas a la agricultura, la ganadería y de obtención mixta. (José Antonio Terán Bonilla 1996).

Las haciendas en esta región estuvieron conformadas por varias construcciones, respetando el esquema tradicional de casa grande, capilla

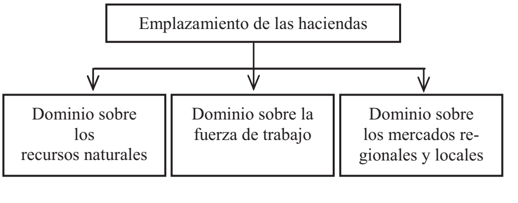

Figura 1. Aspectos primordiales para el asentamiento de las haciendas. Fuente: Nickel Herbert 1996.

Tabla 1. Optimización de los recursos existentes en la región para la construcción de las haciendas.

Recursos naturales	Materiales de construcción obtenidos	Uso en las edificaciones
Tierra	Tapial Adobes Ladrillos Tejas Pigmentos	Construcción de muros Construcción de muros y recubrimiento de cubiertas Cubiertas Aplicación de color en muros Terrado en cubierta
Árboles	Vigas Tablados	Estructura de cubiertas y cerramientos de puertas y ventanas Cubiertas y obscuros de ventanas
Piedra	Lajas Sillares	Rajueleo en muros Labrado en portadas y elementos ornamentales en fachadas e interiores Cimentaciones
Vegetales	Adobes	Fabricación de adobes
Minas (cal, arena)	Cal, arena	Juntas y aplanados en muros, juntas en cimentaciones, juntas de ladrillos en cubiertas, elaboración de pisos y elaboración de adobes
Agua		Juntas y aplanados en muros, juntas en cimentaciones, juntas de ladrillos en cubiertas, elaboración de pisos y elaboración de adobes
Metales	Perfiles	Puertas y ventanas

y calpanerias al cual se le añaden en estos casos principalmente graneros y trojes para el almacenamiento de granos y semillas, sin embargo algunas de estas unidades productivas a partir de la segunda mitad del siglo XVIII se acrecentaron mediante el usufructo del maguey la elaboración de pulque (bebida alcohólica generada a partir de la fermentación del maguey), adaptándose algunas haciendas con la edificación de tinacales a medida de que se incrementó la demanda (José Antonio Terán Bonilla 1996).

Figura 2. Ubicación del estado de Tlaxcala en la República Mexicana.

Por las características físicas y geográficas de la región los materiales y sistemas constructivos que se emplearon son específicos, dando una identidad que muestra el sincretismo de ambas culturas y que hoy en día conforman un legado histórico, entre los que se destaca el empleo del ladrillo, recinto, cantera, tepetate, zacate, madera, tierra arcillosa y adobe entre otros. En la región poniente y norponiente del estado de Tlaxcala se empleó principalmente el adobe y la tapia para la construcción de los muros, el empleo de la tierra cruda fue en gran medida debido a la abundancia de arcillas de excelente calidad, derivadas de la actividad volcánica regional; estos centros productivos son ejemplo de dicho empleo; actualmente se pueden apreciar algunas en perfectas condiciones de conservación, mientras que otras han sido modificadas transformando con ello la lectura arquitectónica afectando su tipología, mientras que otras tantas han perdido su fisonomía, reduciéndose solo a vestigios.

2 HACIENDA SANTA TERESA IXTAFIAYUCA

2.1 *Ubicación de la hacienda de Santa Teresa Ixtafiayuca*

Santa Teresa Ixtafiayuca fue una hacienda pulquera y agrícola cuya edificación corresponde al periodo decimonónica se ubica al poniente del estado de Tlaxcala, en el municipio de Mariano Arista de Nanacamilpa.

2.2 *Sistema constructivo utilizado en Santa Teresa Ixtafiayuca*

En algunas haciendas de la región como la Obra, San Antonio Mazapa y Santa de Teresa Ixtafiayuca se aprecia el sistema constructivo de tapia en los

Figura 3. Ubicación de la Hacienda Santa Teresa Ixtafiayuca en el estado de Tlaxcala, México.

muros, sin embargo esta última es el caso más notable debido a que la presencia de tapia es evidente en la mayoría de las construcciones.

El sistema constructivo empleado para esta hacienda consiste en muros de tapia cuya cimentación es a base de piedra de la región, muro de tapia con encofrado de adobe y cubierta de terrado con vigas de madera, no obstante, cabe mencionar que en las intervenciones que ha tenido no se ha usado este mismo sistema, se han empleado materiales industrializados y modernos.

Esta hacienda es un ejemplo digno de analizar y estudiar puesto que en sus componentes se hallan diferentes estados de conservación de tapia, dado que la casa grande, cuyo edifico se encuentra completo y en optimo estado de preservación, se aprecia la presencia de este sistema constructivo, mismo que por el hecho de mantenerse conservado está en perfecto estado, no obstante, los edificios aledaños a la casa grande presentan deterioros y alteraciones en su composición, afectándose los muros principalmente por la pérdida de cubiertas y la falta de trabajos de mantenimiento y conservación, influyendo considerablemente el abandono y desuso de estos espacios.

2.3 *Antecedentes históricos de Santa Teresa Ixtafiayuca*

La hacienda de Santa Teresa de Ixtafiayuca se erigió a principios del siglo XIX tuvo como principal actividad la producción de pulque. En el año de 1860 Santa Teresa de Ixtafiayuca poseía 3500 hectáreas que eran utilizadas para cultivar maguey, trigo, maíz y cebada, siendo estos productos agrícolas los principales para la labor económica de la hacienda, ya que de la cosecha del maguey se adquiría la cantidad de 250 barriles con una capacidad de 250 litros cada barril al día; es decir, se obtenían 62,500 litros diarios, mismos que eran trasladados por medio de ferrocarril a la Ciudad de México, sin embargo su extensión territorial se vio afectada casi un siglo después.

Figura 4. Muro de tapia en la fachada norte de la fachada de la casa grande. Imagen de autor.

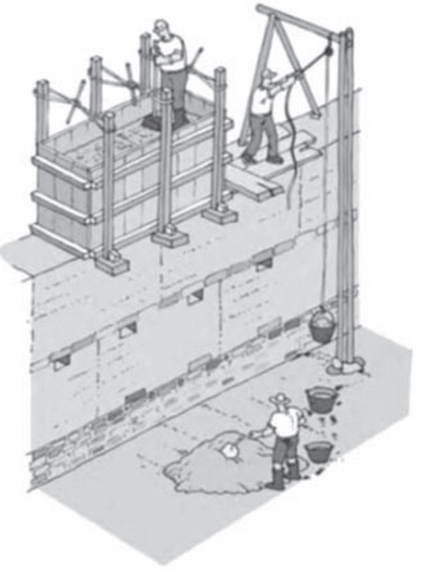

Figura 5. Sistema constructivo de tapia en muros, empleado originalmente en la hacienda de Santa Teresa Ixtafiayuca. Fuente: *Manual para la Rehabilitación de viviendas construidas en adobe y tapia pisada*. 1999.

Para 1950 la hacienda fue confiscada quedando únicamente con 25 hectáreas de extensión para la producción agrícola y solamente seis hectáreas que conformaban el casco, lo que originó la disminución en la producción pulquera y por ende su decadencia por la escasez de terrenos para cultivo; por lo que posteriormente concluyó con la producción agrícola y pulquera. Años más tarde y debido a la merma económica se fue transformando su composición de manera paulatina con la finalidad de poder tener un sustento económico, con lo cual se acondicionaron algunas habitaciones para ofrecer alojamiento a ciertos huéspedes y de

Figura 6. Estados de conservación de distintos espacios componentes de la hacienda. Imágenes de autor.

esta manera obtener recursos económicos para su manutención. (H. Ayuntamiento de Nanacamilpa, Tlaxcala, 2011).

2.4 *Descripción arquitectónica de Santa Teresa Ixtafiayuca*

La disposición arquitectónica de la hacienda es muy similar al prototipo representativo de estas unidades productivas dedicadas a la extracción de pulque, no obstante la lectura de este espacio no se puede hacer en su totalidad ya que no se encuentra completa.

El núcleo de la casa grande cuenta con la capilla y patios (principal y servicios); el cuadrilátero irregular que conforma el conjunto se encuentra delimitado por cuatro torreones ubicándose en sus vértices estos elementos semicirculares, la casa grande y la capilla del Señor de Ixtafiayuca están alineadas a la fachada sur (principal), donde se enfatiza el acceso principal con un pórtico que en la planta alta acoge la terraza; únicamente la casa principal se compone de dos plantas, mientras que la sección aledaña a esta únicamente cuenta con un nivel. (Catálogo de Monumentos Históricos Inmuebles del Estado de Tlaxcala, INAH).

El conjunto conformado por la casa grande se encuentra delimitado por una barda perimetral; en la fisonomía de la fachada principal destaca el volumen correspondiente a la capilla dado que este rompe la horizontalidad del conjunto mediante sus dos torres campanario que alteran la planimetría característica de la fachada, permitiendo con ello un sutil juego de volúmenes que se complementan con matices de luces y sombras propios de las formas.

En la fachada sur predomina el macizo sobre el vano, con aberturas verticales en proporción 1:2 destinados a ventanas principalmente, mientras que los accesos son de mayor dimensión, pero respetando dicho orden; la fachada de la Capilla

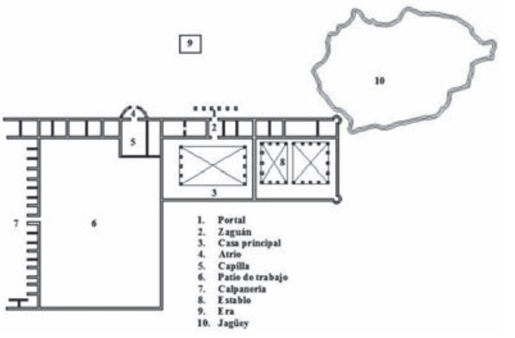

Figura 7. Planta arquitectónica de la hacienda Santa Teresa Ixtafiayuca. Fuente: *Catálogo Nacional de de Monumentos Históricos Inmuebles*, 1994.

Figura 8. Capilla del señor de Ixtafiayuca. Imagen de autor.

Figura 9. Fachada sur (principal) de la casa grande de Santa Teresa Ixtafiayuca. Fuente: H. Ayuntamiento de Nanacamilpa, 2011.

posee ornamentos en argamasa que le dan un detalle distintivo.

La fachada norte (posterior) es casi en su totalidad un muro ciego, únicamente cuenta con un acceso; en esta sección se logra apreciar el muro de tapia con pérdida de aplanados y de policromía.

Figura 10. Fachada posterior de la casa grande de la hacienda. Imagen de autor.

Figura 11. Interior de la casa grande. Fuente: H. Ayuntamiento de Nanacamilpa, 2011.

En 2009, la Sociedad Defensora del Tesoro Artístico de México, fundada en el año de 1964 le otorgó un reconocimiento por su labor de rescate y de conservación.

2.5 *Estado de conservación actual de la hacienda*

Actualmente la casa grande de la hacienda y la capilla se encuentran conservadas casi en la totalidad de su fisonomía, teniendo únicamente adaptaciones de manera parcial para los nuevos usos que se ha dado a este espacio; no obstante, sus muros muestran su temporalidad y sistema constructivo empleado; aunque ha tenido algunas intervenciones actuales con materiales industrializados poco compatibles con los materiales pétreos no ha tenido alteraciones significativas.

Como parte de la misma hacienda, cerca de la casa grande se localiza un núcleo de construcciones que probablemente fueron la troje, graneros y calpanerias cuyos muros están en estado ruinoso y las cubiertas se han perdido en su totalidad pero lo interesante de estos vestigios es analizar el estado de conservación del tapial, ya que se halla en perfectas condiciones y los muros compuestos de este sistema constructivo no muestran mayor deterioro.

La erosión de estos muros es más evidente en los cerramientos y encofrados en los que se utilizó adobe, es decir, se aprecia visiblemente que el adobe se ha deteriorado más que la tapia, en la que únicamente se nota la pérdida de aplanados y ligera disgregación del material.

El sistema constructivo de tapia empleado en la hacienda fue a base de tierra arcillosa de la región conformando muros con un espesor variable de 0.40 a 0.80 m; en las trojes y graneros se localizan los muros con menor grosor, mientras que en la casa grande y capilla el espesor de los muros es mayor.

Analizando el estado de conservación de los muros de tapia con los encofrados de adobe, se toma como referencia el texto de Gernot Minke,

Figura 12. Estado de conservación de muros de tapia con cerramiento de adobe. Imágenes de autor.

en el que hace mención al respecto, al referir que el uso del tapial proporciona una contracción considerablemente más baja, además de tener mayor resistencia; el beneficio que se obtiene con este sistema constructivo consiste en su composición monolítica, lo que le permite trabajar de manera contigua brindando mayor estabilidad. (Minke Hernot 2001).

Lo anterior permite un importante razonamiento propio para esta unidad productiva, ya que muestra que a pesar de la falta de trabajos de conservación, este sistema constructivo ha trabajado de manera adecuada para la preservación de determinados espacios de la hacienda, además de ser sugerente para la restauración y recuperación de las edificaciones deterioradas que se encuentran en estado ruinoso.

Lo interesante de analizar el estado de conservación de distintos fragmentos de muro de tapia en la misma hacienda permite analizar cuáles son las ventajas y desventajas, además de los trabajos de preservación que le han permitido mantenerse y con ello nos damos cuenta que los enemigos de estos muros cuyo sistema constructivo empleado para su composición han sufrido deterioros debido al abandono que los deja en total vulnerabilidad, además de la pérdida de cubiertas así como la presencia de humedades, principalmente

Figura 13. Estado de conservación de muros de tapia con adobe. Imagen de autor.

Figura 14. Distintos estados de conservación de construcciones de tierra. Fuente: Manual para la Rehabilitación de viviendas construidas en adobe y tapia pisada, 1999.

por capilaridad y por absorción, erosionando el material y debilitando la estructura.

La relevancia de la investigación de esta compleja construcción es primeramente su antigüedad y el valor histórico que representa, pero por otro lado, su estado de conservación el cual nos permite conocer las distintas facetas de un sistema constructivo tan bondadoso como lo es el tapial. Asimismo, su fisonomía es importante como ejemplo para las comunidades que cada vez emplean menos los materiales naturales que han sido desplazados por los industrializados, haciéndoles generar conciencia acerca del valor de este material y lo productivo que puede resultar.

El aspecto general en la actualidad permite la lectura del comportamiento de los muros de tapia, mostrando en la realidad una imagen de la publicación colombiana llamada *Manual para la Rehabilitación de viviendas construidas en adobe y tapia pisada,* la cual se muestra a continuación y nos pone como ejemplo la diferencia entre un inmueble que se descuidó y está en total abandono contra uno que se ha mantenido rehabilitándose paulatinamente.

Figura 15. Distintos estados de conservación en muros de tapia de la hacienda Santa Teresa Ixtafiayuca. Imagen de autor.

En la imagen anterior se pueden ver distintos estados de conservación en la arquitectura de tapia, mismos que en hacienda de Santa Teresa Ixtafiayuca están presentes en algunos de los espacios que la componen, mostrando diversas apariencias de este sistema constructivo.

Ello nos da el punto de partida para observar los distintos estados de conservación de la arquitectura de tapia en esta unidad productiva y analizar las causas del deterioro, las cuales van encaminadas principalmente al abandono, falta de trabajos de conservación, pérdida de cubiertas y presencia de humedades; no obstante, la estructura que se halla completa permite comprobar que este sistema constructivo es viable y óptimo para la región; por lo que lo recomendable es la restauración y recuperación de las estructuras que se encuentran en estado ruinoso, por medio de métodos y sistemas que han sido viables en otras estructuras con estas características; enfatizándose además que este sistema constructivo puede ser empleado para edificaciones.

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Restoration of the gypsum wall built with formwork in the tower of the castle of Villel (Teruel, Spain)

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ABSTRACT: The tower of the castle, in the municipality of Villel (Teruel), was built in the Middle Age, previous to the 11th century, with the technique of "*tapia de yeso*". The tower has survived until present, but in a state of regrettable conservation and generalised ruin. In 1989, landslides damaged buildings and roads of the municipality, and because of this, the Administration decided to carry out the necessary interventions on the tower for visitor safety. Among the number of distinct possible options to resolve the problem, the Administration decided to restore the tower using the same techniques and materials with which it was built.

1 INTRODUCCIÓN

El castillo de Villel se emplaza en la cima de una colina que domina el valle del río Turia a su paso por el municipio, y bajo ella se desarrolla el núcleo urbano junto al río (Figs. 1–2).

Villel en la Edad Media perteneció al reino de Albarracín. En 1099 lo ocupó El Cid, perteneció a las órdenes militares del Santo Redentor y del Temple y fue zona fronteriza con el vecino Reino de Valencia. En 1810 fue escenario de las acciones bélicas de los combates entre las tropas de Napoleón y el guerrillero Villacampa, en las que el castillo tuvo un importante protagonismo.

Figura 1. Fotografía aérea con el castillo en lo alto del cerro y el núcleo urbano en la parte baja de sus laderas junto al rio.

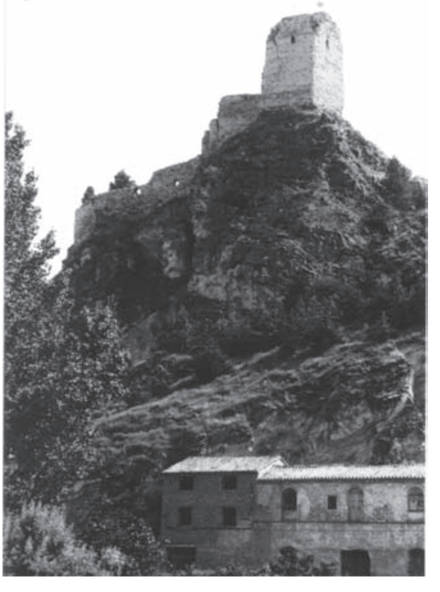

Figura 2. Recinto amurallado y torreón en lo alto del cerro.

El recinto amurallado ocupa una superficie de 1300 m^2 con unas dimensiones aproximadas de de 45 m × 30 m. Dispone de una configuración muy compleja en la que destacan el torreón principal o torre del homenaje, el patio de armas con un aljibe, y restos de numerosas construcciones en su perímetro a distintos niveles adaptándose a la gran pendiente de su topografía.

El torreón se sitúa en el vértice oeste del recinto, en su parte más alta y de difícil acceso. Tiene una planta trapezoidal con unas dimensiones aproximadas de 8.30 m × 6.70 m y una altura de 16 m. Interiormente está dividido en tres niveles o plantas superpuestas con muros perimetrales de espesor decreciente de 2.40 m, 1.90 m y 1.40 m respectivamente en cada una de las plantas (Figs. 3–6).

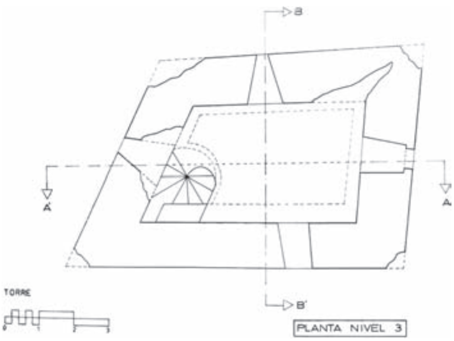

Figura 3. Planta del torreón.

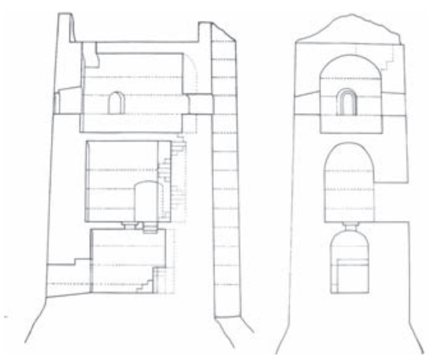

Figura 4. Secciones del torreón.

Figura 5. Torreón de tapia de yeso.

Figura 6. Interior del torreón.

2 ESTADO DE CONSERVACIÓN DEL RECINTO AMURALLADO

La necesidad de intervenir en el castillo de Villel para acometer obras de consolidación se vio en el año 1989 al producirse desprendimientos de piedras del castillo sobre las edificaciones de la población situadas a sus pies y sobre la carretera, lo que obligó a plantear el estudio y ejecución de las obras o demoliciones necesarias para evitar nuevos desprendimientos y garantizar la seguridad de las edificaciones y las personas.

El recinto amurallado se encontraba en un estado de ruina generalizada total debido a su abandono, a los conflictos bélicos ya citados, a la climatología y a haber servido de cantera para la construcción de edificios del pueblo.

De su perímetro exterior sólo se conservaban pequeños tramos de muralla, su interior estaba lleno de escombros, piedras y tierras, con restos emergentes de algunos muros, y un aljibe hundido excavado en el terreno.

El torreón había perdido prácticamente en su totalidad la piel exterior, tenía importantes pérdidas en la masa de sus muros, sobre todo en su parte superior, con grandes grietas que habían roto la unión y continuidad de sus muros, poniendo en riesgo su estabilidad.

Los muros estaban sufriendo un proceso de erosión y degradación progresivo debido a que la pérdida de su extradós había dejado expuesta a las inclemencias meteorológicas su masa interna, dando lugar a una gran erosión progresiva causada por la irregularidad de su superficie expuesta que facilitaba las filtraciones al interior de su masa, la acumulación de agua de lluvia, de nieve, las heladas y las erosiones por el lavado de la masa y el viento.

3 TÉCNICA CONSTRUCTIVA Y MATERIALES DEL TORREÓN

El torreón se había construido utilizando la técnica de construcción en tapia con la singularidad de que ésta, en lugar de ser de tierra estaba realizada con "yeso".

En el exterior de uno de sus lados, el menos erosionado, todavía podían apreciarse las huellas que habían dejado en su superficie las hiladas de los tapiales de madera o encofrados con que se habían levantado sus muros. En las estancias interiores las huellas de las juntas de los tapiales se apreciaban con toda claridad.

La masa que conformaba los muros estaba constituida por un conglomerante de granulometría muy fina de color blanco y piedras de tamaño muy variable dispuestas de forma muy heterogénea en su interior.

El conglomerante por su textura y aspecto exterior indicaba que podía tratarse de yeso, y para confirmarlo se hicieron ensayos de cuatro muestras significativas de los morteros existentes procedentes del intradós, del extradós y del interior de la masa de los muros.

Los resultados de los ensayos de todas las muestras fueron prácticamente coincidentes y, a partir de ellos, se dedujo su composición que era de yeso con un índice de pureza del 93% y un contenido de cal del 4.65% (Fig. 7).

4 NECESIDAD DE INTERVENIR EN EL TORREÓN Y MANERA MÁS ADECUADA DE HACERLO

Una vez obtenida la información necesaria sobre el recinto amurallado y en particular de su torreón,

DETERMINACIÓN DE	Mortero 1	Mortero 2	Mortero 3	Mortero 4
Agua combinada (%H2O)	18,1	20,2	19,0	15,6
Contenido sulfatos (%SO3)	41,2	42,3	43,5	45,9
Resíduo insoluble (%)	3,0	0,8	2,0	1,5
Contenido sesquióxido (%R2O3)	1,1	0,5	0,9	0,9
Contenido calcio (%CaO)	31,3	33,1	32,0	33,1
Contenido carbonatos (%CO2)	1,8	1,6	1,5	1,5
TOTAL	96,5	98,5	98,9	98,5

Figura 7. Resultados de los análisis de las cuatro muestras del conglomerante.

conocidas sus características, tipología y técnica constructiva, materiales que lo componen, los problemas y daños que presenta, y las causas de los mismos, la Administración se planteó cómo conservarlo, para recuperar su identidad y ponerlo en valor como el recurso patrimonial más importante del municipio con el que se identifiquen sus habitantes, con los siguientes objetivos:

1. Garantizar su pervivencia, prolongando su existencia como referente e hito del municipio.
2. Recobrar en la medida de lo posible sus valores deteriorados.
3. Posibilitar que fuese accesible y visitable.

El primero de los objetivos obligó a estudiar medidas relativas al mantenimiento de la estabilidad del torreón y paralización de su proceso de degradación y erosión superficial. Para ello cabía plantear dos tipos de intervención:

1. Demoler las partes superiores descompuestas y más ruinosas del tercer nivel, saneando y consolidando el resto, lo que suponía mutilarlo y aceptar que había agotado su existencia manteniendo las partes conservadas como restos de una ruina arqueológica consolidada.

   Esta opción presentaba el problema de cómo acometer la consolidación de la superficie exterior de yeso de los muros, material muy higroscópico, que además presentaba una superficie muy heterogénea e irregular que facilitaba las filtraciones y acumulación de agua.

   Por otra parte, debía sanearse obligatoriamente la superficie de los muros en toda su altura y estudiar los materiales más adecuados, compatibles con el yeso y que se adhieran al mismo, para utilizar en las reintegraciones volumétricas necesarias para evitar el estancamiento del agua.

   Inevitablemente la imagen final resultante del torreón variaría sustancialmente respecto a la actual, y sería muy próxima a la de una falsa ruina.
2. Plantear la opción de reponer la piel o extradós desaparecido de sus muros empleando la técnica y materiales de la construcción en tapia de yeso con la que se había construido, asumiendo la nueva imagen que se iba a producir, la cual, aunque supusiera un cambio sustancial con respecto a la preexistente, estaría más próxima a la original que a la falsa ruina de la otra opción.

   Esta solución resolvía muy bien los problemas causados por el estancamiento del agua, ya que al reponer la superficie lisa de la superficie exterior de los muros, se facilitaba la escorrentía sin estancamientos.

   Esta opción aportaba además el valor añadido de recuperar la olvidada técnica constructiva de la tapia de yeso.

Para reponer el extradós no pareció adecuado ni respetuoso con el edificio utilizar morteros de cemento ni hormigones cuyo resultado técnico además habría sido dudoso dados sus problemas de retracción y de adherencia sobre los yesos, y de posibles sales solubles.

5 PROCESO DE LA RESTAURACIÓN DE LA TAPIA DE YESO

Como los muros construidos utilizando la técnica de la tapia de yeso habían perdurado más de 8 siglos, se decidió que la solución más adecuada para su restauración sería reponer la masa del extradós que faltaba con el mismo conglomerante con que estaban construidos, yeso con cal, utilizando la obtenida de los análisis de su composición ya realizados. La durabilidad y garantía de esta técnica era la pervivencia del torreón.

Con esta decisión se resolvía el problema de compatibilidad y adherencia entre los nuevos materiales y los preexistentes ya que iban a ser los mismos.

No se conocían antecedentes sobre experiencias en consolidaciones de muros de tapia de yeso, pero la opción de utilizar esta desaparecida técnica en los mismos muros construidos con ella, tiene su paralelismo en la restauración de lienzos de murallas de fábrica de piedra utilizando también piedra.

Se fabricaron los encofrados o tapiales de madera con las mismas dimensiones que tuvieron originalmente ya que se conservaban sus juntas en el interior del torreón y parcialmente en el exterior.

Respecto al cambio de imagen que iba a producir la intervención, un aspecto importante a considerar era el color, pues aunque el yeso de la zona como material de construcción es de color blanco, la superficie del torreón a lo largo de los siglos había adquirido una patina superficial de color ligeramente terroso.

Se optó por envejecer artificialmente el nuevo yeso tratando de reproducir la tonalidad de la patina existente realizando numerosas muestras con colorantes de naturaleza mineral (Fig. 8).

La dosificación final del conglomerante utilizado fue de 94% de yeso, 4.85% de cal, 1% de color sombra natural y 0.15% de color almagre natural.

En la unión de la tapia vieja con la nuevo se dispuso una malla de fibra de vidrio anclada con conectores de acero inoxidable como elemento diferenciador de los conglomerantes viejo y nuevo y como armado del nuevo conglomerante para minimizar las fisuras de retracción y facilitar la adherencia entre ambos (Figs. 9–10).

El espesor del extradós repuesto en algunos lugares alcanzó un espesor de 40 cm, y en previsión de que pudiera necesitar características resistentes se realizaron varios ensayos físicos y mecánicos para conocer la resistencia del nuevo yeso a utilizar (Figs. 11–12).

Figura 8. Muestras de yeso envejecido artificialmente.

Figura 9. Malla de fibra de vidrio y tapia de yeso nueva.

El primer ensayo se hizo utilizando la norma UNE 102.031 "Yesos y escayolas de construcción. Métodos de ensayos físicos y químicos" creada para conocer las características de los yesos para la construcción de falsos techos, enlucidos, escayolas, etc., pero que establece la forma de hacer ensayos de resistencia de esos yesos.

Los resultados de la resistencia media a flexotracción de la dosificación establecida fueron de 27.5 kp/cm^2 lo que supone una resistencia a compresión media de 66.9 kp/cm^2. La relación agua/conglomerante utilizada fue de A/Y = 0.8 (Fig. 13).

Figura 10. Malla de fibra de vidrio y tapia de yeso nueva.

Figura 11. Vano en proceso de restauración con volumen importante de tapia a reponer.

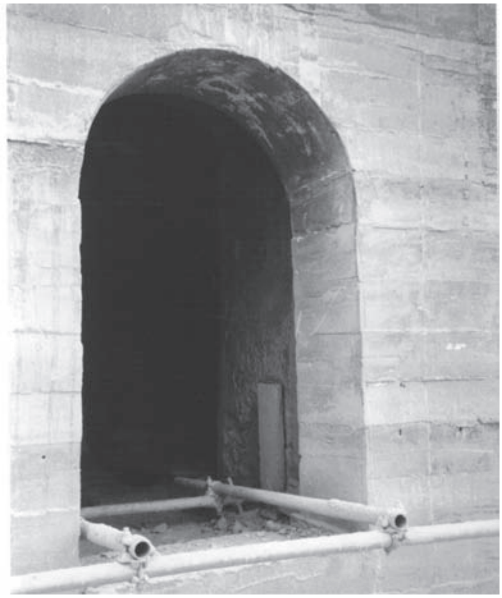

Figura 12. Vano restaurado.

2.1.- MUESTRA Nº 2 A/Y = 0,8

2.1.1.- Resistencia mecánica a flexotracción:

Yeso "mateos" A/Y=0,8	Resistencia a compresión (Kg/cm2)				
	Probeta 1	Probeta 2	Probeta 3	Media amasada	Media muestra
Amasada A	28,0	28,0	28,0	28	
					27,5
Amasada B	28,0	26,5	25,5	26,5	

2.1.2.- Resistencia mecánica a compresión:

Yeso "mateos" A/Y=0,8	Resistencia a compresión (Kg/cm2)						
	Probeta 1		Probeta 2		Probeta 3		Media
	mitad a	mitad b	mitad a	mitad b	mitad a	mitad b	
Amasada A	72,5	68,4	72,5	69,7	73,8	71,9	
							66,9
Amasada B	60,6	65,0	63,1	65,0	61,2	59,4	

Figura 13. Resultados de ensayos con relación A/Y = 0.8.

Aunque esa resistencia podría ser suficiente para las necesidades planteadas, se investigó sobre la forma de conseguir una masa de mayor resistencia sabiendo que la forma de lograrlo es reducir la cantidad de agua.

Para ello se estudió la relación agua/conglomerante con la menor cantidad de agua que podía utilizarse en el vertido del nuevo yeso en el interior de los tapiales. La relación mínima quedó establecida en A/Y = 0.526 y con ella se obtuvo una resistencia media a flexotracción de 47.0 kp/cm^2 y a compresión de 153.6 kp/cm^2 (Fig. 14).

Finalmente, para facilitar el trabajo de vertido del yeso, se optó por utilizar una relación agua/conglomerante de A/Y = 0.533 (Fig. 15).

2.2.- MUESTRA Nº 2 A/Y = 0,526

2.2.1.- Resistencia mecánica a flexotracción:

Yeso "mateos" A/Y=0,526	Resistencia a compresión (Kg/cm2)				
	Probeta 1	Probeta 2	Probeta 3	Media amasada	Media muestra
Amasada A	48,0	46,0	45,0	46,5	
					47,0
Amasada B	49,0	46,0	47,0	47,5	

2.2.2.- Resistencia mecánica a compresión:

Yeso "mateos" A/Y=0,526	Resistencia a compresión (Kg/cm2)						
	Probeta 1		Probeta 2		Probeta 3		Media
	mitad a	mitad b	mitad a	mitad b	mitad a	mitad b	
Amasada A	159,4	170,9	140,9	155,3	152,2	154,1	
							153,6
Amasada B	156,2	158,4	151,9	149,1	149,7	144,4	

Figura 14. Resultados de ensayos con relación A/Y = 0.526.

2.1.- Resistencia mecánica a flexotracción:

Yeso "mateos" A/Y=0,533	Resistencia a compresión (Kg/cm2)				
	Probeta 1	Probeta 2	Probeta 3	Media amasada	Media muestra
Amasada A	42,0	47,5	45,4	45	
					45,0
Amasada B	46,5	46,0	40,5	44,5	

2.2.- Resistencia mecánica a compresión:

Yeso "mateos" A/Y=0,533	Resistencia a compresión (Kg/cm2)						
	Probeta 1		Probeta 2		Probeta 3		Media
	mitad a	mitad b	mitad a	mitad b	mitad a	mitad b	
Amasada A	145,0	156,6	144,1	153,4	150,0	151,2	
							148,7
Amasada B	151,2	145,9	146,9	143,8	145,3	150,6	

Figura 15. Resultados de ensayos con relación A/Y = 0.533.

Esta resistencia a compresión de alrededor de 150 kp/cm^2 es semejante a las que se obtiene con hormigones de cemento fabricados manualmente en las obras sin controles de producción.

El resultado final una vez realizada la intervención respondió a las previsiones realizadas antes del inicio de las obras (Fig. 16).

La conclusión más importante de esta intervención, por tratarse de una experiencia basada en el empleo de técnicas y materiales tradicionales ya olvidados, es que el yeso es un material que se utilizaba y puede seguir utilizándose en el exterior de las construcciones como conglomerante de muros resistentes, lo que resulta muy sorprendente en la

Figura 16. Torreón de tapia de yeso restaurado.

época actual en la que el material de construcción por excelencia es el cemento que ha relegado al yeso a la situación de un material secundario residual utilizado sólo en el interior de los edificios, y que su resistencia puede alcanzar a la de los hormigones con la salvedad de que se trata de un material higroscópico.

Las obras de restauración de la tapia de yeso del torreón de Villel se realizaron en el año 1995, y desde entonces no se ha realizado ninguna labor de conservación salvo unos trabajos de mantenimiento de la cubierta en el año 2010.

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Rammed earth floors in historic orangeries and greenhouses—Belvedere castle in Weimar, Germany

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ABSTRACT: Up until the 20th century, rammed earth floors were most commonly used for agricultural buildings, barns and storages but also for greenhouses and orangeries in historic parks and gardens. The replacement of traditional rammed earth floors with "contemporary" concrete floors in the 1960–1980 ies made it possible to use heavy machinery for transportation and sprinkling devices for plant watering. In Germany, there are several examples of a return to the original flooring: in some historic gardens the concrete floors have been or will be replaced with rammed earth, the authentic historic material. A case study provides information on the reconstruction of rammed earth floors in the historic orangeries of the Belvedere castle in Weimar, the former summer residence of the Grand Duke of Saxony-Weimar-Eisenach. This historic building is part of the UNESCO World Heritage list and a return to the authentic "rammed earth" flooring material is accordingly of great interest and serves as an example for similar future projects.

1 INTRODUCTION

The rammed earth technique is usually associated with earthen walls made with appropriate shuttering. But the same technique has also been used for the construction of rammed earth floors as a primary element of buildings for hundreds if not thousands of years. Rammed earth floors are bounded by the surrounding vertical walls of the building.

Rammed earth floors were used in buildings with different functions: residential houses as well as agricultural and public buildings. Traditional residential houses usually had storage cellars beneath the ground floor. The cellar floors were made of rammed earth creating an optimal indoor climate for storing vegetables and potatoes during the winter period. A compacted layer of gravel was put directly on the levelled ground as a barrier preventing the rise of moisture from the ground through capillary action but enabling the vapour to pass through the gravel. The rammed earth floors were then laid directly on the gravel layer, with thicker floors being made of several layers of earth each compacted individually. Rammed earth floors are vapour permeable and help create an indoor climate with a constant, optimal level of air humidity that ensures garden produce stays fresh.

Nowadays, the year-round availability of fresh vegetables, fruit and potatoes in supermarkets means that storage cellars with vapour permeable floors are no longer required. "Modern" cellars are therefore constructed as concrete floors that incorporate moisture barriers to prevent vapour transfer from the subsoil to indoors.

Orangeries and greenhouses were buildings that typically belonged to castles and park ensembles during the baroque period up until about 1880 and are found predominantly in Central Europe. They were used as winter storage for tropical, frost-sensitive plants which were presented in the parks during the summer. Originally, the orangeries and greenhouses were provided with rammed earth floors because this was the usual technique and "adequate" for gardening purposes. But in the second half of the 20th century, traditional manual gardening work was gradually replaced by mechanised techniques that used heavy machinery for transportation and sprinkling devices for plant watering. For this new machinery, floors needed to have more durable mechanical properties: floors that can sustain greater pressure and resist erosion.

In Germany, there have been several examples in the last two decades of a return to the original flooring material: in some historic gardens, such as in Schwetzingen (1996), Großsedlitz (1996) and Potsdam-Babelsberg (2010), the concrete floors of the orangery buildings have been replaced with rammed earth, the authentic historic material. In summer 2012, the concrete floor of the orangerie of the Belvedere Castle in Weimar will also be replaced with a rammed earth floor as part of general conservation works.

There are three reasons for this development:

– The gardeners are convinced that rammed earth floors will contribute to a better indoor climate compared with the existing vapour impermeable concrete floors. This climate has a more constant level of air humidity due to the earthen floor's ability to "buffer" humidity levels. This is useful for the plants, although its effect on the plants during the storage season has not been investigated up until now.
– The historical authenticity of materials used for the conservation of monuments has acquired greater significance in the light of the principles of the conservation of building monuments issued by ICOMOS (Petzet 2009). However, authentic historic materials do not always meet the requirements of contemporary building materials with regard to parameters such as strength, durability, homogeneity etc.
– Generally, public interest in the conservation of historic monuments is increasing. This includes preserving the building in the first place, maintaining a maximum degree of authenticity when used for its original function or sensitively accommodating a new function for example when used as locations for museums, exhibitions, music and the arts.

A return to using rammed earth floors in historic orangeries is a special kind of "authenticity" with its own set of problems, most notably its instability in "modern" use: spilt water from sprinkling water devices and the subsequent pressure of heavy transportation machinery will rapidly damage earthen floors. As a result, the interval at which repair works need to be carried out will be much shorter than with concrete floors: typically within about ten years.

The Belvedere Castle in Weimar represents an example of the Rococo architectural period in Germany. Today, this castle belongs to the Weimar Classic Foundation which manages all historical locations in the city of Weimar connected with the famous German poets Goethe, Schiller, Wieland and Herder, who together represent the period of "Classical German Literature" in the 18th and 19th centuries. In 1999, this historic building ensemble became part of the UNESCO list of World Cultural Heritage, which also includes the legacy of the Bauhaus period in the early 20th century.

2 CURRENT SITUATION

The Belvedere castle lies 2 km to the south of the city of Weimar and was built between 1730 and 1760 as summer residence for the Grand Dukes of Saxony-Weimar-Eisenach. Figure 1 shows a historical plan of the castle including the parks, gardens and the horseshoe-sized orangerie buildings to the west of the castle. Figure 2 shows a plan of the current situation of the orangerie buildings. The original use of rammed earth for the floors is confirmed by an aquarelle painted in 1836 by C.W. Holdermann showing a view from the festive decorated northern pavilion into the northern oval house with a rammed earth floor covered by a thin layer of sand (Fig. 3) (Ahrendt 1993).

At a later date, the rammed earth floors were replaced by concrete floors as a response to the new technical developments in plant watering and transportation. In 1994, the concrete floors were again replaced with rammed earth floors in order to create a more authentic indoor situation and to improve the indoor climate for the plants during the storage season. Part of the floor of the northern oval house next door to the gardener's house was covered with concrete tiles for storing the collection of historical coaches.

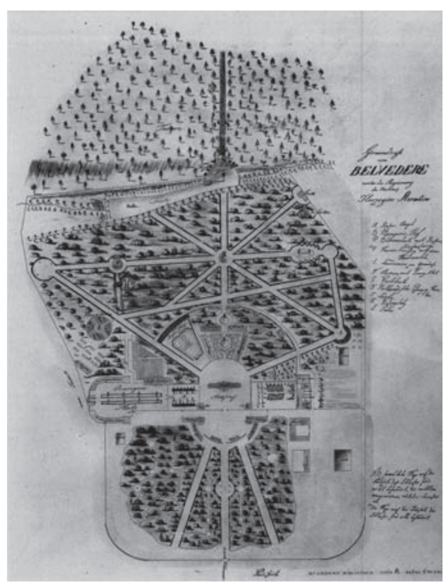

Figure 1. Historic plan of Belvedere Castle with park and orangerie.

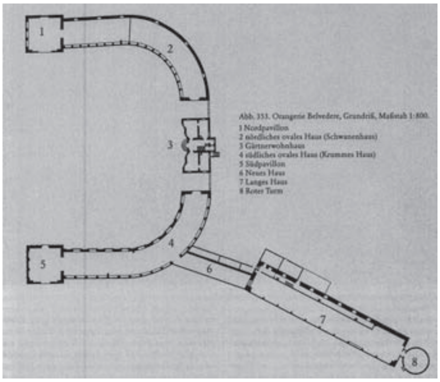

Figure 2. Plan of the Belvedere Orangerie, current situation.

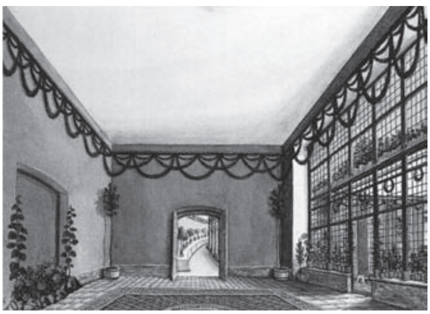

Figure 3. Festively decorated northern pavilion of the orangerie showing the rammed earth floor covered with sand in the northern oval house (aquarelle by C.W. Holdermann, 1836).

Figure 4. Current situation of the rammed earth floor, northern pavilion and northern oval house, Belvedere Orangerie, September 2011.

Figure 5. Current situation of the rammed earth floor showing a regular network of cracks with tyre prints caused by heavy forklift loaders, northern oval house, Belvedere Orangerie, September 2011.

In 2010, a project financed by the Federal Ministry of Culture (UNESCO projects) and the state of Thuringia for the renovation and repair of the orangery buildings was started which included the repair of the existing rammed earth floors from 1994. The "UNESCO World Heritage monument" status requires that the Belvedere Castle is maintained on an ongoing basis, paying special regard to appropriate conservation methods and the use of authentic building materials (Petzet 2009).

Figure 4 shows the situation of the floors in the northern house of the orangerie in September 2011 during the repair works on the building's outer envelope. The pattern of damage shown in Figure 5 is typical for the inappropriate use of rammed earth floors over the last few years: after plants are watered by a sprinkling device, the rammed earth floors are wettened and become soaked. Driving over this floor with heavy forklift loaders bearing large plant containers damages the floor, as documented by the impression of the pneumatic tyres in the floor.

It also seems that the soil mixture used for the existing rammed earth floors was not optimal, that is the clay/silt content was too high resulting in a regular network of cracks that are more then 10 cm deep and in places wider than 1 cm. When water falls on the floor when watering plants, these cracks act like "drinking" gulleys, allowing water to soak into the depth of the floor.

3 PLANNING AND CONSTRUCTION OF THE RAMMED EARTH FLOORS

3.1 *Function*

The requirements for the use of the rammed earth floors in the orangerie buildings were laid out as follows:

– Mechanical stability under heavy applied load resulting from heavy transportation machinery (heavy forklift loaders with plant containers etc.).

– Hydraulic stability when exposed to water from plant sprinklers (and under load).
– Mechanical stability when used for public events (exhibitions, presentations etc.).

The "recommendations" (Schroeder 2011) comprises information for the reconstruction, maintenance and repair of rammed earth floors for the orangerie buildings of the Belvedere Castle.

3.2 *Rammed earth mixture*

Rammed earth floors consist of horizontal layers of a rammed earth mixture applied to the whole floor area up until the surrounding vertical walls. Each layer is poured as a loose and moist earth mixture which must then be *mechanically compacted*, a process that expels the air from the voids in the material. In its compacted state, the overall volume of the material changes minimally as it dries out and the strength of the floor increases to its maximum. The addition of moisture allows the soil particles to slide over each other more easily—the maximum dry density (MDD) occurs at an optimal degree of compaction of a material with optimal water content (OMC).

The earth mixture needs to be *well graded*, which means that composition of the grain sizes in the mixture allows finer particles to fill the voids between coarser particles resulting in a denser packed matrix of particles with minimal void space between them.

3.3 *Fuller's curve*

Rammed earth floors should have the best possible mechanical stability when used. New rammed earth mixtures are usually artificially mixed so that they exhibit properties as near as possible to that described by Fuller's curve which represents an "ideal" well-graded earth mixture. Fuller's formula is as follows:

$$x = 100 \cdot (d_x/d_{100})^n \quad (1)$$

where

x = proportion of grains of a given diameter (% of mass); d_x = diameter of grains for a given value of x (mm); d_{100} = largest grain diameter (mm); and n = grading coefficient, for earth construction n = 0.25 (Houben & Guillaud 1994).

3.4 *Construction*

This principle was used for the planning of the rammed earth floor of the orangerie buildings in Belvedere Castle. A three layer construction was recommended:

– A layer of gravel (or brick chippings) that acts as a barrier for capillary action, thickness 200 mm, compacted on the levelled subsoil.
– A bearing layer of rammed earth, thickness 250 mm, d_{100} = 20 mm.
– An upper pavement of rammed earth, thickness 50 mm, d_{100} = 6 mm.

Figure 6 shows the corresponding grain distribution curves for the composition of both layers of rammed earth as calculated using Fuller's formula (1). The largest grain diameters d_{100} for both rammed earth layers are recommended and an ideal proportion of clay ($d \leq 0.002$ mm) is given as 10% of the entire mass. Experience from similar projects has shown that this proportion will usually provide an earth mixture with properties that are sufficiently plastic for preparation.

In order to improve the material's resistance to erosion and minimise shrinkage deformation as the moist rammed earth mixture dries, the following stabilisation additives were used: 5% (by mass) of lime and 10 kg of straw cuttings with a length of less than 50 mm long per m^3 of earth mixture. Additionally, geogrid was introduced in the upper pavement layer at junctions between areas as reinforcement to prevent and limit shrinkage cracking.

A horizontal vapour barrier was deliberately omitted in the rammed earth floor in order to ensure vapour transport through the compacted gravel and rammed earth layers from the subsoil to indoors. The vapour transport contributes to an optimal indoor climate for the plants during the storage season.

Similarly, no waxes or oils were used to protect the surface of the rammed earth floor so surplus surface water from plant watering can percolate into the floor. A second reason is that waxes and

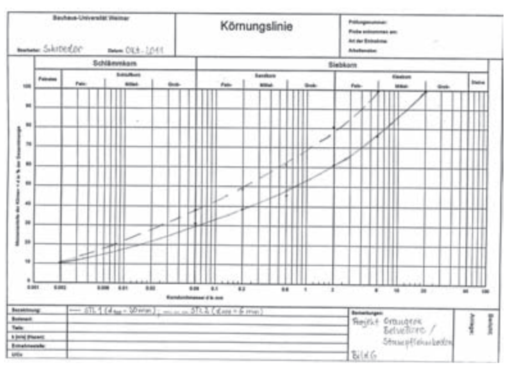

Figure 6. Grain distribution curves of rammed earth mixtures of the orangerie in Belvedere Castle.

oils can also hinder vapour transport through the rammed earth layer.

3.5 *Compaction*

To optimally compact the rammed earth mixture, appropriate mechanical compaction devices are needed. According to experience from comparable projects, a combination of pneumatic manual rammers and manual rammers for smaller floor surfaces was recommended. When using these compaction devices, the thickness of one layer of poured rammed earth mixture should not be more than 10 cm. The compaction process reduces the thickness of the layer of loose earth material by approximately one third.

For the proposed thicknesses of the bearing and pavement rammed earth layers the following plan of compaction was recommended:

– Layer 1 of the bearing layer: 100 mm in poured state, 70 mm after compaction.
– Layers 2, 3 & 4 of the bearing layer: 90 mm each in poured state, 60 mm after compaction.
– Floor pavement layer: 70 mm in poured state, 50 mm after compaction.

The entire thickness of the rammed earth floor after compaction is 300 mm.

4 MAINTENANCE AND REPAIR

The needs of the user with regard to the mechanical stability of rammed earth floors is often at odds with the characteristic parameters of rammed earth mixtures due its mechanical instability when soaked with water. The current plant watering techniques employed in historical orangeries use tubes and sprinkling devices that spill surplus water on the surfaces of the rammed earth floors. Depending on the amount and frequency of the surplus water the rammed earth floors are exposed to, it will soak up water and soften. Subsequent loading of the soaked floor, for example by heavy transportation vehicles, will result in damage patterns of the kind shown in Figure 5.

To accommodate this problem, there are number of different approaches to planning rammed earth floors for historical orangeries and greenhouses:

1. Users do not accept or are unaware of the limited stability of earthen floors: In such cases, floors should be constructed as concrete floors. Alternatively, users need to be educated to substitute their "usual" plant watering techniques with more precise techniques that result in less spillage.
2. Users are aware of the limited stability of earthen building materials: In such cases, users should expect to see damage patterns in the rammed earth floor of the kind shown in Figure 5 which may appear after a few years. The necessary repair interval will depend on the kind of plant watering used and the amount and frequency of surplus water. Appropriate additives can be added to the rammed earth mixture to increase the repair interval period.

The user has to decide which way is acceptable for each given situation.

Single cracks can usually be repaired using moist rammed earth mixture but where a large number of single crack repairs are necessary it can be more effective to completely replace the cracked floor pavement layer with a new rammed earth mixture.

5 CONCLUSIONS

This paper gives an overview of the planning process of a rammed earth floor for the orangerie of Belvedere Castle in Weimar which will be undertaken in summer 2012. This project represents a further example of the replacement of existing "modern" concrete floors with rammed earth floors, the authentic building material used for floors in historic orangeries.

Reasons for using this kind of construction include the creation of better climatic conditions for the plants during the storage season and a more authentic indoor impression of the situation of a historical orangerie/greenhouse. The main problem of this kind of construction is the mechanical instability of the rammed earth mixture when exposed to water. The choice of a more appropriate plant watering technique can prolong the necessary cycle of repairs.

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Optimal rammed earth wall thickness for a single-family house in Serbia

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ABSTRACT: Sustainability and energy efficiency have become important factors in modern architecture, with additional momentum generated by the revised European Building Performance Directive 2010/31/EU, which set the goal that all buildings in European Union constructed after 2020 have to be nearly zero energy buildings. The sustainability of rammed earth walls is unquestionable, however, their large U-value implies that they have to be combined with external insulation in climates with cold winters, as is the case in Serbia. The aim is to study, through building energy performance simulations in Energyplus, to what extent a combination of rammed earth walls and external insulation may accomplish the goal for a single-family house in Serbian city of Belgrade to become a nearly zero energy building, provided the house is equipped with properly shaded, high performance windows, and highly insulated floor slab and roof.

1 INTRODUCTION

Increased demand for sustainability in architecture renewed interest in traditional building methods which use locally available resources. Building with earth is one such method, present in different forms throughout the world since ancient times. Earthen architecture in Serbia mostly used adobe bricks, followed by wattle and daub technique, while rammed earth technique, widespread in arid and semi-arid climates, has been present in Vojvodina region in the Pannonian plane (Kojić 1949; Đekić 1994). However, with the establishment of brick factories in Serbia, and especially after the World War II, the practice of earthen building gave way to building with baked bricks and concrete, due to their better structural characteristics and ability to build taller structures.

An important characteristic that was neglected at the time is earth's much higher ability to control humidity by reducing the amplitude of relative humidity fluctuations inside the building and the frequency of high humidity periods at the wall surface (Allinson & Hall 2010), thus managing to maintain relative humidity levels within the range of 40–60%, deemed as most comfortable for humans. Combined with earth's high thermal inertia, which enables it to store and reradiate heat, this often results in more satisfactory indoor thermal comfort.

Energy efficiency is another important factor in modern architecture, emphasized by the influence that the consumption of energy from nonrenewable sources within buildings has on climate change, and put forward by current legislation, especially in regions with cold winters. For example, the most recent Serbian regulations on energy efficiency in buildings (Government of the Republic of Serbia 2011) prescribe that external walls in new buildings may have the maximal U-value of 0.40 $Wm^{-2}K^{-1}$. Having in mind that rammed earth has a low resistance to heat transfer, with a dry conductivity in the range of 0.8–1.0 $Wm^{-1}K^{-1}$ (Hall 2008), meeting this limit with rammed earth only would result in unacceptably thick walls. Hence, rammed earth walls in Serbia should be coupled with thermal insulation in order to attain higher thermal resistance. Fix (2009) recommends the use of external insulation in combination with rammed earth in cold climates, as it completely protects rammed earth from freezing during winter, and thus from spalling damage, while it leaves unhindered contact with the indoor air, facilitating the use of rammed earth's thermal mass and humidity control.

Even further, the revised European Building Performance Directive 2010/31/EU (European Parliament 2010) sets the goal for all buildings in European Union constructed after 2020 to be nearly zero energy buildings. This means that the building will have very high energy performance, determined on the basis of actual or predicted energy consumption for its typical use, which includes energy for space heating and cooling and sanitary water heating, while the nearly zero or small amount of energy needed should be, in largest part, produced from renewable energy sources at the building site or in its vicinity.

Our goal here is to study to what extent a combination of rammed earth walls and external insulation may be used to accomplish the goal of a nearly zero energy building, through simulations of building energy performance in Energyplus, for a case study of a single-family house in Serbian city of Belgrade, provided the house is equipped with properly shaded, high performance windows and highly insulated floor slab and roof.

The plan of the paper is as follows. In Section 2 we briefly analyze the climate of Belgrade, while in Section 3 we present the structure and characteristics of the case study house. The simulation results for the different combinations of thicknesses of external insulation and rammed earth are discussed in Section 4, while establishment of net zero energy goal is discussed in Section 5.

2 CLIMATE DATA ANALYSIS

Representative Belgrade weather data are analyzed from the aspect of temperatures, wind and solar radiation.

Figure 1 shows the distribution of average and absolute minimal and maximal monthly temperatures in Belgrade. The highest average maximal monthly temperatures are 27.3°C in July and August, while the lowest average minimal monthly temperature is −2.3°C in January. The distribution of monthly temperatures reflects the high demand of heating for buildings in Belgrade, and the low demand of cooling for buildings with no large amounts of internal heat gains.

There are two dominant wind directions in Belgrade: north-west and south-east. The north-west wind from Atlantic mostly blows in late spring and early summer and has smaller speeds, while the south-east wind, so-called *košava*, is turbulent in nature and blows at its fullest in February and March, when the gusts may reach 18 m/s, indicating the need for wind protection from the south-east.

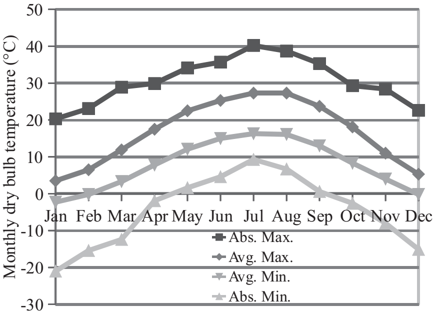

Figure 1. Distribution of monthly temperatures in Belgrade—average and absolute minimal and maximal temperatures.

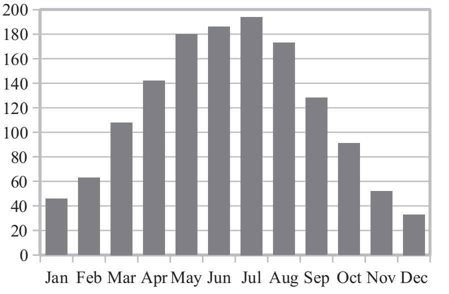

Figure 2. Average monthly global solar radiation on horizontal surface in kWh/m^2 in Belgrade.

Ho ever, about 93% of wind in Belgrade ranges in speed from 1 m/s to 5 m/s.

Figure 2 shows the distribution of average monthly global solar radiation on horizontal surface in Belgrade is 1396 kWh/m^2 with approximately 2025 hours of sunshine. The amount of solar radiation is generally high throughout March-September and is indicative of the possibility to use solar energy both for sanitary water heating and electricity production.

3 CASE STUDY HOUSE

The single-story house under considerations is designed for a four-person family. It has gross area of 83 m^2, featuring an open plan for the living, dining and kitchen area in the southern part of the house, and two bedrooms and a bathroom in the northern part. An option exists to further expand the common areas with an office/studio in the loft above the bedrooms. The house floor plan is shown in Figure 3.

We have already seen that the rammed earth walls have to be externally insulated in order to meet regulatory demand for U-value of at most 0.40 Wm^{-2} K^{-1}, while still providing thermal mass and indoor humidity control. The expanded polystyrene (EPS) is chosen as insulating material for walls in this research, due to its small price and prevalence in Serbia. If sustainability would be the main priority, then the natural fiber or cellulose insulation have to be considered instead of EPS, however we have to note that these materials are not presently available in Serbian market. The external walls consist of 20 mm rendering on the outside, EPS ranging in thickness from 10 cm to 20 cm, stabilized rammed earth (SRE) ranging in thickness from 30 cm to 50 cm, and 13 mm dense plaster on the inside. In order to prevent capillary rise of water from soil, the stabilized rammed earth walls are erected on a concrete foundation with

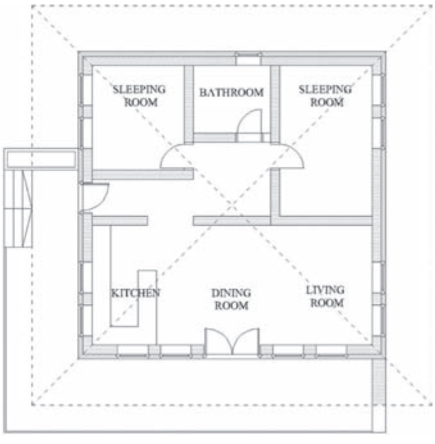

Figure 3. The house floor plan.

Table 1. Structure of simulated rammed earth walls.

Wall	EPS thickness (cm)	SRE thickness (cm)	U-value (Wm^{-2} K^{-1})
1	0	30	2.07
2	0	40	1.76
3	0	50	1.54
4	10	30	0.34
5	10	40	0.33
6	10	50	0.32
7	15	30	0.24
8	15	40	0.23
9	15	50	0.23
10	20	30	0.18
11	20	40	0.18
12	20	50	0.18

a 25 cm base exposed above ground level, and a bituminous painted layer on top of the base.

The internal walls consist of 30 cm thick stabilized rammed earth, covered with13 mm dense plaster on both sides.

Since our goal is to study the effect of thicknesses of external insulation and stabilized rammed earth walls on heating and cooling energy needs, the floor slab and roofs are highly insulated. The floor slab consists of 20 cm extruded polystyrene on the ground and below foundations, 10 cm cast concrete, 5 cm floor screed and ceramic tiles, yielding U-value of 0.158 Wm^{-2} K^{-1}. The roof consists of 25 mm clay tile, 25 cm stone wool and 5 mm roofing felt, covered on inside with gypsum plasterboard, yielding similar U-value of 0.153 Wm^{-2} K^{-1}.

From the same reason, we have chosen for simulation the high performance windows with triple, low-emissivity glazing. Such windows have been shown to be best performers in Serbian climate (Stevanović et al., 2011). The roof has sufficiently large eaves overhangs, in line with Serbian vernacular architectural practice, in order to provide shading to windows during summer.

Finally, the extension of the eastern external wall towards south is designed to provide protection from the turbulent south-eastern winds in late winter.

4 ENERGY PERFORMANCE SIMULATIONS

The house was modeled in Energyplus as a single zone with an infiltration rate of 0.7 ach. Stabilized rammed earth walls are supposed to contain 40% sands. Twelve different external walls types have been simulated. Their structure, exclusive of 20 mm external rendering and 13 mm internal dense plaster, is given in Table 1.

The house was first simulated in a free floating mode, without any HVAC system installed. The average monthly indoor temperatures, together with average monthly outside temperature, are illustrated in Figure 4. As the figure shows, there is a clear distinction between uninsulated walls (types 1–3) and insulated walls (types 4–12), with the uninsulated houses being 2°C to 5°C colder than the insulated houses, both during winter and summer. Interestingly, the range of average temperatures for insulated walls (types 4–12) is narrower than 2°C, except during May and October, when wall types 4 and 5 present outliers.

The house was then simulated with HVAC system installed, which consisted of underfloor heating system using the natural gas boiler and electric chiller. As the heating source is at the floor, the air temperature at the lower level is warm and cool at the higher level (warm feet, cool head), which provides the same thermal comfort level at lower temperature than the conventional heating systems. Hence, the heating setpoint in this case was 18°C, while the cooling setpoint was set at still comfortable 28°C. For all wall types, the cooling energy needs from May until September are extremely low, ranging annually from 64 kWh to 72 kWh of electricity, which is less than monthly lighting electricity use. This can be contributed to rammed earth's thermal mass work, as the thickness of external insulation (or its absence) does not appear to have influence on the cooling energy needs. Thus, this fully confirms numerous subjective claims that the indoor temperatures in earthen houses are very comfortable during the summertime.

Total heating energy needs for different wall types are given in Table 2, while the monthly heating

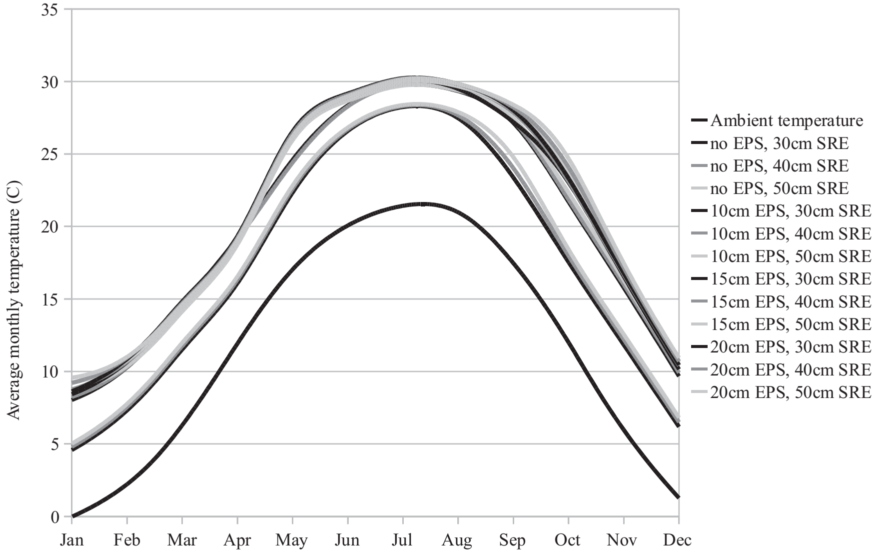

Figure 4. Average monthly indoor temperatures in free floating simulations for different wall types, with ambient temperature shown at the bottom.

Table 2. Total heating energy needs (kWh) for different wall types.

Wall type	1	2	3	4	5	6	7	8	9	10	11	12
Natural gas (kWh)	8340	7596	7004	4361	3412	3366	3120	3083	3047	2931	2901	2870

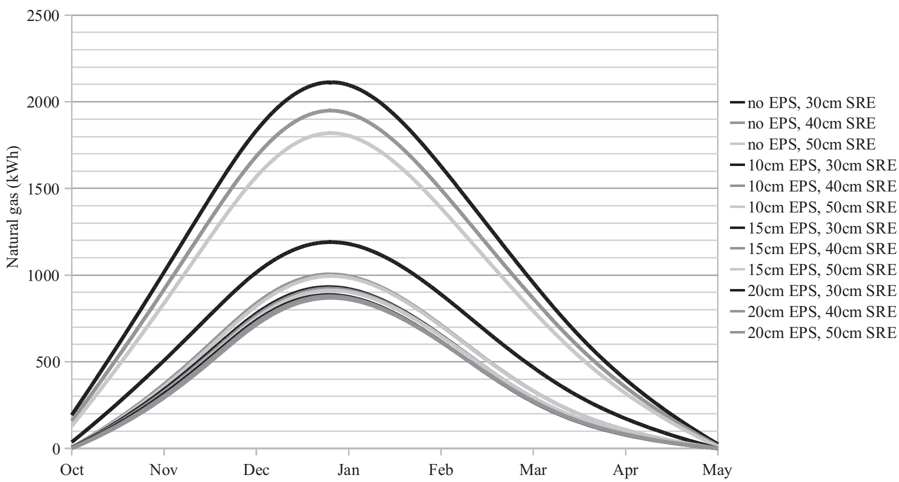

Figure 5. Monthly heating energy needs (kWh) for different wall types.

energy needs from October until April (until May for uninsulated wall types) are illustrated in Figure 5. The role of external insulation in Serbian climate is obvious from this figure, as the presence of at least 10 cm of EPS reduces the heating needs by a factor of two. Still, the thickness of only 10 cm of EPS is apparently below the critical value, as the increase of SRE thickness from 30 cm to 40 cm further decreases heating energy needs for 21.8%. On the other hand, the 15 cm of EPS appears to be above the critical value, since the increase in SRE thickness then has a marginal effect on heating energy needs—the increase in SRE thickness from 30 cm to 50 cm decreases the heating energy needs by at most 2.3%. The increase in EPS thickness from 15 cm to 20 cm yields further 5.8–6.1% decrease in heating energy needs and is worthwhile to be considered, taking into account relative inexpensiveness of EPS and future price escalation of natural gas. Hence, the optimal external wall for the studied house appears to be type 10, consisting of 20 cm expanded polystyrene external insulation and 30 cm of stabilized rammed earth.

5 NEARLY ZERO ENERGY GOAL

For the wall type 10, the total heating and cooling energy needs amount to 3003 kWh, while the simulated annual consumption of electricity for int rior lighting and appliances is 2117 kWh. These amounts do not include sanitary water heating, for which solar water heating system may be used. It was shown in Stevanović & Pucar (2011) that roof-mounted solar collectors with 4.8 m^2 of aperture area in Belgrade yield a solar fraction of 61% for the daily hot water usage of 220 liters. The remaining 39% of hot water needs, when covered by backup electric resistance storage water heater, uses approximately 1300 kWh of electricity. Hence, the case study house total energy needs amount to 6420 kWh.

Solar energy is the most abundant renewable energy source in Belgrade, and Stevanović & Pucar (2012) estimated that the roof-mounted photovoltaic plant, installed at tilt of 35°, has annual specific production of 1246 kWh/kWp in Belgrade. Thus, the house total energy needs may be fully offset by installing 5.15 kWp photovoltaic plant (which takes up approximately 36 m^2 of roof area), in which case the house would become a net zero energy building.

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Rammed earth in Moravia (Czech Republic) in the context of neighboring lands

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ABSTRACT: Rammed earth has a long history throughout many parts of the Danubian region. Moravia is a historic land that is located in what is currently the Czech Republic. Rammed earth coexists here with other earthen techniques (daubed earth, cob, stacked or rammed bread-shaped pieces—*války* and adobe). The popularity of the rammed earth has grown since the end of the 18th century both as a consequence of the state interventions and the influence of earthen construction treatises. The use of the technique before this boom can be demonstrated by several examples identified by a historic structures analysis and can be traced back to the 14th–15th centuries in the written texts. The continuous tradition of rammed earth construction ended in the first decades of the 20th century. The few new constructions after World War II are already part of the general global trends.

1 INTRODUCTION

The building construction manifestations of the historical Czech lands (Bohemia, Moravia and Silesia) are similar to those of other Central European countries, with whom they share since 16th century the history of the Habsbourg monarchy with all its interventions in construction. Earth was used here mainly in conjunction with wooden support as wattle, corner timbering or timber framework, which both are characteristic for the medieval period. With the exception of unbaked bricks the massive earthen walls are present only in Moravia, especially in the lowland regions of its central and southeastern part, where construction materials other than soil were difficult to obtain. Rammed earth coexists here with other earthen techniques (daubed earth, cob, stacked or coffered bread-shaped pieces—*války*, adobe) and makes still an important contribution to the existing building stock of this region.

Use of rammed earth technique is not limited to vernacular buildings. It was identified also in historic town centres. It might exist even in Moravian capital Brno, where according to the building protocols in 1929 house No. 454 with “Pisé” walls in its upper floor was demolished and replaced by well-known funcionalist building of Alfa Passage (Kujelová 2007).

Our current knowledge of earthen materials and techniques used in historic constructions is based on the literary sources, field data gathered since 80th by our own inventory and historic analyses structures works and analyses of historic earthen materials carried out within the project conducted in 90th by Jan Kříž (Kříž & Vorel 1998, Syrová et al., 2000).

2 EARTHEN BUILDING MATERIAL

In the Morava valley loess was used as an universal building material for earthen constructions including traditional rammed earth mounted with wooden formwork (*nabíjenice*). Properties of earthen material could be improved by the addition of ceramic fragments (Jewish ghetto in Uherský Ostroh). On the edges of lowland, in the White and Central Carpatians, where the suitable gravelly soils were available in abundance, the rammed earth even became the main technique for the construction of the massive earthen walls.

2.1 *Extraction of earth (hliník)*

Earth for the construction was extracted usually in quarries called *hliník*, exceptionally on the site itself.

According to the so call stable cadastral plans from the second third of the 19th century mostly every Moravian village had its own *hliník*, which can usually still be easily identified. The area and volume of many old quarries, in which groups of later cottages or wine cellars are often situated, indicates, that the whole villages used them for a long period.

Figure 1. Rammed earth construction in Hroznová Lhota, distr. Hodonín, in 1910 (Karel Chotek).

3 HISTORIC MORAVIAN TECHNIQUES OF MONOLITHIC WALLS USING FORMWORK

Historic Moravian technique based on earth stuffed between formwork to make a homogeneous mass wall can be categorized either by the properties of earthen material or by the type of formwork.

3.1 *Rammed (moist fresh) earth*

Generally known technique is that of compacting moist fresh earth into movable formwork described by many authors (Bartoš 1895, Niederle 1923, Máčel & Vajdiš 1958, Frolec 1974, Mencl 1980). It is particularly widespread in SE Moravia in so called Moravian Slovakia region and in the White and Central Carpatians. Earth was dropped into the formwork in layers, up to 15 cm high. The corners were often reinforced by wattle, which may be found also between the layers.

3.2 *Coffered pressed bread-shaped cob (války)*

The second technique is that of coffered bread-shaped pieces (*války*), introduced in the Czech ethnographic literature by Antonín Václavík in the Slovak village of Chorvátský Grob, where also the technique of rammed earth described above was still used in the first decades of the 20th century (Václavík 1925). The detailed description of coffered *války* was brought by Josef Kšír from the Haná region in central Moravia (Kšír 1956). The hand made *války* were in plastic state thrown or simply put in the formwork and compressed to join together in a compact wall. The corners were usually reinforced by pieces of wood.

This technique, which is closer by the properties of the earthen mixture to cob, was widely used also in Znojmo region in SW Moravia and in the neiboring regions of Slovakia and Hungary (Syrová & Syrový 2007, Buzás 2011). All these regions knew also the technique of stacked *války* built up by hand without formwork (Syrová & Syrový 2007).

3.3 *Formworks*

Two basic methods of setting up formworks were used. They were common for both techniques and known also in other Danubian regions (Buzás 2011).

Formwork sides, made from simple boards or several wooden planks, that are fixed together, can be supported by pairs of external vertical posts driven into holes dug in the ground and tied together on their tops by ropes. This method is considered to be more archaic, if not really older. It is characterized by absence of the holes in the wall.

The second method, when the formwork is supported by horizontal timbers passing through the wall, is more sophisticated. One of the few photographs depicting the course of construction, taken by Czech ethnographer Karel Chotek in 1910 in Hroznová Lhota (Fig. 1), shows this type of formwork (Niederle 1923).

In this case characteristic holes are formed. When the construction was finished, these holes were carefully filled, often with the same earthen and/or lime mortar, that was used for the rendering.

3.4 *Surface finishes*

In the historic Moravian constructions the vast majority of monolithic earthen walls was intended to be rendered. This includes, compared with adobe constructions, also farm building as barns, granaries or cellars. To ensure good adhesion, the surface of the rammed earth was roughened by diagonal cuts. The walls were rendered with lime mortar or traditionally with earth mixed with finely chopped straw, whitened with lime or later brightly coloured in blue or yellow.

In practice of nondestructive historic structures analysis and inventories that means, that it is difficult to distinguish rammed earth from other historic earthen techniques.

4 TRADITIONAL TERMINOLOGY

Traditional terminology of rammed earth as we know it mostly thanks to the ethnographic works is extremely rich and has links to the terms used in other Slavic languages. They derive mostly either from the words refering to the process of ramming: *nabíjenice* or *nabíjenica* (the most common term used in Moravian Slovakia (Niederle 1912, 1923, Máčel & Vajdiš 1958)), *tlučenina, tlučénka, tlčénka* (Moravian Slovakia (Niederle 1923), region of Luhačovické Zálesí (Niederle 1923, Václavík 1930) and Slovakia (Máčel & Vajdiš 1958)), *tlučenica, pichovanica* (Frolec & Vařeka 2007), *pěchovanica* (Niederle 1923), or to the infilling of the formwork: *sypanice* (archaic term used already in medieval texts collected as still commonly used in the dialects of Haná in SW Moravia (Bartoš 1895)). Václavík brings also the terms used for the rammers and pestes (*tlk, chlápač, pich*) in region of Luhačovice (Václavík 1930).

5 RAMMED EARTH HISTORY

5.1 *Rammed earth before the end of the 18th century*

5.1.1 *Archeological references*

References to the rammed earth constructions in published archaeological reports are extremely rare. In fact only in two retrieved cases, the archaeologists have come to a clear interpretation:

Moravian archaeologist Jaroslav Böhm, who led research of late Iron Age La Tène culture (180-30 B.C.) oppidum Staré Hradisko near Prostějov in 1934–1937, found dozens of dwellings with massive earthen walls about 50 cm thick, that he interpreted as rammed earth or adobe and presented with architect Alfred Piffl the ideal reconstructions of 4 types of these dwellings (Böhm 1936).

Latter example belongs to the period of so called "inner" medieval colonization. Team of archeologists discovered during their work in town of Rýmařov in the medieval mining zone of Jeseníky mountains in NW Moravia several remains of constructions, that can be interpreted as rammed earth. The most important is the building dated to the first quarter of the 14th century, situated approximately in the center of the fortified platform, probably residence of *fojt* (officer of the king, who served as administrator and judge). Its lower floor with internal dimensions of 8,3 × 9,5 m was constructed with rammed earth, the upper residential part with daubed corner timbering (Novák & Karel 1972). In the same site several cabins and one three part house built with rammed earth in the period of the foundation of the town in the 13th century were found (Goš et al., 1985).

5.1.2 *Written and literary sources*

In the Moravian written texts the rammed earth can be traced back to the 14th–15th centuries, when terms *sypanice* (dry poured earth) or *tlučenice* (rammed earth) first appear beside general term *blátové domy* (mud houses). In the 16th century the term *hliník* (place of extraction of earth) is mentioned in the village of Petrov as place, where wine cellars were situated (Frolec 1974).

We can find also references of massive earthen constructions in Bohemia. Georgius Agricola includes in his famous handbook of mineralogy, entitled *De natura fossilium* (revised version from 1558) information on Central European clay deposits and argillaceous raw material occurrences, which he probably came to know from his own experience. In book II he describes also the use of earth and clays in building and refers to adobe and the rammed earth built according to Pliny's description in Saxony, Bohemia and Hungary (Agricola 1955; Wilsdorf 1968).

5.1.3 *Constructions identified by surveys*

The use of the rammed earth technique before its boom in 18th–19th centuries can be demonstrated by several examples.

Still inhabited house No. 49 with porch—*žudr* dated 1596 containing two-storey chamber-granary with monolihitic (rammed?) earthen walls in the market town of Pouzdřany (distr. Břeclav) belongs to the oldest Moravian vernacular buildings from the period before the Thirty Years' War.

Coffered *války* were used for the construction of archaic houses with porch—*žudr* dating from 17th–18th centuries in Haná region and wine cellars dating from the same period in Znojmo region.

Also the rammed earth walls identified in several houses on the main square of Uherský Ostroh, though their dating is difficult because of significant reconstructions in 19th and beginning of 20th century, should be mentioned here.

5.2 *Rammed earth since the end of the 18th century till the end of continuous tradition*

5.2.1 *Interventions of modern state or enlightement and bureaucracy*

The reforms of Mary-Therese and Joseph II and interventions of modern state with the first building codes, regulations against fire and repeated interdictions of wooden constructions undoubtedly played an important role in spread of earthen constructions in Czech and Moravian regions, where they replaced wooden and mixed constructions.

At their beginning is the fire patent for Moravian margraviat and for Bohemian kingdom from 1751, followed by patent for extinction of fires (1755), fire order of the emperor Josef II for Bohemian kingdom (1785), fire order for countryside, towns and villages in Moravia and Silesia (1787), decree of general obligation to submit the plans of building construction (1788), general prohibition of wooden constructions (1816), decree authorizing peasants to produce bricks (1819) and orders of the construction for kingdom of Bohemia and margraviat of Moravia (1833, 1835). These slowly and with difficulty enforced regulations set out technical details of use of *clay* for fire protection purposes and conditions under which it is possible to build massive earthen constructions (construction purposes and location, wall thickness, height of plinths) (Ebel 2001, 2007).

The development was influenced also by changing relations between lords and peasants after the serfdom abolition in 1781, when peasants lost access to the construction timber from dominical forests, and the decrease of the forests in general.

5.2.2 *Building permission and the role of master builder*

Thanks to the decree of general obligation to submit the plans of building construction (1788) and the first building codes (1833, 1835) new actors are entering the scene of earthen construction. Only a trained master builder (*stavitel* in Czech, *Baumeister* in German) graduated obligatorily since 1810 from the polytechnic school, or under certain circumstances also a trained master mason, was responsible for the construction and entitled to draw up plans for building permission (Ebel 2007), that had to be, and since around 1850 in general really were, executed even for ordinary farm buildings (Ebel & Škabrada 1996, Syrová & Syrový 2011).

Among the most rich archives conserving plans and building protocols for reconstructions or new constructions we should mention in the context of monolithic earthen walls using formworks that of Příkazy (Olomouc), Uherský Ostroh and Mařatice (Uherské Hradiště). Though it was not custom to indicate the building material and technique with the exception of the firewalls in the plans and protocols, these documents are irreplaceable source especially in case of the structures preserved to these days.

Thanks to their training master builders and even master masons became familiar with contemporary treatises on construction and their knowledge blends with the local building traditions.

5.2.3 *Treatises on construction (Pisé-Bau or lepenice)*

The first treatises on rammed earth, that master builder could meet in Wien or Prague, where the Royal Nobility Engineering School was founded in 1718, were naturally in German, as the Polytechnic Institute was divided in German and Czech one in 1869 and the Imperial Czech Technical University of Franz Joseph in Brno was founded only in 1899.

The works of François Cointeraux were soon translated in German (Cointereaux 1792–1794, 1793) and followed by the works of German speaking propagators of earthen constructions such as David Gilly (Gilly 1797). Builder handbooks and even teaching materials for secondary schools, which describe the rammed earth (*Pisé-Bau*) technique as the most advantageous earth construction method, were published also in Prague (Lengerke 1838, Jöndl 1840a,b, Jöndl et al., 1865) and in Brno (Gabriely 1861).

The first treatise dealing with rammed earth translated in Czech was that on construction, with regard to building in small towns and villages, published in 1840 by Johann Philip Jöndl (Jöndl 1840b), who devoted to the *Pisé-Bau* one chapter (§229–239), in which he gives illustrations and describes all the practical issues and rules of the construction, including its risks and prevention of possible problems. Although Jöndl is critical and distant (he "cannot help laughing at exaggerated enthusiasm of some *Pisé-Bau* propagators"), he is clearly aware of the advantages of *Pisé-Bau*.

Translation into Czech caused to Jan Nepomuk Štěpánek, who spent his entire life in Bohemia and could not come into contact with traditional Moravian buildings, a particular problem in finding a suitable Czech equivalent of the German *Pisé-Bau.* He translates it as *lepeniční stavba*, term, which can be found also as *lepenice* in the building regulations. Paradoxically the term *lepenice* is that used in historical texts and Czech dialects for massive earthen structures built without formwork and daub.

5.2.4 *Preserved building stock*

The end of the 18th and the whole 19th century became the golden age of unbaked bricks and rammed earth. The use of the rammed earth is limited in practice to Moravia with the rare exceptions identified in Bohemia like the farmhouse No. 17 in Bylany near Kutná Hora from the end of 18th century (Kibic 2004).

In Moravia the rammed earth is gradually used not only for the construction of residential and important farm buildings (Fig. 2), but also the most common small structures as vineyard cabines (Fig. 3). It also penetrates to the upland regions like Luhačovické Zálesí and Moravské Kopanice (Dobiáš 1892, Václavík 1930, Máčel & Vajdiš 1958), where the living tradition of rammed earth survived till the 20th century. One of the last documented newly built rammed earth constructions is that of the house No. 126 in Lopeník from 1925 (Máčel & Vajdiš 1958).

Figure 2. Rammed earth barns in Vnorovy, distr. Hodonín.

Figure 3. Wine cellars in Havřice, distr. Uherské Hradiště; recording by Otakar Máčel 1955 (National Heritage Institute).

5.3 *Efforts to introduce new rammed earth construction in 20th century*

5.3.1 *Propagation after the World War I*

The first period after the World War I is represented mainly by the book on local construction materials as contribution to the solution of housing shortage and protection of homeland (Fierlinger 1920).

5.3.2 *Experimentations after the World War II*

Propagation and experimentations in the 50 s and 60 s follow the example of fraternal socialistic states. In the spirit of the time the new term *hlinobit* derived from russian *землебит* appears. Publications from these period are however well informed (Havlíček & Souček 1958, Mach & Plch 1958). The rammed earth or compressed blocs were recommended for the construction of agricultural buildings and family houses. Several constructions were built in Southern Moravia and especially in Slovakia.

5.3.3 *Ecological efforts since the nineties*

Last wave of rammed earth revival after 1989 is also slowly becoming history. It is already part of the general global trends, but except its new ecological look it has many common features with the previous efforts to introduce new rammed earth construction in Czechoslovakia and Czech Republic in 20th century—from the enthusiasm of its propagators to the small number of implemented constructions. It is the restaurant *Rybářská bašta* in Průhonice near Prague from 1997 (Petr Suske and SEA group), experimental building of unburned earth technologies including rammed earth, that should be mentioned for its architectural qualities and for the analyses that accompanied the construction from its preparation to the monitoring after its completion.

The construction of the extension of the farm No. 33 in Lysovice (Vyškov) also served for making the cognitive film for heritage conservation purposes.

6 RAMMED EARTH IN SURVEYS AND DOCUMENTATION

The surveys and documentation of earthen architecture carried out since the end of the 19th century are important source for its understanding.

They have their own history that we have tried to describe in previous texts (Syrová & Syrový 1995), from which we would like to select only few points.

6.1 *Ethnographic surveys and inquiries of the late 19th and early 20th centuries*

Researchers and amateurs of folk culture of this period were lucky to work in the period of still living tradition of rammed earth. The building technologies have not been the main subject of their interest, which regarding to vernacular architecture was focused on the decorative, archaic or likely ancient elements, habits and terms associated with construction or definition of regional types. They enlisted, however, the richness of traditional terminology and the descriptions of the rammed earth techniques as they heard about them or collected through enquiries from their respondents.

Unfortunately, most of the authors do not give reliable link between collected descriptions of constructions, technology and terms.

6.2 *Recordings*

Not counting the first works of ethnographic nature containing schematic plans (Niederle 1923), precise recordings by architects and civil engineers from inventory and documentation campaigns from the regions, where the rammed earth technique was used, are important sources. These are mainly the recordings elaborated by Otakar Máčel (Fig. 3) and Jaroslav Vajdiš and the ambitious work of Antonín Kurial and his students preserved in so called Kurial's archives, from which the districts Zlín, Uherské Hradiště and Hodonín are important in the context of rammed earth (Kurial 1978, 1986, 2007).

These already historical sources are gradually digitized and made accessible to the specialists and the public also through information systems, one of which is the Integrated Czech Heritage Information System. It actually enables also the consultation of the results of the project and surveys of SOVAMM relating to the earthen architecture.

7 CONCLUSIONS

We tried to give here a basic overview of our actual knowledge of the traditional rammed earth constructions in Czech Republic in their historical context including the history of regulations and rediscovery of rammed earth. The study of the sources has to face to the problems of inaccurate identifications and ambiguous interpretations and re-interpretations, that confirm the statement of Czech historian of art Oldřich Stefan, that the only source, that does not lie, is the construction itself.

Considering, that the majority of literary sources referring to our rammed earth constructions is inaccessible by the simple fact, that it is in Czech, we hope, that this overview, even if short and incomplete, may help to better understanding of the context of rammed earth in Europe.

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Valencian *tapia* in the walled city of Mascarell (Castellón, Spain)

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ABSTRACT: Mascarell is a small village, located in the municipality of Nules (Castellón- Spain), which has preserved the integrity of its walled perimeter. It represents a singular example of what is called *valencian tapia* (mud wall joined with bricks and plastered with lime mortar). *Tapia* has been used since ancient times. This makes dating surviving examples difficult. In Mascarell's case, the construction contract document, which is dated 1553, has been preserved. In this document, the characteristics of the works that needed to be done are described in accurate detail. The collapse of a section of the wall due to a heavy rain required restoration. This allowed a detailed study of the original building process, and the recovery of the complete skyline of the city wall. In spite of its declaration as Property of Cultural Interest in the category of 'Historic Site', and its Special Protection Planning, the Mascarell town wall has suffered a historical "slackness". All in all, this has allowed its walls to get drilled, and its moat filled, which deteriorated the original configuration.

1 INTRODUCTION

Interest in earthen architecture can be said to be relatively recent. Perhaps, you may find the first interest in the 1980's. On the one hand, under Unesco's Direction, several French scholars organized a magnificent exhibition of this material at the Pompidou Center in Paris. By then, Spain began to implement different studies, often under the impulse of its regions, special mention Navapalos encounters, which intended to show their heritage. On the other hand, it was also the time for a more scientific basis arising from the various congresses of Construction History. The technique of the wall was then the subject of several papers, which usually corresponded to restoration activities carried out in different parts of Spain and specific publications among which we should note that of Mariano Olcese Segarra, Architectures soil and adobe mud, published by the Official College of Architects of Valladolid, in 1993.

Since 1991 there is a wonderful publication on the subject in the Valencian Community: "*El tapial, una técnica constructiva milenaria*" ("The Mud Wall, an Ancient Building Technique"), by Fermin Font and Pere Hidalgo. Their work extensively deals with the development of this technique, pointing out numerous examples, mainly referred to the province of Castellón. In this province is located the ancient town of Mascarell, today Nules' hamlet. Its main feature is to be protected by a discrete wall that completely surrounds the old town.

In the late 1980's I had the opportunity to develop its Special Protection Planning and to complete the repair of a part of the walls ruined by rain. Then I was able to read the original contract, dated 1553, for the construction of the work, which provided me with valuable information on Mascarell and its walls, which I'll try to explain below.

2 THE VALENCIAN *TAPIA*

Needless to say, the rammed earth technique is ancient stricto senso, and it has been extended and maintained by the most diverse civilizations. In the 1st Century BC, Vitruvius already accurately described the characteristics and uses of soil available for construction. This work became true construction specifications to ensure maximum performance of a technique that, by that time, had been widely used yet.

Accurate descriptions of the procedures for obtaining maximum hardness of the walls can be found in ancient books. Descriptions included some specialization, appearing as a new vocabulary was being created.

Valencian tapia is mentioned for the first time by Fray Lorenzo de San Nicolas in his book "*Arte y uso de la arquitectura*" ("Art and Use of Architecture"), published in 1639. In chapter XXXV, he distinguishes several ways to make rammed earth walls out of soil. He ends up with the following paragraph:

"Valencian tapia walls are made of soil, half bricks and lime, casting alternatively layers of each material. It is very strong work".

Fray Lorenzo was well acquainted with the Vitruvius treaties, Serlio, Vignola, Palladio or Sagredo to which he devotes special attention. Obviously, none of these great writers knew about the art of valencian tapia, so to be able to understand their knowledge of its existence, we must search elsewhere. Their sources, we don't currently know, and by now the only source considered is the oral tradition, as the technique was probably described by a master mason from Valencia.

References to the valencian tapia are generously given in several contracts dating back to the 15th and 16th centuries. However, the technique was few times listed under that name. One such case would be the contract for the work made for the Capuchins of Blood signed in Valencia on March 3rd, 1597, (Galarza, Op.Cit) which specified:

"Item that the walls of the house of the monastery are to be valencian tapia of two feet and a half thick and walls from the Church and the altar to be done, namely, is that of the two sides where loaded facings, just five valencian tapia thickness and spans the front of said church of the same valencian tapia wall three feet thick and the walls of the sacristy and choir chapels of the said church should be of the same valencian tapia three feet thick".

The word tapia (rammed earth wall) is not listed in the *"Vocabulario de Términos de Arte"* ("Vocabulary of Art Terms") by J. Adeline, but by his translator, José Ramón Mélida, in the publication of the work done in 1887. In it, even the term 'steely wall' is recorded, but with no specific reference to the valencian tapia, which does not appear in the manuals -Villanueva or Bails- in the use in that time.

Figure 1. Section of the wall at the rebuilt in 1942 by the Dirección General de Regiones Devastadas.

The valencian tapia has many examples in Valencia city, like the Almudin, the Convent of the Trinity or the College of the Patriarch, as well as in many surrounding hamlets. Tapia is nowadays hidden under various repairing works, plastered, or even whitewashed. Such a situation sometimes makes identification difficult, but it was doubtlessly one of the most widely used bearing systems since the 15th century. Improvement was being done of the resistance of this ancient technique in the way it had been used until then.

In the defensive architecture of Valencian Community, rammed earth has for long been the most widely used construction technique. Mascarell is a good example to see its wide application. Its relatively good state of preservation allows the visitor to appreciate this evolution of steely wall, called valencian *tapia.*

3 MASCARELL VILLAGE

The loss of the municipal archives, and the scarce monograph research works on the ancient village, have not allowed the experts to establish the exact date of its foundation so far. Nevertheless, it is commonly accepted, and so it appears written in the "*Llibre dels Fets*" ("The Facts Book"), that Saracens expelled from Burriana by the king James I of Aragon became the first inhabitants of the settlement.

No documents prior to the Spain Reconquest have been found in which the name of Mascarell appears. Thus is supported the hypothesis of its foundation in the first half of the 13th century.

The earliest citation available for consult appears in the seventh book of the *"Décadas de la Historia de Valencia"* ("Decades of the History of Valencia"), written by Gaspar Escolano in 1610, in which he does a brief description of Nules and its surroundings:

"Are these the first of the town and honor of Nules that is on the royal road of Barcelona, a league from Almenara and half a league from the sea. Their homes are more than 300 Christians, surrounded by wall. It also considers villages such as Villa Vieja, with its castle, and Moncofa and Mascarell; these are next to the sea and the three gather about 250 homes, counting some of Moorish in Mascarell".

Mascarell had its own village council until 1872, when its annexation to Nules was agreed.

The first artistic evaluation of the walled assessment dates back to 1927. It can be attributable to Elías Tormo, who under the heading of Gothic Architecture in Levante's journal guide named Mascarell's walls as an example of fortification.

The Spanish Civil War caused considerable damages in the town and its walls, which were rebuilt in 1942 by the Dirección General de Regiones Devastadas, in the Ministry of Housing: they built a new school and renovated the interior of the church. Damage in the walls and numerous smashed segments framing the Door of Valencia were replaced, too.

However, the restoration of the wall did not adopt the valencian tapia system, but the layer of "valencian steely wall" -with its original bricks- was substituted by masonry. So the resulting wall was composed of a double leaf masonry made of lime mortar and cement mortar coating their outer faces, which hosted inside a mass of soil. As seen in the areas that suffered landslides, such mass was not properly compacted.

In the 1970's major reconstruction works were made, mainly on south, east and a piece of north walls. Materials used were: perforated brick—with no record on the type of fill, if any, used in its interior. Also the towers were rebuilt. They were given disproportionate battlements, whose height was well above the original, in accordance with what is said in the contract terms. The northern wall *rivellino* (little defensive tower), already has got a solid brick, castellated end, probably made along the first five decades of the 17th century.

4 THE WORKS CONTRACT (1553)

A document of major importance to historical and constructive knowledge of the wall of Mascarell is its contract to carry out the work, signed in 1553. Having a specifically dated work explaining such a widely spread technique since the old times, will certainly help to verify, by comparison, other works chronology, whose date of completion has not been determined yet.

In another sense, the document clears the theory of the possible creation of the town as a "city of reconquest" in the 13th century. Several authors had claimed so, based on the appearance: its walled rectangular circuit and rammed earth wall works were common during the Muslim period.

Leaving aside any further historical details, which Mercedes Gómez-Ferrer had already analyzed, let's focus on the description of the work to be done as described in the contract.

It begins with the requirements for the foundation. It must have a width of six palms and the depth will depend on the ground features, digging down to find the right resistance. The excavation is filled with "*cal y canto*" (lime and stone). On its top, a two feet high and five-palms-thick masonry wall is raised. It will be the support for the rammed earth wall itself, which is defined as *terra y crosta* (soil and coating). Specifications on the *crosta* are given: it consists on half a brick on each side, interior and exterior, of the wall. The completion of the wall (designed to be 30 feet tall) is made of *cal y canto*. Finally, in order to give the correct slope to expel rainwater, it is indicated that such completion must be done in "*esquena de gat*" shape, making reference to the curvature of a cat's back.

Nowadays, Mascarell's wall has got the same configuration as described in the original contract.

Figure 2. Mascarell (Nules, Castellón). Overview, photo GVA.

Figure 3. Detail of the original section in the union of two rammed earth walls.

There are four ramparts with four projecting elements, of greater height, qualified as towers, or *rivellini*. In the contract, there is a reference to the existence of a scale model. This justifies the absence of other formal details, or any lack of measurements enclosed. It's true that the works were paid at a certain amount, according to an agreed template, but the length of the wall does not specifically appear in the document.

The site was closed by two doors, protected by two towers, tangentially leading towards the two side walls of the Town Hall. That is to say, the doors were not aligned along a central axis, as described by the valencian Eiximeniç ideal cities, which were organized on a more regular basis as well as a strict symmetry. The two towers stood out just above the height of the wall, and they had at the bottom three trumpet shaped embrasures, made with masonry work.

It also precisely defines the two portals, located next to the towers. They must be made of crushed stone, 12 palms wide and 16 feet high. Holes must be provided in their jambs, in order to place a bar which ensure the closing as well as improve resistance to attacks from outside.

Details describing a simple hollow are striking, moreover when no allusion to the robust hinges of hewn stone - *polleguéras*- still remaining in the portals is done.

As a curiosity, it is worth noting it's stipulated in the contract the requirement for surveillance during the execution of the works against possible attacks. One chosen person must be in charge to check that there were no dangerous enemies around the site. Important data, in a time when there were frequent attacks from the sea by the Saracen armies.

Nevertheless, the greatest interest arising from the contract document primarily lies on two issues: First, the precise dating of the work. Second, the description of the technique used to build the wall, none other than the Valencian rammed earth wall or *tapia*: *"tapia made of 'terra y crosta' (soil and coating). consisting on half a brick on each side, interior and exterior, of the wall"*.

Thus, the material chosen is clearly described. And the technique was strictly taken to the practice. However, several historical events forced various repairs *a posteriori* -not all recorded-, fact that harmed the primal unity of the wall fence.

5 THE RESTORATION WORK IMPLEMENTATION

As mentioned above, in 1987 severe rainfall caused serious damage in the northern part of the wall, just between the Gate of Valencia and the northern rivellino, exposing the rammed earth inside. Immediately, an emergency repair was done in order to prevent water to leak inside, as this should have lead to the total collapse of the wall. Repairing material was slurry lime, which appeared to have an excellent performance, as the restoration works would not begin until 2008 for several reasons.

The ruined part belonged partially to the one restored by the Dirección General de Regiones Devastadas, in which masonry replaced the *soil and coating* brick wall. It could easily be distinguished from the former part, thanks to the remains of its original construction. Similarly to other parts of the rampart, bricks barely show here.

In the restoration, we chose to use the traditional method, trying to build the five original rammed earth modules, of 3.70 m × 1.15 m, up again. The initial idea of demolishing part of the ramparts to redo some walls was completely discarded. The rammed earth wall shuttering was assembled, allowing the dumping and compacting of materials to be done. Thus, the new and the old work were united by stainless steel rods. The soil was moistened into a mixer, receiving a small supply of lime, and it was compacted by a manual rammer. The lime mortar, mixed with the soil of the place, together with a small portion of white cement to accelerate its setting, adopted a slightly pink tone. This is the color it has kept up to now. It contrasts, perhaps in excess, with the rest of the wall that would require a proper cleaning, what unfortunately was beyond the means of the job entrusted.

It was also decided -given the lack of traces left by the rods- to hide the holes left after extraction. For that, 20 × 40 mm metal parts surrounded by plastic material were used, so as they could be easily removed by slightly tapping. The small holes left after rods removal were filled with the same mortar.

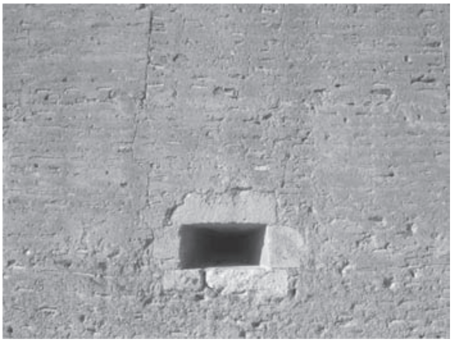

Figure 4. Aspect of the original finish on the tower of the Portal de l'Horta, with the pocket described in the contract.

Figure 5. Appearance of finished wall.

Figure 6. Detail of the wall.

The most complex issue in the works involved the placement of the tapias, as well as the scaffolding needed, on the inner part of the town. Several secondary constructions done along the time by the wall were shored up or even demolished, as they sometimes used it as a support for the beams; other times they had bitten it from inside, leaving only the outside part of the wall, which stood in miraculous balance.

The top of the wall was performed as described in the original Contract: "cal y canto" (lime and mortar), and "esquena de gat" (cat- back shaped).

6 PROJECTS IN FUTURE

There are few towns keeping their walled fence free of obstacles for its vision. This uniqueness implies a great interest by the whole complex, which must be profitably exploited: Cultural benefits, showing its important heritage; Social and Economic, too, as can be deduced from the transformation of what now is a slum inside the city.

In this context, there is a urgent need to draft a Master Plan. It must include the recovery of the original state of the wall, the enclosure of inappropriate holes, and the replacement of unfortunate solid brick repairs done during the 1970's for a new rammed earth wall. Furthermore, access to the ravelins must be restored, replacing their stairs and removing structures using the wall as a support or penetrating the wall. It would also be necessary to recover the original level of the Portal of Valencia, by removing the current palm trees garden, and establishing an adequate lighting system. And finally, expropriations needed should be also done to comfortably implement the outside enclosure ramparts, so as the whole defensive wall could be free of obstacles to its proper visualization. This could be done with a reasonable cost for the town by creating an art and crafts school that would serve to restore this rammed earth technique. New workers could so develop the art, both to recover our heritage and to use it as an efficient construction method. It has been proved to be so along epochs, thanks to many evidences found all over the Valencian Community.

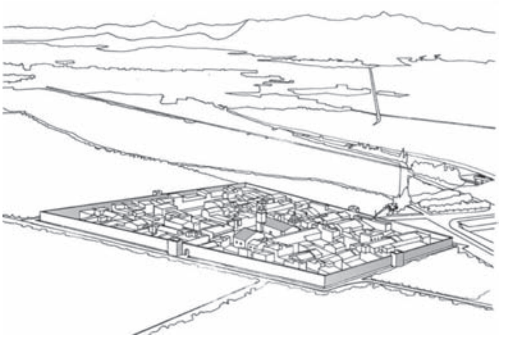

Figure 7. Aerial view of Mascarell.

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Experience of rammed earth construction—rural and urban India

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ABSTRACT: Rammed earth is slowly being adopted in urban India, especially in Bangalore and Auroville located in Pondicherry. There is some acceptance as well as executional issues associated with it from contractors and owners, which will be elaborated in the paper. This will be done through explanation of various formworks used and the resulting aesthetics, and finally by an analysis of the cost of formwork, number of people required, labor time for ramming and cost of the final wall.

In India, cob, adobe, and wattle and daub were the traditional way of building walls. Rammed earth as a system of construction was used only in Ladakh. Indians built with earth extensively, but rarely made it dense. For larger loads and monumental construction, stone was used instead of earth. Where stone was a rarity, being mostly in the floodplains of rivers, clay was abundant and was fired to make bricks. These bricks were used for all purposes, including foundation. There is a need to look at alternative methods of construction that are ecological, low in embodied energy, and cost effective while not compromising on structural aspects—sustainability being the key factor for future constructions.

Stabilized Mud Blocks (As Compressed Earth Blocks are referred to in Bangalore) are making inroads as a walling unit thanks to extensive research work and built examples done in the Centre for Sustainable Technologies, Bangalore, Auroville Earth Institute, Pondicherry and the authors' architectural projects (www.biome-solutions.com). They are a reliable alternative to bricks, concrete blocks or stone.

Construction using earth is being accepted slowly in the cities of Bangalore and Pondicherry. Outside of these two cities, there are a few new constructions in Delhi and a large retreat for ISKCON near Mumbai.

At present, Compressed Earth Blocks are being used extensively in Bangalore because of a good ecosystem for applying this method. There are teams of Compressed Earth Blocks makers, a high level of construction knowledge amongst masons, and a support network of engineers to construct and detail the structural designs. Many architects use this material because of their low-cost, ecological credentials as well as their aesthetics.

Manual Compressed Earth Blocks making machines are available from Mrinmayee in Bangalore and Auroville Earth Institute Auroville, Pondicherry. Compressed Earth Blocks have some constraints like the cheapest of these machines, "Mardini" available from the workshop of "Mrinmayee", Bangalore, costs $1200/-. This is rather a large sum to invest by a home builder. The making process requires the user to understand the proper mix, water content, weight, and compaction. When these issues are not taken care of, the blocks do not perform well, especially with respect to weathering leading to the technology being abandoned.

Compressed Earth Blocks are largely made at site, requiring area for stocking of raw materials, sieved soil, mixing and making blocks. This is a constraint in the urban areas requiring them to be made elsewhere, and transported adding to cost and pollution. On the contrary Rammed Earth being produced in situ does not require any space beyond the storage area for the excavated earth. When the earth is to be transported to site, Rammed Earth walling is easier to manage than Compressed Earth Blocks because ramming can continue while bringing in smaller quantities of earth as and when needed. The authors have also noted other advantages like the use of soil with gravel, flexibility in wall thicknesses and stabilization with respect to the loads and a ready surface finish.

The authors' first experience with Rammed Earth was a garage structure in Mysore, India in 1996, referred to as Building 1. It was made with a simple horizontal form work of wood panels, wooden clamps and wooden inclined supports, all held together with ropes. The available soil was modified by adding quarry dust, and 5% cement was added as a stabilizer. Figure 1 shows the formwork and the rammed earth. This structure has a sloping Reinforced Cement Concrete roof of filler slab with Mangalore tiles.

Figure 1. The rammed earth wall and formwork and finished wall in Building 1.

Figure 2. Rammed earth block making and walls in Building 2.

The authors worked with Prof. M.R. Yogananda for their second rammed earth wall in Building 2 for a project in Bangalore in 2003. In this process earth was poured in small MS box formworks. The result was a block like unit.

Sustainable Technologies, Bangalore and found to be close to 80 kg/cm^2. The surface of these blocks was smooth and well finished. Making the blocks also allowed for the flexibility to redo if the surfaces did not match the desired expectation.

Up to 2.1 m height, these blocks were made in situ above which workers preferred to make the rammed earth blocks on the ground and lifted them in place. The soil was modified by adding 40% quarry dust and 5% cement. The load tests were conducted on the Rammed Earth Blocks at the Centre for Sustainable Technologies, Bangalore and found to be close to 80 kgs/cm^2. The surface of these blocks was smooth and well finished. Making the blocks also allowed for the flexibility to redo if the surfaces did not match the desired expectation.

In the third project in 2004—a residence for Nishwath and Prakash in Bangalore—Building 3—longer horizontal formworks as in Figure 4 were used.

The formwork was made of centering sheets and metal clamps. The walls were rammed in situ. The soil was modified with 40% quarry dust, and had a stabilization of 3% cement. The horizontal formwork provided for long surfaces, and was smooth. The clients did not like the large visible joints as seen in Figure 5.

The internal surface was thus rendered with a stabilized plaster to achieve uniformity and smooth surface, as seen in Figure 5. Externally the surface was left as it is with one exterior wall having a mud cement mural as seen in Figure 6.

The same formwork as Building 3 was repeated in another residence for Dinesh and Sarita in 2005- Building 4. The soil was similar to that of

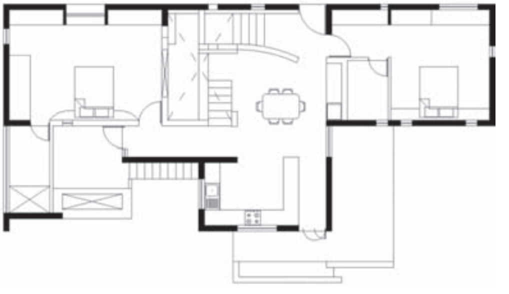

Figure 3. Dark walls indicating rammed earth walls of Building 3.

Figure 4. Rammed earth form work of Building 3.

Figure 5. Walls with the visible joints during construction and after rendering.

Figure 6. Exterior view of Building 3 with mud cement mural.

Figure 8. Traditional rural building near building in central India.

Figure 7. Mud paint rendering on rammed earth walls of Building 4.

Figure 9. Plan of the admin block of Forsyth Lodge, Building 5. The shaded walls are the rammed earth walls.

Building 3. Here too clients did not appreciate the walls being left un-rendered. Both the internal and external walls were rendered with mud paint as seen in Figure 7.

With the above experience, it was noted that the joints which emerge when moving the horizontal formwork resulted in a surface that did not appeal to the owners. This required that designs be worked upon with respect to formworks wherein such joints can be avoided.

Building 5 was in a rural setting. The project was a wildlife lodge in a village bordering anature reserve. There was the need to conserve resources since the building was in a remote area. New constructions in this neighborhood used burnt bricks along with a reinforced cement concrete framed structure. The villagers, however, traditionally constructed using a combination of wattle and daub and cob rendered with mud-cow dung plaster as in Figure 8. The roofs of village houses were thatch or country tiles on reed/bamboo supports like in Figure 8. Both of these types of roofs are light weightand suitable to the climatic conditions, though they require maintenance and replacement which in turn demands skills.

Figure 10. Walls with 90 degree turn and plane panel walls.

The authors and their clients decided it would be good to build in a manner that showcased intelligent use of earth for construction without resorting to polluting and high embodied energy materials like Burnt Bricks and reinforced cement concrete. Design required integrated land management with respect to water, sanitation and wildlife. Therefore it was decided to build the whole resort in mud. Early on in the construction process, mud was excavated from the pool area, the water treatment polishing ponds, and other water holes to provide sufficient earth for construction. Traditional skills of cob with newer details were introduced in the construction of smaller individual rooms with tiled roof. The dining and facilities areas were built with rammed earth.

Rammed Earth walls in Building 5 were tall panels instead of being horizontal types like in Building 3 and 4. The design of the space was based on the panel sizes of walls.Two kinds of formwork were designed—one was a plane panel and the other formwork incorporated a 90-degree turn.

The soil was tested at site and found to be sandy enough, not requiring any modification except for 5% stabilization with cement. The formwork was of centering sheets, wood planks and steel clamps. The clamps shown in Figure 11 were simple enough that they could be manufactured in the town nearby. A wooden rammer was also made at the site.

In a single day, a wall panel was raised to 1.1 meters height and the next day, the planks were removed and another 1.1 meters was added achieving total height in three shifts.

The walls were smooth and without issue, except on two occasions when the panels were not cleaned well before setting up for the next stage. In these occasions, the surface peeled off while dismantling. This peeled surface was covered by a mud cement mural. This method of constructing brings about a vertical joint with round holes where clamps were placed. The vertical joints, though of no consequence with respect to the structural stability, were covered by incorporating a mural as seen in Figure 10. Internally, the surface was plastered and painted.

With the success achieved in Building 5 from its vertical paneled formwork and-90 degree turns, an integrated formwork was designed for the residence for Ms. Hamsa Moily, henceforth referred to as Building 6. This formwork integrated rammed earth piers and walls. This building is 11 meters high with four floors of 2.5 meters and two floors of 5 meters internally as seen in Figure 13.

The site of area141 square meter is hemmed in on two sides by buildings and on the other two sides by a busy road. (Fig. 14).

It was not possible to build with Compressed Earth Blocks due to lack of space for making them. Rammed Earth construction was the obvious choice, since the walls could be made in situ and also modified structurally to take the load of four floors. The ramming at height was an issue, and was overcome with the design and materials used for ramming. The whole perimeter of the building was divided into six parts, minimizing the joints between the panels. Openings were provided where a joint occurred; making the panel joints a feature, with the design following the construction method adopted. The 2.5 meters of height was rammed in three stages.The material for the continuous formwork was centering sheets for panels and mild steel "I" section supports and metal clamps tack welded together as shown in Figure 15.

In Building 6, it was decided to close the loop with respect to the formwork. The final floor plate was designed to use the formwork I sections as supports for the floor boards, as in Figure 16 and the

Figure 11. Clamps used in the formwork and wooden rammer, fabricated locally.

Figure 12. Formwork used in Building 5.

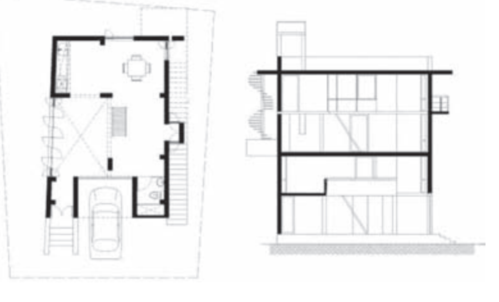

Figure 13. Plan and section of Building 6. All walls of this building are of rammed earth.

panels of centering sheets were used in the casting of reinforced cement concrete slabs in the subsequent project. This approach reduces loss and damage along with unused inventory for the contractor, and thereby reduces the cost to the client.

Figure 14. Exterior view of Building 6 in its context.

Figure 15. Form work used in Building 6.

The authors through their above experience would conclude following:

In developing countries and emerging economies like India, massive construction of infrastructure and housing is taking place. Construction is the top contributor of CO_2 with Iron and Steel and Cement being the main constituent are direct top contributor of CO_2 emissions. Indian housing Census of 2007 mentions that 48% of the houses are built with bricks. With agriculture not being financially viable in small landholdings, farmers tend to lease out their lands for brick making. Brick making depletes land of its nutrients making them totally unsuitable for any kind of future agricultural use.

Figure 16. Form work reused for intermediate floor Building 6. Inferences.

Table 1. Comparison of time and manpower for different kinds of formwork used by the authors.

Formwork type	Cap-ex ($)	Size (M) W D H	Time (hrs) Assembly Dismantle Ramming	Manpower (nos) Mason Helper Other	Area finished in one day (sqm)
Rammed earth block	300	0.23	0.25 to 0.33	1	1.44
		0.6	0.33	1	
		0.3	0.33	0	
Horizontal formwork	600	0.23	0.75	1	2.59
		2.1	0.25 to 0.33	2	
		0.45	1.5	0	
Rammed earth panel	600	0.23	1.66	2	6.79
		2.25	0.33	4–5	
		2.25	5	0	
Continuous centering	1600	0.23	4	2	5.57
		10	2	4	
		0.75	4	1	

Table 2. Comparison of formwork on parameters of durability and reuse possibility.

Formwork type	Comments on formwork
Rammed earth block	Form work can be used to construct walls for approximately 600 sqm floor area, after which the formwork goes waste.
Horizontal formwork	Form work can be used to construct walls for approximately 400 sqm floor area, after which the wood panels of the formwork need replacement.
Rammed earth panel	Can be used for one building only.
Complete centering	Vertical supports can be used back in the building as supports for floor boards.

Table 3. Comparison of rammed earth with other walling units for 10 sqm of wall.

Walling system		Manpower needed					
Other components of work	Nº of man-days of 8 hrs	Different skill levels of workers (mandays)	Wages ($/day)	Description of other costs	Amount ($)	Cost of finished wall ($/sqm), inclusive of overheads and profit	Number of people employed
Rammed earth panel	1.47	2.94 mason	10	Formwork investment	600*	25.84	6–7 people
		7.36 helper	7	Cost of raw material	75.15		
Compressed earth blockwall							
Block making	1000#	8 people	10	Cost of raw material over all items of work	109.46	22.59	13 people
Wall construction	1.08	1.08 mason	10				
		2.16 helpers	7				
Pointing	1.44	1.44 mason	10				
		1.44 helpers	8				
Wall of country fired brick							
Brick making		4 people		Cost of raw material over all items of work	225.86	41.95	8 people
Wall building	0.72	0.72 mason	10				
		1.44 helpers	7				
Plastering	2.16	2.16 mason	10				
		4.32 helpers	7				
Painting with white wash	0.28	0.28 painter	9				

Number of bricks produced per day.
* The form work can be used to build a 200 sqm house with 302 sqm of wall area.

These are important consideration for looking at an alternative technique and material for construction and earth makes for a very logical building material.

The authors experience and inference provides for a platform of discussion and adoption of different construction methods with Rammed Earth being a major player for future of ecological construction in developing countries as a walling material in combination with other sustainable materials and techniques for floors and roofs.

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Conservation of rammed earth

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The restoration of *tapia* structures in the Cuarto Real de Santo Domingo (Granada, Spain)

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ABSTRACT: The Cuarto Real de Santo Domingo (Royal House of St. Dominic) is a building dating back to the beginning of Nasrid times (second half of the 13th century), in which there was a widespread use of the system of *tapia* (rammed earth). In the restoration carried out some years ago it was not only necessary to deal with the deterioration of the original *tapia*, but also of the different historical restorations. This paper presents the methods used in this intervention, including systems of anchorage in the replacement of fallen expanses of construction, as well as the final outer finish of the renovated areas, in an effort to achieve durability and harmony with the remaining original parts.

1 INTRODUCTION

The Cuarto Real de Santo Domingo is a building of enormous historical, artistic and constructive interest, located in the southern area of the Islamic city of Granada, and whose construction dates back to the beginning of the Nasrid period (second half of the 13th century; Rodríguez Trobajo 2008). We refer to what was in its time a royal property of the Granada sultans, which was known as the Huerta Grande (Main Orchard) of Almanxarra at the time of the conquest by Castile, and was donated by the Catholic Monarchs to the Dominican Order to found the convent of Santa Cruz la Real. From then until the seizure of ecclesiastical properties in the middle of the 19th century, it formed part of the convent's lands.

Basically, it consisted of a walled garden and a hall in the shape of a *qubba* inside the fortified tower of the wall of the Potters' Subburb (Arrabal de los Alfareros) (Orihuela, 1996, Almagro & Orihuela 1997). The tower and the city wall that are attached to a considerable slope of the natural ground work as retaining elements of the garden; there is a difference in height of almost ten meters between the garden and the outer city area.

2 DESCRIPTION

The outer measurements of the layout of the tower are 14.30 × 9.50 m with a height of 15.50 m and it is formed of an older nucleus of 10.25 × 6.25 m that was later extended to hold the *qubba* (Fig. 1). Both the heavier construction work of the tower, the interior partition work and the enclosure walling of the garden are built with the *tapia* (rammed earth) technique, and carried out using natural materials from the area; these are known as "Alhambra formation" conglomerates with lime. "Alhambra formation" consists of conglomerates of cobblestones, different sizes of aggregates and red-coloured clay in different degrees of carbonatation, which could be found as completely disintegrated materials or others well cemented together with consistency. The use of this type of materials in the construction of *tapias* means that it is often difficult to distinguish between remains of walls or of natural ground. Execution corresponds to the so-called *tapia calicostrada* wall which presents horizontal coating with richer layers of lime, coinciding with ramming beds, as well as an outer crust especially rich in conglomerate material that protects the whole of the inner mass.

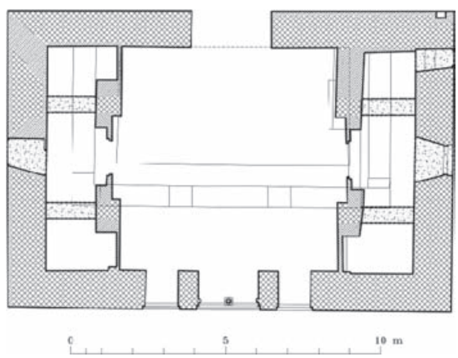

Figure 1. Plan of the *qubba*, showing phases and alterations.

The changes in direction of the walls, i.e., the corners, are resolved having made both the formwork and the filling of the courses in a continuous manner. Not so with the interior walls done in a second phase, attached to the perimeter walls with no type of bonding together. The jambs of the openings and the extremities of the walls that are free were made of brick with tuskings that coincide with the height of the courses. The brickwork was carried out prior to filling the courses, serving as a closure at the height of the extreme end of the wall. At present only the wall faces of the later structure are visible, therefore more precise details of just these can be provided.

In spite of this, we are able to state that the original tower was constructed of a wall of two attached parts, both made of *tapia* and with a similar thickness, 0.70 m. The external part had brick corners throughout the whole width. There are also two brick piers on the southern face, set out symmetrically; they could correspond to the base of the jambs of an opening, but as the whole of this structure was destroyed above the level of the floor of the *qubba*, this hypothesis cannot be confirmed. The inner panel is all of *tapia* and was built putting formwork on the inner face only. This attached wall served as a support for the vault covering the resulting space and as an infrastructure or perhaps an accessible basement, leaving most of this first tower empty (Fig. 2). The vault pointed in an east-west direction. In an important process of consolidation, no doubt carried out at the beginning of the 18th century, and which we shall mention later, the covering was demolished and the whole of that space was filled with rubble. In spite of this, and thanks to the traces that have survived, we can confirm that the vault was built of bricks composed of rings of flat bricks set edgeways, i.e., with their flat faces parallel to the end sides, to avoid using centering (Almagro 2001), and that its construction began on the western side. For support, a groove was made along the side walls, similarly to how it was done in the tower of Romilla (Almagro 1991).This groove only survives along the southern side of the room, because on the northern side the re-rendering of this facing eliminated all remains of the support. It seems that the profile of the vault was slightly pointed or maybe parabolic. The courses of the interior wall of *tapia* show the signs of the *tapiales* (side shuttering) with the impression of the nails joining the boards. These boards measured 0,80 m in height.

The oldest tower, as we have already mentioned, was extended by an attachment on its outer surface of thick walls, also of *tapia*, that had formwork put on the outer surface only. Here we can see that the average height of the courses is 0.87 m and that they were filled in a continuous way, so we cannot

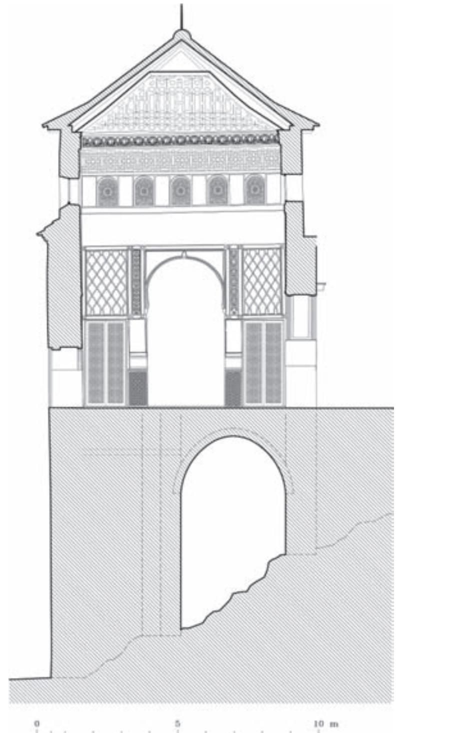

Figure 2. Hypothetical section of the tower and the *qubba*.

observe any joints or discontinuous elements in the material. In some places, particularly above opening of the lower windows in the *qubba*, we can still see the marks left by the nails of the *tapiales* in the fresh mass, as well as their vertical joints. To uphold the increase in thickness of the original walls, it seems that logs of wood were set out horizontally and at every set distance more or less regularly. In some parts, where the exterior crust was deteriorated or where a greater loss of material has occurred, we can see holes left by the *agujas* (pieces of wood for sustaining the shuttering) that disappeared on all except the northern face, where those holes were formed with flagstones from the river to allow the wood to be extracted. The thickness of the increase in width varied between 3.35 m on the southern side and 2.00 m on the eastern and western sides.

Above the floor level of the *qubba*, the external walls have a constant thickness of 1.20 m on all sides and are made of *tapia* throughout, except for the jambs of the openings which are made of brick with tusking, as already explained. The exterior walls leave an inner space of 11.87 × 7.22 m, subdivided in seven spaces by means of transversal walls defining a central square hall measuring

7.20 m, the *qubba* and three satellite spaces each side, communicating with the main one by means of arches and doorways. The walls separating these spaces were also of *tapia*, although the extremities giving on to the central room are of brick with tusking as already mentioned. As we have indicated, these internal walls had no bonding with those of the perimeter, but were simply in contact.

As from 6 m from the floor of the *qubba* the external walls are cut short, and from this height a square body stands out, like a lantern (Fig. 3), sustained on the northern and southern walls and on the header faces of the interior transversal walls. This lantern body has five small arches on each side to light the interior and is finished with a square trough collar-beam roof. Constructively, the way in which this higher body was made, of mixed masonry brickwork and *tapia*, turns out to be very appropriate. Prior to making the lantern, the six satellite spaces were covered with panelled ceilings with beams supported on the eastern and western outer walls and on some thin wooden beams supported on the header faces of the partition walls, and placed very near the wall face of the central hall. Under neath this beam, in the two central wall openings, plaster arches with decoration without any tectonic function were built. The four side wall openings were closed with wooden doors. Over these panelled ceilings the *tapiales* were prepared, to continue the construction with rammed earth. To avoid loading the weight of the wall which otherwise would have rested on the previously mentioned beams, other beams of a greater section, formed like tree trunks were set into the mixture and were practically concealed. The lantern wall is of *tapia* up to the height of the windows. They are formed with brickwork, both in the jambs and arches, and above them the *tapia* continues up to the eaves; the present one is the result of the 18th century restoration. The original one would no doubt have been of leaning wooden corbels, characteristic of Nasrid architecture.

Figure 3. Southern elevation of the tower.

3 DETERIORATION

In spite of the fact that the monument has been regularly maintained and has never reached a state of abandon or ruin, due to the nature of the materials and its topographical situation as a building attached to a sloping ground, certain deterioration has occurred that is typical of this type of building work and that has essentially affected the superficial layers, which have been repaired in different periods and using diverse methods.

The main cause of this deterioration has been the effect of damp coming from the land itself, due to the phenomenon of capillary action, and from rainwater that has in this case particularly affected the walls orientated towards the southwest, the direction of the heaviest rains. In both cases, the presence of water in the mass of the *tapia* and the consequent process of drying and crystallization of salts that have filtered through have provoked deterioration in the surfaces exposed to the air, though more limited when these surfaces are formed by layers that are strongly carbonatized and in increasing progression as the material exposed has less resistance due to containing less lime. The action of the humidity from rain was particularly serious in the support of the lantern on the western side, as we may assume that the trunks set into the mass of the *tapia* must have rotted away and meant a turn in the wall that was controlled by substituting those beams for other squared ones. We imagine that this was achieved in the repair work in the 18th century, although it meant that the panelled ceilings on that side disappeared together with part of the interior decoration.

Nor should we forget actions caused by man, opening up windows to adapt the building to uses other than those originally designed, and some of the restoration work that in specific cases has been definitely aggressive.

4 RESTORATION WORKS

This historic monument has been subjected to multiple restoration work, although we must specify the most important one in the 18th century, and another one in 1910 (Fernández-Puertas 2000). Finally, the latest restoration was carried out between 2001 and 2003 under the direction of the authors of this paper.

The restoration of the 18th century, whose date we know from some indications through dendrochronological analysis as well as from stylistic features of some decoration carried out at that time, led to the demolition of the cellar vault and to the underpinning of some walls that rested on the vault or served as a support. So all the lower part of the northern wall below the level of the floor of the *qubba* was repaired, and the outer part of the *tapia* was substituted by a course with masonry courses. We can imagine that as this wall was supporting the earth it had deteriorated considerably, and must have affected the vault that rested on it. When the vault was demolished and the face of the wall was remade, all traces of its support were lost, as we have mentioned. This underpinning and repair work of the wall face must also have affected the two faces of the same northern wall above ground level, at present covered in brick. This operation meant that the panels of tiling covering the lower area were lost.

Another important operation at this moment was the repair of the west side of the lantern, already mentioned, which must have involved renovation of the eaves. On the cornice of the wall of the lantern, which must have been in bad condition, part of the work of the *tapia* was substituted by brickwork that on the western side reached almost the whole of what existed above the small arches of the windows.

Finally, on the western façade of the tower the *tapia* was covered with masonry brickwork after having cleaned up and enlarged the corresponding space, to be able to place at least half bat of it. The masonry brickwork was covered with mortar and certain ornamental motifs were set on the higher part while at the same time some windows with balconies were opened in the outer walls (Fig. 4).

The 1910 restoration involved both structural aspects and interior adornment. Regarding the exterior, repair work was done on the southern front elevation, incorporating coverings of brick which were in this case facing brick, without any mortar. At some stage between the 18th and 20th centuries the interior compartmentalization walls were eliminated, leaving only their brick header faces as mere pillars, and because of losing their bracing they were subjected to serious deformation. For this reason other new pillars were attached to them, closing up the original accesses of communication of the auxiliary spaces with the main hall. The lantern also proceeded to be stabilized by means of metallic tie bars that were visible from the inside, attached by means of metallic profiles fixed to the outer wall faces, all of which gave considerably unfortunate visual effects.

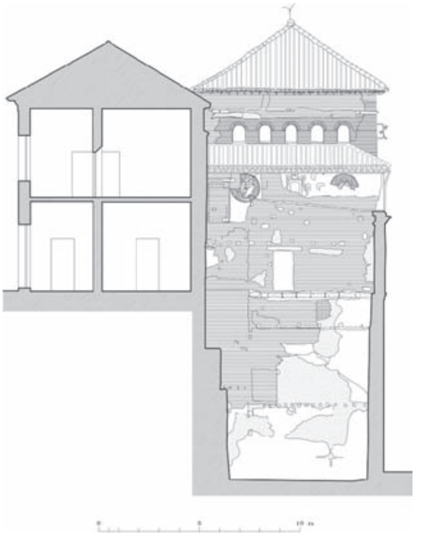

Figure 4. Western elevation of the tower.

In the last restoration not only the deterioration of the original *tapia* had to be dealt with, but also the historic restoration work that showed signs of decay, incompatibility of the materials used with the original masonry and detachment from this.

In our restoration we have followed criteria based on an effort to recuperate the original structure of the building, and repairs have been accomplished using materials and techniques similar to the original ones, therefore trying to safeguard the aesthetics of the monument itself. Whenever possible we have maintained the transformations that had some symbolic historic value, just as long as they did not involve aggressive action or deterioration of the fundamental values of the original work. Anyway, we have endeavoured to achieve correct documentation of all the information that the monument provided.

As far as the *tapia* is concerned, we would like to point out that we have followed methods that are very similar to those used in previous actions, with the intention of improving and resolving the problems that were presented.

We must recognize that when *tapia* is dilapidated it is difficult to reintegrate, since the new masonry of one type of earth or another has less powers of adherence than the old materials. We can say that historically two methods have been applied, according to the degree of deterioration. If it was only superficial and hardly reached a few centimeters down, it was generally reinstated with a straightforward rendering of mortar, which always has the difficulty of achieving adequate adherence. But normally, the deeper the damage, the lesser the resistance and compactness of the material of the *tapia*, and although the new mortar sticks to the layer on the exterior, with any tension it will detach itself from the rest together with wide expanses of the new mortar.

When the loss of material was more serious and it was impossible to reinstate it with layers of mortar, what was missing was rarely completed with new *tapia* because of the difficulty of implementing the work as well as the problems of adherence. The most frequent solution was to complete the lost areas with masses of masonry brickwork or rubble work of sufficient thickness to be stable on its own and not to have to depend on adherence to the old part. In many cases part of the eroded part in the old material was enlarged to allow at least one whole brick to fit in the new filling. These patches were later plastered, the same as the other less serious damage, so in many cases it was quite possible to manage an almost complete plastering of the whole construction work.

All the historical interventions carried out on this monument followed these techniques, and almost all the deterioration affected the restoration with which in many cases the initial damage had been aggravated. This was particularly visible in many of the brick coverings; in spite of being apparently firm on their own, having at least half bat of thickness, their excessive slenderness when detached from the nucleus of the wall and the pressure exerted on them by the materials that became detached from the wall because of disintegration from the *tapia*, had caused them to fall or at least had created instability.

Under these circumstances we must realize that the possibilities of action are still quite limited. Our intention has been to endeavour to improve the integration and adherence of the new materials supplied with the original building work, although we have continued to use the same repair methods as we recognize that there are no other procedures with a better guarantee. What is quite clear is that the deteriorated masonry cannot be left in this state, because as it has lost the strongly carbonated crust of the initial surface, there will definitely be progressive deterioration. On the other hand, the appearance of the *tapia* is totally different from the original; therefore there may be a rather undesirable aesthetic alteration in safeguarding the values of the monument.

The methods we have resorted to in our intervention have included attachment systems both in the replacement of important expanses of fallen masonry and in the rendering used in repairing superficial losses. To carry out this attachment we have resorted to very traditional materials and processes, inspired in the solutions used in old times.

The attachment has been made with wood, since that was the material that was used to a great extent in the *tapia*, as we have been able to establish in this building itself and in other places. Therefore, in the constructions in Meknes (Morocco), probably one of the most impressive complexes of *tapia* constructions, with over 30 km of walls built with this technique, we have been able to observe a systematic use of wooden elements set into the mass of the walls to give them greater bonding, in particular in the angles and corners where cracks tend to happen with ease, due to differential settlements or other earth movements.With this experience behind us, we began to take advantage of any opening in the original wall, whether of *agujas* (pieces of wood for sustaining the shuttering), or previous strengthening elements, to introduce pieces of wood covered with plaster and hemp to guarantee good adherence to the masonry and protection of the material. These pieces had sufficient length to reach a few centimetres from the outer face of the walls. In the areas where there were no holes or they were set a long distance away, orifices were opened using an electric drill with a bit and wooden laths were put in, of the type used to make tenon joints in carpentry and which have a high degree of resistance and a fluted surface that improves adherence. They were covered with plaster and hemp like the pieces of a wider section (Fig. 5). All of these attachment elements, placed every 40 or 50 cm and entering 25 cm into the old wall, were absorbed into the brickwork masonry with which we reestablished the openings produced due to the *tapia* having receded or previous repair work having fallen away. This brickwork was made with lime mortar scarce in conglomerates (1:3) and the openings existing behind it were filled in to ensure some adherence with this method.

Figure 5. Insertion of the wall ties with plaster and hemp.

To repair superficial deterioration a similar method was followed, using wall ties of shorter wooden laths, similarly coated in plaster and hemp joined together with bands of these fibers covered in plaster. Over this mesh the lime mortar rendering was extended, and in this way it was more solidly secured to the wall (Fig. 6). We consider that this simple and economic procedure improves the bonding between the two materials, the restored and the original; by maintaining the methods of traditional restoration, which are certainly not perfect, we must admit that up until now there are not other methods that offer a better guarantee or durability.

A particularly delicate problem is the one referring to the final outer layer of the restored areas regarding their adherence to the crumbled masonry which we have already dealt with, their durability and impermeability and their harmony with the remains of original wall faces. In this case a rendering of lime mortar was used, to which a superficial texture was given which was very similar to that of the original wall, and making richer in conglomerate the outer layer which was smoothed under pressure to reduce the pores and achieve a surface richer in lime. This rendering was applied in horizontal bands that were made to coincide in both position and height with the courses of the original *tapia*. The joints that are generated between the application of one band and the next produce a similar visual effect to that of the joints of the courses. In this process we did not only cover the brickwork masonry replaced by us, but also the previous masonry that had been left uncovered and that had a disconcerting effect on the overall aspect of the monument.

A final and none too trivial issue was to achieve an adequate chromatic tone. Although from the beginning aggregates were used to give the mortar the colour that was most similar to the existing surfaces of the original *tapia*, these had great variations in tone between some areas and others. This was due to the action of water and other

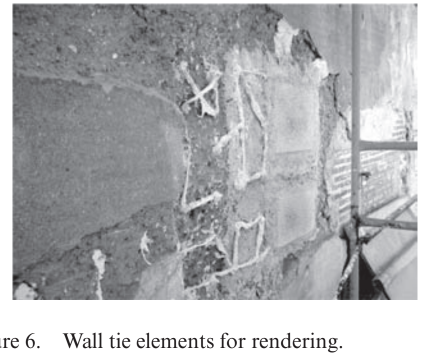

Figure 6. Wall tie elements for rendering.

Figure 7. Restored tower of the Cuarto Real de Santo.

atmospheric agents that had taken effect in various ways, therefore it was impossible to achieve an overall tone, nor on the other hand would this have been desirable, since it would have deprived the monument of its original image. Finally, we chose to apply a medium toned mortar and to apply glazes to smooth the differences in those parts that are in contact with old and darker rammed earth parts. As a final result the original areas of wall are clearly distinguishable, while there is a homogenous and coherent image in the wall faces as a whole (Fig. 7).

NOTE

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The Moroccan Drâa Valley earthen architecture: Pathology and intervention criteria

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ABSTRACT: The Drâa Valley is located in the southeast of Morocco, near the Sahara desert and houses one of the greatest earthen architecture heritages in the World, consisting of *ksur* (villages) and *kasbah* (fortified houses). The building's walls are entirely realized with rammed earth and adobe techniques, and the roofs are made with palms wood structure and covered with canes and compacted earth. Unfortunately, life style changes and the "progress race" have produced a gradual lost of the constructive and technical know-how accumulated during the centuries. This has also contributed to the lack of experienced Master Craftsmen and new labourers and is jointly in response to the massive diffusion of concrete construction. The article will describe the vernacular architecture and construction technique of the Drâa Valley, analyzing the type of pathology and proposing some intervention criteria for its conservation and preservation.

1 INTRODUCTION

1.1 *The Drâa Valley location*

The Drâa valley is located in the south east of Morocco, near the Sahara desert, and consist in the central part of the homonymous river; the Drâa river, in fact, born in the Saharan side of the High Atlas Mountains, creates a wide valley at the base of the Anti Atlas Mountains, crossing in the Sahara Desert and finally reaches the Atlantic Ocean. Actually the river has a very scarce water flow, and can lead to the Ocean on average once every 30 years.

The Drâa valley consists of 6 oasis systems and is characterised by date-palms groves. The date palm is a base of the pre-desert oasis ecosystem because it creates shade and humidity, and permits the cultivations of fruit trees and vegetables under it. The climate is hostile, warm and dry, with very marked temperature changes, both daily and seasonally.

Due to the richness of the palms groves, inserted in a very arid and rocky landscape, this area was chosen, already in antiquity, for human settlements and supported ancient agricultural communities.

1.2 *Drâa Valley architectural heritage*

The Drâa Valley houses one of the greatest earthen architectural heritages in the World; it consists in over 300 *ksur*, Berber villages constructed entirely with raw earth techniques. These village, rural and fortified, are characteristic of the Drâa and Dades Valleys and date from the 15th century, when the sedentary Berber population needed to enclose the villages with high walls and defensive towers, because of the continuous attacks of the nomadic Berber tribes (Fig. 1); from the 11th to 15th century the Drâa Valley was also one of the most important caravan routes between Europe and Timbuktu city, in Mali.

The *ksur* (sing. *ksar*) shows a very dense urban fabric, with houses (*dâr*) built each against other in order to defend each other from the warmth; in addition, often the first floor is built as a bridge over the road, thus creating, below, a fresh and dark grid of tunnels that protect from heat and sand storms. It is interesting to see how this type of aggregation simulate the underground architectures, enjoying the advantage of thermal insulation and, at the same time, solving the big problem of ventilation (Bourgeois 1988, p. 1).

In addition to *ksur*, the Valley is populated with *Kasbahs*, big fortified houses belonging to Berber families that protected the villages and adjacent

Figure 1. The Tissergatt *ksar* (credit by L. Rovero 2009).

territories, or, later, belonging to the representatives of Pasha Glaoui, who exercised administrative control until the Morocco independence.

2 DRÂA VALLEY CONSTRUCTIVE COLTURE

2.1 *Housing typology*

Both in the *kasbah* (big fortified houses) and in the *dâr* (houses) in the *ksur* (villages), the housing type used is constant and recognisable: it is a patio house. This type, with its specific and different models, is spread not only throughout Morocco, but also throughout the Arab World and the Mediterranean. The "patio" is a typical space of the Arab-Muslim housing and it is identified with the centre and the heart of home and family life; it is a place where to live, active, but at the same time intimate and collected. In the Drâa Valley buildings, the patio is defined by a perimeter gallery present at all floors, which creates a transit area between the central vacuum and the private rooms; its size and shape are determined partly by the local building techniques and the climate, and partly by the local traditional culture. The importance of this space, fundamental for illumination and ventilation, is also expressed by the very rich architectural details and decorations (Baglioni 2009, pp. 38–43 & 51–55).

The *dâr* are generally built with 3 floors. The ground floor rooms are normally used as stables, for agricultural equipment and non-perishable domestic reserves. The exception is the central patio, which is used as a summer living room, when it is covered on the top, and stays fresh because it does not receive direct radiation. The first floor, called *assfalou*, is a more private sphere reserved for women: it contains the kitchen, the bedrooms and the storeroom for food reserves; this part of the house is forbidden to strangers. The second floor is accessible and enjoyed by the guests and has direct access from the stairs, without crossing the *assfalou*. This floor has a covered part, where there is a living room called *mesria*, and a big terrace that is used to sleep on summer nights and to perform other household activities. High walls, so as to maintain privacy from neighbours, always surround the terrace. The house looks modest, but hospitable and is adapted to the needs of a peasant society, once nomad. For these reasons, the spaces do not have a great specialisation. The same room can be used as a living room, dining room or bedroom, depending on needs and circumstances; the people practise the daily or seasonal nomadism in the house, which consists of living, according to the different periods of the day (or of the year), in different rooms of the house, to enjoy the best possible comfort conditions (Bounar & Chahid 2004).

Figure 2. Example of a patio (credit by E. Baglioni 2009).

The *kasbah*, in the simplest case, maintains the quadrangular type plan with the central patio, but, unlike the common house (*dâr*), is larger, both in plan and in height (it can reach 6 floors), and has corner towers. Belonging to large families, powerful and wealthy, often the *kasbah* is more articulate and occupies large areas by combining several central patio buildings. The *kasbah* is thus divided into different areas, private or public, available for the various members of the family, servants or guests, and with distinct uses (VV. AA. 2005).

In the Drâa Valley, characterized by a pre-desert climate, the use of patio houses and a compact urban aggregation represent an effective response to weather conditions, due to the reduction of the external surfaces and to the function of the patio as a source of light and ventilation. The patio limits the direct insulation of ground floor and guaranties the indirect lighting of all the facing rooms; it also, like a chimney, pulls up the warm air, contributing to the rooms cooling and creating a pleasant ventilation.

The house is almost completely introverted, only rarely can windows be found on the external walls, and never on the ground floor, in order to ensure privacy and confidentiality. The windows are quite small and shielded with wood or metal gratings, called *musharabia*. They filter the strong outdoor light and limit the interior visibility, while ensuring cross-ventilation.

2.2 *Earthen building techniques (Baglioni 2009)*

In the traditional building techniques of Drâa Valley, the earth material plays the major role. Used in many different situations, it proves to be the most suitable material for an effective response to the warm and dry climate of the place.

The raw earth buildings sites are traditional and are managed by small artisan "company" consisting of a master chief, called *maâlem*, and a variable number of workers -no more than a few units-. The working tools are proportional to the type of site, traditional and craftsmanship.

The masonry techniques used are the rammed earth, called *alleuh*, and the mud brick, called *toub*, used separately in different parts of the building.

The rammed earth technique allows building a very thick (40–100 cm) continuous bearing wall. This construction system, performed by shifting a single formwork, from block to block, involves the adoption of a constant thickness of the wall along the entire perimeter, and generally also on the whole height; possible variation of the wall's thickness is in the change of storey. For a 3-storey building, such as the *dâr*, 40–50 cm thick masonry walls are enough, while for higher buildings, such as the *kasbah*, more relevant thicknesses are needed, until about 60–100 cm. The height of the floors is very variable, from 2.5 to 5 m, but is always proportional to the height of an entire number of rammed earth blocks. As for masonry buildings, particular attention is needed in the connections in order to ensure mutual collaboration among the blocks, among walls, or among walls and partitions. Analysing the actual situation, it is evident that the overlapping and interlocking of the corners and among walls and partitions is not always successfully; thereby this determines a non-cooperation and non-linked walls that tend to detach and act as single sheet walled. In the Drâa Valley, rammed earth is principally used for the walls of the lower storeys, and for the propriety division walls. The walls are generally built on a base of stones, varying in height. The rammed earth, for its mode of implementation, exhibits discontinuity points, consisting of holes left by the inferior transverse tie of the formwork, once removed. The holes and the joints between the rammed earth blocks are the weak points in the masonry and favourite channels for water infiltration; for this reason, the cracks in the walls usually corresponds to them.

Adobe masonry is generally used for the perimeter walls of the upper floors, which are subject to minor weight, and where it is better suited for finishing and decor (it is true that the work in adobe is more focused and also more expensive). In rammed earth masonry, there are areas that are difficult or even impossible to compact the earth inside the formwork, and so, adobe masonry is used. The adobe is used to complete the upper floors or to support the wooden lintels or floor beams, becoming a stringcourse in the rammed earth masonry. Whole monumental openings in prestigious buildings (*kasbah*) or in the fortified walls of the villages are built with adobe, so that arches and decorations can be built using different dispositions in the masonry. Adobe plays its major role in the patios, reaching the maximum of its bearing and decorative capacity: the patio, pillars and walls are entirely made of adobe. Even the interior non-load bearing partitions, and the bounding walls of the light shafts along the tunnel routes, are made of adobe.

The adobes are produced in different sizes but they are handcrafted products, so, their size varies from site to site and from village to village. The walls have a typically thicknesses of about 40, 50 or 60 cm and can be taper in the upper floors; it is a masonry based on a disposition of 2, 3 or 4 heads (for bricks), depending on the size of the adobe but very variable. The mortar consists of a mixture of earth and water, in which straw is rarely added. In adobe masonry, the mortar is laid in 2 to 4 cm thick horizontal joints between the courses, but rarely used in the vertical joints.

The lack of a bonding pattern in the adobe, the inadequate attention to the offset of adobe, the presence of mortar only in the horizontal joints, does not ensure a proper connection of the elements and therefore, produces a lack of bonding and low resistance of the adobe masonry. However, where a load-bearing capacity is required, usually on the lower floors or patios, the adobe disposition is clearly more regular and well executed.

The date palm, as the only usable wooden material for construction, is used as lintels for doors and windows and the horizontal structure of the floors. Its mechanical performance is low, because its trunk consists of bundles of parallel fibres that, subjected to loads, does not have an effective resistance and suffer intense inflections. This structural problem is overcome and controlled by maintaining a relatively short beam span, generally from 2 to 2.5 m (up to 4 m); this dimension becomes a real "module" for any building's construction. The beams, both for the floor and roof structure, are always disposed perpendicular to the patio perimeter, with a varied inner axis depending of the presence or absence of further structural elements.When the joists are absence, the beams are very close, with an inner axis of about 30–50 cm, otherwise the beams distance is about 2 m, and the joists have an inner axis about 15–20 cm.

A layer of canes, called *tataoui*, is laid on the top of the wood structure. The cane not only functions as a decoration, but also helps to distribute the loads on the wooden structure and limit the falling of dust.

Traditionally, a layer of sun-dried palm leaves was placed above the *tataoui* in order to further reduce the dust. Today, a plastic sheet, which can be easily found in the local market, replaces the palm leaves.

The floor is built with two layers of compacted earth, rich in clay. The first layer is made with dry earth, and the second is made with a humid earthen mixture.

The roof is constructed with three layers of pressed earth. The first layer is a humid mixture, prepared with a finer grain earth. The function of second layer of earth is to absorb the eventual water infiltrations, so, it is composed of dry earth. The final layer, in addition to serving as a finishing, must be impermeable to water; it is therefore implemented with a moist mixture of earth and lime or earth and straw. Lime is a natural stabiliser that makes the clay impermeable and, once dry, the mix stronger.

The roof needs frequent maintenance because it is subject to degradation due to rain, wind and sandstorms. Maintenance is performed every 4 or 5 years, covering the existing with a new layer of earth and lime or earth and straw mixture, so the roof thickness increases gradually over the years.

Although, rammed earth and adobe masonry are often exposed (without plaster), the plaster on earthen buildings plays an important role, as the protection against wind, rain, humidity and temperature fluctuations.

The exterior plaster of the Drâa Valley's architecture is made with a plastic mixture of extracted clay from the palm groves, water and straw, to which are often added, animal dung and urine. The straw is used to "arm" the plaster, therefore, limiting the shrinkage and cracking. The animal dung, however, enhances the cohesion of the mixture and the waterproofing properties.The interior plaster is achieved in two layers: the first layer, coarser, is a mixture of earth, water and straw; the second layer is a mixture of finer earth and water. To ensure its protective function, the exterior plaster needs constant maintenance, which, in the Drâa Valley is made every 4–5 years.

3 THE EARTHEN CONSTRUCTION PATHOLOGIES IN THE DRÂA VALLEY

The earthen construction pathologies in the Drâa Valley are mainly related to three factors: the action of the atmospheric agents (water and wind), the defects in design, and the defects in the building construction system; all are related to the lack or the inadequacy of maintenance (Baglioni 2009).

3.1 *Pathologies due to the atmospheric agents*

Although the buildings are located in a pre-desert climate where rain is very scarce, water related pathologies are very common.The earthen buildings are particularly sensitive to water and humidity and are easily attacked.

All earthen techniques are very sensitive to moisture, which contributes to an important feature of functioning as a hydrothermal regulator; absorbing the air moisture and releasing it when the air is drier. But, this also generates the continuous onset of expansion and contraction in the material that, in the long run, may lead to a cohesion loss.

The direct action of the rain on the wall surfaces determines the progressive removal of the surface plaster, through run-off, which, with the passage of time, can unveil the walls and expose them to the atmospheric agents. The surface degradation phenomenon is accelerated by the continuous wind action, especially during the frequent sandstorms, which exerts an abrasive action.

If the surfaces are compromised, the water migrates and gradually infiltrates into the masonry. The infiltration may take place by capillarity, entering deep into the masonry, or by gravity, percolating from top to bottom, inside the masonry. In both cases, there is a progressive dissolution and/or transport of material, with the occurrence of cracks. The internal construction wall joints become the evident channels, for water infiltration.

In rammed earth masonry, even if the wall is built continually along the perimeter, two adjacent blocks have differences in shrinkage. This causes the separation of the vertical joints during the drying phase. In the rammed earth wall, other evident channels for water infiltration are the holes left by the transverse ties of the formwork. For the adobe masonry, the presence of mortar provides better bonding. It is common practise to use mortar only in the horizontal joints, especially in the plugging masonry or in the terraces crowns.

In earthen construction, the plaster that protects the walls from the action of the atmospheric agents plays a fundamental role. A proper and frequent maintenance of the plaster is essential, even if only limited to areas with potential deterioration. In fact, cases of more advanced degradation are related to the lack of maintenance or to the abandonment state of the buildings.

A widespread phenomenon is capillary rise, which affects both base and corner walls: the water, through capillary action, rises from the ground and leads to various pathologies, including swelling and detachment of parts of plaster and consequently of masonry layers.

In relation to the increase of rising moisture, the degradation can grow and also undermine the structure equilibrium. Due to the dissolution of the underlying masonry layers, the above masonry tends to settle, causing cracks that promote infiltration and further degradation.

3.2 *Pathologies due to construction defects*

The water-related pathologies are often linked to construction "defects", as are the inefficiency of the foundation wall and the weakness of some construction connections, particularly with regard to the drip pipe.

The construction of a good stone foundation wall limits the capillary rise of water and protects the wall from water splashes and human actions. However, in the Drâa Valley's architecture, the foundation walls are not always present or of sufficient height.

The connexion between the rainwater drip pipe and the wall represents a weak point in the buildings construction, because leakage or water see page is often generated; such phenomena cause heavy wall erosion where the water drains. Comparing the two drip pipe solutions used in the Drâa Valley, one made with wood, or the most recent made with metal tube, the traditional wood solutions is certainly more compatible with the earth material. One of the most efficient solutions is the vertical gutter or runnel that is recessed into wall and waterproofed with lime plaster. This effectively channels the rainwater from the roof to the ground. However, this does not solve the problem of diverting the water away from the base of the wall, and it is therefore subjected to the pathologies related to rising moisture. In any case, a good maintenance of the plaster can limit the damage.

3.3 *Pathologies related to the limits of the construction techniques*

A different class of pathologies are linked to the "limitations" of the construction techniques, related to the specific place, to local cultures, and to the skills of local workers. All these causes influence the construction process (VV. AA. 2009). In analysing the built heritage, it was observed that the rammed earth layeris often built without offsetting the vertical and corner lap joints. This was also noted in the perimeter wall and the partitions -whether in rammed earth or adobe. Both cases are related to economy factors, which tend to minimise the use of rammed earth sub-module. From a structural point of view, in the absence of mutual bonding, the walls work separately. The lack of a perimeter ring beam at floor level prevents the wall sections from creating a "box" that would spread the loads more evenly. Due to the natural joint separation and the weathering action, the walls gradually tend to separate from each other. This phenomenon is affirmed by the presence of recognisable vertical cracks. These processes are accelerated by the sagging or settling of the soil, which often generate rotations of the walls—with overturning tendency- and the onset of "out of plumb". To limit such effects in these cases, stone buttresses are often used against the walls.

Weak elements of the Drâa Valley buildings are also the horizontal structural elements (beams and lintels) made with palm wood, which -due of its fibrous nature- does not guarantee high structural performance. The fibres of the palm trunk, when under load, tend to work separately and produce a strong deflexion of the timber elements; such repeated action require an adjustment of the wall with the subsequent onset of cracking, mainly visible in the adobe walls.

Figure 3. Earthen construction pathologies in the Drâa Valley (credit by CERKAS 2005 and E. Baglioni 2009).

The last relevant issue to be mentioned is tied to the construction of arches, frequently used in the patios of the houses and in the entrance doors of the villages. The lack of a key element, especially in lancet arches, combined with the use of considerable thick jointsthat amplifies the sagging, generates cracks. This is particularly related to the central part of the arch, which causes a gradual and "natural" separation in two parts. This can lead to dangerous kinematics.

4 INTERVENTION CRITERIA

In a restoration project of an existing building, the diagnostic analysis is crucial to recognise the causes of the problems, and consequently to develop a targeted and specific intervention (Rovero & Tonietti, 2011). In addition, a restoration project may exhibit different "levels" of intervention, such as the reconstruction (partial or total), the structural strengthening, and the introduction of new technological solutions. A good building preservation relies, first, on a good and constant maintenance and on the recovery of the traditional construction know-how (by which such buildings were generated). Unfortunately, in the Drâa Valley there is a progressive abandonment of the earthen houses, in order to move to houses built with conventional materials. Furthermore, there is a loss of building knowledge due to the scarce presence of the *maâlem* (master builders) and young apprentices.

However, starting with the most common pathologies, there are some general intervention criteria that can be proposed. These criteria are based substantially on the constructive "rule of art".

1. The first big problem is the water action. In regards to the water infiltration by gravity, both for the rammed earth and adobe masonry, it is recommended to properly seal the natural joints separationwith a mortar of earth and lime. The lime will increase the cohesion and will make the material more resistant to water. It is also important to create a good slope on the top of the wall. For the rainwater canalisation, it is suggested to strengthen the techniques already in place. Also, a long drip pipe (rain gutters) and long downspouts—excavated in the wall and plastered with lime- able to "accompany" the water away from the base of the wall.

   To limit the capillary rise phenomenon, not only is a high stone foundation wall, of the same thickness as the wall, necessary, but also the creation of a perimeter drainage system. This can be achieved by gravel insertion along the foundation and an adequate ground slope, which could help to remove water from the base of the walls and avoid stagnation.
2. The plaster and the top "sacrificial layer" of the building play a fundamental role. The plasters must be frequently renewed and possibly stabilised with lime. Maintaining both is important in order to protect the building from the weather agents: rain, wind, and sandstorms.
3. From a structural point of view, an important aspect is ensuring the walls continuity. First of all, the vertical joints in the adobe masonry have to be filled with an earthen mortar (or even better earth and lime mortar). Also, a correct connection (bonding) among the wall elements, near the corners, has to be guaranteed. With this aim, the "stitch-unstitch" technique, both for the rammed earth and adobe masonry, can be used if necessary. It is also important to intervene on the cracks, according to the cases, through the insertion of horizontal timber elements, alternating on both sides of the wall; a different solution may consist in the use of the "stitch-unstitch" technique (using adobe even in the case of rammed earth masonry); finally a casting of earth and lime mortar (which increases the cohesion and the strength of the mortar) may be adopted.

   A ring beam can be inserted, at the level of the floors, in order to ensure the operation of the building as a box; for this purpose wooden ties keyed into the walls may be useful too.
4. Finally, in regard to the construction defects of local techniques, it is suggested to avoid concentrated loads, which often occur in the beams supporting floors and roofs, by inserting the ring beams (curbs) or some distributing devices for the loads (dormant). In the special case of the arcs, a more accurate control of geometry and the introduction of an appropriate key element are necessary.

For all the described operations the use of materials, as much as possible, similar to the originals is recommended. In the Drâa Valley they are mainly stone, earth, straw, and palm wood; introducing different materials has to be avoided since this is often an inadequate solution.

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Characterization of the rammed-earth structure of the Moon Castle in Mairena del Alcor (Seville, Spain)

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ABSTRACT: In February 2008, in the laboratories of Vorsevi S.A., a series of analyses and tests were conducted on the rammed-earth walls, towers, and sections of barbican walls of the Moon Castle in Mairena del Alcor (Seville, Spain) in order to characterize the constituent material and to collect data that would enable the valuation and quantification of the future actions to consolidate the walls. Data related to the particle size and the physical, mechanical and chemical characteristics were provided, and information was obtained pertaining to the composition, conservation, and behavior of the wall when faced with consolidation and waterproofing treatments. These treatments form the basis of the consolidation and reinforcement techniques which, in these pages, are referred to as the most appropriate for these walls.

1 INTRODUCCIÓN

The Moon Castle in Mairena del Alcor, Seville (Spain), whose first stages were built in the mid-fourteenth century and later completed and refurbished in the second half of the fifteenth, is not only one of the most important castles of the province, but also constitutes one of its civil buildings of greatest magnitude constructed in rammed earth (Fig. 1).

In both stages, walls were constructed with rammed earth (Fig. 2) of diverse typology, which nowadays can be observed as having been greatly altered by successive consolidation work throughout its history, but especially by those interventions carried out in the early twentieth century by the English archaeologist George Bonsor (1822–1930) who bought the castle and set up his residence there.

The building is located on a steep slope in the eastern quarter of the town, organized around a rectangular courtyard (Fig. 3), which is delimited by four towers linked together by stretches of wall, oriented to the cardinal points.

Figure 1. View of the castle.

Figure 2. Bell tower.

Access is via two entrances: one from an urban street in the north sector, and the other to the south. Bonsor's house-museum is located in the eastern zone.

This Castle is situated in a very special geological region, defined by its alcoriza stone, that gives its name to the town (Mairena del Alcor) and by the "albero" sandstone traditionally used in mortar;

Figure 3. Plan of the castle.

this circumstance, together with the historical continuity of the construction, where it is assumed that there must have previously been an Islamic building, make this castle an extraordinary example to address the evolution of the Christian rammed-earth wall in the different phases of this period and also with respect to preceding Almohads.

Consequently, within the frame of the Project I+D+I BIA2004–1092 (Graciani 2005) we perform a study into the constructive solutions and types of these rammed-earth walls, as published by Graciani, A. Barrios, J. Barrios, and L.A. Núñez (2008).

In this context, in 2008, a series of analyses were carried out in order to first characterize the constituent material for a comparison with the conclusions obtained in the aforementioned study, and secondly to collect enough data to quantify future consolidation work on the walls.

2 DESCRIPTION OF THE RAMMED-EARTH WALLS

As explained earlier, in the Moon Castle, two different types of rammed earth are observed, corresponding to the simple and chained types, as established by Graciani and Tabales (2008).

Two of the four towers, which flank the southern front, that is, the SE tower (the Bell or Chapel tower) and the SW tower (Mocha Tower), were constructed in simple rammed earth, that is to say, the courses of the rammed-earth boxes were placed directly upon each other, thereby generating monolithic structures which lack both intermediate elements and vertical links.

The towers that delimit the northern front are of a mixed type of rammed-earth wall; in its chained variant, since it presents stone reinforcement at its edges. The chained rammed-earth walls were an Almohad contribution to the History of Construction, and constitute one of the many advances they brought to the *tapia* technique; while in the Almohad period, very few examples of stone chained *tapia* can be found (exemplified in the Torre del Oro, 1221) in relation to the proliferation of latericio chains. However, in the Mudejar era, there were some contemporary examples at the Moon Castle, such as the Mocha Tower in Albaida del Aljarafe (in the middle of the thirteenth century) and some other towers of castles in the Banda Morisca, such as those of Alcala de Guadaira and Los Molares.

In the composition of the walls, abundant use of "albero" is observed; the typical ochre sedimentary rock of this zone, rich in calcite, poor in quartz and with a variable content of iron oxides in the form of goethite (Fig. 4). This material has been widely used in construction in Seville, since it gives mortars the good qualities of high mechanical strength and a low reduction in volume.

Many reconstructions in the walls related to different stages can be observed, and these have very varied construction type, ranging from reconstructions with stone and brickwork to modern *tapia* wall, but generally lacking protection from water, such as that provided by coatings or by consolidation and reinforcement of the lower part or top section of a wall.

In some areas, there are examples of paving and gardening elements, carried out in recent years.

In the less sun exposed walls, facing to prevailing winds, and next to streets, we can find zones with moisture concentration and partial loss of volume.

The state of walls is good, although it would be recommendable to undertake some works for protection and consolidation, in order to reduce cleaning and repair works, which continuously carries out the maintenance staff and to ensure the durability of the walls.

Figure 4. South barbican.

3 CHARACTERIZATION TESTS

In February 2008, under the I+D+I BIA 2004-C1092 project entitled “Proposals for maintenance, assessment and restoration for the rehabilitation of buildings and urban infrastructure with historic *tapia* wall in Seville’s province”, we carried out a study in the castle to analyze the types of walls and characterize the *tapia* in order to evaluate and quantify the future consolidation works.

Samples were taken from the walls, towers and from the Barbican (Fig. 5), and conducted the tests listed below.

3.1 *Granulometry*

Classification by grain size, to determine proportions of gravel, ceramic pieces, sand and clay. In this type of test, sample is prepared with previous manual shredded and dispersion in water, and sieved, separating grain size fractions bigger than 4 mm, between 4 and 0.06 mm, and of smaller size, related to, silts and clays.

3.2 *Physical properties*

Density and porosity, were tested, which are properties that evaluate compactness of the material and give us an idea of the permeability of the wall to water, and to waterproofing and consolidation treatments.

Results from testing compressive strength, gives us an idea of the components used, the dosage of binder and water addition, etc.

3.3 *Chemical properties*

We determined the content of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), lime (CaO),

Figure 5. Location of samples.

Table 1. Samples location.

nº		
1	Bell tower. North wall	Outside
2	Barbican southeast	Outside
3	Duque tower east	Outside
4	Barbican east	Inside
5	Office	Inside
6	Dining room	Inside
7	Torre Southeast	Inside
8	Mocha Tower	Outside
9	Barbican Northeast	Outside
10	Barbican south.	Outside

Figure 6. Samples.

Figure 7. Sample 7.

magnesia (MgO), loss on calcinations (%), and sulfate (SO_3), and also aggressive compounds such as nitrates (NO_3) and chloride (Cl), to consider in consolidation works of the walls, to improve the effectiveness.

In order to obtain its composition, ten samples (Figure 6) were taken in the four towers and the barbican, in the more representative walls, numbered and located as following:

The samples extracted were mostly of *tapia* with different aggregate: sand and gravel, pieces of ceramic material, clay, silt and lime, and abundant "albero", easily found on site.

Most of the samples extracted show a high density and homogeneity in composition, not detecting disrupted areas.

In the case of samples number 7 (ruined tower, Fig. 7) and 10 (south barbican) sandstone samples were extracted.

4 LABORATORY TESTS RESULTS

Granulometry tests were done in order to detect fractions of sand, gravel and clay contained in the *tapia* samples, obtaining a maximum aggregate size exceeding 40 mm in sample 2, and lower in the

Table 2. Granulometry tests (% passing through sieves).

Size (mm)	Samples						
	1	2	3	4	6	8	9
50	100	100	100	100	100	100	100
40	100	80	100	100	100	100	100
25	100	75	100	88	86	79	100
20	93	72	92	87	83	75	95
10	68	69	85	80	75	69	82
5	49	66	77	69	70	63	69
2	34	60	67	52	62	56	58
0,4	20	36	40	30	32	37	35
0.08	9	16	12	17	14	18	13

Table 3. Physical properties.

Sample	Density (gr/cc)	Compressive strength (N/mm^2)	Porosity (%)
M1	1.60	4.70	34.80
M2	1.47	1.50	36.40
M3	1.51	1.30	35.10
M4	1.69	4.40	28.60
M5	–	–	–
M6	1.55	3.20	33.80
M7	1.79	6.00	8.60
M8	1.58	1.80	34.90
M9	1.70	5.20	27.40
M10	1.34	1.10	38.60
M10	1.55	5.30	10.80

Table 4. Chemical compound.

Compound	Content (%)					
	1	2	3	6	8	9
SiO_2	33.50	35.00	31.70	66.10	30.30	29.40
Al_2O_3	1.30	0.80	7.00	0.30	0.50	0.70
Fe_2O_3	2.30	1.50	1.30	0.60	1.20	1.30
CaO	34.70	33.60	35.60	13.90	33.20	37.10
MgO	0.00	0.00	0.00	0.00	0.00	0.00
Calcinations (%)	27.30	28.30	30.30	18.90	34.00	31.00
SO_3	0.25	0.30	0.41	0.31	0.32	0.35
NO_3	0.024	0.040	0.040	0.018	0.016	0.034
Cl	0.021	0.014	0.014	0.021	0.014	0.014

Figure 8. Sample 1.

rest, and detecting a 80–90% of sand, containing a higher quantity of silts and clays than 10% in all samples except for No. 1 (Fig. 8).

The physical properties tested, show high values of compressive strength in samples number 1, 4, 7 and 9 and medium porosity.

Chemical properties tested show that the fraction obtained of limestone is high, corresponding to the lime used for making the mortar, and the fraction of "albero" used as aggregate.

The fraction of sulfate ranges between 0.25 and 0.41%, equivalent to 0.38% and 0.50% of gypsum, concluding that the lime used as binder was contaminated with a small fraction of this material.

No presence of organic compounds, or aggressive substances (the fraction of nitrates and chlorides is very small), and no fractions of magnesia (dolomite) are detected:

We cannot define the dosage of lime and aggregates—clay used in the *tapia* wall, because of the "albero", which is a calcium carbonate in a 70–85%, with silica and iron oxide in an 15–30%, that distorts the result.

5 CONCLUSIONS

The *tapia* walls of the Moon castle in Mairena del Alcor, Seville, are made with 15% clay, lime, and a variety of aggregate: sand, pieces of ceramic, and "albero", the ochre sedimentary rock rich in calcite, which was traditionally used in mortar and paving, mixed with lime, in order to improve the mechanical strength and compactness, limiting volume changes and cracking through shrinkage.

From the tests carried out, we can conclude that the *tapia* walls show medium-to-high resistance to compression, and yield similar values to the walls of brick or stone with lime mortar, and an average level of porosity, which, make it suitable to receive treatment and water repellent liquids.

The state of the walls is generally good, and only a few areas are detected as having partial loss of material, damp, and rooting of plant species.

We recommend protection of the walls from the action of water, both due to capillarity, or infiltration and splashing, through the provision of rigid discontinuous or continuous lime coatings, in upper and lower zones, and also in those walls exposed to prevailing winds, or by means of applying waterproofing and consolidant products, after cleaning and restoring.

The heterogeneity of the types of walls and the dispersion of the areas to repair lead us to suggest a reinforced coating of lime mortar and "albero".

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)
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Structural criteria for the restoration of rammed earth buildings in Barcelona province (Spain)

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ABSTRACT: Rammed earth is a constructive technique with raw earth used for centuries in buildings construction in Catalonia. Changes occurred during the 18th century in the field of the construction in Barcelona were the basis of the disappearance of rammed earth as a usual constructive technique, insomuch there is very little local literature in relation to how to intervene in this type of structure. Even so, there is still much local heritage built on earth. This article is a reflection about the intervention criteria in buildings that have rammed earth structural elements in Barcelona province, being a singular case the stables of Gaudí's Güell Country Estate. From the studied cases, the article deepens in the restoration project of Ca La Dona building, a four-storey building located in Ciutat Vella, in the Centre of Barcelona. In the building part of the load-bearing walls are rammed-earth made, and it has been kept its structural function after the intervention.

1 INTRODUCTION

1.1 *Rammed earth construction in Catalonia*

Rammed earth construction is a constructive technique with raw earth present in an important part of the Catalan territory, but which has generally been not much studied. Usually this technology is exclusively linked to agricultural and low specialization economies (Cuchí Burgos 1994). Unlike other parts of the Iberian Peninsula where there is an important earth monumental heritage, in Catalonia this kind of technique usually appears in *arrabal* (suburb) houses (Fig. 3) or isolated houses like the *masia* (farmhouse) (Fig. 1), basic structure of agricultural management, where we can find many examples total or partially solved in rammed earth. This technique also appears in some singular buildings in Barcelona like the Güell stables or the kitchens in Pedralbes monastery.

It has been proven the existence of rammed earth buildings in almost all the Catalan territory except for the Pyrenean area, where easy access to the stone, on one side, and the wettest weather on the other, have been determinants in the use of other construction techniques (Fig. 2).

The early incorporation of Catalonia to the industrialization processes of society in the mid-19th century, came together with an intensive use of already familiar materials such as brick and other new ones like metallic sections for pillars and beams, that left forgotten techniques like rammed earth, which had been used until mid-18th century (Montaner 1990).

Figure 1. Building called la Masia in Masquefa (Barcelona). General plan view. It is partially built in rammed earth. Picture: R. Palomino—S. Pitarch (Final Degree Project-UPC, Tutor: Emilio Hormías).

An important part of earth heritage has been lost by abandonment. When agricultural auxiliary buildings were outdated farmers would remove them the roof tiles and beams of wood, and in many cases just reintegrated into the earth of the terrain.

Figure 2. Map of the earth architecture distribution in Catalonia. Source: thesis A. Cuchí.

1.2 *State of the art*

There isn't much documented information about the interventions on rammed earth structures in Catalonia. This article is an approach to this field from interventions carried out during the past five years.

We have found that generally, interventions in buildings where there is rammed earth presence in walls, have no established diagnosis protocols supported by laboratory tests or non-destructive techniques.

1.3 *Prior diagnosis*

Usually, the diagnosis is based on a previous visual analysis of damages both structural and linked to the erosion by generalized presence of water. It is particularly important to find out that there are not structural problems linked to the foundations. In some cases it is also made an analytical calculation to know the actual loads of the walls. In turn, if we have an intervention with use change it is also usually analyzed the new load to check if the rammed earth wall may assume new internal forces. Decisions on the criteria for intervention are made from this brief information.

From the diagnosis point of view, it must be said that there are few technical studies on the behavior of rammed earth in buildings subject to intervention. There is a 2007 study led by Professor César Díaz Gómez (Díaz et al., 2008) of the Politechnical University of Catalonia—UPC, which analyzes the behavior of rammed earth on a few dwelling buildings in the centre of Manresa in Barcelona Province (Fig. 3). The aim of the study does not focus in their restoration but in their behaviour during the execution of the works of a new housing building

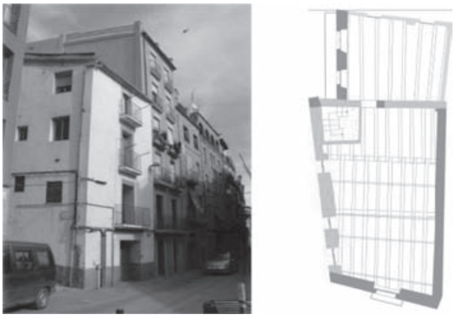

Figure 3. Earth building in the centre of Manresa (Barcelona) partially built in rammed earth. Picture: Cristina Fernández (Final Degree Project-UPC, Tutor: Emilio Hormías).

in the same block, since it is expected to generate significant vibrations during the construction of the cut-off walls.

1.4 *Factors which influence structural intervention criteria*

The criteria for intervention are influenced by different factors to take into consideration: existence of prior structural damages (problems in foundation and humidity); remains of cross-section area; changes in the horizontal structure. Based on structural analysis and the conditions above mentioned different intervention solutions are used.

2 STRUCTURAL INTERVENTION CRITERIA: TYPOLOGIES

2.1 *Full removal of rammed earth wall*

The more drastic intervention criteria and, quite common until a few years ago, is the removal of the rammed earth structures by new structures. Generally, this kind of intervention responds to situations where rammed earth is in an advanced state of degradation.

2.2 *Functional replacement*

The functional replacement consists in generating a new load bearing structure, while preserving the existing walls, but releasing them from any bearing function. There are many examples based on concrete frames or metallic structures. Another solution of replacement is to double the wall with a new ceramic wall which transmits the weight of roofs directly to the ground (Fig. 4). Rammed earth walls become a simple enclosure element while this new wall allows the bracing of structural

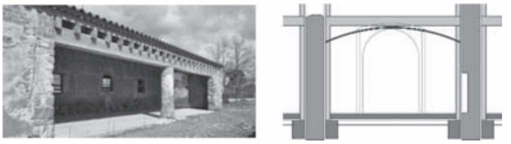

Figure 4. Restoration of Can Falguera. Functional replacement of rammed earth wall. Architect: David Lladó.

elements and can improve the overall behavior. In some cases, the enclosure may retain the original volumetry although this has disappeared in some parts, keeping the characteristic rammed earth wall thickness.

However, this solution restricts the visibility of the rammed earth wall, which prevents the detection of possible damages. A serious pathology can be the presence of moisture by capillary action, which weakens the strength capacity of the wall. New brick wall must allow the ventilation of the air chamber through perforations to prevent the problem of humidity increased by the difficulty of water evaporation that causes the new ceramic wall (Fig. 4).

2.3 *Conservation of the bearing function*

There are cases where it is tried to keep the bearing function of the rammed earth wall from strategies like not increasing the resulting loads that the walls have to support after a comprehensive intervention. An example of this option is found in the project of Ca la Dona, developed in point 3 of this paper.

In some cases rammed earth is preserved but needs a performance by an important consolidation, as in the particular case of the Güell stables, constructed by Antoni Gaudí in the second half of the 19th century. For the construction of the walls, all made of rammed earth, the count of Güell brought some builders of Sucs (Almacelles, Lleida), population where the Catalan patron had a property. This fact shows that the loss at that time of the rammed earth technique in Barcelona, didn't mean it wasn't still alive in other parts of Catalonia.

The ground floor of the stables is a rectangle of 10×28 m where stucks an irregular pentagonal surface that configures the gate and access area, among other volumes. Rammed earth walls are 50 cm thick with brick rows every 40 cm, made with royal rammed earth also called lime strata rammed earth. All the walls are supported on a brick masonry stem walls. Walls are reinforced with brick pilasters, brick edges in corners and brick jambs in openings as a stabilizing function of the horizontal rows.

Figures 5–6. Previous and later view of the rammed earth restoration carried out by architect and Professor Joan Bassegoda Nonell, Gaudí Chair director until the year 2000. Pictures: Joan Bassegoda.

Between 1967 and 1980 UPC Professor UPC Joan Bassegoda i Nonell carried out the restoration of the buildings that become the headquarters of the Gaudí Chair until a few years ago. The restoration of the building kept the rammed earth as it was found, since no significant damages were detected. Only in a few areas where the rammed earth sections were affected by erosion caused by water seepage of deck were restored according to the original technique. The original finishes were respected as far as possible. Some decorative paintings were redone on the basis of a sample of the paintings that were in a good condition. In the same way, the precast mortar pieces that were damaged were replaced by new parts from a mold taken in situ (Bassegoda 2000- Andruet 2002). (Figs. 5–6).

3 RAMMED EARTH RESTORATION CRITERIA IN CA LA DONA

3.1 *Background*

The 25 Ripoll Street building of Barcelona, is listed by the Special Plan for the protection of the architectural heritage of Barcelona's Ciutat Vella district. In 2005 the Ca la Dona association supported by all the Catalan public administrations began a restoration process with sustainability criteria. The value of the project here presented lays not only in the technological effort of the intervention, but in the intangible value of the six years of participatory gender process as a transformative and design tool.

3.2 *Historical evolution of the building*

The building subject of restoration, is the result of a historical evolution which has its beginnings in Roman times. There were originally discovered in the building unique elements such as the foundations of two pilasters of the roman aqueduct (R. González i F. Caballé 2002) and the constructive section of the vase which is embedded in a wall (R. González i F. Caballé 2002). There were also found roman remains of a road to access the city (7).

Between the 11th and the 13th century, it was born the first neighborhood outside the walls known as Vilanova dels Arcs, where houses would stuck to the aqueduct, as the building in study. The presence of a hostel on the estate which consisted of two storey building is documented in the 13th century. The presence of the Escuelas Mayores de la Ciudad, the first secular University in Barcelona is documented in the 15th century (R. González i F. Caballé 2002).

During the 16th century, after the reforms, the residence of the Sorts family is documented. Subsequently, from 1636 until 1700 it is configured a large property with successive acquisitions of neighboring farms, many of them in a bad shape. In 1735 a widespread reconstruction is performed and the estate is modified to a three-storey building (R. González i F. Caballé 2002).

During the 19th century occur the works of reform such as the release of the ground floor and the construction of a fourth floor, in 1874. Finally, the 20th century saw different modifications of the interior which obliged to build new arches that would generate a large open space on the ground floor (R. González i F. Caballé 2002).

3.3 *Constructive description*

The complex evolution history of the building translates into a great heterogeneity of constructive solutions both in roofs and walls.

The vertical structure of the plant and main floor is formed by walls of stone masonry and some medieval original walls of rammed earth. The ground floor has also pilasters and medieval stone arches as well as solid brick arches from the 19th century. The addition of second and third floors was made with solid manual brick 15 cm thick (Fig. 8).

The horizontal structure is mainly formed by wooden framework, where 9 different solutions have been found. Wood joists with ceramic small vaults, wood joists with coffered ceilings or steel beams. Some of the wood slabs had metal reinforcements, usually solved with mullions. On the second floor some roofs were uneven and had inclinations, due to their deck role at some point in its history.

The vertical communication core of the stairs is formed by brick masonry walls and rammed earth walls. The one meter wide stairs consist of corresponding timbrel vaults which connect the four floors of the building until the deck.

The foundation is part of the medieval two-storey building, made of stone with really little depth, less than 30 cm in some areas.

3.4 *Presence of rammed earth in the building.*

In the ground and main (first) floors of the building there are some rammed earth walls. Widths range from 55–65 cm and mostly have load bearing function.

Rammed earth walls found in ground floor date from the 14th and 15th centuries, while the ones in the main floor date 16th century. All rammed earth walls have been made with lime strata rammed earth technique. The general state of the found rammed earth walls is good and they have no major damages. In addition to the identified rammed earth walls, also appear small rammed earth sections that fill small areas between stone walls. (Figs. 9–12).

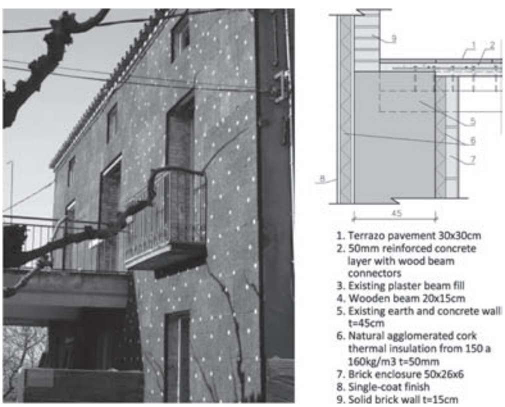

Figure 7. Rammed earth cladding with natural cork. Isolated housing. Rufea, Lleida. Architect: Josep Maria Puigdemassa.

Figure 8. Location of rammed earth walls in the main (first) floor. Picture: S. Bestraten–E. Hormías.

Figure 9. (left) 15th century rammed earth, facade main floor.
Figure 10. (right) 16th century rammed earth. Main floor. Perpendicular wall to the romantic garden. Pictures: S. Bestraten–E. Hormías.

Figure 11. (left) 14th century rammed earth, perpendicular wall to Ripoll facade.
Figure 12. Rammed earth from the 14th century, main floor. Facade Hostal En García. Romantic garden. Pictures: ATICS.

3.5 *Structural diagnosis*

From the structural point of view the building presents important stability problems both on walls and roofs. Walls forming the staircase were opened by the lack of brace and the thrust of the stairs vault. This movement was transmitted to the roofs which in turn generated important displacements on facade.

Rammed earth walls are generally in a good condition. Rammed earth's ground floor wall is over a 1.7 m stone wall, so no rammed earth has suffered moisture problems. The wooden lintels which support some of the openings on the ramed earth walls were affected by xylophagous.

The wooden framework was also affected by xylophagous and rot caused by fungus, mainly in the wooden elements in contact with the facades.

3.6 *Intervention proposal in Ca la Dona*

The initial approach of the project aims to keep the structural scheme, both in walls and roofs, so as to explain the evolution of the building that configures its historical value. The open space in ground floor is configured by a series of medieval and 19th century arches which give this floor a special architectonical interest. Over decades, these arches have been bricked up. In the recent intervention a detailed study was carried out because of the punctual loads transmitted from the upper floors.

The impossibility to maintain the load bearing function of the existing wooden joists due to its bad condition, forced a new consolidation of the horizontal structure. The applied solution consists in the functional replacement with light decks using cross laminated timber boards as a building material (Fig. 13). This constructive solution makes it compatible to the original structural walls of the building, including those of rammed earth, that can continue assuming its bearing function thanks to the lightness of the new slabs. The slab weight ranges 1.02 KN/m^2, the 202 mm width and 1.24 KN/m^2 the 248 mm width. The aim has been to make the final state of permanent loads as similar as possible to the original state of loads of the building. After the intervention, the slabs' weight has been reduced by 4% in relation to its initial weight.

However, because of the use change, there is a considerable increase in live loads (from 2 KN/m^2 at 5 KN/m^2) which determines the thickness of the new wood boards, as well as supporting walls and foundations. The bidirectional effect provided by the cross laminated wood boards properly connected with each other and to the walls, provides a greater degree of stability to the building, improving its behavior against static and dynamic actions.

The boards' connection to the vertical structure is solved with a 2 m length steel profile on L shape 150.90.10 mm. On the rammed earth walls there have been two forms of connection.

In the 4.5 m spans facing Ripoll street walls supporting the new slabs are made of different types of brickwork: solid brick, stone and rammed earth. The connection with the rammed earth wall has

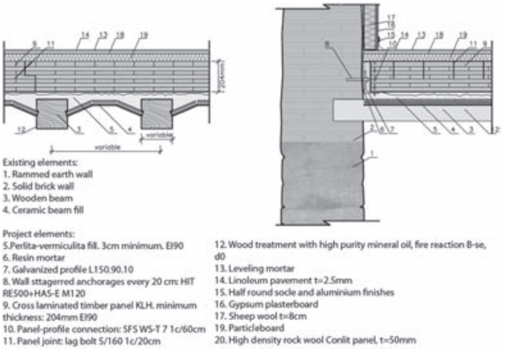

Figure 13. Solution of lightweight slab in Ca la Dona restoration (Barcelona). Picture: S. Bestraten–E. Hormías.

been possible thanks to the presence of a few brick rows which allows the distribution of the punctual loads of the beams and prevents load concentrations on rammed earth walls. The steel profiles connect to the vertical support by mechanichal anchor Hilti HIT RE500 + rebar HAS-E M12. For the calculation of the number of necessary anchorages there were previously carried out tension strength test on the walls. The heterogeneity of the support walls, means the linear placement of an anchor every 20 cm, arranged staggered.

In the case of the rammed earth walls close to the back part of the building, next to the romantic garden, have the singularity that they support almost a 6 m span due to the reconfiguration of space, reason why the existing wooden joist floors could not be hold. Galvanized steel L shape profiles have been replaced by a U shape 300 mm width to better distribute the loads. This U can act as a lintel to transmit the loads to the adjacent stone walls.

4 CRITERIA FOR FINISHING

4.1 *Continuous coating with mortars*

The case of Can Falguera (Fig. 14) is a good solution when using lime or bastard mortar to let internal rammed earth perspire, avoiding a moisture inside. But there are commonly found situations using portland mortars which don't have a good behavior in long term with the rammed earth wall, since their different stiffness and its impermeability cause plaster detachments.

4.2 *Rammed earth cladding*

Another option is to clad the wall both outside and inside, with Cork and plasterboard respectively. Although this solution does not allow the view of the walls in a historicist perception, they allow the incorporation of thermal insulation in the enclosure and the free passage of installations by a new air chamber. But the hiding of the structural wall means the impossibility of detecting any possible fault in rammed earth walls.

Figure 14. Restoration of Can Falguera. Facade rendered with lime mortar. Architect: David Lladó, DAC Arquitectura.

Figure 15. Intervention in Can Muscó. Vilanova del Camí, in the proximities of Igualada (Barcelona). Example of conservation of the bearing function and later new wall. Architect: Josep Vendrell.

5 CONCLUSIONS

Rammed earth is a material present in many buildings in Barcelona province and in Catalonia. The most up-to-date literature refers to the presence of this material in the Catalan farmhouses (Gonzalez et al., 2005) or in village houses (Sanz et al., 2006), but no pictures or construction details appear relative to this technique, even though it is always reflected with stone masonry buildings.

It would be useful the existence of a manual diagnosis for this type of earth structures that can establish the aspects to analyze. This manual should include from the study of the stability of the whole system, to the most common structural failures or the kinds of analysis by destructive and nondestructive testing of the characteristic strength of the wall.

The intervention criteria today reflect an important distrust in the material by the lack of technical information.

The case of the restoration of Ca la Dona building in Barcelona, is another example of the complexity that professionals face when recovering an existing building for a new use. The thorough knowledge of the building given by the historical and archaeological studies and the prior diagnosis are a basic tool to establish the criteria for intervention. It has also been necessary a new value: the participatory work.

The users of Ca la Dona have been sharing the knowledge of the building, debating together about it to define an intervention respectful with the intrinsic values of the building. The role of Ca la Dona has been the key to guarantee a restoration with sustainability criteria. The aim of the structural reinforcement of the floors has been to create a lightweight solution respectful with the building and environmentally friendly. This solution opens a new path that can guarantee the accomplishment of the current regulatory constraints reducing the loads, especially the permanent ones, which are usually increased when using concrete slabs.

This global view of the building can respect the original structure of walls even if they are rammed earth made. This light solution also allows the integration of archaeological founds, and the reversibility and recyclability of the structural proposal.

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Restoration of the rammed earth walls of the Generalife, (Granada, Spain)

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ABSTRACT: This paper addresses the research works being carried out on the gardens of the Generalife, in Granada, Spain. The works on a rammed earth wall have brought to light not only building aspects, but other factors regarding the layout and composition that may affect all the gardens. At least in the section that has been worked on, the visible 14th century wall had another large wall attached to it, entirely built with the rammed earth technique, without a masonry base. Up to date, this was the wall that could be seen from the Alhambra, and was understood to be the only one, despite the difficult interpretation of the south end. Among others, another quite unexpected aspect before starting the works was the ramp system that appeared and the prolongation of the length of the walls that suggest a much more geometric layout of the famous Generalife gardens than previously imagined.

1 FOREWORD

The Generalife, beside the citadel of the Alhambra, in Granada, constitutes a unique monumental site. It represents a sequence of buildings surrounded by a series of gardens and orchards. The site is laid out on a slope.

In 2004, the Patronato (Board of Management) de la Alhambra y el Generalife began research on the walls surrounding the orchards in order to understand them and conserve them properly.

In 2006, the Patronato commissioned a project for the restoration of one of the rammed earth walls in the orchards of the Generalife.

In 2011, the Instituto de Patrimonio Cultural Español (Spanish Cultural Heritage Institute) took over the task of contracting the works.

Figure 1. Location of the wall being worked on.

At present, the project is under way. Due to the research carried out during the works, the intervention is to undergo some changes, which has slowed it down somewhat, so at the moment, we can only speak about the initial stage but not any conclusive results.

2 EXAMINATION OF THE STRUCTURE OF THE GARDENS

The Generalife gardens differ from other gardens in that they are located on the west slope of a hill and their relationship with the palace complex.

The building occupies a prominent position over an also constructed surrounding area of gardens and orchards, that is, over a paradise of vegetation whose aim was to give personal pleasure and supply fruit and garden produce.

Its location on a slope permits the existence of terraces but, above all, it implies the need for special solutions to turn a wild slope into fertile cultivated havens.

In the first place, these solutions involve ensuring a supply of water from the River Darro; in the second place, and this is the issue that interests us most, the creation of artificial terraces to place suitable soil on and the irrigation necessary for the plants.

The terraces or banks of the Generalife are made with large containing walls laid on the natural terrain of the mountainside: the Alhambra complex.

The wall the project was designed for is in what is known as the Huerta Grande, or Large Orchard, situated between the second and third terraces. The north end borders on the medieval lane leading into the Generalife from the Cuesta de los Chinos (Chinese Slope). The south end was relatively unknown at the start of the works.

The archaeological excavations threw a great deal of light on the interpretation of the structures. What could have been considered a single wall were in fact two parallel walls joined together. The oldest wall seems to date from the 14th century and the other from the 15th.

Located on the east side, the highest area, the first wall has a hefty base of large boulders, on which several lime-crusted rammed earth modules are laid.

That first wall contains the garden soil on the inside (the east). On the outside (west), it forms the façade of the terrace.

Figure 2. South end of the wall before the intervention, seen from the south.

Figure 3. South end of the wall before the intervention, seen from the north east.

We do not know exactly how tall the first wall was, but we do know how far it stretched: from the medieval lane (in the north) to the border we knew (in the south). However, according to the research carried out, that border is only a temporary interruption, for after about 2.80 m, the wall continued southwards along the garden, a much longer extension than what we can see today.

Other interesting information gleaned was the fact that the structure goes not only in a longitudinal, but also in a transversal direction. Precisely, the south edge as it could be seen until 2011 joined with a perpendicular wall; at this point the wall was interrupted by a sloping path whose existence was unknown. In the excavated part on the other side of the ramp (running from east to west) a repetition of the same structural solution could be seen: two perpendicular walls on a base of boulders; the longitudinal one follows a curve in the level more or less, and the transversal one runs down a very deep slope.

At least in the section that was being worked on, the 14th century wall had another large wall attached to it, entirely built with the rammed earth technique, without a masonry base. Until 2011, this was the wall that could be seen from the Alhambra, and was understood to be the only one, despite the difficult interpretation of the south end.

Important questions that need to be answered are: what was the second wall built for? What condition was the original wall in before the second one was built? What other changes were made when the second wall was being built?

It can be gathered from the evidence that the first wall must have been fairly seriously deteriorated, with large gaps in some places. It is not clear whether it was also unstable enough to warrant reinforcing as well as repairs.

The second wall thickens the first wall, fills its gaps and crowns it. The operation did not only consist in reinforcing it but in cladding the west side and the coping, which is what made it difficult to read both structures even after the upper part had been cleaned. According to the evidence, for the construction of the second wall putlogs were only used on the west side, although it has a façade towards the east because on this side the wall was always built against a previously laid and compacted filling.

The base of the second wall is scattered with pipes at irregular intervals; these orifices do not seem to continue through the older wall, and may even be at a lower level than the base of the original wall because of the slope of the land.

However, on the north side of the wall near where it gives on to the medieval lane, there is a larger section pipe that happened to lead east to a well that rises to the level of the upper terrace. The head of this well is not connected to any pipe that can be seen in the upper terrace, but seems to be an isolated item, at least on the surface. To the west, on the lower terrace, the piping leads to another superficial channel that runs parallel to the wall of the lane.

3 THE WORKS

The current deterioration of the structure made up of the two walls seems to have been caused mainly by the overgrown vegetation, whose roots have undermined and separated the two walls in search of the interface.

The restoration works will attempt to establish a safety distance between the retaining structures and the cultivated garden area.

For the moment, after digging up the base of the wall, half concealed by a terrace lined with fig trees, it was cleaned and consolidated and the edges and critical spots were anchored.

Most of the cleaning was carried out by means of a dry procedure. General consolidation was performed with lime wash and ethylene silicate was used only for the most seriously damaged parts.

The first step after cleaning was to fill in the large gap in the interface between the two walls by pouring in a mixture of silica sand and calcium hydroxide. This in turn will be sealed with new coping over the whole ensemble.

The restoration of the wall will involve several types of solutions, focusing on several aspects.

On the one hand, there is no intention to cover up the putlog holes, taking into account the fact that they could only be seen when the wall had lost part of its mass.

As regards the surfaces, the idea is not to restore their original form but to fill in the gaps to a certain depth in order to preserve the current image and the signs of the passage of time to a certain extent.

As regards the coping, there will be an attempt to give continuity to the last modules of rammed

Figure 4. View from the NW before the intervention. The wall, half hidden behind the vegetation at the beginning of the autumn.

Figure 5. The wall before the intervention. The slope conceals the height of almost two rammed earth sections.

Figure 6. Mechanical cleaning of the crust conserved.

Figure 7. Hand cleaning of the wall with no crust conserved.

Figure 8. Irrigation with lime wash.

earth walls conserved so that they may serve as a finish and protection for the ensemble.

An adequate drainage mechanism does not seem to have existed. Nevertheless, the intrados of the wall needs to have rainwater or irrigation water removed from its surface. So, on the upper terrace, on the strip of orchard running parallel to it next to the wall, for the moment the solution will be based on draining off and controlling water rather than laying new channels and drains.

A quite unexpected aspect before starting the works was the ramp that appeared and the prolongation of the walls that suggest a much more

Figure 9. View towards the south. Separation between the two walls. V.

Figure 10. View towards the north. Half-filled interface.

Figure 11. View towards the north. Filled interface.

Figure 12. Essays of walls with different crusts.

Figure 13. View from the west. South end.

Figure 14. View from the west. South end with remains of the ramp.

geometric layout of the gardens than previously imagined.

4 CONCLUSION

As we can see, works on a complex monument like the Alhambra and the Generalife and, specially, in this case, can only be performed properly by using methodology that includes archaeology.

We have presented here just the preliminary results of both the works and the research on the Generalife gardens, as they are still in the initial stages, since there are many questions and a great deal of investigation, some ongoing, that need to be answered.

NOTES

Project design and works management: Isabel Bestué Cardiel & Francisco Javier López Martínez.
Works management and execution: Juan Carlos Molina Gaitán & Antonio Puertas Contreras.
Archaeological management: Luca Mattei.
Safety and health coordination: Antonio Puertas Contreras.
Contracting company: GEOCISA.
Promotor: Instituto del Patrimonio Cultural Español. Patronato de la Alhambra y el Generalife.
Picture credits: Photographs by Francisco Javier López Martínez.
Picture nº 1 is made on a map of the Patronato de la Alhambra y el Generalife.

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Characterization methodology to efficiently manage the conservation of historical rammed-earth buildings

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ABSTRACT: Over recent centuries, earthen-building techniques have been falling into disuse despite the long tradition of using earth as a building material. Rammed-earth walls have a rich heritage value in Spain. These structures are at high risk mainly due to a lack of maintenance. It is therefore necessary to underline their characteristics, often much less known, in order to ensure proper management of their conservation and maintenance. The management of a heritage object requires greater understanding for medium and long-term planning. To this end, a study of vulnerability and risk is introduced, as was alleged by several international organizations. Since no specific methodology has been developed to evaluate historical rammed-earth walls, this research is intended to indicate a new system of approach to any type of restoration or even facilitate the decision-making when managing a large heritage site.

1 INTRODUCTION

New initiatives related to the promotion and value of earth construction arose in the middle of the twentieth century. Hence, in recent decades, the research in this field has experienced a progressive development. As a result, a new network of knowledge has been generated, by means of a great number of individual contributions.

Initially, the lack of scientific and technological studies on earthen construction methods, and on their strategies of preservation and conservation led to the usage and adaptation of techniques from other systems without previous assessment of potential damages due to the incompatibility between materials. As a result, the random application of these techniques failed or aggravated the damage, especially where industrialized materials, such as cement, steel or certain chemical consolidants, are involved.

There is a lack of knowledge about historical rammed-earth walls. Nevertheless, despite the latest studies carried out on this field, it is still necessary to undertake some works/actions to provide convenient background for proper assessment and value enhancement strategies. Some research projects have already pointed out the main principles of this research line for historical rammed-earth technique, i.e. projects BIA 2004-1092 and BIA 2011-18921 (National Research Plan) or Terra Incognita project (project n° 2009-0758 of the European Programme "Culture 2007–2013").

This paper is aimed to study the main characteristics of historical rammed-earth walls, providing guidelines for intervention and helping in the decision-making, by means of assessment methodology based mainly on a comprehensive/proper understanding of the damaging process and vulnerability of these kinds of earthen walls. Likewise, the proposed methodology is part of a recent research work carried out by the current author (Canivell 2011).

2 CHARACTERIZATION METHODOLOGY

In general terms and regardless of the area of knowledge, a wide variety of diagnostic methodologies is currently available. Among other concerns, they may differ from each other according to the method of data collection, the typology of the data, and the level of conclusion that may be drawn (whether enhancement proposals may be included).

As for clinical diagnosis, the current methodology is based on a preliminary characterization, also known as an anamnesis. Before any diagnosis can be offered, it is necessary a prior step that enables the later collection of all the relevant information from the rammed-earth wall, related both to its material and to its state of conservation together with any weaknesses. Once a preliminary study is completed, it is not only feasible to give a diagnosis which determines the current state of decay, but also to suggest suitable conservation repairs.

Studies for the analysis of this kind of wall are mainly organoleptic and straightforward to be carriedy out through a visual inspection, although they may be completed by means of laboratory tests. The various aspects to be analyzed are as detailed:

– Constructive characterization. This encompasses all the studies related to the rammed-earth technique, its components and their proportions. It may be divided into several independent analyses as follows. Firstly, the Technical characterization that specifies the constructive system details and defines each kind of rammed-earth wall. Material characterization points out the chemical and physical properties of a rammed-earth wall. Finally, Measurement characterization focuses on the main magnitudes and proportions of a rammed-earth wall.
– Characterization of the state of conservation. The current damages of a wall are evaluated in order to determine their origin and the agents of the damage.
– Vulnerability and Risk characterization. Rammed-earth hazards are assessed as a complement to the damage evaluation.

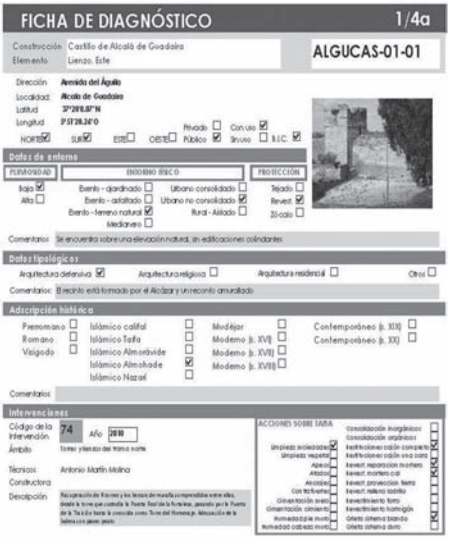
In order to perform this analysis, diagnosis data forms are proposed, gathering all those necessary parameters. These forms are used during a data-collection phase on the field. Their contents are managed by a database, not only to collect data, but also to create a comprehensive management tool for a heritage group of selected buildings. The database is designed to generate the following diagnosis data forms as reports, matching each part of the stated analysis:

Form 1 (Fig. 1). General data from the building and its rammed-earth wall are included indentifying the record by a unique alphanumeric code.

Form 2. Wall characteristics include all the physical and dimensional parameters needed from the rammed-earth wall, such as those of the rammed-earth box, putlocks and putlog holes. This data is structured according to the three aspects of constructive characterization: technical, material and dimensional.

Form 3. Pathological process. This third form is assigned to the study of current damage, its sources and causes, and it is focus on the development of a pre-diagnosis. Nevertheless, in order to facilitate the reading and completion of the form, it has been decided to gather all the damages into three general groups, (material, structural and surface damages). In addition, the form enables the decision-making regarding the more feasible causes and sources in the pathological process.

Form 4. Risk assessment. Risks and damage are evaluated in order to design a methodology which will allow a better understanding of feasible failures. In order to help the assignation of values to each risk factor, an auxiliary form is attached, which briefly holds all the criteria.


FICHA DE DIAGNÓSTICO 1/4a
Construcción: Castillo de Alcalá de Guadaira
Elemento: Lienzo. Este
ALGUCAS-01-01
Dirección: Avenida del Águila
Localidad: Alcala de Guadaira
Latitud
Longitud
NORTE SUR ESTE OESTE
Privado Público Con uso Sin uso B.I.C.
Datos de entorno
PLUVIOSIDAD: Baja, Alta
ENTORNO FÍSICO: Exento - ajardinado, Exento - asfaltado, Exento - terreno natural, Medianero, Urbano consolidado, Urbano no consolidado, Rural - Aislado
PROTECCIÓN: Tejado, Revest., Zócalo
Comentarios: Se encuentra sobre una elevación natural, sin edificaciones colindantes
Datos tipológicos
Arquitectura defensiva, Arquitectura religiosa, Arquitectura residencial, Otros
Comentarios: El recinto está formado por el Alcázar y un reconto amurallado
Adscripción histórica
Prerromano, Romano, Visigodo
Islámico califal, Islámico Taifa, Islámico Almorávide, Islámico Almohade, Islámico Nazarí
Mudéjar, Moderno (s. XVI), Moderno (s. XVII), Moderno (s. XVIII)
Contemporáneo (s. XIX), Contemporáneo (s. XX)
Comentarios
Intervenciones
Código de la Intervención: 74
Año: 2010
Ámbito
Técnicos: Antonio Martín Molina
Constructora
Descripción
ACCIONES SOBRE TAPIA
Figure 1. Example of a diagnosis data form 1, regarding general information of a sample of historical rammed-earth wall.

3 CONSTRUCTIVE CHARACTERIZATION

With the purpose of describing a rammed-earth wall, it is necessary to review its constructive process. Hence, we become familiar with the materials, the auxiliary resources and processes that should be used, when restoration work is needed. Constructive analysis is divided into three parts corresponding to three main aspects of any constructive system, gathered on diagnosis data form 2.

3.1 *Technical characterization*

Firstly the generic construction system of a traditional rammed-earth wall is analyzed, although it is already described by other authors.

Facing the constructive analysis, the chrono-typological classification of Graciani and Tabales (2008) is proposed, together with the addition of fields deduced through the study of the selected walls. Therefore, a definition is obtained, in terms of the complexity of the constructive system, from the simple monolithic rammed-earth wall, to the more complex "fraga" type, which consists on a wall reinforced with inner columns and courses, usually made of stones or fired bricks.

According to the constructive process studied, certain aspects considered for the preliminary studies have been proposed on diagnosis data form 2. Hence, for instance, it is possible to identify the type of constructive rammed-earth blocks, (in the form of single blocks or of long blocks), or the rhythm of the putlocks, which describes interesting characteristics to take into account in any evaluation.

3.2 *Material characterization*

The first aspect that may be highlighted is the great diversity in the dosage for the rammed-earth mass, and hence it is impossible to attain general models or rules, and each case should be studied independently. Nevertheless, it is viable to identify the variety of materials normally used.

The main aim is to register the basic components through a visual inspection, which could be confirmed later by means of laboratory analysis. To this end, several parameters are designed in order to help towards the characterization: ranging from the estimated lime content and the aggregate maximum size or their shape (round or coarse shape) and even to other kinds of foreign materials in a rammed-earth wall, such as boulders and ceramic rubble. All these parameters are classified on diagnosis data form 3. Some outstanding parameters are detailed below:

- Soil content. Usually this is the basic component for this kind of wall and its nature will depend directly on the nature of the soil of the extraction site.
- Lime content. Depending on the hardness or the strength of the wall and on the abundant presence of lime nodules, a preliminary assessment may be made.
- Maximum size of the gravel. The gravel is an important part of the mass, especially in military rammed-earth walls. Knowledge of the gravel content may be useful for the design of repair material that matches properly with the eroded wall.
- Type of coarse aggregate. Based on the nature of the extraction site, either sharp or rounded aggregate can be found in a wall.
- Presence of stone blocks or ceramic rubble. Considerable quantities of these materials sometimes used to strengthen the wall, to take advantage of spare materials, and also to speed up the building process.

Moreover, laboratory tests may be ran once this organoleptic evaluation is over. These tests are useful in the identification of the soil and of its suitability in earthen buildings. Some of these proposals are based on a critical review carried out within the project BIA-2004.1092 (Graciani, et al., 2005), as well as in earthen-building manuals (Ontiveros et al., 2006).

3.3 *Dimensional characterization*

In order to complete the constructive characterization of a rammed-earth wall, it is necessary to analyze the dimensional parameters, both those related to the whole wall and those to each of its auxiliary items. For this reason the analysis is split into three parts, each one related to a different concern, such as the rammed-earth blocks, the shuttering (tapial), and the putlocks. It should be pointed out that the relationship between the dimensions of a wall and its historical period has yet to be exactly determined. Hence, the following parameters have been chosen:

- The rammed-earth box. This may be considered as the essential constructive unit of a wall, in the same way as a fired brick is to brickwork. Although it is not always feasible to define it as a unit of the wall, it is sometimes possible to register its three dimensions: the height, the length, and the width. The heights are summed up in just three types: short module (≤80 cm), high module (85–95 cm) (Graciani & Tabales 2008:137), and special module (≥100 cm). It is always feasible to measure the length of the box whenever the wall is built with short blocks of rammed earth. Otherwise the wall would show some slanting joints instead of vertical joints.
- The formwork. This should be the most useful parameter for the characterization of a rammed-earth wall, but unfortunately there are no formworks remaining. There only remain some prints on the surfaces showing their dimensions and the number of wooden planks that formed the shuttering. These marks are, to a certain point, more constant than the measures from the rammed-earth box.
- The putlocks (or, in their absence, the putlog holes), are very specific items of any rammed-earth wall. Certain tendencies in the use of several types of putlocks may be registered, which are mainly made of a tough wood. The shape may vary from a circular or semi-circular timber to square o rectangular sections, usually of about 3 × 7 cm (Martín 2005). The gaps between consecutive putlocks and their rhythm may be used as a rough parameter of characterization.

4 CHARACTERIZATION OF THE STATE OF CONSERVATION

The goal is to determine the origin of the pathologies so that strategy for suitable intervention may be planned. It must be borne in mind that there is no singular cause for any failure. Normally several types of damage can be linked, since the diagnosis becomes more complex when determining which is the original area of damage is necessary.

The diagnosis Data Form 3 groups all the damage into three groups according to their nature. The first group is material damage which is related to the erosion, although at some extend they could affect structural stability. This one is normally caused by weathering agents such as water, rain, ice, wind, thermal changes, and chemical attacks.

The next group concerns structural damage, which occurs when the limits of strength and tension in the rammed-earth wall are exceeded. The last group represents the surface damage, which, although it may be similar to material damage in some ways, is treated separately since this damage only affects the external face of the wall or its coating, and, in contrast to material damage, no loss of material has to occur. Dirtiness, efflorescence, and all pathologies with regarding the coating, are examples of this kind of damage.

The first step in the pathological analysis is to arrange the data according to the type of damage and discuss about their feasible causes. Hence, the agents and causes are classified according to their nature. Firstly, mechanical causes are those which lead to structural tension in the wall. They usually lead to cracking, bending, distortions, and a slanting of the wall. In the other hand, physical causes concerning the group of atmospheric agents, and therefore are practically unavoidable; thereby it is only possible to take measures in order to mitigate their effects. Chemical causes involve any chemical substance that may react to the components of the wall and cause unexpected effects. Urban pollution, efflorescence, fungus and lichen attacks are common examples.

The causes can also be classified as direct or indirect. When the causes are external and they do not belong to the wall itself, they are called direct causes, since they may generate damages whenever they appear. Any cause can be considered as indirect if they are part of the characteristics of the rammed-earth wall. Furthermore, could happen that no indication of deterioration will arise unless a specific external circumstance appears. For instance, low quality rammed earth may remain in good condition until dampness arises.

5 VULNERABILITY AND RISK CHARACTERIZATION

In order to assess the risks, it is essential to thoroughly know how rammed earth functions and also its pathological response in order to obtain a better base for decision-making. If solely current damages are considered, only corrective measures can be applied. Nevertheless, the management of a heritage object requires greater understanding for medium and long-term planning. To this end, a study of vulnerability and risks has been introduced, as claimed by several international organizations (Iscarsah 2000).

5.1 *Concepts involved in risk assessment*

First of all, in order to properly comprehend the whole evaluation process an introduction of the main terms and issues related to risk assessment is needed.

Risk factor and risk level. Risk and hazard are separate terms that are commonly confused. Hazard refers to the inherent capacity of a circumstance to generate damage, whereas risk is the combination of the probability of a defined hazard and the magnitude of the consequences of damage. For instance, weathering is always a hazardous circumstance for rammed-earth buildings; however the chance of damage occurring (risk) might be low or null. Risk factor is a condition from the object or the environment that helps towards the evolution of new damage, or aggravates damage. The Risk Level (NR) is the parameter that measures the rate of risk.

Vulnerability and Vulnerability Level. Vulnerability for a rammed-earth wall is defined as its incapability to be adjusted by itself to a certain change in the environment, due to the influence of certain risk factors (Wilches-Chaux 1993). In addition, Vulnerability is always linked to an aspect. The concept of Vulnerability does not exist alone. By analyzing the failure process, the main weaknesses of this kind of wall may be concluded, and so the aspects the vulnerability that is joined to. The vulnerability level is a measure of this concept, in order to describe the state of the wall. Therefore, the weakness of a wall can be characterized by the Vulnerability level (NV) and the Risk level (NR), among other parameters.

Durability. This concern is strongly bound to Vulnerability. Monjo (2007) defines it as proportionally inverse to vulnerability. Therefore, the more vulnerable a wall is, the less durability it shows. The objective is to achieve the greatest Durability.

Risk map. This is a graphical tool that represents and classifies risk factors in order to determine patterns and trends in wall behaviour. Likewise, risk maps constitute the last step to a more accurately description of some of the measurement parameters described above.

5.2 *Risk assessment methodology*

Since Vulnerability is always linked to something, it had been selected three aspects that any rammed-earth wall is vulnerable to: vulnerability to water, to erosion and to structural instability.

In order to carry out this risk assessment, it has been developed a tool which focuses both on the risks of the wall and on the current damage. This tool aims to plan preventive actions to avoid new pathological processes from occurring. Likewise, it is intended to design corrective actions to repair the current damage, and also to bring up to date or to enhance the conditions of maintenance.

Therefore, an improvement in durability may be achieved by identifying and limiting any weaknesses. As a conceptual model, a risk assessment method is applied. More precisely the NTP-330: A simplified method for risk assessment in accidents (Bestraten & Pareja 1994) it is used as a support and layout. This simplified method enables the identification of conventional risk situations (risk level) through minimum resources, so that the designation of a suitable preventive and corrective action can be made. Broadly speaking, the method outlined is based on setting the probability of damage (accidents) and the consequences (material, intangible, and personal) that this would involve.

Therefore, the risk level (NR) of an element is established based on the probability of damage (NP) and on the consequences (NC) of this damage. Likewise, the probability of the damage occurring (NP) depends on the deficiency level (ND) of the risk under analysis and on the exposure rate (NE) for the assessed risk.

Next, the evaluation process is to be briefly described.

5.2.1 *Determining vulnerabilities and risk factors*

First of all, three types of vulnerabilities should be studied and characterized, corresponding to those stated weak aspects of rammed earth: vulnerability to water, physical vulnerability (erosion) and structural vulnerability (structural instability). Each type of vulnerability depends on several risk factors that must be determined and classified in order to identify any weaknesses of the rammed-earth wall. Therefore, according to their nature all the risk factors, for each type of vulnerability, are organised into the three groups detailed below:

– Material risk factors. Those refer to characteristics of the rammed earth itself.
– External risk factors. These risks do not depend directly on the rammed-earth wall, but on the environment where it is found.
– Anthropic risk factors. Those are also external risks, but their origin is related to human activities.

5.2.2 *Risk factor assessment*

The next step involves the assessment of each risk factor by assigning exposure levels (NE). Exposure levels are used in an effort to measure how the wall is affected by a specific circumstance that may generate damage. Each exposure level is designed within a range, in this case it consists on five consecutive levels. In order to work with these levels, each range has been assigned a numbered scale, whereby 10 corresponds to the highest level of exposure. These ranges are inserted into diagnosis data form 4, and also into the data base. Each risk factor is assessed according with the pre-designed rules and criteria.

5.2.3 *Setting the probability of damage*

Not all risk factors are of the same significance in the generation of pathological processes. High exposure levels of certain risk factors might induce a greater possibility of damage than others. However, in order to carry out a suitable classification, a simple criticality analysis of risk factors is used (Canivell 2011). It consists on a scale of three types of risk factors: key, moderate factors and secondary factors, which are applied directly to each exposure level (NE) in order to obtain probability levels (NP) for each risk factor.

5.2.4 *Characterization of the vulnerability*

Once Probability levels (NP) are characterized for each factor, their global evaluation is then sought in order to achieve a parameter which measures a general state of risk. To this end, risk maps are used since they allow both the plotting of a chart and the characterization of the state of levels of selected risk factors.

Radial chart is the selected representation for risk maps (Figure 2), where each axis represents a probability level (NP) for certain vulnerability. Through the reading of these maps, it is possible to deduce trends, prevailing values, certain parallels, and/or differences between measurements.

The area or the perimeter of the charts characterizes the Vulnerability levels (NV) of each rammed-earth wall: vulnerability to water (NV-HID), physical vulnerability (NV-FIS), and structural vulnerability (NV-EST).

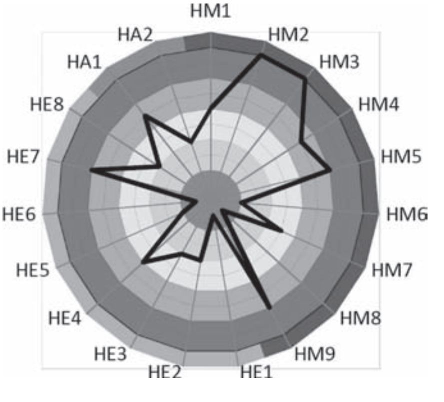


Figure 2. Example of a Water risk map. Polygonal chart which sets out risk factors for water vulnerability.

WATER RISK LEVEL (NR-HID) WATER INTERVENTION LEVEL (NI-HID)						
		CONSEQUENCE LEVEL (NC)				
		[illegible] Very high	48-37 High	37-26 Moderate	26-15 Low	[illegible] Very low
WATER VULNERABILITY LEVEL (NV)	[illegible] VH	V	V	V	IV	III
	225-135 H	V	V	IV	IV	III
	135-65 M	IV	IV	III	III	II
	65 - 20 L	III	II	II	II	I
	20 - 0 VL	II	I	I	I	I

Figure 3. Example of matrix for water vulnerability.

5.2.5 *Characterization of risk and decision making*

According to NTP-330 methodology, the impact of both the potential material and potential personal damage must be assessed. As stated before, risk level depends on the impact of the feasible damages on the wall. The parameter which measures this impact is the consequence level (NC) and it is obtained through a similar procedure as vulnerability level, but antrophic risk factor are used instead.

Through risk matrix (Figure 3), whose usage is widespread in risk evaluation, vulnerability and consequence levels (NV, NC) are crossed in order to obtain the risk level (NR). One specific risk matrix has been built for each vulnerability, hence, as an outcome, three kinds of risk level will be obtained. Risk levels are scaled in a range of five steps, from trivial risk level to unbearable risk level. As it is shown in Figure 3, a five-step colour scale also matches each risk level.

Once risk level (NR) is known, it is possible to determine a suitable set of actions, which is regarded as intervention level (NI). Each state of risk (NR) matches an Intervention level (NI) for which preventive, corrective and maintenance actions are designed. The higher the risk level becomes, the more urgently the actions (preventive, corrective and maintenance) should be taken. There are five intervention levels for each type of vulnerability, ranging from low Intervention to urgent Intervention level. This is created just to help the decision-making, when actions are to be taken in order to reduce vulnerability and maximize durability of rammed-earth walls.

6 CONCLUSION

A complete anamnesis is necessary in order to carry out a proper wall diagnoses that may lead to effective treatments. The anamnesis must include the full history of the rammed-earth wall, by considering carefully its constructive and pathologic aspects plus its risk factors.

The diagnostic system should be considered as a tool for guiding and supporting during the decision-making. It does not offer automatically a closed and definite solution, but a synthesis of the essential aspects required to design an adequate treatment, either for maintenance or prevention.

The organoleptic analysis represents the first stage in data collection. However, when detailed laboratory tests are not feasible or available, the parametric evaluation here proposed points out the main aspects to consider in order to diagnose and design a treatment.

The damage evaluation proposed in diagnosis data Form 3 represents the current conservation state of the construction, being thus useful for the proposal of corrective action on the walls. On the other hand, the tool for the evaluation of vulnerability puts together risk factors, probable damage evolution and the seriousness of their consequences, which makes it more suitable for the design of maintenance and preventative measures.

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Critical analysis of interventions in historical rammed-earth walls—military buildings in the ancient Kingdom of Seville

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ABSTRACT: Despite the general acceptance regarding the interest of dealing with heritage interventions using specialized approaches, thanks to the Charter of Krakow, actions on historical rammed earth walls are to often undertaken without support from any preliminary critical assessment. Hence, in recent decades, this has contributed towards the generation of a wide disparity of intervention criteria and technical solutions. This paper addresses a critical analysis of interventions carried out over a specific period of time on military buildings of the ancient Kingdom of Seville. Prior recording and cataloguing of interventions was carried out in order to propose criteria for their value, in terms of their adaptation to formal and technical interventions characteristics.

1 INTRODUCTION

Andalusia possesses a long military heritage as a result of its ancient territorial and political structure, consisting of towers, castles and city walls, which have been restored over the last 7 years under the framework of the Andalusian Plan of Defensive Architecture (PADA), designed and developed by the Dirección de Bienes Culturales de la Junta de Andalucía.

These buildings, whose most common constructive technique is rammed-earth, are especially vulnerable to external agents that, together with inappropriate conservation and maintenance techniques, have frequently increased their state of risk.

Hence, it is appropriate to propose a critical revision of the latest interventions on military rammed-earth walls in order to establish those material factors and technical solutions that must be assessed, and as far as possible to estimate the efficiency and durability of their responses over time. This analysis will lead to the establishment of objective criteria which may allow a classification of interventions according to their responses to these criteria.

The proposed critical analysis has been applied to a group of military buildings of the ancient Kingdom of Seville that have been totally or partially built with military rammed-earth during the North-African (Almoravid and Almohad, XII–XIII centuries) and Mudejar periods (XIII–XIV centuries), and have been restored in recent decades. In spite of the clear predominance of monolithic rammed-earth walls in the cases selected, it was intended to cover the maximum number of constructive techniques and states of conservation, so that conclusions would be stronger and could be extrapolated to include a variety of geographic locations.

Specifically, this study takes the following building as case studies: the Castle of Alcala de Guadaira, Castle of the Guardas, Alcazar of the City Gate to Seville (Carmona), Hacienda de los Quintos (Dos Hermanas), Ecija City Walls, Castle of Lebrija, Castles of Los Molares, Niebla City Walls (Huelva), Tower of Saint Antonio (Olivares), Sanlucar la Mayor City Walls, San Juan de Aznalfarache City Walls, Seville City Walls, Alcazaba of Reina (Badajoz), Castle of Utrera, and the Tower of Alcantarilla (Utrera).

2 INTERVENTION COMPARISON

The analysis presented in this paper of the main intervention criteria used in the case studies has been developed according to the most frequent technical and formal solutions, as well as to their results and responses. Furthermore, repair work due to water erosion, and in the form of consolidations, restitution/restoration of mass, renderings and crack repairs are pointed out for each study case.

2.1 *Repairs due to water*

The vulnerability to water of rammed-earth walls and its weakening effect on the inner structure are normally manifested at the base and top of a wall. Several techniques may be considered in order to prevent the gathering of water through capillary action and through filtration at the base. First, passive techniques limit the access of water but fail to remove it. In comparison to the proposed technique of Macías & Espino (2001) to dry out interior walls of low ventilation, which consists of the placing of a ventilation pipe with the two ends at different heights, or similar solutions based on ventilated chambers (Ashurst 1988, Monjo 2001), other kinds of simple actions may help the proper hydrothermic performance of the wall. For instance, when rammed-earth walls are confined between hard and impermeable surfaces (such as the Seville City Walls in the Macarena sector, which are surrounded by concrete and asphalt), the removal of these materials and the action of leaving 50 mm free from the surface of the wall (Ashurt 1988) or the replacement of those dense materials with softer materials (Walker et al., 2005) constitute a major step towards correct hydrothermic behaviour. Nevertheless, in the restoration of the Seville City walls, as in other case studies (Écija, Niebla, Córdoba, and Cáceres), no action has been carried out to prevent this situation, and the consequent erosion of the base of the wall due to water splashing. In contrast, in the Portuguese Alentejo, certain straightforward and inexpensive solutions have been accomplished through the placement of a small slope along the base of the wall in the form of a narrow pavement, in order to prevent the water from gathering (Guillaud 2004).

Although the usage of drains, prudentially placed away from the wall, is very effective in order to control the amount of water that reaches the base of the wall, is has not been possible to check neither analyze this situation on the study cases.

Other passive systems, such as certain kinds of waterproof barriers (Ashurst 1988; Keefe 2005; Walker et al., 2005; Easton 2007), may be applied in order to control capillary rising damp. Although it is a simple solution in case of new buildings, it becomes seriously complicated when dealing with restoration work. Siloxane injection systems into historical walls (Ashurst 1988, Ortega 1994) show certain difficulties for military rammed-earth walls, due to their great thickness and inner irregular void distribution. This technique is therefore proved less feasible, and hence its responses have not been assessed for this study.

The tops of walls, principally in the lengths of city walls, tend to constitute the most eroded area due to their high exposure to weathering agents. Although the placement of a roof and overhangs might appear to present a straightforward solution, this is not the case when dealing with military walls, since it would be necessary to choose an alternative solution such as the placing of coverings or layers of a sacrifice material at the top of the wall, which would have to be permeable to water vapour exchange in order to prevent water ponding under this protection. To this end, Oliver (2000), considering erosion as an unavoidable process, suggests using adobe as a sacrifice material that should be replaced within a regular maintenance program. A number of technical solutions have been applied in the case studies, commonly in the form of sacrificing layers made of lime or lime-cement mortars. Some examples, such as restoration work at the Castle of Lebrija and the City Walls of Sanlúcar la Mayor, show this solution, in the latter case with the worst esthetical results. As an alternative, at the Castle of Alcalá de Guadaría, special pieces of steel-reinforced limecrete were produced on-site, designed with sufficient slope and overhang for the correct protection, and were simply laid on top of the walls. However, it is remarkable how, for such outstanding restorations as those carried out on the Seville City Walls, no effective technical solution has yet been accomplished.

Although the protection of the base and the top of the wall would suffice, high exposure levels to weathering agents may demand greater attention to be paid to the surface of the wall by means of an adequate rendering. When dealing with retaining walls, opening certain channels through the wall could help the drainage of water from the terrain, so that infiltrations may be prevented for the whole surface. This technique was efficiently put into practice in Alcazaba of Reina, however for other case studies under similar circumstances (Castle of Lebrija and the City Walls of San Juan de Aznalfarache) no technical solutions were planned even where damp and consequent damage is currently evident.

2.2 *Consolidations*

Consolidation is one of the most frequent actions on rammed-earth walls due to their specific characteristics. Through industrial or traditional products, it is intended to stabilize the deterioration process of the inner structure of the mass and likewise to improve cohesion and adherence of its particles. The efficiency of the consolidation usually depends on the infiltration capacity of the product.

Inorganic consolidants fill up the accessible pore system thanks to their chemical precipitation in water, thereby cementing particles of the inner structure of the earth. Limewash or lime water, of 1:5, 1:7 lime/water proportions respectively, applied with brush or spray improve cohesion when the carbonation process occurs inside the wall. To this end, consecutive layers are spread leaving one day between each application in order to let each layer properly harden (Goreti 2005). For instance, surfaces of the Alcazaba of Reina (Rocha 2005) were brushed with limewash containing a small proportion of sand, not only to harden the wall but also to smooth over the contrasts between restored and original surfaces. Nevertheless, the current state of conservation of both covering and wall implies that restoration work was largely ineffective mainly due to the low infiltration of the limewash that would have required a regular maintenance on order to be effective.

Another kind of inorganic compound in the form of ethil silicate has been used in several cases studies of restoration work, although it was not designed specifically for earthen construction. Its usage is widely used for the enhancement of stone cohesion, and is especially appropriate in the case of sandstone and limestone (Zoghlami 2003). Furthermore, this compound is permeable to water vapour, is suitable to siliceous materials, and presents no chromatic change. Ethil silicate was used in the restoration of the Golden Tower in Seville (2004) and in the case of the restoration of the Macarena sector of the City Wall of Seville (2008). The performance in the Tower seems to have yielded positive results so far, mainly since no damage has appeared because its rammed earth is protected by a lime mortar. Regarding the Macarena sector of the City Wall of Seville, there is currently no serious damage where ethil silicate has been sprayed in consecutive layers. However, due to the lack of maintenance, earth is beginning to appear at the base of the wall, as a consequence of erosion and loss of cohesion of its consolidated surface. Some specialists (Aymat 2000) argue that this compound is the direct cause of some losses of surface material in certain earthen walls. Hence, it is always recommended to test the response of rammed earth before any application since this is not a reversible technique.

Organic compounds, such as asphaltic emulsions and acrilic epoxie resins, constitute another line of consolidant products. These have been proved to be non-suitable products however, mainly due to the low permeability of the layers generated on the surface of wall, which drastically changes the hygrometric behaviour of the wall and consequently weakens the structure of the rammed earth due to water ponding.

Therefore, polymeric and resin-based consolidants have proved to be largely unreliable due to their major physical and chemical differences to earthen wall characteristics. The use of inorganic compounds is currently more common in restoration work. Some authors argue that lime in the form of limewash, lime water, or fluid mortar may present the best option in consolidations whether they be rammed earth or any other kind of earthen walls (Goreti 2005). Lime provides extraordinary compatibility, and induces no damage. On the other hand, certain compoundds such as ethil silicate currently display a good response, although further studies are needed in order to prove its efficiency in medium—and long-term responses. Even so, there is no permanent treatment; therefore periodical maintenance is required, whose cycle and intensity depends on the level of exposure of the wall, among other factors.

2.3 *Restitution/restoration of mass*

The restoration of mass occurs when the loss of the original mass, due to erosion, is significant, and may even render the wall unstable, or when integration or reconstruction of certain sections is intended. This technique is much more destructive than consolidation since the carving of original rammed earth is required. In addition, new volumes of rammed earth are placed covering and hiding the wall, and may even lead to the wrong interpretation of constructive characteristics when no criteria is borne in mind. Moreover, since this technique is permanent, International Restoration Charters advise against its indiscriminate use.

Various techniques of the restitution of rammed earth may be carried out according to the specific circumstances of the wall. All of these techniques are based first on the placement and stabilization of a formwork and the later compaction of a certain mixture of earth. Both one-sided and two-sided restitutions have been registered corresponding to surface restitutions and those of whole sections.

However, it remains essential to design the technique in accordance both with the physical and chemical parameters of the old wall and with the constructive characteristics of each component of the rammed-earth wall. If these guidelines are followed, the restoration will certainly be appropriate and coherent.

There are several solutions for fixing the formworks, whether they be wooden or metallic, from ancient techniques based on ropes and nails to modern systems. The first step is always the placement of the needles, which will support the entire formwork structure. To this end, a small aperture is carved in the lower course, allowing the formwork to enclose a few centimetres of the top of this lower course. Before setting the wooden needles in place, it is necessary to completely soak them in water for one day in order to prevent any unexpected increase in their volume. The dimension of wooden needles may widely vary, from those square needles used in the Alcazaba of Reina and the City Walls of Seville, to those of a rectangular cross-section of the Monteagudo Castle in Murcia (López 1999). The typology of the needles should be carefully chosen in accordance with the characteristics of the original needles; a consideration largely ignored in the past.

Regarding the case studies, both formwork systems have been used; in certain restorations in the form of traditional wooden formworks made of 4 or 5 nailed planks (walls of Seville, Alcazaba of Reina, Castle of Paderne, walls of Niebla), on other sites in the form of metallic boards for concrete (Castle of Toral de los Guzmanes). Despite this, it is clear that the key to accomplishing an adequate response is to guarantee the adherence of the material of the new restitution with that of the original. A number of techniques have been proposed and applied, based on protected or unprotected metallic connectors (Castle of Paderne), insertion of ceramic pieces, stones or creosote-protected wooden beams and carving of hollows or cavities in the existing wall (walls of Niebla). However, prior cleaning and soaking of the surface by means of limewash or lime water (Goreti 2005) is essential. Since rammed-earth walls depend largely on vertical compression, it is crucial to assure a maximum of horizontal surfaces to properly hold newly rammed earth. To this end, the original wall will be cut out, in order to generate a stair-shaped cross-section. It is also essential to protect the upper end of the restitution, especially the interface, in order to prevent infiltration of water, internal erosion, and the consequent collapse of the restitution. This is the reason why intervention of the walls of Niebla (1982–83) failed and currently entire sections of restituted one-sided rammed earth are falling apart. An adequate selection of soils and stabilizers and their compaction is also crucial. Restoration in both this last cases and in the City Walls of Seville (1987), failed to properly deal with these factors. The latest experiences carried out in Niebla in 2010, Reina in 2009 and at the City Gate of Seville (Carmona) are currently showing good technical responses thanks to constructive solutions suitable for the original rammed-earth walls. Nevertheless, other restoration work, even where technical solutions are working appropriately, have failed to observe and follow the constructive patterns of the original wall, since, for example, the dimensions, measures and chromatism of its constructive elements are utterly distinct. Work undertaken on the City Walls of Sanlucar la Mayor show sequences of putlock holes totally different to those of the original wall; at Castillo de las Guardas lime mortars were supposedly used to repair losses of mass, but no constructive or even aesthetic criteria were applied. For other examples, as in the Hacienda de los Quintos, rough fired bricks were used all over the rammed-earth surfaces, thereby totally enclosing and hiding the perception of the original wall. Finally, other restorations, such as that of the Castle of Paderne (Cóias & Paulo 2004), chose to project earth into the hollows, hence generating an unsuitable texture to the original rammed earth.

In general, there is a certain trend towards a greater respect for original rammed-earth constructive characteristics, and a greater focus on restitutions and consolidations of a more controlled and limited nature.

2.4 *Rendering/coating*

When rammed earth is appropriately protected, it may be unnecessary to render the surface. Classic coverings may be applied, such as lime mortar and limewash, after the wall is built, or even during the construction process as crusting layers of lime mortar (calicastrados), which are more commonly found in military buildings.

Although earth rendering may be the most suitable material for rammed earth, it is not widely used for repairs in military rammed-earth walls. Lime mortar rendering is the most frequent technique under these circumstances, and should be spread in several layers; the first layers being thicker and with an embedded mesh to reinforce where necessary, and with less lime to adapt to the original wall. External layers should be thinner and more resistant in order to obtain a longer-lasting surface (Doat et al., 1991). In the same way as for restitutions, surfaces should be clean and free of loose chunks before any render is spread. Lime mortars provide the correct protection since they guarantee adequate hygrometric performance due to the ability of these mortars to transpire and their similarity in rigidity to that of rammed earth.

In general, the responses in the case studies of lime mortars are satisfactory. For instance, the mortars of The Golden Tower, the Castle of Los Molares and the Tower of Saint Antonio are currently preventing any new pathological processes. On the other hand, lime mortars used for the restoration of the City Walls of Niebla (2010) have recently shown new damage due to infiltrations of water from the back of the wall. In other cases, such as in certain sections of the City Walls of Écija, the incompatibility of the technical solution is evident since extensive areas of the rendering are coming off and revealing a rusty mesh. For the same sample, the formal solution criteria of the new covering do not match the constructive parameters of the original wall, since proposed courses, location and shapes of needles do not correspond to the original wall.

Other rendering than lime mortar has been observed in certain analyzed interventions, and has resulted in a variety of responses. Brickwork is a common alternative technique to mortars when the protection of a military wall is needed, although Compressed Earth Blocks could have been used instead. Rough fired brick, with typical Islamic dimensions, 28 × 14 × 4 cm, inherited from the Taifal models (Tabales 2000), is normally used. When brickwork is carried out with a prior cleaning of the original wall and breathable mortars, a new suitable surface can be achieved, although the real constructive identity of the rammed-earth wall shifts into the background. In certain cases, as in the Tower of Saint Antonio, brickwork is limited to restricted areas where it was required as a structural reinforcement or simply to rebuild the original shape whereby restored areas are evident. However, there are other kinds of repairs whose responses are controversial. This is the case of the restoration of the Southern sector of the wall of San Juan de Aznalfarache, where both formal and constructive parameters from original rammed earth have been utterly ignored, since a new covering made of dark stone and cement mortar has generated a barely transpirable skin, which, as a consequence, has led to further damage in the rammed earth due to water gathering.

Finally, a special rendering made of lime mortar is worth mentioning, which is reinforced by means of an embedded steel mesh in both sides of the wall, which are stitched together with steel bars through the thickness of the wall. This rendering aims to increase the compression strength of rammed earth, and it was put into practice in the Hacienda de los Quintos in order to reinforce a load-bearing wall faced with an increase of vertical loads. Other similar interventions in adobe or CEB walls have chosen nervometal (AIS 2009) and plastic meshes (Vargas et al., 2007) in order to improve seismic performance. Nevertheless, these experiments have never been carried out for military rammed-earth walls, partly owing to the inconvenience of their great thickness.

2.5 *Crack and fissure repairs*

Rammed earth tends to suffer from cracking due to the scarce tensile and shear strength. Thus, vertical cracks are more frequent since horizontal cracks are linked to compression and buckling.

It is necessary to start repairs by analyzing the state and evolution of the crack or fissure in order to determine whether it is due to a degenerative damage process in order to assess not only its scope and severity but also whether the crack is going through the thickness of the wall. These parameters will help to define the most suitable repair method, which may be classified as soft and hard methods (Jaquin 2008). Soft techniques are appropriate when the crack is not under any kind of tension, while hard techniques are more suitable if certain tension or movement is likely. In any case, these methods are not applied until the wall is completely stabilized since they are not designed to properly withstand and transmit the tension caused by unexpected movements (Pearson 1977).

Soft methods consist of simply filling up the crack in order to prevent weathering agents from attacking and progressively eroding the core of the wall, and hence structural continuity of the rammed earth is not completely achieved. New filling material should have similar characteristics to those of rammed earth in order to prevent or minimize differential shrinkage. Before any application, cleaning should be undertaken. Narrower fissures and cracks are easily repaired by successive injections of limewash (Goreti 2005). When the opening is wider, a denser material is needed; to this end first a fluid lime mortar might be used and afterwards the aperture could be finished with a limewash. If the aperture is significant, say of 5–10 cm, it will be necessary to first apply lime mortar containing ceramic, brick or adobe rubble or even small chunks of rammed earth.

In the restoration of the Castle of Alcalá de Guadaría in April 2010, cracks were sealed up with a lime mortar leaving an inner void. Several plastic tubes were then placed at various heights which entered the mortar inside the cracks, and these were used to pour a fluid lime mortar into the wall until the cavity was completely filled. Finally, these tubes were cut off. The main inconvenience is the major lack of control in the application and the great loss of fluid mortar that this technique involves. As an alternative, in the Macarena sector of the City Walls of Seville, crushed chunks from the original rammed earth together with lime mortar were used to fill the widest cracks. Although a simulation of original textures and colours was intended, aesthetic results remain questionable.

Hard tying techniques are developed from soft techniques by means of embedding a connector that stitches the crack and improves the structural continuity. Several authors suggest cutting a horizontal chase into the face of the wall, across the crack. Reinforced courses of adobe or CEB are then laid (Ashurst 1988; Pearson 1997; Hurd 2006). When the hollow is narrow, mesh-reinforced layers of mortar may be used instead (Keefe 2005). As an alternative, Guillaud (2004) suggests using various types of wooden staple. However, none of these techniques have been carried out in the case studies. For instance, in both the restorations of the Castle of Lebrija (Torrecillas & Romero 2006) and the walls of Sanlúcar la Mayor (Callejas & Martín 2005), steel staples were set across the cracks, and sealed by an epoxy mortar, showing how techniques designed for other materials are indiscriminately used in earthen building repairs.

3 CONCLUSIONS

From the analysis and comparative evaluation of the case studies, it may be concluded that there is a need to establish certain criteria that reflect the different responses of each intervention, thereby allowing objective comparisons and improving future technical strategies of rammed-earth walls. In order to accomplish a more precise classification of interventions, the selected criteria may be gathered into three categories according to formal-constructive, pathological-risk, and technical reliability responses. To this end, characterization and classification of the interventions is intended under the same perspective, in order to obtain reliable and consistent conclusions.

In reference to the formal-constructive response, it is concluded that evaluating formal and constructive parameters of the intervention is essential, setting aside issues of style or aesthetics since they are subjective and hard to measure. In fact, any coherent intervention should deal with the chronotypology of the original rammed earth in order to properly match its constructive parameters (Graciani & Tabales 2008). Other significant issues, such as the type, location and the approximate distance between consecutive needles should be borne in mind, as well as the dimensions and form of the rammed-earth wall, the height of the courses (module of rammed-earth box) or the length, the type of joints between rammed-earth boxes on the same course and the recording and study of formwork traces or other kinds of decorative elements. Conclusively, this analysis points out whether the constructive correlation between old and new is consistent.

The pathological response and the state of conservation of restored rammed earth are assessed, through the identification of new damage, whether it be material, structural or superficial. Furthermore, the presence of a certain risk factor can be evaluated as a way to indicate how effective the corrective, preventive and maintenance actions are.

Finally, it will be essential to analyze the suitability of the material of the technical solutions to the repair carried out in the particular case on military rammed-earth walls. In this way, the physical-chemical compatibility of construction materials can be assessed, as well as the technical viability of the proposed solution.

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Core, connectors and crust: Methodological restoration options for reinforced rammed earth wall with bricks

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ABSTRACT: Rammed earth walls with bricks (*tapia valenciana*) belong to the "family" of earthen structural techniques, where reinforcements, by means of layers of bricks protected by a crust of lime, are present. This ensemble of materials obeys secular constructive technology and a balanced system based on specific material hierarchy. This is because walls made using this technique base their constructive logic on the union of the strata, in response to possible low lying forces (movements, settling) as well as absorption of horizontal pressure from the inner filling. Today, understanding the historical technique is necessary in order to weigh up possible intervention criteria. In doing so, various questions arise: in which areas of the combination of core + connectors + crust can we intervene? How are we able to do this? The authors will outline an excursus of guidelines used in recent interventions, and consider the different methodological criteria visible in the several cases of study analyzed.

1 INTRODUCTION

1.1 *General features about this type of wall*

Tapia valenciana is a hybrid wall, where the earthen and lime mortar work together with specific brick reinforcements, a mixture of lime, gravel and rammed earth. Because of this, the resulting coating of the wall face is sometimes misleading, halfway between traditional rammed earth wall and brick masonry. In the majority of cases, the finish is comprised of the same crust of lime which, due to the removal of the planks, creates a peculiar texture in the form of a fine layer of mortar overflowing on the bricks' edges (Fig. 1).

This technique, a curious blend of earthen and brick application, is not documented in any archaeological sources until the second half of the 13th century (Siam, *Servicio de Investigación Arqueológico Municipal de Valencia*). In fact, the name itself is not explicitly detected until the 16th century (Galarza 1996). The name "Valencian walls" is significant, despite the fact that the employment of this technique spreads far beyond the city of Valencia (Vegas, Mileto, Cristini, García 2011a/b) and its surroundings (Alcira, Xàtiva, Alaquàs, Castellón, Mascarell, Masamagrell, Sagunto, villages among others …), and even beyond the Valencian Community (Murcia, Aragón, Andalucian city of Guadix up to north Africa coastal regions- Chennaoui 1997).

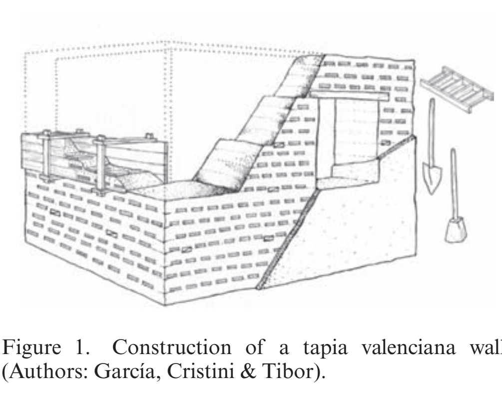

Figure 1. Construction of a tapia valenciana wall. (Authors: García, Cristini & Tibor).

In fact *tapia valenciana* walls offer an appearance of simple brickwork but, after careful observation, it is possible to see that the mortar joints can reach a thickness of up to 10 cm, so that the walls are made by planks form.

If on the other hand we are to analyze the metric characteristics of these walls, we have to recognize the heterogeneous nature of the used bricks. In spite of the arrangement of regular "key" bricks, it's always possible to find bricks of multiple sizes and clay types, varying along the same wall (Font-Hidalgo 2009). That is why it is necessary to consider the use of recycled raw materials, perhaps defective or recovered, in the configuration of these walls (Cristini-Ruiz Checa 2009 a/b/c).

The presence of irregular bricks is not gratuitous, since it is a question of punctual reinforcement, by way of ceramic connectors, and as such the constructive/structural logic moves away from a "simple bond concept". For this reason,

Figure 2. Mortar core, ceramic connectors and crust. Three detached parts of a *tapia valenciana* wall. (Authors: Cristini & Ruiz Checa).

the heterogeneity of the raw materials is not unintentional. In this case, the bricks' function is more that of connecting the strata rather than traditional brickwork masonry. Because of this, it is possible to identify three detached and well defined parts that form a *tapia valenciana* wall: a rammed earth and lime mortar core, a few ceramic connectors and finally a lime crust (Fig. 2).

2 HOW IS POSSIBLE TO RESTORE A *TAPIA VALENCIANA* WALL?

The present study has arisen from an empirical demand of the authors who proposed the analysis of *tapia valenciana* walls, focusing particular attention on the connectors (bricks) and their role in the wall bond.

Nevertheless, when it came to analyzing, measuring and drawing the walls, we inevitably found different examples of restored or modified walls, transformed using inconsistent logics and heterogeneous criteria.

Hence the idea of documenting these cases and collating different intervention techniques, with the final aim of proposing possible actions and identifying common practices and different alternatives.

2.1 *The core*

Tapia valenciana walls usually present different thicknesses, depending on the destined use of the constructed buildings, varying from simple fences and dividing walls, to city walls or load-bearing walls. For this reason, it's possible to say that, of the three variables that form this type of wall (the core, connectors and the crust), the mortar core is in fact the part that can vary the most according to different cases studied, both due to its depth, and its composition (mortar/sand).

2.2 *The connectors*

The bricks, in this type of wall, are not really bonded, but in fact are more like pieces arranged in the frame, positioned in each layer, in a non-random way, always placed next to the lateral boards.

The connectors are always heterogeneous, both in color and dimension, as well as raw material and texture. In some cases it is possible to find fragmented pieces of bricks, a feature that also helps establish possible hypotheses on the reuse of bricks as raw materials. Another common point is the halo of crust around the bricks' surface. The connectors remain misaligned, invariably embedded in the crust. Nevertheless, the presence of bricks can change from a headers pattern into a traditional bond, with stretchers and headers, especially in buttresses, corners or pillars (Cristini-Ruiz Checa 2009 a/b/c).

2.3 *The crust*

As already touched upon in the previous point, the lime crust that seals the wall surface is formed by a combination of layers that overflow into the plank frame (Fig. 3).

In addition, the distribution and thickness of the bricks, as well as the crust, do not change according to the wall sections of the wall or the building's purpose; instead finer and more sifted sand, and more pure lime can sometimes be seen … but the final coating of the wall is always the same.

Figure 3. Well preserved surface of a *tapia valenciana* wall, *Iglesia de S. Juan de la Cruz*, Valencia (Authors: Cristini & Ruiz Checa).

Undoubtedly, the fact that this type of wall is formed by an "all in one" constructive process, characterized by a single sequenced operation (the preparation of earthen and lime layers set into a timber board frame, with ceramic brick connectors arranged in each strata), inevitably opens up possible questions on possible intervention options at later stages in the walls' lifespan.

It is quite difficult to find examples of *tapia valenciana* walls that have not been modified (AA.VV. 2007), in good condition, and without pathological signs, that could be used as basis for case-study (Cristini 2012). Precisely because of this, the authors have relied on the different interventions, which in part have helped in understanding the structural technique and process (Amando Llopis, R.F. 1998; Tormo Esteve, S & Cortés Meseguer, L. 2008; García Martínez, V. 2008 … between others).

3 INTERVENTION ANALYSIS

After the interventions, the majority of the analyzed walls reveal processes carried out mainly in the crust. Many of the cases deal with plasters, anti graffiti treatments, or coatings that distress on the walls' "surface of sacrifice", and replace or cover the original surface (Figs. 4–5). A few cases display simple epidermis consolidation, in order to avoid micro-fissures and discontinuities, thanks to jointing processes.

In reality, crust interventions on these walls, carried out in many cases by puncturing the crust and then coating the structure with a new thick layer, have been due to the fact that historically they have not enjoyed extensive aesthetic consensus.

This irregular wall surface is historically associated with more humble structures, and as such considered less "respectable" than most regular brick masonries.

Figure 4. Whitewashed surface of *tapia valenciana* wall, *Ermita de S. Jaume de Fadrell*, Castellón (Authors: Cristini & Ruiz Checa).

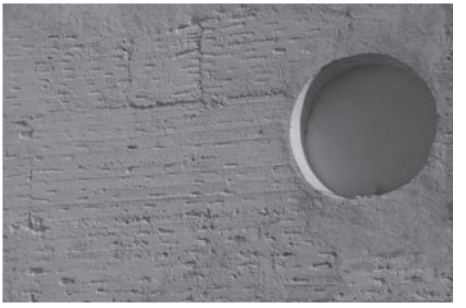

Figure 5. Whitewashed surface detail, *Ermita de S. Jaume de Fadrell*, Castellón (Authors: Cristini & Ruiz Checa).

For this reason the tendency was to conceal these rammed earth walls with matt finishing, thus improving the surface aesthetics (many of today's monumental buildings can be found amongst these cases). In the last few years this was a widely accepted practice.

This process, depending on the material used (more or less compatible with the support), has either produced well-adhered finishes or, in some cases, layers with pulverization, chipping and erosion problems.

Moreover, in some cases, the original wall texture displays new renderings that simulate the primitive wall bond, which they aspire to, with more or less successful results. Some contemporary interventions have featured stencil decoration and graphic images, in search for abstract plans that recall and simulate the header bricks (Figs. 6–7).

Other, more structural interventions, replace the connectors, typically the most degraded and flakey ones, extracting the deteriorated elements and replacing them with new bricks.

In these cases the operation can also be more or less compatible with the support that acts in the exterior layer, i.e. the crust (it is recommended to use ancient, handcrafted bricks, in tune with the size, color and texture of the originals).

The interventions thus create patches of mortar in the areas next to the bricks, in a process carried out after the placement of the new connectors.

On the other hand, interventions in the core are less common. The depth of this type of intervention in itself signifies the need for a change in approach; these types of interventions need to be considered as volumetric reconstructions. Undoubtedly a huge loss in percentage of historical wall is inevitable in these cases, often rebuilt solely with mortar without brick connectors.

These cases are those that usually use new timber-frame designs (for both single face or double face) with mortars of different compositions, textures

Figure 6. A surface detail, simulating header bricks. *Almudin*, Valencia (Medieval Granary) (Authors: Cristini & Ruiz Checa).

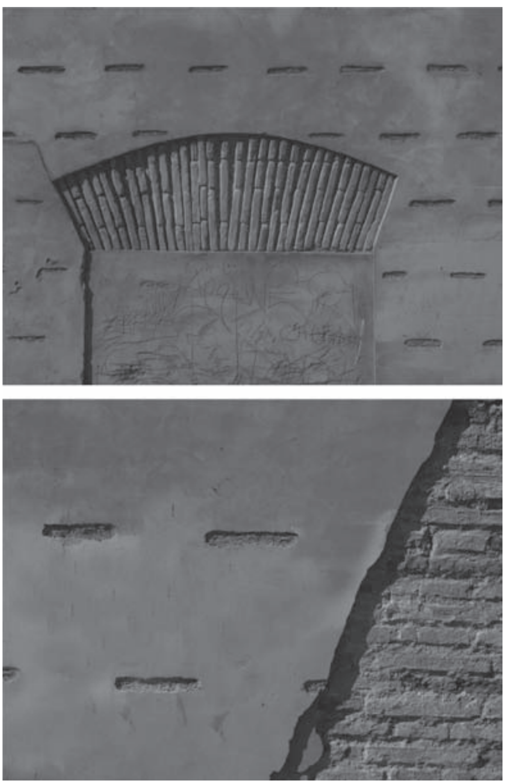

Figure 7. A surface detail, simulating header bricks. *Palacio del Gremio de Carpinteros* (Ancient Carpenters' Trade Centre) (Authors: Cristini & Ruiz Checa).

and relations with the pre existing structure (with new alignments, overlaps and cuts). Following these observations new limits and challenges can be established for restoring the different parts of *tapia valenciana*.

Figure 8. Core and surface interventions: *Alaquás* Castle, Valencia and *Palacio d'en Bou*, Valencia (Authors: Cristini & Ruiz Checa).

But why is it so complicated to work in this tripartite system, made up of core, connectors and crust? Perhaps in order to answer the question, we have to refresh our understanding of the constructive technique itself. The *Tapia valenciana* wall, formed by three different materials, mortar, cooked bricks and lime crust, owes its characteristic features in particular to the inlay bricks.

It is these connectors, which partly contribute to the absorption of low-lying forces, which play a fundamental role in the wall. They are, as explained before, the real connectors that join and fix the crust with the core; anchoring the parts and helping to join the exterior and the interior layer. Working on a *tapia valenciana* wall means dealing with a structure that features a non-refundable frame adhered to it (Fig. 8). It is this mold itself, made up of binomial bricks and crust that provides decent protection of the earthen and lime mortar core, this being the most vulnerable part of the structure.

4 CONCLUSIONS

The analyzed interventions in *tapia valenciana* walls usually answer to different needs, often guided by wall degradation levels and by a change in the use of the building. The degree of manipulation ranges from processes with minimal levels of intervention (such as consolidation/re-filling of the crust), the substitution and repair of parts (relaying, renewing or supplementing bricks) to pure volumetric reconstruction (Fig. 9).

We can therefore say that the intensity of the intervention is greater the deeper or closer you get to the rammed earth and lime core. However, if we consider *tapia valenciana* a structure with a non-refundable form adhered to it, the interpretations

Figure 9. Example of *tapia valenciana* volumetric reconstruction. *Mascarell* city wall, Castellón (Author: Cristini & Ruiz Checa).

of the technique, and the possible interventions, change.

Working on a non-refundable form incorporated into the wall (created by the bricks + crust system) is an extremely delicate process, based on the assumption that the wall works as an "all in one system". It is possible therefore to consider two extremes: on the one hand minimal intervention, which scarcely fixes thin skin crust and guarantees its adhesion, or on the other hand the ex-novo volumetric reconstruction.

Thus an "intermediate" position which proposes changes in the key connectors (removal, substitution, repair or addition) is possibly the most delicate. Since the risk of separating the parts is quite high, the bricks in these cases tend to drag part of the mortar with them, the repair of mortar ends up by being heterogeneous (both regarding the core and the finishing layer). Therefore the risk of adhesion loss is more marked, and the connection between the parts is weaker.

Finally it is possible to conclude that crust interventions, in many cases with partial substitution and puncturing/pitting, are not always influenced by the thickness of the walls/are not always determined by the thickness of the walls. In some cases load-bearing walls with sections thicker than 60 cm, are modified by the removal of renderings and in there-joining process. These processes are not necessarily structural; instead they tend to be carried out for urban decoration or project purposes. These considerations regarding the intervention criteria on *tapia valenciana* are proposed as short summarized guidelines, without want of criticism, but rather to collate common practice and understanding of these walls and their constructive/structural logic.

NOTE

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Preliminary study to the restoration of the Tower Keep in Jérica (Castellón, Spain)

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ABSTRACT: The Tower Keep, a symbolic monument located in Jérica (Castellón, Spain) is, upon being considered of historical significance, in need of intervention through an adequate study of its traditional construction techniques. Strategically placed upon a hill, with a rectangular base (7 × 8 m) and an average height of 13 m, created with both masonry and rammed earth, the tower conveys great structural integrity. Interiors are vaulted, partially detached, dividing the volume into two levels. Cracking in the blocks is evident at the corners, caused by differences in settlement. The rammed earth facade alone reveals peeling on the upper level due to the degradation of the roof. The analysis was completed through rudimentary techniques at minimum cost. The condition of the rammed earth allows an economical intervention, since the necessary methods are very elementary and the passing of centuries has proven the structure's reliability and sustainability.

La Torre del Homenaje de Jérica (Castellón, España), forma uno de los hitos más significativos de la población junto a la Torre mudéjar de la Alcudia.

Se conoce popularmente como la "Torreta" y formaba parte de un antiguo castillo que se extendía por la Peña Tajada, comenzado a construir en el siglo XIII. El edificio se compone de un prisma rectangular cuyos muros tienen un espesor de metro y medio, utilizando para su construcción una técnica mixta de sillería y tapial. Su función principal era la de vigía dado que desde su emplazamiento no sólo se abarca una amplia visión de todo el castillo sino también de la gran extensión de terreno colindante. Pese a la protección del monumento, el estado que presenta actualmente es consecuencia de una conservación prácticamente nula.

El interés académico y la preocupación por devolver a la Torre del Homenaje su dignidad y valor histórico plantean la necesidad de realizar una intervención sobre el monumento. Para formular una propuesta de proyecto acorde con las necesidades del edificio es necesario efectuar un estudio previo, recopilando información de su estado actual que nos permita tener una visión global del mismo.

Teniendo en cuenta nuestra condición de estudiantes universitarios y la situación económica

Figura 1. Vista general.

vigente, se pretende demostrar que es posible realizar el levantamiento métrico y un análisis suficientemente descriptivo, sin necesidad de acudir a métodos costosos y complejos que, siendo en la mayoría de los casos inaccesibles, propician el abandono de la obra y la pérdida de interés en su conservación.

Los resultados que se consiguen con métodos económicos y rudimentarios son adecuados para el fin perseguido. Este estudio se compone de varias fases que se desarrollan a continuación.

1 INVESTIGACIÓN HISTÓRICA

La Torre del Homenaje se ubica en la cumbre de la Peña Tajada, Jérica, Castellón. Es propiedad del Ayuntamiento de Jérica y en la actualidad se encuentra en desuso. El castillo en su conjunto (en el cual se encuentra incluida la Torre del Homenaje), la ermita de San Roque y las cintas murarias se consideraron Bien de Interés Cultural (código BIC: 12.07.071-009) en 2004 (Decreto 273/2004, 2004).

Existe poca documentación escrita acerca de la Torre del Homenaje y ésta se encuentra generalmente englobada dentro de documentos relacionados con la totalidad del castillo o de la población, tales como las excavaciones arqueológicas realizadas en el entorno del castillo de Jérica durante los años 1999–2001 al frente de la arqueóloga Pilar Vañó Arándiga cuyas conclusiones se encuentran recogidas en la Exposición y el Estudio del Castillo de Jérica (no se encuentra editado pero aparecen los hallazgos y explicaciones en la página web del ayuntamiento del pueblo).

Figura 2. Plano de situación.

Así mismo se han consultado pasajes del libro "La historia de Xérica" del historiador Francisco del Vayo que recoge los hechos sucedidos en el pueblo durante los años 1235 a 1570 y que Rosa Gómez Casañ recoge en su tesis de licenciatura en la Universidad de Valencia, publicación editada por la Caja de Ahorros y Monte de Piedad de Segorbe en 1986 (Gómez Casañ 1986). Han resultado de importancia la información conseguida mediante fuentes orales y fotografías de distintas épocas (archivos municipales), mediante las cuales se han podido determinar distintos aspectos relacionados con las grietas, la caída de las bóvedas interiores o el cambio de aspecto de la torreta en el último siglo.

En general, de la investigación histórica se han extraído conclusiones acerca de la importancia de la Torre del Homenaje para el castillo, no sólo como lugar de vigilancia, sino también como la construcción más emblemática de aquella época. Además, se considera que todo el castillo fue comenzado a construir durante el siglo XIII tras la reconquista por Jaime I en 1235 (Rodríguez Culebras 1983), estableciéndose sobre la anterior muralla árabe, aunque cabe destacar que el asentamiento inicial data de la época romana. Remarcar, sobre el monumento objeto de estudio, la intención de orientar sus fachadas hacia los cuatro puntos cardinales y la posterior destrucción de su coronamiento, así como del resto del castillo, durante las Guerras Carlistas (Guerrero Carot, F.J. & Domènech Zornoza, J.L. 2007).

2 LEVANTAMIENTO MÉTRICO-DESCRIPTIVO

Consiste en estudiar detalladamente la geometría de las partes que componen el edificio, para posteriormente generar planos y dibujos sobre los que trabajar. Estos planos deben reproducir fielmente el objeto de estudio, ya que se tomarán como base de posteriores análisis. En el caso que nos ocupa, el proceso de toma de datos se realizó empleando únicamente cuerdas, nivel de burbuja, metro, tizas, una escalera y una cámara fotográfica.

El levantamiento métrico se llevó a cabo mediante el método de la triangulación. Se tomaron como referencia varios puntos fijos del entorno, a partir de los cuales se establecieron relaciones métricas entre el interior y el exterior de la Torre. Se debe tener en cuenta que todos estos puntos deben estar a la misma cota para obtener un plano fiable en planta. Para establecer la altura se realizó una geometrización exhaustiva de la parte inferior de la torre; de esta forma se pudo rectificar, a través de programas informáticos, las fotografías tomadas para que tuvieran validez métrica y pudieran suplir la escasez de medios. Una vez realizada la toma de datos se dibujó el edificio de manera fiable, diferenciándose las partes conocidas de las no visibles o inaccesibles.

3 ESTUDIO CONSTRUCTIVO

La fachada principal es de sillería y en las otras tres se utilizó una técnica mixta de tapia reforzada en las esquinas con sillares, lo que otorgó a los muros de mayor rigidez. Toda la Torreta se apoya sobre una base de mampuestos irregulares procedentes del sustrato rocoso del entorno.

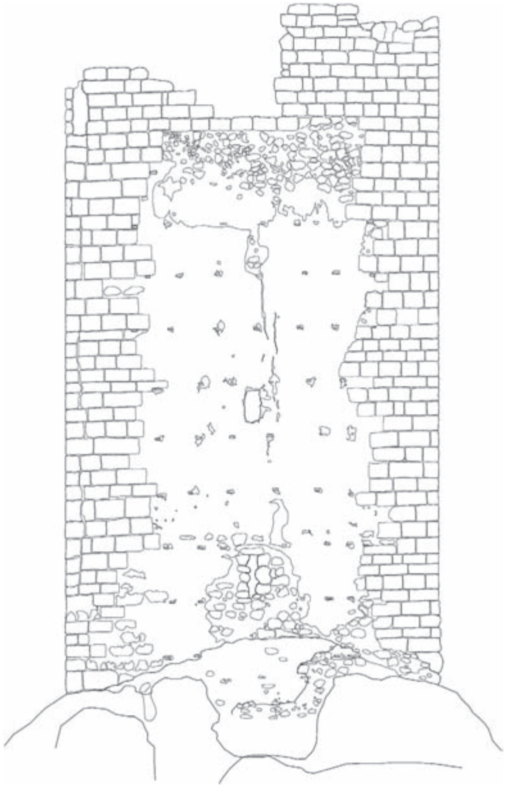

Figura 3. Alzado sur.

Los sillares empleados son de piedra caliza y proceden de canteras próximas al lugar. El mortero de asiento utilizado está compuesto de arena, agua y cal, presentando un aspecto blanquecino y siendo su espesor aproximado de 2.5 cm. No se han realizado análisis en laboratorio pero se ha llegado a la conclusión de la existencia de calcita tanto en el árido como en el conglomerante mediante una sencilla prueba con ácido. El jugo de un limón sobre muestras de mortero y árido hace que el ácido cítrico de la fruta reaccione con el carbonato cálcico de los materiales causando un burbujeo en el cual se desprende agua y dióxido de carbono (Prado Herrero 2004).

La fachada norte en la cual se encuentra el acceso se erigió disponiendo los sillares de forma regular al modo *opus quadratum* con hiladas de altura constante. El muro se compone de tres hojas, las dos exteriores realizadas de manera que encajan perfectamente los sillares entre ellos, no coincidiendo sus llagas, trabándose ambas hojas con llaves en todo su espesor y la hoja interior realizada con sillarejos facilitando así la adherencia del revestimiento final.

Las otras tres fachadas se conforman con tapia calicostrada y sillares dispuestos en las esquinas de forma similar a la descrita anteriormente. En la tapia se aprecian las marcas de las agujas de madera propias de su construcción, separadas entre sí un metro en vertical y 80 cm en horizontal. Una vez construido el encofrado se rellena con una mezcla compuesta de cal, agua, arena y mampuestos del lugar, se apisona en sus diferentes tongadas, y se deja endurecer, momento en el que se retiran los tableros de forma que se podía construir el siguiente tramo del muro.

En el caso de la Torreta no se utilizaron andamios para su construcción, debido a que en el mismo tiempo que se ejecutaba el tapial, se construían las esquinas de sillar, lo que permitió a los operarios desplazarse libremente por la anchura de la fábrica y proseguir con la construcción.

4 ESTUDIO ESTRATIGRÁFICO

Consiste en analizar las diferentes fases constructivas del edificio, las ampliaciones que ha podido sufrir y las modificaciones que se han llevado a cabo a lo largo de la historia del mismo (Vegas, F. & Mileto, C. 2011).

Se realiza directamente leyendo el edificio y observando toda clase de huellas que pueda haber en los materiales, no siendo necesaria la documentación histórica, pero puede servir de ayuda.

El objetivo es ordenar de forma cronológica las distintas fases constructivas, los daños sufridos y las intervenciones llevadas a cabo. La forma de

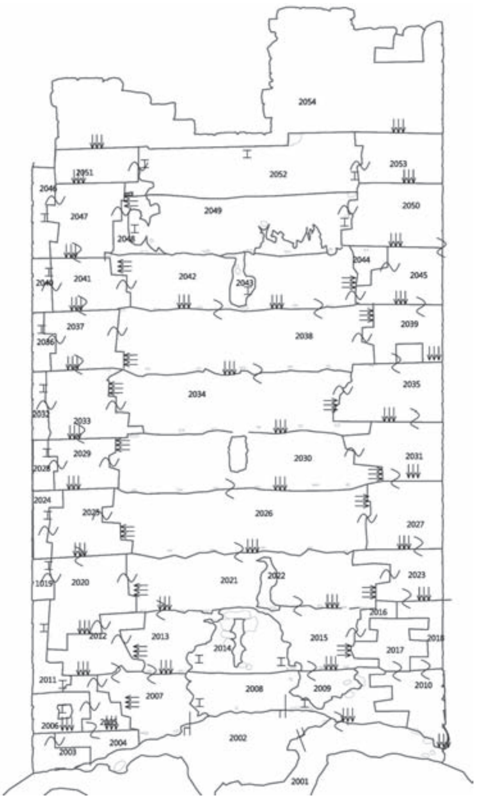

Figura 4. Alzado sur. Estudio estratigráfico.

hacer el estudio es in situ ya que la lectura debe ser directa. El método consiste en ir indicando las diferentes partes homogéneas que presentan las fachadas, con el mismo material y deterioro en el paso de los años.

Se establecen relaciones de anterioridad y posterioridad con el simple hecho de ver como se ha colocado el mortero, si rebasa sobre partes antiguas … A la vez se establecen relaciones de contemporaneidad de los huecos o posibles agujeros realizados en la piedra, si se ha empleado el mismo método como en nuestro caso el arco de medio punto. En el caso de la Torreta se distingue una fase de construcción data en siglo XIII, con pequeñas intervenciones en los sillares de inicios del siglo XX y una clara actuación en el arco de acceso en el siglo XXI.

5 ESTUDIO DE DEGRADACIÓN DE MATERIALES

En el exterior se aprecian problemas en los sillares producidos por la erosión a niveles muy distintos: desde sillares que presentan una simple erosión superficial, hasta otros en los que los sillares prácticamente no se reconocen, debido todo ello a agentes atmosféricos. En la tapia se ha desprendido una parte importante de la costra superficial en algunas fachadas por falta de un alero de coronación, y en otras debido a que en los sillares situados sobre el muro, se producen filtraciones que tienden a disgregar el tapial, produciendo su desprendimiento. Algo similar sucede en el contorno de los huecos dejados por las agujas del muro; en gran parte de ellos se ha producido desprendimiento del material.

En el interior, los paramentos de tapial aparecen protegidos por una capa superficial de mortero, gravemente afectada en algunos puntos por las filtraciones de agua y por acciones antrópicas, ya que el acceso a la torre no está controlado. La parte inferior de los paramentos interiores carece totalmente de esta costra protectora, que ha derivado en que muchos de ellos se desprendan. Como consecuencia de la humedad, en determinadas zonas, sobre todo de la bóveda, es notable la presencia de hongos.

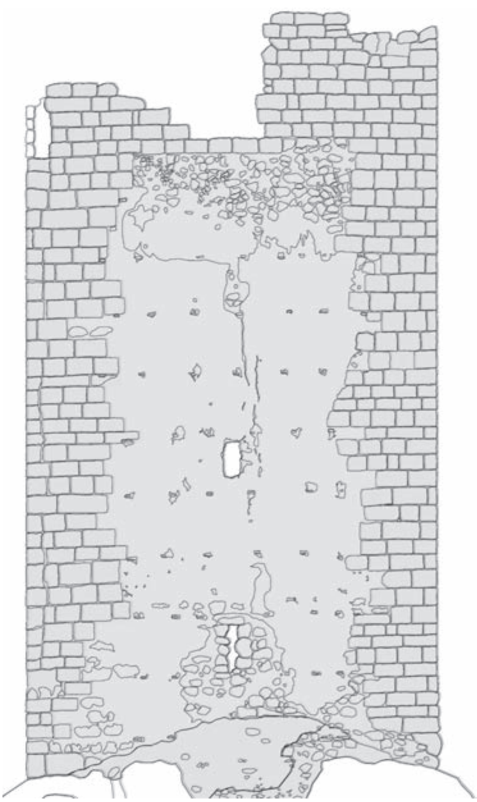

Figura 5. Alzado sur. Mapeado materiales.

Figura 6. Vista interior de la Torreta. Se aprecia el deterioro del acabado interior de los muros y el desprendimiento parcial de la bóveda de cañón.

6 ESTUDIO DE DAÑOS ESTRUCTURALES

Se realizó in situ a través de un análisis del estado actual en el que se encuentra la construcción. Lo más destacado es el desprendimiento parcial en las dos bóvedas interiores, la del nivel inferior, producido en el lugar donde hipotéticamente debió existir una abertura de acceso a planta intermedia, y la de nivel superior provocado por el desprendimiento del coronamiento que dañó la cubierta. Estos daños generan cierta inestabilidad a los sillares y un mayor deterioro del tapial e impiden, en el caso de la bóveda, la correcta transmisión de cargas.

Se acometió posteriormente un estudio de las distintas fisuras y grietas que se encuentran en la Torre.

De entre todas ellas cabe destacar una grieta vertical en la fachada sur, la más expuesta a los agentes atmosféricos, con abertura en la parte superior de 2 cm de ancho y longitud total de 7.5 metros. Consideramos que no confiere riesgo estructural puesto que tan solo afecta a la hoja exterior de sillería, siendo, no obstante, necesaria su revisión y posterior consolidación de la esquina.

7 PROPUESTA DE ESTUDIOS COMPLEMENTARIOS

La realización de estudios complementarios supone un mayor conocimiento del edificio. Su elaboración dependerá de las necesidades de la obra y de las condiciones económicas que disponga el equipo. Sin ser técnicas complejas y costosas, enunciamos algunos procedimientos que podrían ser de interés para la Torreta: datación por radiocarbono a realizar en la madera de las agujas de la tapia, empleo de sistemas instrumentales específicos que permitan un levantamiento métrico-descriptivo mucho más rápido y preciso como el empleo de teodolitos, láser-scanner para un levantamiento tridimensional, usar de mono-cámaras o estéreo-cámaras …

8 OBJETIVOS DEL PROYECTO

En la actualidad, alcanzar la cumbre de la Peña Tajada supone la culminación del paseo que atraviesa la montaña. La presencia de la Torre del Homenaje enriquece la experiencia y subraya el carácter histórico que identifica la población de Jérica. Teniendo en cuenta que durante el pasado se ha aprovechado su situación estratégica para utilizar el edificio como punto de vigilancia, parece apropiado que, en caso de restablecer una función en el monumento, ésta se incluyera dentro de la contemplación, tal y como sucede en los miradores para disfrute del paisaje.

Se debería tener en cuenta la reparación de los espacios degradados y la consolidación de los elementos estructurales, dotando de mayor consistencia al conjunto y evitando un posible peligro para los visitantes de la Torreta y su entorno.

Figura 7. Vista de la fachada sur. Se aprecia la técnica mixta de tapia y sillares reforzando las esquinas.

Consideramos adecuado moverse en el ámbito de la conservación, diferenciando en todo momento la prexistencia de las intervenciones. Se establecerán métodos de mantenimiento continuado para prolongar el buen estado del monumento en el futuro, siempre preservando el aspecto natural del paso del tiempo.

9 CONCLUSIÓN

Una vez ejecutado el estudio previo, y conociendo ya de una forma más precisa el estado de la Torre, se plantea el camino de inicio de una posible intervención para su conservación.

Se ha podido comprobar que el estudio previo no ha supuesto ningún coste económico elevado y se llega a soluciones muy precisas, siguiendo con esta línea, el proyecto de conservación del monumento se puede abordar con el empleo de técnicas y materiales actuales que no dañen la imagen conjunta del monumento y completen las partes faltantes. Se percibe que la Torre presenta una imagen adecuada del paso de los años y no presenta importantes daños estructurales, por lo que la intención es la mantener la imagen actual y evitar un futuro deterioro que perjudique su estabilidad.

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Interventions in Portuguese rammed earth architecture—from ignorance to good practices

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ABSTRACT: Until the 1940s, rammed earth in Portugal was a technique still in use in vernacular architecture, but ignored in monumental heritage. Reused for centuries, monumental rammed earth was very altered in fortifications and hidden under layers of plaster in palaces and outstanding buildings. Portuguese rammed earth architecture has always had this dichotomy between monumental military rammed earth architecture, the treatises and the major engineering works and vernacular architecture, of local tradition, handicraft, the *taipeiros*, masters and the apprentices of the trade. The paper covers the historical evolution of the conservation of rammed earth walls in the cities and historical towns of Silves, Beja, Moura, Évora, Elvas and Lisboa among others. The paper has a special reference to the trend of current practices and the effort made during the last years to reverse a potentially destructive situation.

1 INTRODUCIÓN

La tapia militar fue en cierta forma descubierta en el ámbito de la conservación a partir de los años treinta del siglo XX, cuando se iniciaron las grandes intervenciones en las fortificaciones portuguesas de cara a la doble conmemoración histórica de 1940 de la fundación y restauración de Portugal (1140 y 1640). Hasta entonces los monumentos de tapia eran destruidos o mantenidos dentro de una lógica de continuidad histórica porque eran necesarios, reutilizables en otras construcciones o útiles para la vida cotidiana.

Frecuentemente, los restos de murallas de tapia eran reutilizados como muros de habitaciones o parcialmente en el interior de nuevas fortificaciones construidas en albañilería de piedra o incluso cortados como piedra y vendidos como tal. Estos casos fueron comunes en casi todo Portugal durante los siglos XIX y XX, ya que se vivía en paz y las ciudades carecían de espacio para expandirse. Muchas de las fortificaciones han sido destruidas simple y llanamente porque ya no tenían utilidad y, consecuentemente, se han transformado en pedreras o productoras de sal, como ocurrió respectivamente en los castillos de Alcacér do Sal (Castelo de Alcácer do Sal, 2010) y Moura (Castelo de Moura, 1994).

En el caso de la arquitectura vernácula de tapia, las cosas ocurrieron de forma diferente. Casas habitadas hasta los años 60 (AAP, 1984) pasaron rápidamente a convertirse en casas abandonadas en los años 70 y 80 debido al éxodo rural. En los centros urbanos, la tapia, siempre muy relacionada con pobreza, acabó siendo sustituida por construcciones de otros materiales que imitaban la apariencia de las casas antiguas. La tapia urbana, de peor calidad, era más frecuente en los barrios históricos de origen medieval, como las *Mourarias*—barrio de los *Mouros*—construidos después de la conquista cristiana en el siglo XII. Esos barrios, ya sin *Mouros*, se transformaron a lo largo del tiempo, en las áreas más pobres de todas las ciudades históricas. Ejemplos de esta situación son las *Mourarias* de Lisboa, Moura, Beja y Évora, por citar únicamente las más importantes. Con los programas de rehabilitación urbana de los años 80 del siglo XX, se inició una intervención general en las ciudades históricas portuguesas y, con ella, la rehabilitación de las innumerables casas de tapia que aún existían en los barrios históricos (Aguiar & Pinho, 2010).

Aparte de estas dos situaciones (murallas y barrios) hay que tomar en consideración los sitios arqueológicos de tapia. Práctica frecuente en el transcurso de los años 90 y primeros años del siglo XXI fueron las excavaciones y puesta en valor de las *Alcaçovas* de los castillos. Hoy día, muchos de estos sitios construidos en tapia y expuestos al aire libre están en avanzado estado de degradación, lo que supone una irremediable pérdida patrimonial Seguramente estos sean los casos más difíciles de superar, pero están empezando a realizarse esfuerzos en ese sentido en Portugal.

2 MURALLAS

2.1 *Castillos y murallas*

La diferencia entre castillo y muralla no era muy clara en la terminología portuguesa de 1940. Lo que sí era prioritario en esa época era la reconstrucción de los castillos que, desde el punto de vista histórico, habían sido importantes en la conquista y restauración portuguesa (1140 y 1640 respectivamente). La identificación de ese valor histórico favoreció que terminase la abusiva venta de piedras y bloques de tapia pertenecientes a las murallas.

Del mismo modo que en otros países, los criterios de intervención se rigieron por la reconstrucción histórica y, en la práctica, por la construcción de paramentos de albañilería de piedra vista que aglutinaban en su interior los vestigios de tapia militar. Véase, a título de ejemplo, el castillo de Noudar (Castelo de Noudar, 2005). Dicha práctica había sido corriente y visible en la reestructuración de fortificaciones durante los siglos XIV, XVI y XVII (Armas, 1990). La DGEMN (Dirección General de los Edificios y Monumentos Nacionales 1929–2007), única institución responsable de las restauraciones, tan solo implementó, con algo de imaginación, una cierta continuidad constructiva (Correia, 2010), creyendo profundamente que todos los castillos portugueses tenían *ameias* y torres como las diseñadas por Duarte Darmas en el siglo XVII.

Pero muchas de las murallas de tapia no tenían importancia histórica y el periodo designado de la ocupación *Moura* fue considerado de importancia menor durante años en el panorama de la historiografía portuguesa.

Esa primera intervención de consolidación con doble paramento de albañilería piedra no afectó a muchas murallas de tapia consideradas islámicas y contrarias al espíritu simbólico de conquista católica de la fundación de Portugal (Fernandes, 2005). Ejemplos como las fortificaciones de Moura (Fig. 1), Elvas (Castelo de Elvas, 1997), Mértola (Castelo de Mértola, 2007), Serpa (Muralhas de Srpa, 2003), Beja y Silves (Fig. 2) fueron parcialmente restauradas en modo “neo medieval revisitado” únicamente porque contaban con castillos del periodo de la fundación en la cumbre de la correspondiente ciudad fortificada.

Otra característica de la conservación de las fortificaciones portuguesas fue, sin duda, el paralelismo entre la clasificación y la intervención. A medida que avanzaba la historia portuguesa, ingresaron progresivamente en la lista de clasificaciones murallas islámicas de tapia. De una primera fase de acción de consolidación con piedra se pasó rápidamente a la consolidación con hormigón y morteros de cemento en los años 70–80 y, posteriormente, con morteros de cal en los años 90 del siglo XX (Fig. 2).

Murallas como las de Silves (Castelo de Silves, 1991), Juromenha (Bruno, 2005b) y Alcácer do Sal (Chagas, 2005) son excelentes ejemplos de ese recorrido del uso primero del cemento, hormigón y finalmente cal en la reparación de lagunas. Las consecuencias de esas intervenciones con cemento y hormigón son notables en las fortificaciones de Juromenha y Alcácer do Sal, casos extremos de aceleración y destrucción irreversible de las tapias.

En los últimos años se ha invertido la tendencia de consolidar tapias con materiales irreversibles e incompatibles química y físicamente con la tierra.

Hubo una época, durante los años 80, en que se musealizaron algunos vestigios de tapias halladas. Uno de esos casos fue el de la muralla de tapia hallada tras la demolición del Teatro del *Ginásio,* en Lisboa y su posterior integración en el centro comercial que allí se construyó. Esta acción, única y poco afortunada, llevó años más tarde a otras integraciones mejor conseguidas, como ocurrió con la muralla de tapia próxima a la anterior hallada

Figura 1. Reparaciones de 1995 en la torre de tapia militar. Castillo de Moura. Imagen de 2003.

Figura 2. Intervenciones de los años 80 y 90 en las murallas de Silves, Portugal. Imagen de 2012.

en los *Terraços de Bragança*, de cuyo proyecto es autor de Siza Vieira (Fernandes, 2005). En ese caso se optó por integrar la muralla en los espacios exteriores, entre los bloques habitacionales, protegiendo los vestigios con morteros de cal y nuevas tapias en los jardines.

Con el desarrollo del conocimiento científico referente al comportamiento estructural de las tapias, así como de los materiales constituyentes, se han llevado a cabo experiencias de reconstrucción/protección con tierra proyectada (Fig. 3), así como inyecciones en las tapias antiguas (Luso et al., 2007). Paderne, un castillo construido durante el período *Almorávia—Almoáda* (Bruno, 2005a) y que prácticamente no había sufrido intervenciones de restauración, fue un verdadero laboratorio de prácticas donde se aplicaron todas esas técnicas, con resultados estéticos absolutamente innovadores en Portugal (Costa et al., 2007).

La experiencia con tierra proyectada demostró ser algo ineficaz debido a las retracciones visibles en muchos de los paramentos. A día de hoy (pasados seis años de la intervención) y en comparación con otras experiencias como las de Moura (Fernandes, 2005) y Elvas (Muralhas e obras, 2006), se puede constatar que las intervenciones con morteros de cal y tierra en lagunas dan mejor resultado que las proyecciones con tierra y aditivos.

Figura 3. Tierra proyectada para colmatación de lagunas en las murallas del castillo de Paderne, en Albufeira. 2005.

Figura 4. Tapias expuestas en el sitio arqueológico *Alcaçova*, en el interior del castillo de Silves. 2012.

2.2 *Alcáçovas y sitios arqueológicos*

Los sitios arqueológicos en las llamadas *Alcácovas* y arrabales de las ciudades con fuerte implantación *Moura*, fueron objeto de excavación intensiva en los años 80. La curiosidad científica por este período histórico, a la vez que los nuevos métodos de excavación que permitían identificar las técnicas de tierra sin destruirlas, han sido los motivos para operaciones de esa naturaleza en Mértola (Macías, 2005), Silves, Paderne y Salir (Catarino, 2005).

Como en los años 1990–2000 el financiamiento provenía casi exclusivamente del turismo y con el fin de permitir el uso público de los sitios, estos fueron objeto de intervenciones profundas. En casi todos ellos se construyeron estructuras con pasadizos y edificios de carácter permanente, cafés y centros de interpretación. Esta tendencia no consideró la necesidad de invertir en la protección de los restos arqueológicos, cuya situación es hoy desastrosa e irreversible debido a pérdidas del material original de casi el 50%, aparición de nuevas patologías como la presencia constante de vegetación, sales en los muros, vasta colonización biológica …

A pesar de todo, hubo algún aspecto positivo en todo esto. A partir de determinado momento, las excavaciones que no contaban con un programa de conservación posterior, pasaron a ser recubiertas con tierra después realizar el correspondiente levantamiento y registro completo y obligatorio de las mismas. Lo que era una práctica poco corriente en la arqueología portuguesa pasó a ser un método eficaz de uso general a partir de entonces.

3 ARQUITETURA VERNÁCULA

3.1 *Barrios históricos*

Las llamadas ciudades de tapia portuguesas se ubican mayoritariamente en las regiones de

Alentejo y Algarve, en el sur de Portugal. Según Claudio Torres, existen tres tipos de tapias: la militar, la rural y la tapia negra o urbana (Torres, 1993). Aunque no todos los barrios históricos de las ciudades medievales fortificadas portuguesas se caracterizan por tener tapia negra; Serpa, Évora, Elvas y Estremoz son ciudades que se caracterizan por contar con tapia urbana de buena calidad, muchas veces copia en dimensiones reducidas de las tapias militares (Fig. 6). Las casas de estas ciudades históricas de matriz medieval son mayoritariamente de dos tipos: ambas rectangulares en planta, pero con desarrollo en profundidad cuando cuentan con dos pisos y desarrollo longitudinal frente a la calle cuando cuentan con un único piso (Conde, 2010).

Figura 5. Vestigios de muros de tapia en el barrio de la *Mouraria* en Lisboa, con granulometría semejante a la muralla Fernandina de tapia. Imagen de 2010.

Figura 6. Casas de tapia, rehabilitadas y mantenidas en el centro histórico de Évora en el año 1982–1983, *Mouraria*. Imagen de 2006.

Caso distinto es el de Mértola y parcialmente Beja, donde por la falta de espacio e imposibilidad del sitio, la tierra utilizada para la construcción de las habitaciones provenía de las huertas urbanas, carga-da de sulfatos y materia orgánica, no apta para construir (Torres, 1993). Mértola siempre fue un centro histórico de difícil de rehabilitación por motivos intrínsecos al material de construcción existente. Por eso, la opción tomada en el municipio en las situaciones extremas, fue la de la reconstrucción de las casas con el mismo método, pero con sustitución de las tierras.

Los demás barrios y ciudades históricos de tapia cuentan con otros problemas de conservación, más relacionados con la gestión urbana. Los muros de tapia, demasiado anchos, ocupan mucho espacio en el exiguo espacio interior disponible en las habitaciones urbanas. Una práctica común era la demolición de los muros divisorios de tapia y la disminución del espesor de los muros exteriores portantes. Se dieron casos en que los propietarios llegaron a reducir espesor de las murallas de tapia que funcionaban como muros de la casa en los pisos inferiores. En Beja y Elvas se han dado situaciones alarmantes debido a intervenciones de ese tipo. En ambas ciudades, la tapia militar quedó suspendida en el aire: en Beja (Núcleo urbano de la ciudad de Beja, 2009) fue debido a la remoción de tapia en la parte inferior, mientras que en Elvas (Muralhas e obras, 2006) fue debido al desagüe del agua sin drenaje en la parte superior de la muralla.

Otra situación normal se daba con la apertura de rozas en los muros de tapia para el paso de las infraestructuras de electricidad, aguas y drenajes. Poco a poco, esta mala práctica ha desaparecido gracias en parte a las nuevas redes disponibles y a la formación en ese sentido llevada a cabo por los municipios.

En 1982–1983, el municipio de Évora llevó a cabo, en colaboración con la UNESCO, una operación modelo en el barrio de la *Mouraria* (CIDEHUS, 2006). Dicha operación tenía como objetivo primordial dotar al centro histórico de Évora (candidato a Patrimonio Mundial de la UNESCO), un barrio pobre, construido en tapia, de una mejor calidad de vida. Era ahí donde ocurrían las peores intervenciones posibles, además del rechazo total al plan por parte de la población de las viviendas de tapia, consideradas símbolos de la pobreza. Por sugerencia de los técnicos de la UNESCO, el municipio realizó tres intervenciones modelos que se calificaron como profunda, rehabilitación y mantenimiento respectivamente. Así, de una forma pedagógica, se enseñó a la población a utilizar las cubiertas como espacio sin destruirlas, a construir baños en el interior sin daños para la construcción y a mantener los muros con lechada de cal y las puertas y ventanas de madera con tintes tradicionales (Fig. 6).

La operación fue todo un éxito y durante muchos años, la población dejó de destruir edificaciones y pasó a solicitar ayuda municipal para adaptar las viviendas siguiendo esos modelos.

3.2 *Arquitectura rural*

La arquitectura rural de tapia es más generosa que la anterior en cuanto a espacio y se caracteriza por una buena construcción. La región sur de Portugal presenta, en general, un riesgo sísmico medio. Las intervenciones llevadas a cabo durante muchos años eran muy intrusivas desde el punto de vista estructural: los edificios, que en muchas ocasiones presentaban fendas y fisuras debidas al hecho de que se trataba de arquitecturas con una gran longitud horizontal y, por tanto, sufrían asentamiento diferencial en su cimentación, eran objeto de introducción de estructuras nuevas con pórticos de hormigón en el interior del los muros. Lo mismo ocurría con las cubiertas: raros eran los casos en los que las estructuras de madera no eran sustituidas por otras de materiales diversos.

Esta situación ha cambiado en los últimos años gracias a varios factores. Por un lado, los avances en la investigación en ingeniería civil permiten el empleo de otras soluciones estructurales, sacando partido del comportamiento a compresión de los muros de tapia. Por otro lado, el uso generalizado de la madera, gracias a la disponibilidad de nuevos tipos como los laminados de madera estructurales para cubiertas, que han sido fundamentales en ese cambio.

Inês Fonseca enumeró en la investigación que realizó sobre el municipio de Avis (Fonseca, 2007) una serie de acciones y soluciones arquitectónicas simples, no destructivas, basadas en las carencias de la población rural, que implementó en las construcciones de tapia. Estudios de ese tipo empiezan surgir en los municipios portugueses en forma de manuales de buenas prácticas. De una situación de vacío y destrucción sistemática por desconocimiento, se pasó a la aparición de buenos ejemplos de intervención, con una intrusión mínima en las estructuras existentes.

4 CONCLUSIONES

De todo lo anteriormente mencionado, destaca la difícil situación de conservación que se da en los sitios arqueológicos, hoy día con pocos medios para su mantenimiento y sujetos al vandalismo y destrucción causada por el turismo.

Por otra parte, cabe mencionar otro hecho arquitectónico reciente: la aparición de patologías en los casos de tapia contemporánea debidas a la exagerada exposición de los muros, demasiado estética y poco resistente. Estas tapias "modernas" emplean en pocas ocasiones los revoques, porque conceptualmente son para estar a la vista.

Esta conjugación de factores estéticos y la fragilidad desde el punto de vista de las condiciones ambientales existentes en Portugal, son responsables de nuevas degradaciones de difícil solución. Por ello, sería deseable el desarrollo de proyectos arquitectónicos en los que se conjugaran los aspectos estético y resistente. Se espera, además, que con la actual crisis, se extienda el uso de los materiales tradicionales y las buenas prácticas de mantenimiento. Los materiales tradicionales, además de ser más baratos, son compatibles física y químicamente con la tierra, lo que contribuye en gran medida a la buena salud futura de los edificios de tapia.

Finalmente y como última reflexión, añadir que los nuevos reglamentos de térmica y acústica de Portugal no reconocen a la arquitectura de tapia como material ventajoso desde el punto de vista térmico y acústico. ¿Estaremos ante un nuevo paradigma? Ahora que se han demostrado las ventajas de rehabilitar edificios, que se ha reconocido la tierra como material sostenible, que se han empezado a utilizar realmente las técnicas de tierra para la arquitectura contemporánea, ¿no se permite construir ni rehabilitar un edifico sin quebrantar esas leyes? Y únicamente porque un simples cálculo matemático no considera la densidad de la tierra como una variable para la obtención de valores acústicos y térmicos. Esta nueva legislación portuguesa es responsable de las dificultades y obstáculos a la rehabilitación de edificios de tapia.

NOTES

Esta comunicación forma parte del proyecto de investigación científica "La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas" (ref. BIA 2010-18921) financiado por el Ministerio Español de Ciencia e Innovación en el marco del Plan de Ayudas Nacional del año 2010.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Intervention in a rammed earth tower at the castle of Oropesa del Mar (Castellón, Spain)

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ABSTRACT: During the reconstruction work carried out in 2011 on the tower of the castle in Oropesa del Mar, Castellón, partially ruined in 2008, the collapsed masonry wall was found to contain two rammed earth structures built by the Moors in different periods. Despite their serious level of deterioration, we were able to determine many of the characteristics of these walls and the formwork support systems, once again demonstrating the mastery of the Moors in rammed earth techniques. This discovery called for a modification to the initial project proposal in order to expose the composition of the tower and highlight the lime strata constructions. A series of solutions were adapted, which are described in this presentation.

1 INTRODUCCIÓN

A principios de enero del año 2011se iniciaron los trabajos de consolidación de parte de las estructuras murarías del castillo de la localidad castellonense de Oropesa del Mar, contemplados en el proyecto "Consolidación de lienzos en el Castillo de Oropesa del Mar", redactado por el arquitecto J. Ignacio Gil-Mascarell. Las obras, financiadas íntegramente por el propio ayuntamiento de la localidad (el presupuesto de ejecución ascendió a la cantidad de 91,043.94 euros), finalizaron a finales del mes de julio de dicho año, participando, además del arquitecto Gil-Mascarell, el arqueólogo Sergi Selma Castell y el autor de este trabajo como director de la ejecución material, siendo Cyrespa Arquitectónico la empresa constructora.

El castillo se encuentra sobre una pequeña colina elevada una treintena de metros sobre el terreno circundante, en un enclave que controlaba el acceso norte a la plana litoral de Castellón, allí donde el paso se estrechaba, entre las montañas, terrenos pantanosos y el mar. Se accede desde la propia población, ascendiendo por una escalera que discurre adosada a un depósito de agua municipal, ubicado parcialmente en el propio recinto defensivo.

Es de origen incierto pues, sobre estructuras previas se levantó un castillo musulmán. Está documentado que en 1379 Fray Pere de Thous, bajo mandato del rey Pere IV el Ceremonioso, realiza obras de fortificación del castillo y de construcción de las murallas urbanas, y también las realizadas en la primera mitad del XVI por Joan de Cervelló.

A juzgar por la inscripción realizada en un dintel hallado en los años 70 entre los escombros del castillo, la reforma más importante se debió de producir en 1623. En dicha inscripción se dice que "*(…) se acaba de edificar esta fortalea any 1623 (…) per a seguritat de aquesta vila de Oropesa* …" Durante la guerra de la independencia es atacado y conquistado en octubre de 1811 por las tropas francesas al mando del general Suchet. El historiador Bernardo Mundina, en 1873, reseña que la población tenía un fuerte castillo que fue volado por los franceses. En los años ochenta del pasado siglo se acometieron diversas obras de consolidación, adecuándose posteriormente para visitas turísticas.

El castillo es de planta poligonal alargada en dirección este-oeste, conservándose la práctica totalidad de su trazado perimetral y parte de las estructuras que conformaban los distintos recintos y dependencias, destacando entre todos la potente torre del homenaje situada en la parte central del conjunto. Diversas dependencias como el cuerpo de guardia, las cocinas o las caballerizas, aunque arrasadas, se identifican claramente con la ayuda de unos planos datados hacia 1730 que se conservan en el Archivo Cartográfico del Ejército. El aljibe, formado por dos espacios abovedados, se ubica en el nivel superior del recinto.

Las estructuras visibles son en su mayor parte de mampostería. No obstante, tapiales de mampuestos con hormigón de cal y de tierra calicostrada se observan en la base de los muros perimetrales del castillo, los primeros, y dispersos en distintas zonas de la edificación, los segundos. Pero lo que aparentemente es sobre todo una edificación de mampostería, fue, durante buena parte de la vida

Figura 1. Vista oeste de la torre norte antes de la intervención.

de esta fortaleza, de tapia, de tierra sobre todo. Así está documentado en los planos antiguos citados en los que puede leerse que algunos de los muros de mampostería son el revestimiento de antiguos tapiales. También pudimos corroborarlo durante las excavaciones donde constatamos que el muro de mampostería de la torre norte, levantado probablemente en el primer tercio de siglo XVII, envolvía el núcleo de una anterior torre de tapia de tierra, circunstancia de la que, por otra parte, ya teníamos conocimiento por los trabajos que realizó en los años 80 el arquitecto J.I. Gil-Mascarell.

En el proyecto se contemplaba como intervención principal la reconstrucción de la torre norte, parcialmente derruida en el año 2008 (Fig. 1).

2 DESCRIPCIÓN DE LA TORRE NORTE Y DE LOS MUROS DE TIERRA QUE LA CONFORMAN

2.1 *Descripción general de la torre*

Adosada al muro norte del recinto, es de planta próxima al rectángulo, con 8.86 metros en su frente paralelo al muro norte, 4.04 m. en el lado este y 5.26 m. en el oeste, dimensiones que corresponden a las de los paramentos exteriores del muro de mampostería. Este muro, de ancho variable, pues oscila entre 1.25 y 1.55 metros, alcanzaba una altura, antes del derrumbe, de entre 6.50 y 4.00 m.

Durante los trabajos de desescombro y excavación observamos que el muro de mampostería envolvía no solamente un muro de tapia calicostrada, sino dos muros de tapia. Un primero de unos 90 cm de grosor, que era el que constituía la torre original, mientras que el segundo, de unos 108 cm, se realizó como refuerzo en un momento posterior.

La torre original era una construcción hueca con una longitud de 1.91 metros entre los dos muros de la torre perpendiculares al lienzo norte, 3.31 metros en el paramento interior del muro oeste y 2.81 metros en el lado opuesto, consecuencia esto de producirse una discontinuidad en el trazado del lienzo norte en su encuentro con la torre (Fig. 2).

Asimismo observamos que el lienzo que acomete contra la torre por su flanco oeste está compuesto de dos hojas (Fig. 3). Una interior de tapia de 60 cm de espesor de tres hiladas de 90 cm de altura cada una de ellas, realizada con tierra de color oscuro y trabada en origen con la torre. Y una segunda también de tierra de una tonalidad rojiza de unos 88 cm de espesor. Es esta la que en una época indeterminada se reviste con mampostería.

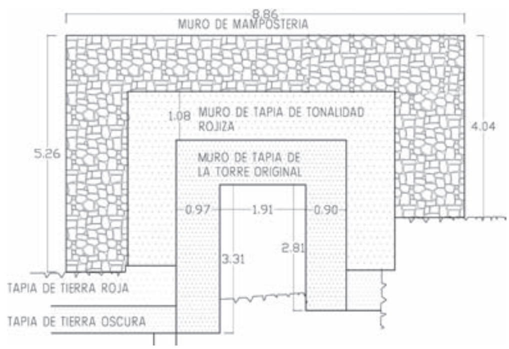

Figura 2. Planta de la torre norte.

Figura 3. Las dos hojas en el entronque con la torre de tapia.

2.2 *Muro de la torre original*

Se sacaron a la luz un total de cinco hiladas, todas en mal estado e incompletas, particularmente las tres últimas (Fig. 4). Pese a su grado de deterioro, aún se han podido determinar algunas de sus características, que nos aportan valiosa información sobre los procedimientos constructivos empleados y que, además, nos serán de gran utilidad para acometer los trabajos. Así pues, sobre los muros de la torre original, podemos decir lo siguiente:

- Se construyeron con tapiales modulares y agujas pasantes de sección rectangular.
- En el interior de los muros se colocaron rollizos de madera, a modo de zunchado y traba entre la tapiadas contiguas.
- El paramento interior no se realizó calicostrado, no apreciándose revestimiento alguno.
- Los mechinales de las agujas se taparon con ripios y argamasa.
- El paramento exterior se decoró con incisiones en el calicostrado a modo de espiga.
- La tierra es de tonalidad oscura, similar a la de la hoja interior del lienzo que envuelve el recinto que vemos en la Figura 3.

Otras informaciones, particularmente las relativas a dimensiones, ofrecen resultados imprecisos y por lo tanto poco concluyentes. Citaremos, no obstante a titulo de información, que la máxima longitud de tapiada observada es de 1,93 m, y que la altura de las tapiadas oscila entre 75 y 90 cm, siendo la primera dimensión la que más se repite.

2.3 *Muro de tapia de refuerzo de la torre original*

El desmontaje parcial del muro de mampostería nos permitió visualizar una porción del paramento del muro de refuerzo de la torre de tapia original. Pese a ser pequeña la superficie la descubierta, del orden de 1 m^2, aún pudimos obtener algunos datos. Mostramos los que consideramos de mayor interés:

Figura 4. Interior de la torre. Se aprecia el elevado grado de deterioro de las tres últimas hiladas.

- Este paramento estaba constituido por un calicostrado de gran calidad y, a diferencia del de la torre, no presentaba decoración alguna.
- Su ancho es de 108 cm, idéntico en sus tres lados.
- La tierra que se empleó era de color rojizo.
- Pudimos apreciar la altura de una hilada que resulto de 92 cm, y las huellas de las cuatro tablas que formaban el encofrado, tres de ellas de 22 cm y de 26 la restante.
- Fue construido mediante un encofrado corrido a una sola cara. Se observaban en el paramento, sobre una misma línea horizontal, varias parejas de orificios de sección circular, a distancias entre ellas de entre 48 y 57 cm. La separación entre los orificios oscilaba entre 5 y 10 cm.

Sin duda lo más destacable son los orificios mencionados, pues nos ofrecen la posibilidad de indagar sobre el sistema de sujeción del encofrado empleado para construir este muro (se encuentran señales similares en los castillos castellonenses de Azuebar, en el Castell Vell de Castellón y Onda, entre otros, tanto en muros encofrados a una como a dos caras), que, por levantarse contra otro ya realizado, debía de ser necesariamente a una sola cara. Después de una atenta observación pensamos que podría ser del siguiente modo: Los tapiales se sujetarían en su parte inferior, con la ayuda de los costeros, a unos tirantes amarrados a unas estacas situadas en el encuentro de los dos muros. La diferencia de sección entre los orificios, que varía entre 1.5 y 2 cm, y los restos de serrín hallados nos lleva a pensar que los tirantes eran de madera, ramas de avellano, probablemente, por la facilidad que ofrece esta madera en convertirse, mediante golpes, en un material fibroso y susceptible de transformarse en sogas. Unos costeros se encajarían y se sujetarían con cuñas en estas ramas anudadas en su parte inferior, atirantándose con sogas superiormente.

Otro dato de interés por lo que respecta al orden de construcción de estas estructuras es que este muro no se trababa con el de tonalidad rojiza del cierre del recinto, si no que entestaba contra él en toda su altura. Este se construyó también con encofrado a una sola cara pero con un sistema de medias agujas de sección rectangular del orden de 2 × 7 cm y en hiladas de unos 88 cm de altura (este sistema de agujas ha sido profusamente empleado en el periodo andalusí en la ejecución de muros de gran ancho o encofrados a una sola cara. Font, F. 2011). Un nuevo sistema, el tercero que encontramos, para resolver el ajuste y colocación de los tapiales.

3 INTERVENCIÓN EN LA TORRE NORTE

En el proyecto se contemplaba la reconstrucción del muro de mampostería derruido y la consolidación de la torre de tapia con la elevación de una nueva hilada, dejando un espacio entre las dos fábricas a modo de pasillo, que permitiera visualizar una parte de los paramentos originales de la torre. A la vista del hallazgo del segundo muro de tapia se juzgó conveniente modificar los planes iniciales para mostrar las tres estructuras que componen el elemento, compatibilizando esto, en la medida de lo posible, con el mantenimiento de su volumen inicial, el existente antes del derrumbe.

Para favorecer la lectura del conjunto se levantaron los tres muros a distintos niveles, de forma escalonada los dos exteriores, quedando el de mampostería en la cota más baja. Se completaron las tres hiladas superiores de la torre elevando una nueva sobre estas, hasta enrasar con el nivel superior del muro de tapia del lienzo de lado oeste, con el que se trabó (Figura 5). Así pues la fábrica de tapia y la de mampostería, desde distintos niveles crecen escalonadamente desde el lado oeste de la torre hasta el lado este, donde alcanzan sus cotas máximas.

Este planteamiento, pese a considerarlo desde el punto de vista morfológico el más adecuado, presentaba dos inconvenientes. Primeramente que buena parte de la poca superficie calicostrada descubierta quedaría oculta, y en segundo lugar que la práctica totalidad de la tapia visible, y sería bastante, seria obra nueva, con la dificultad de integración por los acabados lisos y tensos de las tapias calicostradas. Sobre el primer problema no había más solución que documentar y dejar una parte como ventana arqueológica, respecto del segundo, consideramos que reproducir las tapias con el aspecto que tendrían en origen no era en este caso conveniente, por lo que decidimos adoptar algunas soluciones que seguidamente comentaremos.

Figura 5. Levantando la última hilada de la torre original de tapia con los dos restantes muros a distintos niveles.

4 MATERIALES, TAPIALES, PROCESO CONSTRUCTIVO SEGUIDO Y SOLUCIONES ADOPTADAS

La construcción de la tapias de tierra se realizó empleando los materiales, medios y procedimientos propios de esta antigua técnica constructiva.

4.1 *Materiales empleados, tapiales y el proceso seguido*

La tierra empleada fue la procedente de las excavaciones. A diferencia de otras ocasiones en las que este equipo ha realizado trabajos similares (En los trabajos realizados en el Castell Vell de Castellón, además de la caracterizaron de tierras, se estableció una metodología para el control del grado de compactación alcanzado.), no se realizaron ensayos de caracterización del material. Por la mínima intervención prevista no se contempló en el proyecto y, aunque finalmente el volumen apisonado fue del orden de 45 m^3, consideramos, por el aspecto de las tierras que íbamos retirando y basándonos en la experiencia adquirida, que podíamos determinar su idoneidad con escaso margen de error.

El hormigón para las costras y las uniones entre las tapiadas se confeccionó con cal, cemento blanco, árido natural de 20 mm de tamaño máximo y tierra, en una proporción en volumen de estos componentes de 2:0, 5:5:1, con una consistencia entre seca y plástica. Se empleó cemento para la estabilización de la tierra, en una proporción en volumen de una parte de conglomerante por ocho de tierra.

Por motivos económicos se emplearon para encofrados paneles de contrachapado fenólico de pino, como los que se muestran en la Figura 5. Se sujetaron en su parte inferior mediante agujas pasantes de madera que alojábamos, cuando era posible, en los mechinales existentes, con un sistema de costales y agujas superiores similar al empleado tradicionalmente en la comarca de Els Ports de Castellón (Font, F & Hidalgo, P. 2009). Cabe decir que la experiencia con este tipo de tableros no resultó satisfactoria pues se deformaban, por lo que tuvimos que incrementar el número de sujeciones y prescindir del apisonado mecánico en buena parte del trabajo. Por facilidad de ejecución se realizó el encofrado de la torre corrido, elevando el conjunto completo sobre la hilada ya finalizada.

La tierra humedecida, amontonaba y cubierta con plásticos, se iba vertiendo en los moldes al ritmo demandado por los tapiadores. El apisonado se realizó inicialmente con una bandeja vibrante. La anchura total de los dos muros permitió este recurso. Al alcanzar la cota prevista del muro exterior, ya se continuó compactando manualmente. Se emplearon de pisones puntales metálicos a los que se les atornilló en la base una madera de 15 × 15 cm con las esquinas achaflanadas.

4.2 *Soluciones adoptadas*

Con la intención de lograr unos acabados que manifestaran la técnica y las soluciones originalmente empleadas en el levantamiento de los muros, al tiempo que paliar en lo posible el llamativo efecto de obra nueva favoreciendo su integración con el resto de fábricas, se adoptaron las soluciones que a continuación se describen:

- Retirados los encofrados se procedió a cepillar las superficies calicostradas con un cepillo de plástico hasta la aparición en el paramento del árido grueso.
- Se dejaron intencionadamente a la vista, en el propio paramento, los mampuestos de apoyo de las losas de piedra que cubrían las agujas. Estas losas, que tenían por misión facilitar la posterior retirada de las agujas para su reutilización, también se dejaron a la vista (Fig. 6).
- Los mechinales de las agujas, habitualmente tapados al finalizar los trabajos, los dejamos sin cegar.
- En el muro de tierra rojiza se alojaron pequeñas maderas de sección circular para manifestar el tipo de sujeción de los encofrados.
- En la coronación de la última hilada dejamos alojadas maderas en las posiciones necesarias para un posible recrecido futuro. De momento sirven para romper la continuidad de la coronación y controlar posibles fisuras por dilataciones térmicas (Fig. 7).
- En el escalonamiento de los muros, las secciones transversales se terminaron sin calicostrado. Se alternaron las tongadas de tierra con lechos de hormigón, mostrando así la constitución del muro y la característica solución de lengüetas del calicostrado penetrando en la masa de tierra (Fig. 8).
- Pese al empleo de un encofrado corrido, hemos logrado que en los paramentos se visualicen juntas verticales, como si de una estructura hecha con tapial modular se tratara, colocando tablas allá donde interesaba manifestar la discontinuidad de la fábrica.
- El interior de la torre se dejo, como estaba en origen, sin revestimiento alguno. Con toda seguridad el acabado excesivamente liso de los paramentos pronto cambiará de aspecto, envejeciendo, esperemos, saludablemente.

Figura 6. Paramento calicostrado cepillado con los mampuestos vistos y las marcas verticales de las tapiadas.

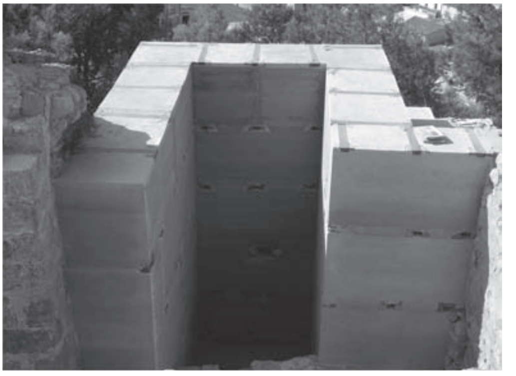

Figura 7. Obsérvense las maderas en el remate en la torre terminada. Compárese esta imagen con la de la figura 4.

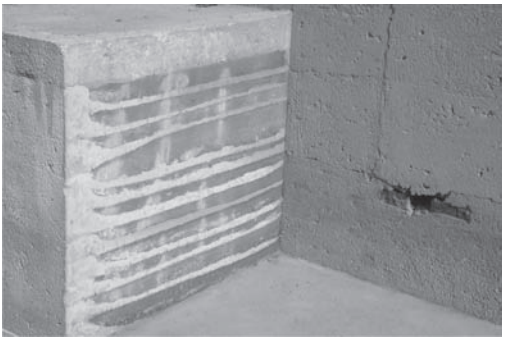

Figura 8. Sección con tierra estabilizada y lechos de hormigón.

5 CONCLUSIONES

Hemos podido constatar nuevamente lo observado en numerosos recintos defensivos ocupados por los musulmanes: Bajo lo que aparentemente son obras hechas de mampostería, encontramos con frecuencia estructuras de tapia. Ya sea de hormigón de cal con mampuestos, que en muchos casos se confunden con fábricas de mampostería, de tapia valenciana o, como en este castillo, de tierra calicostrada.

Encontrar vestigios de tapiales en una simple inspección ocular no suele ser labor complicada, lo que, consecuentemente, nos lleva a deducir la existencia pasada o presente de muros levantados con esta técnica. Sin embargo, es mediante las excavaciones arqueológicas como conocemos de su pervivencia, sorprendiéndonos en muchos casos observar que las previsiones iniciales son ampliamente superadas por la relevancia de las estructuras exhumadas. Que la tãbiya árabe es el elemento característico de las tradiciones constructivas andalusíes es bien conocido, pero no deja de sorprendernos el absoluto dominio de la técnica que atesoraban aquellas gentes. Basta con observar cómo en un espacio tan reducido como el descrito, encontramos hasta tres sistemas diferentes de tapiales.

Las estructuras de tapia encontradas durante las excavaciones van más allá de lo descubierto en la torre, extendiéndose muy probablemente a la totalidad del castillo. Se dispone por lo tanto ahora de valiosa información para acometer otras actuaciones y afrontar en mejores condiciones las dificultades que entraña la actividad restauradora de muros de tapia de tierra. Ya sea bajo el planteamiento de una intervención mínima, a fin de mantener la materialidad original de la tapia, o acometiendo restituciones volumétricas, estas intervenciones son siempre difíciles.

En el primer caso, si es la propia tierra por la pérdida de las costras la que ha de soportar directamente la acción del agua, difícilmente podremos asegurar plenamente su preservación mediante impregnaciones consolidantes o soluciones similares, solamente la protección de la intemperie, si es que es posible, o la calidad de la propia fábrica, pueden permitirnos conservar la fábrica original asumiendo, eso sí, determinados niveles de deterioro. Lamentablemente, al igual que ocurre en tantos aspectos relacionados con la construcción con tierra, las consolidaciones del material es todavía un campo a explorar en profundidad (Castilla, F.J. 2011 *Informes de la Construcción, nº 523: 143–152*.). La restitución de volúmenes, como en el caso que nos ocupa (Fig. 9), conlleva

Figura 9. Vista oeste de la torre norte al finalizar los trabajos. Compárese esta imagen con la de la figura 1.

inevitablemente la ejecución de paramentos lisos, tersos y con aspecto de recién construidos que, normalmente, atraen en exceso la atención.

Está previsto iniciar en breve una nueva intervención en el castillo de Oropesa del Mar, veremos si el tiempo transcurrido, aunque breve ciertamente, puede aportarnos alguna pista sobre los aciertos o erro-res de nuestro actuar. En cualquier caso, de estos últimos, siempre estamos dispuestos a aprender.

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Restoration of Llotja del Cànem (Castellón, Spain) walls—"Witnesses of History"

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ABSTRACT: The Llotja del Cànem (ancient Hemp Market), located between the streets of Colon and Caballeros in Castellón, Spain, is a building of reference in the image of the city and the local memory. The analysis and study of the walls and its materials clearly shows the process and the different interventions performed on the building over time. The walls are important witnesses of the accumulative change made to adapt the building to each phase of its history, according to techniques in each period. This intervention intends to be coherent and to adapt the building to present needs. It assures a construction solution that is adequate as technically possible, and it defines clearly the moment in history of its execution. This retains the evidence of the time that has gone by, and preserves traces that have been left, to be able to emphasize the most characteristic moments of this building.

1 THE LLOTJA IN THE CITY OF CASTELLÓN

The *Llotja* occupies and creates a particular spot in the city, where the traces and volumes of *Santa María*, the height of *El Fadrí*, the squares of the Town hall and the market, the *Casa de la Villa* itself, the old square of *Yerba*, the trail of the streets of *Colon* and *Caballeros*, convert the building in its position in one of the milestones of the town center. Precisely this character of open space of the *LLotja*, its traces and dimensions, is what connects the building to the public space, a civil building well implanted in the traces of the city, with the huge tradition of Mediterranean markets, those spaces for trade and commerce characteristic of the ancient Kingdom of Aragon.

Figure 1. Location map: (1) *Llotja*, (2) Cathedral, (3) *Fadrí,* (4) *Town hall*.

In 1606, the juries of Castellón ask for a space for commerce to be built, following local tradition, but in this case in a corner defined by two streets, and in an Italian way, designed in the classical manner of that time. The relationship between inside and outside in this kind of architecture, the open space of arches, the open corner to two streets of such importance, are very important conditions in the intervention on the building. Thus, the project enhances the elongation of the interior space towards the exterior, unifying materials and textures of floors, opening physically and visually the whole space, in a way that only the shade and the projection of the architecture separate inside and outside.

2 ORIGIN AND HISTORICAL EVOLUTION OF THE BUILDING

In the present-day building of the *Llotja,* several phases can be distinguished that allow an understanding of the accumulative process over time of the building. The intervention consisted of analyzing and taking into account, in an active way, the process of consolidation of the existing architecture and which have been the most important phases in its development. This effort, along with a qualified team of different professionals, has identified three constructive periods in the building itself, plus, the building prior to the construction of the *Llotja*.

2.1 *The building before the Llotja: Previous state (15th–16th centuries)*

According to Vicente Traver, the late 15th Century plans showed that there was a house belonging to the Gumbau family, which was almost totally demolished for the construction of the *Llotja del Cànem* (Traver Tomás, 1958). Of the medieval building, the walls that defined the inner corner were kept, lasting up to present time. These walls were built with the local construction technique known as "*tapia"*, consisting of rammed earth with a thin coat of lime concrete (2–4 cm). The clay inside is placed in layers of about 4 cm, and it does not present an optimum plasticity and consistency. This kind of construction is found in the mid-14th Century. In one of the walls, thanks to the archaeological follow-up of archaeologist Víctor Algarra, the dimensions of the layers of rammed earth were observed. Their height was 1.05 m (One *vara* and one half of a *pie valenciano*, traditional measurements), a length of 2.94 m (3 *varas* and one *palmo valenciano*) The forms were built using fiveplanks, three with 22.6 cm (one *palmo*), and two with 17 cm (9 *dedos valencianos*). The rammed earth was reinforced with brick in the extremes.

2.2 *Construction of the original structure of the Llotja of Commerce of the City of Castellón: 17th century (1606–1617)*

The building, with its public scale, presents the most aggressive classicist project in the city. The street-side façades are connected with double arches, a central column of a very evident entasis and a short shaft, and two pilasters in the extremes. The corner is beautifully composed with two semicircular pilasters in the inner part of the arch, and a straight pilaster reaching the whole height of the building.

The municipal coat of arms in stone, on one of the elevations is the only element over the arches. The decoration, archivolts, capitals, arch keys, basing, etc. are done in a severe classical composition, of lovely proportions, with an elegant impost line before the cornice. The project and supervision, according to the references of the "Guía d´Arquitectura de Castelló" (Castelló Diputación, 1996), was completed by Francesc Galiança, and the stone work was done by Roberto Sala, together with officials in carpentry, iron and floors. Miguel Borda produced the wooden formwork, Pere Rey, Tomás Moliner and Antoni Rogera finished the building in 1617. Being a reference in the history of Castellón, there are references in several publications, such as Vicente Traver in his book "*Antigüedades de Castellón de la Plana*" (Traver Tomás, 1958) and those of Sánchez Adell, J. Rodríguez Culebras, R and Olucha Montins, F. in their "*Castellón de la Plana y su Provincia*" (Sánchez Adell, J. et al., 1990).

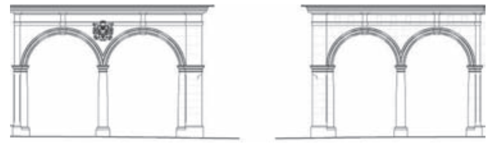


Figure 2. Llotja Elevations 17th Century.

Figures 3 and 4. Corner arcade of the *Llotja*. Detail of column and wall texture.

The internal display of the inner spaces was configured according to the second project description, which was the one finally built: *"ab arcades a modo de llonja y quesfasen entornbanchs"*.

2.3 *End of the 18th-beginning of the 19th centuries*

This period represents the first important architectural transformation of the building. It is enlarged by two more floors over the *Llotja*, with the purpose of placing a bourgeois house. At the same time, two small houses were attached to its sides, in the medieval traces of the city. The architectural mass balance, particularly of the *Llotja*, the annex buildings and their shape, create a system of great quality that provides a new scale for the city. The transformation of the cornice in the balcony, and the correspondence between the arches and the openings in the walls provides a special strength to the compound building. The coloring of the façade is one of the most characteristic elements of this period. It is a new order that opposes the classical system of a base, and offers a late baroque reading of the building.

Old photographs and drawings give account of this 19th Century configuration, the restoration works have allowed a better view of the paintings on the walls by Joaquín Oliet, and approach his strokes, perfectly connected to the geometry of the architectural elements. The double pilasters were placed on both sides of the window openings, and were also placed symmetrically from the corner. Between them, the paintings represented the Allegory of

Figure 5. Image of the *Llotja* around 1900.

Figure 6. 20th Century Façades after recent restoration.

the four seasons. The windows had flat jambs and flared arches, not including the semicircular pediments that can be seen now, built in the beginning of the 20th Century, during a later intervention.

2.4 *Beginning of the 20th century (around 1910)*

In the beginning of the 20th Century, the configuration of the building consists of a bourgeois house on the upper level and a store on the lower level, occupying the *Llotja*. The sale of the *Llotja* in 1906 resulted in an intervention that can be considered late eclecticism, of an academic design that defines both interior and exterior. In the façade, it incorporates a historicist decoration over the windows, with pilasters and frontispieces, it creates a balustrade over the ledge, with terracotta amphora design over it, and it includes the attached buildings, to create a new stylistic set, with the main building as an element of reference.

The openings now include semicircular tympanums, similar to those in the main theatre of Castellón, projected by Godofredo Ros in that emblematic building. This reorganization of the openings implied a modification of the paintings, influenced by the neoclassicism of the time. It was developed by the local artist Vicente Castells, who creates the new design preserving only the figures of the allegory, breaking the rest and producing a new image. This eclectic intervention with the fascias over the 18th Century openings is very important in the character of the building and its future restoration. The new width of the openings was implanted over the pilasters designed by Oliet, so the proposal of Castells is unable to keep the designs, proposing therefore a change in concept; the ancient design of pilasters evolves into a geometrical design in the way of a ceiling over which he redesigned Oliet's themes. This proposal is probably less interesting, but given its nature it is impossible to recover the previous paintings.

The ironwork of the rail of the staircase and the balcony are reinterpreted in the modernist fashion, with some discreet organic motives. In the pavement, very small tiles of a kind of locally produced stoneware "*Gres de Nolla*", defining mosaics very regular at the time, also combined with a colored cement tile of a slightly larger dimension "*BaldosaHidráulica*".

Given these conditions, a methodical archaeological intervention was completed, multifaceted in the analysis of the set of wall structures, and the subsoil, providing results for a strategy of recovery of the subsoil, walls, and finishing.

3 WALL STRUCTURE OF THE BUILDING

Today, the Llotja is composed of several buildings of different periods, thus its wall structures are heterogeneous and it is necessary to identify, classify, and study every one of them before the intervention. The evaluation of the group provides knowledge of the buildings over time. Essentially they can be classified as:

3.1 *The ancient house in Caballeros street*

The building has a quite rectangular geometry with access from Caballeros street. The construction was around the 16th Century, and as the Llotja, it uses the intermediate medieval wall for its structure, being slightly higher than the Llotja. The walls are made of rammed earth with a lime mortar coating, and brick reinforcement.

Later, during the 17th and 18th Centuries it was enlarged, having the second floor built.

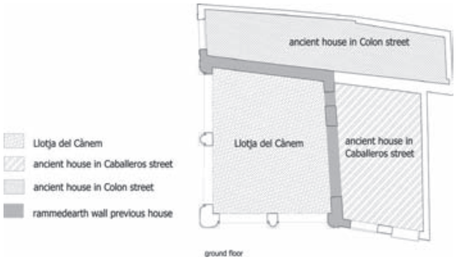


Figure 7. Buildings that define the *Llotja* group.

Figure 8. Stratigraphy of the wall of the building on Caballeros Street. Extract from the archaeological report.

Figure 9. Inner side western wall of the *Llotja* (photo collage).

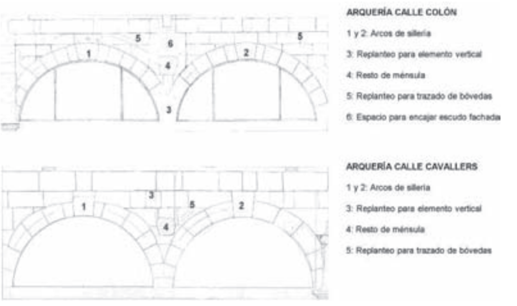


Figure 10. Interior elevation of the arches (extracted from the archaeological report).

3.2 *The ancient house in Colon street*

It is a very deep and long building with a main access from Colon Street. The original walls of this house are of rammed earth without brick reinforcement. In some areas of these walls, there are up to 6 different interventions.

The building has its origin between the late 14th and the early 15th Centuries, probably around the same period in which the building prior to the Lonja was constructed. During the 17th and 18th Centuries, it had an important reconstruction and extension, reorganizing the inner space and tearing down the inner wall of the first floor, plus adding a second floor. The emergence of a historical graffiti on the first floor of the western wall *"Francisco Antolí en octubre lañ 1766 e a 17"*, probably shows the year of intervention and the property.

3.3 *The Llotja*

The building has a trapezoidal geometry of around 75 sqm, and its southern and eastern façades are built with limestone, using rectangular ashlars of 67×37 cm, and square ashlars of 39×39 cm, and 27×27 cm. Each façade has two half round arches with molded archivolts, emerging from columns and pilasters of Tuscan order.

The limestone, from Borriol, was cut with a toothed ax, but without polishing. It was probably left rough intentionally, to resemble to the huge ashlars of the mountain range of Madrid. The intention might had been to give this effect, of being similar to the image of the architecture of the Kingdom of the Hapsburgs of the time.

There were side remains on the walls of the cross vault that existed for the roof of the original building, but there were no remains of the intermediate support that necessarily existed. Therefore, it is impossible to recover the vaults.

3.4 *The construction over the Llotja*

This is without any doubt the most important intervention and the one that has brought the *Llotja* to present times. It was started in the 1790s and finished around 1978. In 1792, the merchant Joan Matheu bought from the town hall the right to build another floor over the *Llotja*. That same year he also bought the house of Caballeros from Josep Antolí, so probably the hypothesis suggested by the archaeologist that both houses belonged to the Antonelli family is well founded.

This intervention, placing a new level over the *Llotja* meant the destruction of the previous roof and vaults, probably due to a poor state of conservation and the addition of the two other houses to the buildings therefore producing variations in heights of floors, wall reinforcements, etc. The intervention was very intense, but the fact of not substituting the original walls of the ancient houses implied stability problems for the whole building.

The late medieval walls of the attached houses were reinforced, specially the one in Colon, over which five discharging brick arches were placed, even replacing parts of the wall with brick. The two upper levels were done with a bonding pattern of face-end-end-face.

The joints were of limestone mortar. The wall was coated with a first a layer of reddish sand mortar, and a second layer of an earthy color made of sand and plaster. It was finally plastered and painted in a light brown color.

The big openings in the façade providing access to the corner balcony were made as flared brick arches with a front part rising to give a more rounded image. The upper level, used as an attic, was enlightened by oval openings.

In the intervention in the beginning of the 20th Century, the openings were changed and the pediments added. At this point, two important actions took place, as described in section 2. *Origin and Historical Evolution* and section 2.4 *Beginning of the 20th Century*.

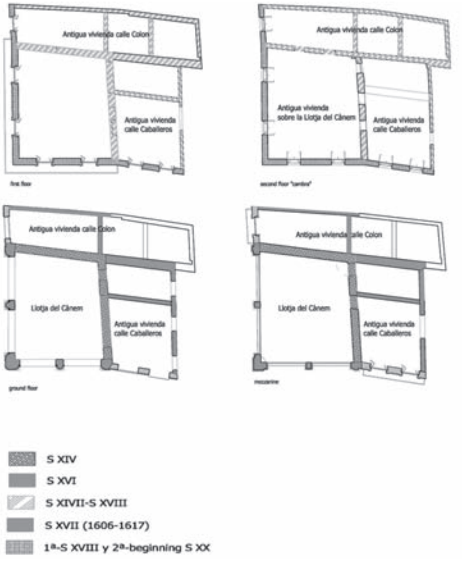


Figure 11. Wall scheme of different periods and floors.

4 STRUCTURAL CONSOLIDATION AND ADJUSTMENT TO PRESENT NEEDS

The result of the analysis and investigation showed the heterogeneous nature of the different structures. On one hand, it is interesting to highlight the good state of conservation of the stone façades due to their high quality. They are well cut and placed, and built correctly. On the other hand, the brick and rammed earth walls, of a medium-low quality, were very heterogeneous due to the interventions in different periods (reinforcements, morphological and functional changes) resulting in presence of cracks, fissures and even unattached fragments. Also the direct support of the iron joists on the wall implied a concentration of tensions, causing fissures in the supports, and oxidation stains.

Other remarkable circumstances were the scarce (sometimes inexistent) foundations of the building, and also the huge cavities found in the sub-soil (2 big septic tanks and an air-raid shelter from the Civil War in Spain during the 30s), which converted the sub-soil into a huge *Gruyère* cheese. The new status of the loads resulting from the new uses and the pathologies detected made the following interventions necessary.

4.1 *Foundations*

All existing cavities in the sub-soil were filled with a poor quality concrete, the existing foundations were underpinned and the surfaces enlarged, intending not to increase, but to reduce, tensions on the ground. Those enlargements were connected with each other in order to guarantee the transmission of tensions to the new foundation in every possible way.

4.2 *Central walls*

In the central walls of the interior corner of the *Llotja*, the broken parts were refilled, cracks were sealed and tied, and each wall was confined by adding a coating of low-speed projected concrete, attached to the wall with a width of 6–10 cm on both sides, with connection bars between them.

4.3 *Divisor walls*

In the property division walls, given the slenderness and the weak structural capacity of the existing walls, a complete concrete wall was built, as a cladding connected with the original wall.

4.4 *Openings*

In the external openings of the building placed above the *Llotja*, openings and lintels were reinforced

Figures 12 and 13. Condition of property division walls. Access to the air-raid shelter.

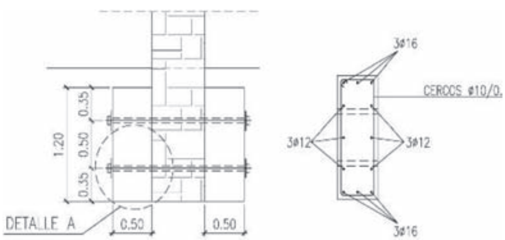
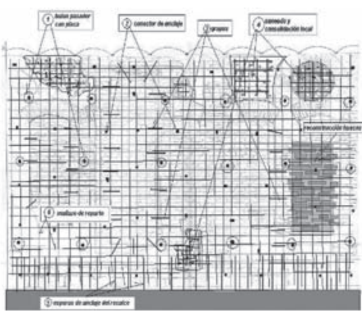
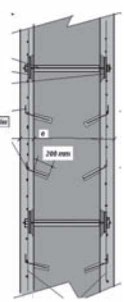


Figure 14. Enlargement of wall foundations.





Figures 15 and 16. Details of wall confinement and reinforcement.

from the inside, with lateral concrete jambs and steel lintels.

4.5 *Stone façades*

In the stone façade, the increase in the eccentricity load sadding up on the corner column from the arches, made it necessary to propose a strengthening system. For that reason, the arches were cable-stayed with a steel bar.

5 CONCLUSION

The intervention, concluded in February 2007, is no more than one more step throughout the existence of the building of the *Llotja del Cànem*.

It was attempted, not only to adapt the building to its new needs, but also to allow a clear evaluation of the documented interventions. The recovery of the most representative elements—those that were possible to recover—guaranteed a solution, as correct as technically possible, and clearly defined the moment in history of its execution. Preserving traces that have been left in the building to emphasize the most characteristic moments over its 400 years of existence has transformed the building together with the city of Castellón.

NOTES

1. The restoration project of the *Llotja del Cánem* was requested by the *Universidad Jaime I de Castellón* and executed by the Office of Architecture and Landscape *VAM10 arquitectura y paisaje*. Responsible professors are: D.J. Ignacio Fuster, D. Miguel del Rey and D. Antonio Gallud.
2. The archaeological study and the on-site supervision was done by the archaeologist Victor Algarra.
3. The structural analysis of the building was done by the engineer *CC y PD*. Javier Yuste.
4. The building company was *LUBASA*.

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Restoration criteria of the Valencian rammed earth walls

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ABSTRACT: The technical, historically known like *tapia valenciana or Valencian rammed earth walls*, seems to be that in the last times it has become in fashion among the studious and every day it is detected, or at least it is attempted to identify as such its use in the building of numerous and many era monuments of very different and distant places. Sometimes the conclusion it arrives in a diagnostic and therefore in its restoration it is not completely right because it is not disposed of the minimum necessary knowledges about the factory that it is intended to restore. The purpose of this communication it is to try to clarify as the composition of the factory, known like *tapia valenciana*, as the causes of its possible pathologies. The accumulated professional experience accumulated in different restorations and the consult of the agreements of works in the Notarial Archives allow to bring some light to the object.

1 DEFINICIÓN

El procedimiento o técnica constructiva, hoy ya conocido como *tapia valenciana*, es, como su propio nombre indica, una técnica de construcción de muros, cuyo principal componente material es la tierra (de ahí su denominación de *tapia*), mediante el sistema de *tapial*, es decir, encofrando a las dos caras. Su singularidad consiste en que, tal vez siguiendo la técnica del *emplecton* romano, muy generalizado para construcciones de cantería, se consigue mejorar los cierres superficiales, más proclives a su degradación en las tapias, ahorrando la forma tradicional de conseguir esta mejora necesaria en una segunda fase mediante el correspondiente enfoscado, realizándolo todo de una sola vez. Es decir, se trata de un muro con doble piel, piel resistente y acabada que permite dejarla vista, pero sin dejar de ser una fábrica realizada con tierra. Podríamos decir que es, por tanto, una técnica tan perfecta como el *emplecton*, sin cantería, y tan económica como la *tapia*, sin sus debilidades superficiales. La *tapia valenciana* en principio no pretende aumentar la resistencia del muro, aunque lo consigue, sino mejorar su durabilidad, dilatando las intervenciones para su mantenimiento.

El principal motivo por el cual se decide, en general, realizar una fábrica de *tapia* es precisamente su economía: la tierra que se utiliza para su ejecución es la propia tierra que se ha extraído de los cimientos o del propio solar, y los ladrillos que se utilizan en la *tapia valenciana* son piezas reutilizadas, en la mayoría de los casos, procedentes de demoliciones:

"*... Adovar y cavar la tierra que huviere menester de la que está dentro del ámbito*" (de la obra) (Boronat 1904).

"*… y para estas tapias se a de tomar la tierra del corral...*" (Borrás).

La resistencia del muro dependerá más de la calidad del relleno -la tapia -que de la apariencia o conservación de la piel. Los ladrillos que aparecen en sus superficies no son más que la piel que contiene la tierra. No obstante ambos componentes constituyen la sección resistente de la fábrica. Frecuentemente se hace referencia a la calidad que debe tener la tierra y los distintos componentes y proporciones que debe reunir para considerarla adecuada para dicha función. Incluso se ha llegado a confeccionar una especie de normativa referida a tales condicionantes. Cualquier condición que se le imponga a esta fábrica, cuyo resultado sea el encarecimiento del producto, estará en contra del principio básico de su adopción. Creo que con esta simple pero precisa definición ya podremos abordar y decidir cuál debe ser el procedimiento a seguir para su restauración, según las patologías y degradaciones que pudiera presentar el objeto en cuestión.

2 ELEMENTOS AUXILIARES

Tanto los elementos auxiliares como las distintas operaciones necesarias para construir un *muro de tapia*, en general, reciben nombres específicos, que es conveniente conocer.

Previo a la descripción e identificación de cada uno de los elementos auxiliares necesarios para la construcción de la *tapia*, así como a la definición y cuantificación de sus partes diferenciadas, considero imprescindible hacer un inciso respecto a las unidades y módulos utilizados para definir sus magnitudes. Puede llevar a confusión la definición de estas magnitudes según las equivalencias hoy vigentes en el sistema métrico decimal. Los documentos siempre nos aportarán el dato en la unidad utilizada en cada momento y en cada región.

El principal y prácticamente único elemento auxiliar necesario para poder ejecutar un muro de tapia por el procedimiento del *tapial* es el propio *tapial o encofrado*. Los útiles y accesorios necesarios para realizar dicha operación son: las *revilleras o agujas*, los *costeros*, las *cadenas o cuerdas*, las *puertas*, cuyas dimensiones oscilaban entre 2 y 2.50 varas de longitud y 1 vara de altura, equivalentes aproximadamente a 1.80 × 0.77 m; en Aragón y en Valencia tenían unas dimensiones de 3 por 1 varas valencianas, equivalentes a 2.718 por 0.906 m. *Tapón* se denomina al tablero que, situado entre las puertas, cierra el lado libre del paralelepípedo, fijando su longitud útil. No detallo ni defino ni los procesos para su colocación en obra ni las características de cada uno de los distintos útiles, porque los considero generalmente conocidos o de fácil consulta en su caso.

3 PARTES DIFERENCIADAS DEL MURO

Durante el proceso de ejecución del muro, podemos diferenciar varias partes, cuya identificación nos permite describir de forma ordenada las distintas operaciones.

3.1 *Tapialada, tapialzada o simplemente tapia*

Se denomina a aquella porción de muro que se construye con cada puesta del encofrado. Su dimensión estaba establecida en cada zona según sus módulos métricos: "*Dar cada una tapia de ocho quartas de largo e quatro de alto*" (Luján 1987). En algunas zonas se le daba *tres quartas de alto* (Rubio 1980). En valenciano se le denominaba *presa* (plural, *preses*): "*y lo primer fil de la tapia tinga tretze preses*..." (Galarza 1989).

3.2 *Hilo*

Es la altura útil de *tapialada*. En los contratos de obra del siglo XVI encontramos que escuetamente se dice: "*... se haya de tornar a tapiar el mismo hilo que se ha de derribar*..." (Boronat 1904). También esta altura útil era variable, según las zonas, aunque en general era equivalente, como se ha dicho, a una *vara*. En algunos contratos se habla indistintamente de *tapias o varas* (Luján 1987). En Valencia se especificaba en ocasiones esta dimensión; si no se puntualizaba, equivalía a una *vara* de cuatro *palmos*: "*... se hayan de hazer cinco paradas de alto dexando de lumbre en todos los aposentos veynte palmos de altura*..." (Boronat 1904). En el caso contrario, se definía expresamente: "*... y dichos hylos de tapia han de tener tres palmos y medio de altaria*..." (Galarza 1989). "*... y cada hylo a de tener catorçe palmos de largo, çinco de alto y dos ladrillos de grueso de garrote*..." (Borrás). Vemos que en este caso las dimensiones varían respecto a las definidas para Valencia. *Parada* se denomina al conjunto de tapialadas de un mismo hilo: "*... se ha de alçar de tapia de gruixa de tres pams todo lo güeco de la capella pujant dita tapieria fins una parada damunt lo arch*..." (Galarza 1990).

4 EL MURO Y SUS PARTES

En todo muro debemos diferenciar tres partes importantes: el *zócalo o puntido*, el *muro* propiamente dicho con su fábrica y la *coronación* formada por una *albardilla*, *cerro*, *rafe*, *cornisa*, *alero*, *tejaroz o chanfrante*, que todas estas denominaciones se utilizan según los lugares (Fig. 1).

El mayor enemigo de la *tapia*, como fábrica cuyo principal componente es la tierra, es el agua.

Figura 1. Monasterio San Miguel de los Reyes, Valencia. Partes diferenciadas de una tapia.

Los puntos patológicos de toda *tapia*, y cuya durabilidad debemos prevenir, vienen definidos por el *zócalo o puntido*, con el fin de evitar las humedades por capilaridad; por los *acabados superficiales*, para evitar la degradación por los agentes climáticos -lluvia y viento-; y por el *sellado* o protección de su *remate superior*, mediante la correspondiente *albardilla*. Si conseguimos un perfecto sellado de estos puntos mediante los tratamientos adecuados, podremos garantizar la calidad del producto. La restauración de la *tapia*, sea o no *valenciana*, deberá contemplar la actuación integral sobre estos tres elementos.

4.1 *Zócalo o puntido*

En todos los sistemas de construcción de muros siempre se ha destacado la importancia del *zócalo* por la función que ejerce sobre la propia estructura. Por una parte, sirve como elemento transmisor de las cargas del muro sobre el cimiento: debe ser por tanto un elemento rígido. En nuestro caso, su principal función consiste en evitar que la *tapia* esté en contacto directo con el terreno natural, para prevenir su degradación por humedades de capilaridad: deberá ser un elemento estanco. De acuerdo con estas solicitaciones demandadas, deberán escogerse los materiales adecuados. Y así nos lo demuestran los contratos:

"*... Que sobre los tres dichos palmos de cal y piedra, se comienze la tapieria...*" (Rubio 1980).

"*... que hechado que sea el illo de la argamasa en la manera arriba dicha, se hayan de subir las tres paredes de tapia balenciana...*" (Borrás).

"*... que sobre los tres dichos palmos de cal y piedra, se comienze la tapieria...*" (Rubio 1980).

En ocasiones, se realizaba un murete de ladrillo, o incluso de tapia de costra o calicostra, sobre el cual se apoyaba la tapia:

"*Todas las paredes de la yglesia, altar mayor, coro, sacristía, capillas y de toda la casa del dicho monasterio, han de tener ensima de los simientos tres palmos de alto de paredado de ladrillo... Y de allí en adelante se han de continuar de tapia*" (Galarza 1989).

"... Y las primeras tapias sobre el cimiento sean de costra picada..." (Galarza 1990).

El procedimiento que más ha llegado hasta noso-tros, sobre todo en edificios de una cierta entidad monumental, es aquel en el que el zócalo se hace de sillares de cantería, y luego sigue la tapia (Fig. 2).

La degradación del zócalo es la principal causa de las humedades de capilaridad. Por tanto, no de-bemos dejar como terminada una restauración que no haya abordado la intervención, de uno u otro modo, sobre el zócalo para evitar estas humedades.

Figura 2. Colegio Corpus Christi de Valencia. Potente zócalo de sillería.

4.2 *Albardilla o Rafe*

Entendemos por *albardilla* el caballete o tejadillo que se pone en la coronación o remate de los muros para que el agua de lluvia no los penetre; también los salientes que se colocan en los muros con el único fin de cortar las escorrentías por los paramentos. Según las distintas zonas y épocas, este detalle constructivo también se conoce como cerro.

Se trata de un detalle constructivo, históricamente muy valorado pero frecuentemente olvidado, y me atrevería a decir incluso *despreciado*, en las actuales restauraciones, con las consiguientes patologías inducidas que puede provocar. Idénticas nefastas patologías puede provocar una albardilla mal construida.

La albardilla asume una doble función. Por una parte, y tal vez la más evidente, actúa como elemento que sirve para *alejar* lo máximo posible del muro el vertido de las aguas de la cubierta. Pero por otro lado, debe *sellar* la superficie de remate del muro, en evitación de que dichas aguas lleguen a degradarlo. Ya Vitruvio incidía en la importancia de este detalle: "*En el remate de las paredes y por debajo del alero, se hará una albardilla a base de ladrillo cocido, con una altura aproximada de pie y medio, que sobresalga a modo de cornisa*" (Vitruvio 1787).

Los propios contratos de obra nos confirmarán la vigencia en el tiempo de estos criterios. Cuando el muro correspondía a una simple valla de cerramiento, se dice:

"*... Ensima de dicha paret se han de hazer dos salidas de ladrillo la una, a la una parte de la paret y la otra, a la otra y ensima de las dichas salidas se ha de hazer un cavallón de mortero y medias...*" (Galarza 1989).

"*Concluida la tapia se le pone para resguardo un coronamiento de ladrillo o de piedra llana, unida con cal o yeso en forma de albardilla, con lo cual se consigue mucha más duración, y que el agua no se infiltre por la pared... también se cierran estas tapias con ramaje, paja o retama...*" (Perier 1853).

Esta *albardilla*, según zonas, recibía el nombre de *rafe, cornisa, alero, tejaroz o chanfrante* (Bails 1983).

"*En muros de ladrillo crudo, construye una cornisa de ladrillo cocido, para que, si escurre el agua de lo alto del tejado o de los aleros, no cause ningún daño, sino que proteja la cubierta*" (Alberti 1975).

"*Este tejado ha de salir tan a fuera por sobre las paredes del Tenplo, que haya un rafe muy cumplido, por la hermosura del edificio y defensa de las paredes y ventanas de él...*" (Aliaga 1995).

Es este uno de los puntos que mayores patologías provocan en las obras, debido a que, en general, su ejecución en las cubiertas se realiza en dos unidades totalmente independientes: por una parte, la *albardilla*, cuya función se confía exclusivamente a las propias tejas; por otra parte, el *rafe* con su estructura independiente. Por eso, deberá exigir una atención especial la solución de este detalle (Fig. 3).

Pero esta protección de la superficie superior no sólo se ejecutaba cuando se trataba del remate de la tapia para proceder a la colocación de la cubierta; se puede comprobar que, según el volumen del muro y, por tanto, del tiempo que podía transcurrir entre la construcción de un hilo y el superior, se realizaba también al finalizar cada hilo de tapialadas, evidentemente sin la entidad que se le supone a una albardilla. Esta formación provisional de la albardilla no sólo adoptaba la función de proteger el muro, sino que además servía como una especie de verdugada que repartía las cargas que le debía transmitir la tapialada superior (Fig. 4).

La colocación de la cubierta o, en su caso, la construcción del correspondiente abovedamiento, exigía que previamente la fábrica estuviera totalmente fraguada. Por ello, se exigía que la obra se parase por un período no inferior a tres meses. En tal caso, resultaba imprescindible proteger la coronación del muro durante este período de parada:

"*Que quant estiga anivellada la obra fins dites capitellades y arrancaments de archs ha de parar la obra lo temps que els elets volran per a que exuge per a poder carregar los archs*" (APPV 1681).

"*... advertint que en aço no se ha de atenir lo mestre a la traça per raho que en aquella se mostra la cuberta de carrerons, y hara se ha de cubrir de fusta, parant la obra per espay de tres mesos, y a tot temps se ha de visurar per a determinar si es pot carregar y cubrir dita obra, que se unix nova ab vella, ha menester que fasa asiento*" (APPV 1683).

Entre las patologías que puede provocar la degradación de la *albardilla*, si nos referimos en concreto a la tapia valenciana, está el abombamiento aparente del muro. La solución de esta patología dependerá de la superficie afectada por dicho abombamiento, que en general suele ser puntual, y sólo afecta a la hoja exterior que se despega del conjunto, por lo que es relativamente sencillo reponerla.

Figura 3. Capilla del Rosario. Iglesia del Pilar, Valencia. Coronación del muro de fachada con rafe independiente, sin albardilla de sellado.

Figura 4. Sección de la antigua muralla cristiana de Valencia. Tapia valenciana. Albardillas de protección de los distintos hilos.

5 LA TAPIA VALENCIANA

La formación de la piel característica de la *tapia valenciana* viene definida, generalmente, por la colocación en su superficie de unas cintas de fábrica de *ladrillo amorterado*, del mismo espesor que las tongadas de tierra que se van a apisonar, colocadas previamente junto a los tapiales; esta fábrica se verá afectada por las mismas vibraciones producidas por los golpes del mazo consolidador, lo que producirá unos efectos visuales en la superficie que le conferirán al muro su aspecto singular: el elemento sólido -ladrillo -se retranqueará dando lugar a que el mortero fluya por el exterior; el resultado aparente será el de una fábrica de ladrillo con el llagueado—irregular—saliente (Fig. 5).

La composición de la tapia valenciana no sólo consiste en la introducción de este elemento superficial. La propia mezcla de la masa formada por la tierra tiene sus propias características que le confieren una calidad específica. Ello le conferirá que, como se ha dicho, el propio muro de tapia pueda soportar ciertas solicitaciones resistentes, independientemente de los recubrimientos superficiales.

Los artífices tenían estandarizado no solo el método para hacer este tipo de tapia, sino incluso cuántas capas de ladrillo debían de ponerse en cada tapialada, siendo el cumplimiento o no de esta condición un método aceptado para considerar la calidad de la correspondiente tapia:

Figura 5. Monasterio de la Trinidad, Valencia.

«... *que les tapies estan bones y ben fetes y ab les filades que son menester y sacostuma de posar en qualsevol tapia molt bona*...» (Galarza 1990)

Otra singularidad a tener en cuenta es aquella en la cual, una vez desmontados los tapiales, se procedía a limpiar el ladrillo de las escorrentías producidas durante el proceso de ejecución:

«... *llebando en cada ilo tres iladas de ladrillo sentados con cal, y uno sin otro de burceria, con la obligación de raspar o descubrir los ladrillos por el exterior*...» (Borrás).

6 CRITERIOS DE INTERVENCIÓN

Las degradaciones que pueden aparecer en la *tapia* pueden ser o *superficiales o profundas*, es decir, *que sólo afecten a la piel o recubrimiento*, sin haber llegado de forma alarmante al interior, o bien *que hayan afectado al conjunto*, llegando a la ruina del propio muro. En el primer caso, yo diría que el más generalizado cuando hablamos de restauración, podemos y debemos proceder a su consolidación, mantenimiento y recuperación; en el segundo, será necesario cuantificar los distintos parámetros económicos, culturales e incluso prácticos (conocimiento de la técnica, no inventarla), antes de decidir su *reconstrucción* o su total *eliminación*, sustituyendo el muro por otra técnica más adecuada, según los casos.

En general, la intención que nos induce a proceder a la restauración de un muro de *tapia valenciana* puede venir condicionada por diversos criterios:

- frenar una incipiente o posible degradación.
- el deseo y posibilidad de recuperar esta técnica constructiva.
- intentar aprovechar su lenguaje estético como escusa decorativa de un paramento.
- la necesidad de actuar ante una evidente degradación parcial de un conjunto.
- y finalmente, movidos por un afán de inventar aquello que ya está descubierto pero que se ignoran, intentando reconstruir algo ya desaparecido.

En el primer supuesto, como vemos, la intervención es respetuosa, puesto que no falsea la esencia de la técnica constructiva.

El aprovechamiento de la posible *carga estética* (tercer supuesto), nos puede llevar a intervenciones totalmente kafkianas, y más si no se sabe actuar correctamente (Fig. 6).

La *reconstrucción* (quinto supuesto) es para mí una actuación totalmente fuera de lugar, puesto que falsea la propia esencia de una técnica constructiva, utilizando materiales impropios de la época que se quiere reflejar y despreciando los criterios básicos

Figura 6. Sede Gremio de Carpinteros de Valencia. Deficiente restauración de la tapia. Humedades de capilaridad por falta de puntido, desconchones en el enlucido y anárquica distribución de las hiladas.

Figura 7. Capilla del Rosario. Iglesia del Pilar, Valencia. Restauración mediante la consolidación de las distintas fábricas.

condicionantes de esta técnica (economía, facilidad de adquisición del material básico, reutilización de otros materiales, uso de los conglomerantes en cada caso disponibles, etc.). Las razones que nos decidan a recurrir a esta solución deben ser muy poderosas y ampliamente meditadas. Tal vez la única razón justificable estribe en el deseo de mantener una adecuada *lectura* del hipotético estado original; pero esta misma razón se vería ampliamente satisfecha con la utilización de otra técnica constructiva, sin necesidad de *falsear* la pretendida técnica, pretendiendo presentarla como *original*.

Con el fin de plasmar en un ejemplo concreto cuanto hasta aquí se ha expuesto, bueno será comentar la restauración realizada en la fachada de la denominada Capilla del Rosario, construcción aneja al templo parroquial del Pilar, de Valencia.

Se trata de una construcción datada en la primera mitad del siglo XVII (1634–1637), como germen de un posterior convento promovido por los Dominicos. La evolución constructiva, como solía ocurrir en la mayoría de los monasterios, se dilatará en el tiempo, provocando sucesivas reformas y ampliaciones.

La obra ha sufrido los avatares políticos de las distintas épocas, entre los cuales no es el menor haber sido objeto de profanación y expolio durante la Guerra de la Independencia en 1808; luego la expropiación durante la Desamortización en 1835 y convertida en cuartel; posteriormente olvidada y abandonada por más de medio siglo; y, por si algo le podía faltar, compartir durante otro medio siglo el anual incendio (*la cremà*) de una monumental *falla* a escasos metros de su fachada. Todos estos *accidentes* habían dejado huella indeleble en sus paramentos y estructura. En la restauración se ha pretendido confirmar en parte aquella evolución constructiva del conjunto, manteniendo las sucesivas técnicas.

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Consolidation and restoration of the Castle of Biar, Spain

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ABSTRACT: The project exposed in this paper proposes the intervention over the towers and sections of wall of the upper enclosure, given the generalized state of ruin they present, and the danger it supposes for the visitors of the monument. During the process of intervention it has been possible to know, identify and analyze the nature of the walls, and restore the original elements that configured the Islamic closure of the 12th Century, the different levels of wall enlargement until the maximum height level reached in the 15th and 16th Centuries. This enabled the enhancement of all of these elements and historical phases throughout a logical didactical project, within the discipline of contemporary architectural restoration.

1 INTRODUCTION

The intervention of consolidation and restoration of the Castle of Biar intends to stabilize the walls using traditional materials and techniques for rammed earth walls (known as "*tapia*") and masonry built in formwork, and to enhance the architecture and the constructive process that this walled enclosure has had throughout time, also simplifying the appreciation of the monument in different scales; from the inside, intending a historical reading of the different construction phases of the castle itself, between the 11th and 16th centuries, and from the outside, preserving the ultimate volume, allowing the historical profile of the castle to be seen from the distance.

It has been possible to know, identify and analyze the nature of the walls, and restore the original elements that configured the Islamic closure of the 12th Century, the different levels of wall enlargement until the maximum height level reached in the 15th and 16th Centuries, plus to acknowledge the original floor plan, without corner towers in its origin, and the successive incorporation of them in enlargements and transformations during the Christian period. This enabled the enhancement of all of these elements and historical phases throughout a logical didactical project, within the discipline of contemporary architectural restoration.

Figure 1. Northern view of the Castle of Biar.

The consolidation of the Castle of Biar was a request from the Ministry of Culture executed by PAISAR Investigation Group *(Paisaje y Arquitectura Rural)* included in the *Instituto de Restauración de la Universidad Politécnica de Valencia*. The responsibles of the project were the professors: D. Miguel del Rey, D. Antonio Gallud, D. Carlos Campos and D. Ignacio Fuster.

2 THE CASTLE AND ITS LANDSCAPE

The urban center of Biar is positioned in the slope of a hill governed by its castle. The landscape of olive trees embraces us and over it, the silhouette of the castle cut away on the sky stands out. This image is part of the local memory of the inhabitants of the area, and has become a milestone. As we come closer, the elements which define the landscape appear before us, agricultural terraces, paths, the dwellings, the tree mass, and outstandingly, the castle walls and the homage tower.

From the North we see the naked rock from a huge vertical cut on the hill, melting itself with the castle wall and its tower. From the other orientations, bathed by sunlight, the castle appears with its walls in a dominant position, halfway a pine forest divides the houses that climb the slope with a vibration of rooftops only interrupted by this green trace of the city wall of Biar.

3 DESCRIPTION OF THE CASTLE

The castle has a double wall enclosure adapting itself to the uneven ground, with semicircular towers limiting pieces of canvas, and topped by the homage tower, in the way of a main tower placed at the higher spot of the set and becoming part of the defense perimeter. The canvases of the first closure are built with masonry and over it, a defense walkway with merlons and loopholes. The walls of the inner closure, the ones dealt with in this project, are of a very diverse nature, with fragments of rammed earth with slides of masonry, with very different sections and finishings including walkways of different widths, remains of merlons and fragments of parapets.

The entrance of the castle is at the closest spot to the town, its door being a half round arch made of stone in the outside, and an inner basket arch, flanked by two towers. The canvas defining the door includes two fronts of the castle, given that the other sides are placed over the rock cliff described. Between this pre-wall and the inner wall appears one of the cisterns of the fortification.

The inner enclosure includes three towers, one of them next to the access to the parade ground. The extreme towers are semi-circular, but the central tower by the access to this enclosure is almost cylindrical. In its latest period it had no merlons but it did have certain remains of a parapet. The access to the upper enclosure is again a stone half round arch that allows the approach to a rectangular room covered by a vault. The access is twisted, turning right.

The main tower has three floors, with a half round arch in the outside, flattened in the inside. Its base is made of masonry, over which the rammed earth is built, with blocks of four hand spans in length, an average width of 135 cm, and a total height of 19 m.

This tower has several interesting elements, such as vaulted rooms on every level, and its topping with machicolations.

The castle presents a very different state of conservation in each of its parts. The main (homage) tower has been previously restored, being a representative element of the set. The outer enclosure is in a better state than the inner one; however, its walls are also much damaged although it was restored in the 70's.

On the contrary, the walls of the upper enclosure are in an advanced state of ruin, with some of its sections having even disappeared. The section on the western end is the only one preserving the height of the last walkway, corresponding to the last period in which the castle was still in use.

4 DATA COLLECTION AND AREA OF INTERVENTION

The castle plan surveying was done with the aid of a 3-dimensional scan, allowing the plans and sections of the castle to be drawn with the necessary precision as to support the intervention process. The photographic data was collected by Pablo Navarro and José Herráez, from the group of architectural photogrammetry of the *Instituto de Restauración de la Universidad Politécnica de Valencia.*

The scope of the intervention involves the upper wall enclosure in its southern, western and northwestern positions, including the canvas in which the old access door is situated, and arriving at the main tower itself.

This second core has lost a big part of the wall mass, risking becoming a dangerous spot given the continuous partial demolitions due to the poor quality of the mortar and the disappearance of the original materials. Humidity and the disaggregation of walls caused by the rainwater flow collected from the same walls in the parade ground are the responsible of this ruin, added to massive burials done in the castle walls during the time in which it was a village cemetery.

Figure 2. Original view inner side of the wall.

Figure 3. Original view of the outer face of the wall.

The falling down of big parts of its mass has complicated the visual recognition of the castle in the distance because it has lost part of its references.

The architectural intervention, aside of the purely constructive effect, has the goal of providing a historical recognition, simplifying the appreciation of the monument in different scales; from the outside, allowing the historical profile of the castle to be seen from the distance, and from the inside, intending a historical reading of the building throughout its constructive methods and finishings along time. The intervention is based on a different use of materials and techniques according to the moment of construction.

5 AIMS OF THE INTERVENTION

5.1 *Protection of architectural remains*

The first goal of the project is the conservation and consolidation of the architectural remains, both those corresponding to the external wall and to the small patches remaining of the internal wall. Given the state of damage of the majority of the walls, it was initially suggested to clean and consolidate them. Each fragment was studied individually in order to define the adequate strategy of approach in each case.

5.2 *Reconfiguration of the space of the inner enclosure*

The consolidation of the architectural remains allows the space of the parade ground to recover its condition, making it possible to understand the idea of a closed space in this part of the castle, as opposed to the open and uneven space in which it had turned to in recent times.

It is also necessary to underline the importance that the presence and definition of the walkway acquires, contributing to the understanding of each of the elements of the intervention area.

5.3 *Visual recovery of the upper wall as a key element of the silhouette of the castle*

The unquestionable visual and landscape interest of the Castle of Biar is one of the most relevant issues of the intervention, as it defines and strengthens its profile. The situation of the castle at the highest point provides it with a visual singularity that makes it a priority. The restoration of the walls, the definition of its towers, the protective enlargement reaching the walkway level, all help to enhance the image that exists in the historical memory of the area.

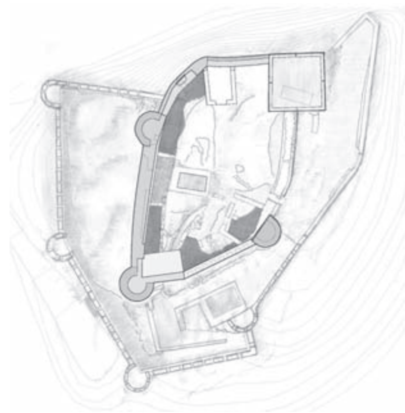

Figure 4. Plan of the Castle of Biar.

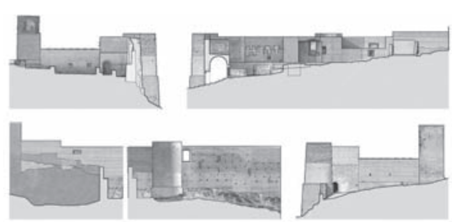

Figure 5. Inner and outer elevations of the walls.

5.4 *Improvement of the means for understanding the architectural structure and the history of the monument*

Given the richness of the information obtained by the tests done, and the actual presence of remains of merlons, walkways, parapets, and different building techniques used in different periods, there is precious information to reconstruct in a detailed way the internal side of the wall, summarizing in it all the constructive history of the castle, keeping instead a cleaner and simpler image in the outer side of the wall, the one observed from the distance, which defines the consistent profile of the castle.

Therefore the remains of the internal closure appear and acquire physical presence, from its first Islamic period throughout the subsequent enlargements, improvements and reconstructions that it had up to the 16th Century.

6 DESCRIPTION OF THE INTERVENTIONS OF EACH PART OF THE WALL

6.1 *The Southern wall*

This wall includes one of the most heterogeneous constructions found in the inner defense line, it probably suffered intensely, given that it contained the access and before it, little space for attack, due to the scraped rock around it. It includes the semi round arch of worn limestone, probably original of the Islamic period, surrounded by masonry built with formwork. Over it, a more modern canvas with a very different masonry, both in shape and size of stones.

Towards the southeast the canvas is composed by a masonry base that evens the wall over the rock, and over this, a poor quality rammed earth wall with traces of irregular stone and without the proper covering. It is a thin wall with partial demolitions, partly due to its poor quality, and partly because of its slenderness. It has no walkway like that of the western wall, but there is a small path which probably was completed with a light wooden structure in its origin. There are traces of an intermediate level connecting this wall with the western one, which is the level reached for the reconstruction of this side, given its slenderness provides no guarantees in for a further enlargement, unless some of the crossing walls that existed were reconstructed too, to supply more stability to the compound wall.

Every one of the walls has been restored according to its particular nature and combining traditional techniques with high quality products in specific interventions, such as consolidating the bases of the walls, filling and sealing cracks in mortars, anchorage of different slides of wall, toning and waterproofing of the walls, etc.

The constructive techniques and the size of the formworks have been maintained in every spot, solving the rammed earth blocks with wood strips of a handspan width ("*palmo valenciano*", traditional local measurement equivalent to 22.6 cm), preserving

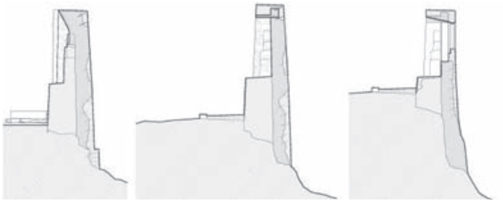

Figure 6. Western wall sections.

Figure 7. Inner side of Western Wall.

mortars, finishings and texture where these existed, preparing the bases of the walls when these had to be refilled, introducing a base of silicate, slightly diluted to improve absorbance. For the treatment of small cracks, there were injections of a grout of mixed lacked and hydraulic lime, with acrylic resin dissolved in water. The proportion of the mixture of lime was varied depending on the width of the cracks. For the treatment of fissures and the consolidation of old *graffiti*, bases of silicate and marble dust were used to provide the necessary strength but keeping the fluidity to allow proper penetration.

In eroded zones, the plane has been replaced with formwork containing lime mortar coloured with the sand itself, of a very similar colour to the original. The chromatic definition was further toned with silicate diluters. Dissolved in water using the silicate specific colourings, a base is developed, in order to apply it 2 or 3 times until the mortar is toned and even. If the base was darker than the surface tone, silicate paste was dissolved and used to get the proper tone.

Finally, walls have been waterproofed, specially the higher ones and the wall decorations. Waterproofing of the upper elements was done by applying 3 phases of sprayed water-repellent until it saturated. The materials used were produced by the industry working at the site, it consisted of a water-repellent made of siloxane, diluted in a non-smelly dissolver.

Concerning the *graffiti* found, the most interesting corresponds to two boats, corresponding to one of the few canvas that were not covered with cement during the 70's restoration, specifically the wall left when entering the upper enclosure. Accompanying the boats, there are also traces of a flag, a weapon and a star. Its reference is:

BOAT
Incision situated in the upper enclosure
IV, Late medieval period (12th–14th Centuries)
Dimension of set: 1.8 × 0.8 m (aprox.).
All of it restored and stabilized.

6.2 *The South-Southeast tower*

The cylindrical tower we can see today was possibly built over an old corner in a right angle existing in the Islamic closure. It was enlarged with successive sheets, even covering partially the access. Its finishings are diverse, in some cases direct masonry, in others covered by a lime mortar. The traces of ancient attached walls have been kept.

6.3 *The Western wall*

This canvas is particularly significant, due to the burials done inside it, and to the demolition of

Figure 8. View of the outer face of the wall.

parts of it, caused by the lack of consistency of the original mortars. It shows a wide range of kind and periods of interventions, we can observe the first line of defense of the castle, in its original Islamic height, and the following enlargements built over the years, in height and width.

We find in the Western Wall three very different situations. The first, built with a formwork masonry finished with limestone mortar, the second the walkway and merlons over it, that can be seen in the west-northwest part, at only around 1.5 m from the ground.

Over the line of this walkway, there is a second phase that supports its merlons over the older ones, rising about 1 m over the previous level. Its nature is similar, although finished with lime mortar. This line exists in other canvases of the wall, and there are remains of it in walls, and towers. Fragments of both walls have been cleaned and left visible in the inside of the Western Wall.

The last increasement in height and width of the wall was during the Christian period, when there were several very different interventions done; rammed earth for an external coating up to the higher walkway level, in the inside of the wall a masonry coating hiding the older tissues, many different walls of the interior buildings which were developed in the interior of the parade ground, one of them with a palace window, probably of the warden's house open to the west, which preserves the ledge and jambs plus the upper arch, which have been restored, although it probably had a mullion that has disappeared throughout time.

In this canvas the total height has been recovered, without elevating the parapet of which there was no remains or information for its restoration. The towers have been left slightly higher than the walkway, as the remains suggested. The section of the wall had originally a slight slope in its external side, whereas in the inside, there have been openings left to appreciate the different moments of construction of the wall already mentioned. This has forced to recover the full width of the most recent interventions even in the highest spots, showing the walkway of that time, to allow a variable section that sometimes presents an inclined plane in diminution towards the medium height of the wall.

The constructive techniques have been respected in every spot, solving the exterior coating with a formwork of wooden strips with a hand span in width, preserving wide areas of original wall with its texture and finishing, preparing the bases of the wall with a base of silicates as in the southern wall. In the same way, cracks and fissures have been restored as previously explained.

Finally the walls have been toned and waterproofed as described before.

6.4 *The Western tower*

This tower has an even section in all its height, is of a semicircular shape from the outside and plane in the inside, to access the walkway of the walls which are attached to it. In the inside there are remains of the original closing that runs behind the tower, thus showing that there was no such tower in origin.

6.5 *The Northern and Northwestern wall*

This wall has a curved trace with a slight inflection point when it changes from North to Northwest. It was in a state of complete ruin in the part attached to the northwestern tower up to the spot where the remains of a chapel were found. From that spot, the wall presented a more constant section, at least in height, where it was possible to appreciate the position of the walkway and the protections it had, being in this case a parapet. The walls were of rammed earth, similar to those in the eastern part of the southern wall.

The wall in the first part described, has been increased up to the Islamic walkway level in the inside, how it was built originally, with formwork masonry, after that level it rises with a lime mortar. In the outside, the wall has been increased to its full height, restoring with formwork the rammed earth with lime mortar. In the lower part of the wall we find a big loophole, probably from the Christian period, which defended the external canvas of the first walled enclosure.

In this spot and in the outer side, remains have been found of what could have been a corner tower built over an outgoing in the rock. The traces of it on the walls have been preserved.

The rest of the wall, up to the homage tower, has been restored with rammed earth, as the remains found. The walkway was rebuilt in order to complete its full width, and so was the existing parapet. The traces of the walls of what was once the chapel or the cemetery have been left on the inside of the defense wall.

7 CONCLUSIONS

After a period of almost two years of an intense relationship with the castle, we were particularly interested in the evolution of the inner closure and the techniques used during each period.

At first, we searched and analyzed the canvases of the walls, looking for hits or traces that helped us to understand the construction, it process, its materials… The imprints found gave us frequently information of constructive elements overlapped and built urgently probably between moments of attack to the castle. The joint labor of that attentive look of the architectural team, the historical information and the work of the archaeologist (Carpetania *Arqueología y Restauración*, SL.), managed to put relatively in order the complex history of the walls. At that time, it became necessary to give a consistent image to that history to be able to show it and explain it, displaying in the construction itself the values of the castle. Equally important is the knowledge of the constructive techniques and the support of a building company (ARTEMON) that is able to execute them and contribute with their experience on these methods.

Finally the result of the intervention is a canvas in which all the different constructive techniques over time are present.

The project has from our point of view an important side; on one hand the enhancement of the image that the town and area have in their local memory of the castle, an image partly based on the landscape, of the profile that dominates the land. On the other hand, we were interested in describing the more intimate and domestic scale of the castle and its construction, describing in the parade ground the different constructive phases, with the diverse constructive techniques used over time. A landscape view completed by an up-close reading when the visitor enters the castle.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Restoration of monumental rammed earth buildings in Spain between 1980 and 2011 according to the Archives of the IPCE

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ABSTRACT: This study has been carried out as part of the research project called "Restoration of Rammed Earth Architecture in the Iberian Peninsula. Technical criteria, results and perspectives" (ref. BIA 2010-18921), funded by the Spanish Ministry of Science & Innovation. The research presented here consisted in reviewing the collection of the archives of the Cultural Heritage Institute of Spain (IPCE), with a view to providing an initial approach to the interventions on buildings made of rammed earth in the last thirty years (from 1980 until the present day) and funded by the Ministry of Culture of the Spanish Government. The paper strives to provide a preliminary global analysis that will make it possible to draw certain more specific conclusions about intervention criteria and the construction solutions adopted in the different interventions.

1 FOREWORD

1.1 *Aims of the study*

This research strives to provide an analysis of the restoration works carried out on rammed earth architecture in Spain funded by the Ministry of Culture of the Spanish Government during the period going from 1980 to 2011. The documentation about the interventions on Spanish cultural heritage is kept in the institution created in 1985 with the name Instituto de Conservación y Restauración de Bienes Culturales (Institute for the Conservation and Restoration of Cultural Assets), and whose name was changed to Instituto del Patrimonio Cultural de España (Cultural Heritage Institute of Spain, IPCE) in 2008. Therefore the research comprised a first phase of pursuit and compilation of information from the archives and a second phase of revision and analysis.

1.2 *Metodología de investigación*

To carry out the study in the first place we worked with the complete collection of the Cultural Heritage Institute of Spain regarding projects for intervention on buildings from 1980 to the present day. From all the documentation in the archives during this period, those related with buildings made partly or entirely out of rammed earth were selected, and constitute the totality of the study cases.

1.3 *Selection of the study cases*

The first step in the research consisted in selecting from among the 2,779 files in the IPCE belonging to the period 1980–2011 the interventions on rammed earth buildings, which yielded a total study sample of 147 files.

An initial analysis of the chronological evolution of the interventions showed that, of all the records in the archives in the period studied, approximately 73% (2,029 cases) dated from the eighties, that is, almost three quarters of the total; the rest comprised 427 files from the nineties and 323 from the two thousands (Fig. 1).

This situation is very similar if we take only the dossiers selected. Of the 147 records of interventions on rammed earth buildings, a total of 128 were performed in the eighties, which means about 87%; in the nineties there were only 10 dossiers, and 9 in the two thousands.

Due to this irregular disposition of the study cases, as a second step it is necessary to analyse the temporal distribution of the cases that arose in the

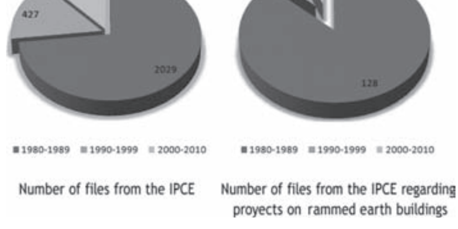

Figure 1. Diagrams of the temporal distribution of the records.

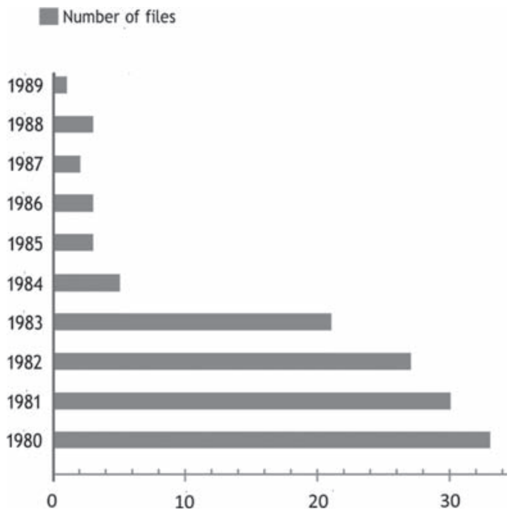

Figure 2. Diagram of the temporal disposition of the cases that arose between 1980 and 1989.

eighties year by year, since this is the most numerous group within the period studied (Fig. 2).

We observe that of the 128 files registered in the eighties, over 86% (111 cases) were lodged in the first four years. This may have been due to the fact that in this period of time great changes came about in the Ministry of Culture, such as those arising as a result of the transfer of powers related to culture to the different Autonomous Communities (Royal Decree 565/1985, of 24 April). With this transfer of powers to the Autonomous Communities, the budget assigned to the IPCE decreased according as the different communities made their own investments in different restoration areas.

Therefore, in these first steps for selecting the sample the records of intervention on rammed earth buildings over the last thirty years could be identified, but it must be taken into account that in all these cases the intervention was not necessarily on the rammed earth walls, but some are of another type, such as works to rearrange the exterior of the buildings or works on the pavements, roofs, etc.

So taking this aspect into account and looking over the 147 files that comprise the sample, we can extract a study made up of 99 files where the works were performed on rammed earth walls and 48 files related to other types of intervention.

2 GEOGRAPHIC MAP OF THE STUDY CASES

When the study sample is analysed, we find that of the 99 files where rammed earth walls were intervened on, a total of 60 different buildings underwent one or several interventions during this period.

From the point of view of geographic analysis of these buildings, three autonomous communities had the largest number of files: Andalucía, with 17 different buildings; Castilla y León, with 13 interventions and the Comunidad Valenciana, with 12 buildings (Figs. 3 and 4).

Of course, this is not a random occurrence, because as we can see on the map showing a scheme of the geographic disposition of the different buildings worked on, there is a fairly uniform distribution, taking into account the territories in Spain where there are larger numbers of monuments made with this building technique. The remaining interventions, in order, were in the communities of Castilla y La Mancha, Murcia, Aragón, Extremadura and Madrid.

It is also interesting to review these buildings according to their typology. In order to draw up this analysis, the buildings have been classi-

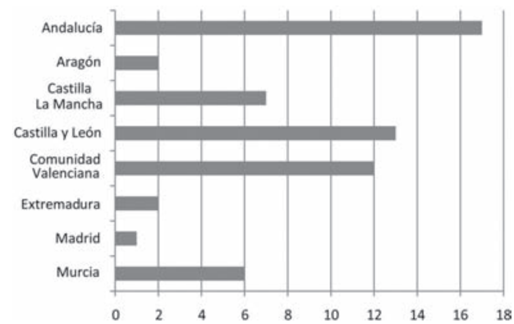

Figure 3. Diagram of the distribution of interventions in each autonomous community.

Figure 4. Map of the interventions studied.

fied in three large groups: military architecture (castles, towers, bulwarks…), religious architecture (churches, convents, monasteries…) and civil architecture (palaces, hospitals, dwellings…).

If we compare all the dossiers of intervention on rammed earth buildings and the 99 files where the interventions were on the walls, we can see that in both cases there is a majority of military buildings, since rammed earth was a very typical construction technique in this type of monumental building (Fig. 5).

If we examine the number of files according to construction typology and year, we find that, as we pointed out above, the vast majority of cases date from the first half of the eighties, but there have also been a series of more recent interventions, because in 1997 a subproject called “Programme of Military Architecture” was included in the budgets assigned to the IPCE in the general State Budget. Thanks to this fact, interventions were carried out on this type of building, which were, moreover, State property. The dossiers from this period are not very numerous, for in many cases the works were performed jointly with the different autonomous communities and provincial and city councils, etc., and also with the Ministry of Defence when the interventions were on buildings belonging to it, so a great deal of this documentation is filed in the relevant archives.

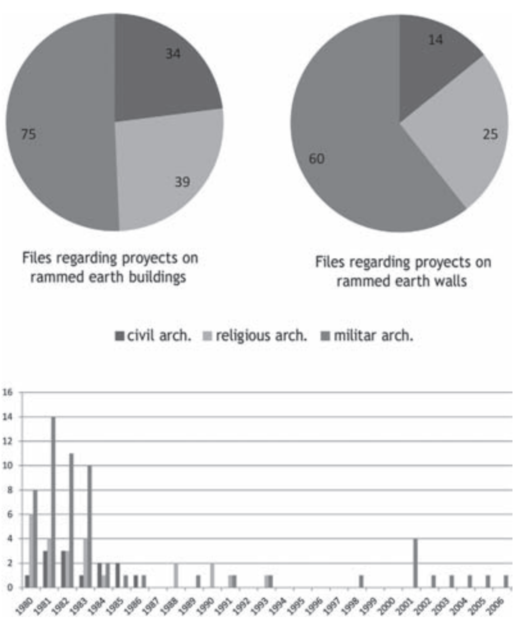

Figure 5. Graphs of the distribution according to typology.

3 ANALYSIS OF THE CASE STUDIES

3.1 *Analysis of the intervention criteria*

The study of the criteria followed in these interventions requires a detailed analysis, because the most contemporary dossiers must be examined in order to find explicit reference to these criteria in the project reports.

On the other hand, in the files from the eighties, which comprise the majority of our sample, the report tends to be a fairly brief text, just a few pages long, which usually contains two basic sections: a historical-artistic description of the monument and a section explaining the works planned. In some cases, the report of the project is a little longer and contains a few more sections, such as a description of the construction system of the building and its current state of repair (before the intervention). Therefore, in most of the files the intervention criteria are not included, or only a few specific ideas are put forward. For example, an idea that appears repeatedly is the desire to differentiate between the new elements and the old, often using new materials but the same building methods. This option can be found in the report of the intervention on the Castillo de Tabernas (Almería) in 1983, in which the author, Roberto Puig Álvarez, proposes that “as the walls of this castle are made of rammed earth, we shall use the same construction system, replacing the mortar of the rammed earth with a mortar of lime and cement mixed with sand and dyed to obtain the same shade as the original wall, using formwork and placing holes with boards the same size as the original ones as deduced from the remains of the wall and the layout of the putlogs. These concrete walls will be reinforced with concrete tie beams with 4ø 16 mm diameter concealed in the rammed earth with the same materials and colours” (File PI 0009.02 of the IPCE archives).

In other cases, we find the opposite idea: using the same materials as the original ones, as in the case of the intervention on Jumilla Castle (Murcia) in 1982, where Ignacio Mendaro Corsini states that “coffered walls (lime concrete) will be used in the areas where the existing parts indicate it.” (File PI 0926.07 of the IPCE archives).

It is also a fundamental point in the analysis of the intervention criteria, especially in military architecture, to address the issue of reconstruction. In many cases, the reports speak of “consolidation” as a synonym of “reconstruction”. But, as far as reconstruction is concerned, there are several different tendencies. In some cases only some parts are reconstructed, such as the coping of the walls of the Albaicín in 1982, where the architect Ana Iglesias Gonzales said, “Once the floors partly concealed by the outer walls are removed, we may find traces of the apron and merlons of the battlements, which will allow us to recompose the profile of the top of the monument, that is, its modulation and dimensions, after which we can proceed to re-execute the original apron." (File PI 0077.03 of the IPCE archives).

In some interventions reconstructions are seen as partial volumetric restitution, as Ismael Guarner González writes when speaking about his intervention on the walls of Niebla in 1980 (Fig. 6). "Restore the monument while striving to endow it with a more defined image more like what it once used to be, without having to reproduce the original volume" (File PI 0102.09 of the IPCE archives).

This criterion can also be seen in the intervention on the Castillo de la Mola (Novelda) in 1983 (Fig. 7), where Ramón Valls Navascués stated, "This project is aimed at consolidating the existing ruins, arranging the current volumes in such a way that by completing the shapes which can be deduced from the existing parts, the appearance, the colour, the well-known romantic character of this type of building and this one in particular will not be substantially altered" (File PI 0987.02 of the IPCE archives).

Figure 6. General view of the Niebla city walls after restoration (Huelva, Spain) (Vegas & Mileto).

Figure 7. Part of the external wall of the castle of La Mola (Novelda, Alicante, Spain) with the regularization of the volumes (Vegas & Mileto).

Some of the interventions mentioned attempt to use reconstruction to restore the building to its original appearance, whereas other interventions aim at just the opposite, like in the Alcázar of Jerez de la Frontera (Cádiz) in the intervention performed by Fernando Villanueva Sandino: "When planning the restoration, we tried to be faithful to this historic constant, so we do not wish to restore the site of the Alcázar to the splendour of a given historic moment, but, critically assuming all the interventions that characterise it, provide it with a new appearance…" (File PI 0024.01 of the IPCE archives).

In some dossiers they go as far as to claim that the intervention must be limited to the strictly necessary, as Mariano Bayón Álvarez says in his report on the intervention on the Palacio de Juan II (Madrigal de las Altas Torres) in 1981 (Fig. 8), affirming that "the overall restoration works try to adjust to contingent, really direct, compulsory and necessary principles, without making any concessions to rhetoric" (File PI 0482.01 of the IPCE archives).

On the other hand, in other contemporary interventions they contemplate the complete reconstruction of the walls and even of the coping (battlements…), as is the case, for example, of the intervention made on the Castillo de la Judería in Córdoba in 1983 by the architect Carlos Luca de Tena y Alvear, where "the intention is to reconstruct a wall with the rammed earth method that will make it conserve its primitive character, treating the rammed earth adequately, and on the other hand protecting the upper area so as to avoid loss of height in relation with the original structure." On the other hand, this intervention strives to be an example of intervention criteria in its own right, for as the report says, "we aim to provide an example of the criterion of the ministry that the council can follow. This solution is adopted because the criterion put into practice by the council in the first phase did

Figure 8. Restored building at the first patio of the Palace of Juan II at Madrigal de las Altas Torres (Ávila, Spain) (Vegas & Mileto).

not comply with the criteria of the Córdoba Delegation, confirmed by the technicians of the Ministry of Culture" (File PI 0042.04 of the IPCE archives).

Therefore, we see that the intervention criteria are very diverse in the different study cases, even in buildings of the same construction typology, as is the case of military architecture.

If we analyse civil and religious buildings, the criteria for intervention on the walls are not so diverse, since the very building method (in many cases, rammed earth placed between bricks) has different pathologies that, in many cases, require interventions not so much on the volume of the walls as on their surfaces.

Figure 9. Restored wall of the castle of Petrel (Alicante, Spain) (Vegas & Mileto).

3.2 *Analysis of the construction techniques proposed*

To make an analysis of the construction techniques proposed in the different case studies, it was decided to group the records according to the construction typology of the building, since the construction techniques for the intervention respond to the pathologies usually found.

In the interventions on buildings of the "military architecture" group, such as ramparts, castles, towers…, the construction solutions proposed can be classified broadly into three groups according to the material used on them: restoration with concrete or cement, restoration with masonry and one last group of restoration with newly-applied rammed earth.

In the first group we find, for example, the intervention on the Castillo de Orce in 1980, where José Antonio Llopis Solves explains that the works proposed contemplate the "demolition of the buildings attached. Once the surfaces of the walls and the middle tower have been bared, it will be necessary to proceed to underpin the walls and fill in the gaps that have appeared over the years. All this operation will be performed with mass concrete, making sure to use yellow and reddish sand in the outer layers to blend in with the rest of the wall, differentiating the texture by the way the planks are set out" (File PI 0089.07 of the IPCE archives).

The connection between the original material, rammed earth, and the new material, concrete, depends on the construction detail proposed in each case, but the detail proposed for the Castillo de Petrel in 1982 is common: "Restoration of the surface of the wall with mixed cement and lime concrete, with timber planks fixed with wire, which will be cut off when the planks are removed and the putlog holes will be left visible. Dovetail profiles will be used to attach the rammed earth wall to the existing fabric" (File PI 0988.03 of the IPCE archives) (Fig. 9).

As regards restoration with masonry, we can mention the statement made for the intervention on the Alcazaba in Almería in 1981, where Roberto Puig Álvarez suggests "consolidating with masonry in the existing gaps, first proceeding to clear away the rubble at the base of the wall, to which will be added the rubble from chipping off all the false rendering and plaster in order to restore a stony appearance to the wall, which, even if it is not quite the original Arabic rammed earth, would be more appropriate than all the Christian reconstructions" (Fig. 10) (File PI 0001.01 of the IPCE archives).

Figure 10. South wall of the Islamic castle at Almería (Spain) (Vegas & Mileto).

In other cases, the interventions use traditional methods although, as we pointed out above, the intervention criterion is usually to make sure the new construction will not be confused with the original one.

In civil and religious architecture, the interventions proposed are different, because, as we suggested above, the pathologies that affect these buildings are usually different too. Interventions on these buildings are usually on the surfaces, as we can see in the intervention on the Iglesia de la Merced (Murcia, 1981), where they proposed "the recuperation of the rammed earth fabrics, to which end an average of 5 cm will be removed from all the damaged surfaces, which will then be rebuilt with lime mortar and the old surfaces will be duly treated" (File PI 0938.04 of the IPCE archives).

When the intervention is to be on structural pathologies, mainly cracks, the intervention methods

Figure 11. South façade of the Church of La Merced (Murcia) (Vegas & Mileto).

Figure 12. Restored wall of Jorquera (Albacete, Spain) (Vegas & Mileto).

chosen also depend on the original building techniques. For example, in the intervention on the walls of Jorquera in 1982 (Fig. 12), they said "as the building material is not stone but mortar, we do not think the solution is to clamp the cracks. Therefore we prefer to fill them in with lime mortar, stone and local soil, to which formwork will be applied in the places where it is deemed necessary and a finish similar to the original will be applied" (File PI 0363.03 of the IPCE archives). In other cases, such as the intervention on the church in Écija in 1983, since it is rammed earth confined between brick buttresses, the solution proposed is completely different: "the surface is cracked just between the two vertical joints that define the rammed earth walls. We propose to consolidate this wall by clamping these cracks by means of toothers or brick repointing" (File PI 0157.04 of the IPCE archives).

4 CONCLUSION

After making this first analysis regarding the intervention criteria and building techniques proposed in the case studies, we can draw some initial conclusions. It is necessary to point out that since the vast majority of records of the study cases date from the first half of the eighties, the ideas put forward below must be seen as pertaining to that period.

With regard to the construction techniques, it is interesting to note that although modern materials like concrete are used, they are applied by traditional methods, since the aim sought is to achieve an exterior appearance similar to that of the traditional material. It is important to underscore also the fact that some interventions serve as models or examples for ensuing interventions, as is the case mentioned by Carlos Luca de Tena y Alvear regarding the intervention on the Judería in Córdoba in 1985: "The study and the solution put forward are based on similar solutions to those adopted under the sponsorship of the Dirección General on the wall of Palma del Río (Córdoba) and on the Castillo de Obejo (Córdoba), under the orders of the architect of that ministry, Eduardo Barceló, and the technique used by my colleague Guarner for the walls of Niebla" (File PI 0042.05 of the IPCE archives). The reference to Ismael Guarner's intervention on the walls of Niebla in 1980 would still be found in future interventions, like the intervention on the walled centre of Cáceres in 1989: "Consolidation with new rammed earth enriched with lime mortar and 5% cement, a system that gave a good result in the consolidation of the walls of Niebla, performed by the architect Ismael Guarner" (File PI 0735.06 of the IPCE archives).

With all this, we can affirm that the first half of the eighties was a fruitful period in interventions on rammed earth constructions from the point of view of the actions supervised by the Ministry of Culture. This first research and analysis has provided information about the situation during a short period of time, and for that reason it must be seen as a first step in broader research that will be carried out in future and that will address different cases.

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Preliminary studies for intervention, interpretation and value enhancement of Tower of Don Fadrique (Albaida, Seville, Spain)

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ABSTRACT: A multi-disciplinary team from the University of Sevilla studied the Tower of Don Fadrique (Albaida, Seville, Spain), carrying out an analysis of its history, materials, construction, and pathologies. The aim was to provide local authorities with information to guide their technicians in assessing the possibilities of an intervention on the tower based on a better understanding of its masonry and an evaluation of its hazards and levels of vulnerability. A synthesis of the preliminary phase of this study is presented below.

1 BACKGROUND

This work provides the first results of the preliminary studies for an intervention on the Tower of Don Fadrique, an interesting medieval guard tower built of rammed earth chained in ashlar masonry con door and window frames on a stone wall, probably built in the early decades of the 13th century. The tower is located in the municipality of Albaida del Aljarafe in Seville and is the main monument there; after the destruction of its upper portion, it became known as the Torre Mocha (the *Topless Tower*). The study was undertaken by a multi-disciplinary team from the University of Seville (Spain) implementing a work methodology established in the framework of project BIA2004-1092 (Graciani et al., 2004).

It was declared an Asset of Cultural Interest in the Monument category, the first legal status of the Tower was as an Artistic Historical Monument by Decree 22/04/1949 for the General Protection of Spanish Castles. Currently it has its own file in the Andalusian Heritage Site Database (Code 410030003), which specifies it as a Defensive Guard Tower and dates it at 1245–54, an early medieval timeframe, an estimate that this study casts considerable doubt upon.

It was strategically built to overlook the floodplain of the Guadiamar River. It lies on land that cannot be built on to the N, E, and W, as classified in 1997. At that time, due to its R2 status (progressive ruin), the tower and its immediate urban surroundings were intervened by the Las Torres School Workshop under the direction of the architect Ricardo Moreno Moratinos, stabilizing part of its structure (uncovered) and enclosing and adapting its public access. Despite this, the current state of the tower makes it advisable to undertake a future intervention to optimize its conservation status and provide a complete analysis regarding its origin and historical evolution in order to provide the local administration with guidelines for their technicians. Consequently, a group of researchers from the Department of Architectonic Construction 2 of the Institute of Technology of Building Engineering at the University of Seville set out a preliminary intervention plan fitting the needs of this building. The preliminary results are presented herein. Specifically, for a better understanding of the tower's masonry and a more complete evaluation of its hazards and vulnerability levels, we undertook multi-disciplinary historical, material, construction, and pathology analyses of the tower in order to address intervention proposals on this Historical Heritage Site.

2 TOWER DESCRIPTION

The preserved remains of the tower correspond to its base and to 5.5 m of the body since the tower's top was demolished at some point, perhaps in the mid-13th century or in the late 15th century. The tower may have been demolished during the reconquest of the village by Pelay Correa (Pelayo Pérez Correa), a Master of the Order of Santiago, or it may have happened at the end of the 15th century, when the Catholic Kings demolished a considerable number of guard towers to limit the power of the local nobility.

The base measures 11.20 × 9.50 × 2.50 m and extends 0.50 m beyond the body's wall. The remains of said tower body correspond to the lower chamber and the first two stretches of the inner staircase. The chamber (2.30 × 2.20 m) is accessed directly from the NW face (facing the Guadiamar lowlands) through an archway (3.25 m above ground level) with a flat arch with a segmental arch on top of it (2.35 × 1.15 m of span covered by a groin vault (redone in 1997).

The W and S walls of the tower both have sections of staircase (of 1 m) leading to the chamber(s). The existence of merlons is logically accepted, but the possible tower height is cast into doubt as is whether the inside had two or three chambers. The upper ones were probably residential and were the reason for its being demolished; this last option seems to be the most widely accepted due to the solid construction of the remains, the proportions of the base, and the existence of local coetaneous parallels (Olivares y Benacazón, Valor 1991).

The vaults restored in 1997 are, in the first stretch of the stairway, two groin vaults, a barrel vault, and another groin vault higher than the one at the landing and lower than the previous one. On the south side, there are two groin vaults and a barrel vault at the landing, both of which are stepped as they are neither splayed nor rampant.

3 CONSTRUCTIVE ANALYSIS

3.1 *Methodological approaches: Wall analysis*

In the tower's architectonic analysis, the researchers applied the stratigraphic model in order to supply new data to unveil the building's evolution by studying its masonry, the types of bonds, and the relations amongst the various parts.

The study, performed according to the methodology of Tabales (2002), is based on a graphic representation of the elevations of the bastion, identifying noteworthy corresponding to periods of its evolution, how they are related to each other (through bonding, abutment, breakage or embedding), and the relation or temporal nuance between them (of coetaneity, antecedence, or subsequence).

The evolutionary sequence parted from the historical study provided by the prior historiography since, due to the diagnostic level, we could not obtain data by other means such as an archaeological dig. The final result has been graphically represented in planimetrics for the four sides of the tower, some stratigraphic (noting the physical relation between the units) and the others evolutionary (defining their timeframe).

The most interesting sides of the tower are the NW (Fig. 1) and the SW face, where appear the main elements contributing to clarify the tower's origin.

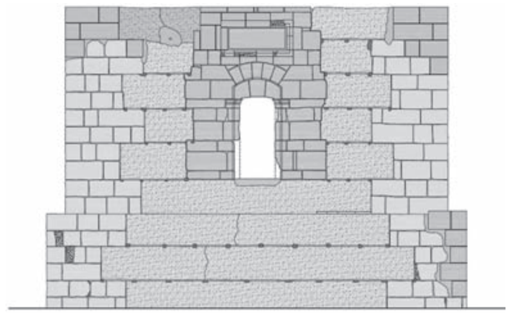

Figure 1. NW face of the tower (L.A. Núñez Arce).

3.2 *Timeframe and constructive stages*

The stratigraphic study allowed us to determine, for the first time, that the tower did not undergo a single construction process. Instead, there was an initial Islamic building (Almohad) that was subject to a Christian intervention over the course of a few decades, led by the Prince Don Fadrique. The existing remains correspond to three different construction processes (Almohad, Christian, and 20th century) that are analyzed below.

3.2.1 *Phase 1 (Almohad), early 13th century*

The original Almohad building was raised at the start of the 13th century. It was attached to a walled recinct of which we have found no remains to date. However, we have traced its existence in the course of our research. In fact, images from the 1930s preserved at the Photography Library of the Art Laboratory of the University of Seville (Fig. 2), allow us to refute previous hypotheses and confirm that the Torre Mocha was not a guard tower or a Fort Tower (Ortiz de Zúñiga 1975) in contrast to the San Antonio Tower, a nearby coeval building.

The tower was built of mixed rammed-earth and stone masonry (Fig. 3). The chain was carried out with coursed ashlars of local stone and some pieces were re-used. The courses have a height ranging between 0.88 to 0.90 m and are separated by a 0.03 m thick layer of lime. It is executed with overlapping formworks creating 6–7 meter sections of continuous rammed earth between the stone chains. Its NW face, towards the plain, must have housed its original entry point, of which there is currently no evidence.

Two arrows slits in the rear of the bastion (SW) flare out into an embrasure inside the chamber, thus also serving to provide light to the upper chambers. Today, these spaces have been altered from their original shape, appearing now as a break in the masonry; they were also partially redone in brickwork in recent interventions.

Figure 2. Image from the 1930s (Photography Library of the Art Laboratory of the University of Seville).

Figure 3. NW wall of the tower (A. Graciani).

Three building characteristics of the rammed-earth wall masonry make it unquestionably Almohad, and even more specifically as from the early 13th century: the use of flat horizontal timbers, continuous rammed-earth walls, and chained stone masonry. These features make their first appearance with the Almohads and show considerable care in their execution and the use of the best materials (Fig. 3). The use of chained stone masonry on the corners, not recorded in Seville until the start of the 13th century in towers (such as the Tower of Gold in Seville), also constrains the building of the Tower of Don Fadrique to this period.

3.2.2 *Phase 2 (Mudejar), middle of the 13th century*

The second phase corresponded to the intervention by Don Fadrique (Fadrique of Burgundy and Swabia, Prince of Castille 1224–1277, son of Ferdinand III the Saint and Beatrice of Swabia) and took place between 1248 and 1260 during the Reconquest of Seville and its fall into disfavor. After this, Alfonso X handed it over to the Church of Seville, to which it belonged until the end of the 15th century. The intervention of Don Fadrique on the tower has been dated at 1253, in which year, with the Apportionment of Seville, the Prince received the farmhouse of Solúcar de Albaydar for having participated in the siege of Seville.

Consequently, the only entry point to the tower, on the NW face overlooking the plain, was altered to incorporate a segmental arch, probably topped with an emblem or coat of arms. Above the doorway was placed a notice in pink marble and upper-case gothic lettering reading “The Prince Don Frederic had this tower built”.

Different construction evidence confirms that the current doorway is not coeval with the rest of the masonry. In fact, the entry point was made by breaking up the original masonry and demolishing the necessary area. This could be undertaken due to the extreme hardness of the lime-rich rammed-earth wall, incorporating headers to make the necessary adjustments to fit the frame size to the new doorway.

The doorway, made of the same local stone as used in the Almohad tower, is made of semi-coursed ashlars, with an evident height difference between the courses of ashlars. Although this is a chained layout in order to adapt to the rammed-earth wall masonry insofar as possible, the lift of the rammed-earth walls and the pattern of these chains do not coincide in height, noticeable in the adjustments that had to be made to admit the opening. The portal shows features typical of Gothic stonework such as the joins of the voussoirs of the entry archway and the moulding of its jambs.

It was probably in this phase that the original arrow slits were expanded, shaping them into brick lancet arches on the SE face at both ends of the second ramp stretch and in the NE face at the start of the third stretch, although only the base remains of this last loop hole.

3.2.3 *Phase 3 (modern), 1997*

During this phase, various interventions were undertaken in the tower’s surrounding to lend it an air of distinction, define it, and provide it with a garden. The curtain wall was removed, a garden was planted, and the perimeter zone was landscaped. Vehicular traffic was detoured from the area to surrounding lots and access was given to the inside of the tower and to its current roof. A semi-circular overlook was also built, with panoramic views, a guardrail along its edge, and a brick bench built into the wall.

In the tower itself, all the horizontal surfaces were waterproofed, including the roof. The rain-water was channeled by water spouts draining to the outside, and a system was established allowing public access to the inside. Some ashlars in poor condition were replaced with ashlars of the same type, and the ashlars, rammed-earth walls, and brick masonry were consolidated and waterproofed. Inside, the chamber and section of hallway that were uncovered were protected from the elements. The chamber, rampant stair, and the arrow slits were restored with materials, textures, and tones similar to the originals. The chamber floor was filled in with cast-in-place concrete. The rampant stairs were rebuilt using permanent formwork with a bridge-on-edge course and filled in with a ramp of cast-in-place concrete. They also substituted lost material in rammed-earth walls, vaults, and arrow slit embrasures using brick masonry and lime bastard mortar.

4 CHARACTERIZATION: MATERIALS AND METHODS

The study carried out in this unique place has consisted of characterizing two samples: two rammed-earth walls. The names assigned to them and the types of materials are REW1 (internal rammed-earth wall) and REW2 (internal rammed-earth wall).

The carbonate content was determined by Bernard's calcimeter according to UNE 103200: 1993, with the aim of approximating the original amounts of lime in the rammed-earth wall since lime becomes calcium carbonate. One must take into account, however, that both soil and the aggregates used in their making might contain natural carbonated fractions, so that the entire carbonate content cannot always be explained by the addition of lime.

Physical and mechanical properties were determined. The water-accessible porosity was calculated through the vacuum method according to UNE-EN-1936 (2007). In order to determine the compressive strength, 10 × 10 × 10 cm cubic test cores were used for the rammed-earth wall samples. Cement mortar with a 1:1 ratio was later used to cap those wall pieces, the samples were broken, using a strength testing machine TCCSL model PCI-30 Tn., according to UNE-EN 1015-11:2000 standard.

4.1 *Results and discussion*

4.1.1 *Carbonate analyses by Bernard's calcimeter*

The carbonate contents determined in both samples are shown in Table 1.

Both samples have low $CaCO_3$ contents (18.0% and 18.2%). Since the $CaCO_3$ contents from 1:2 and 1:3 reference lime mortars (siliceous sand/lime ratio in weight) are 40% and 31% respectively (Martín-del-Río et al. 2008), our samples seem to be very poor in lime conglomerates. However, it is not certain that all analyzed $CaCO_3$ comes from lime since $CaCO_3$ might also come from the aggregates. Therefore, the percentage of binder could be even lower.

Table 1. Carbonate content (%) of Don Fadrique's tower samples.

Sample	REW1	REW2
$CO_3^{=}$	10.8	10.9
$CaCO_3$*	18.0	18.2

*$CO_3^{=}$ expressed as $CaCO_3$.

4.1.2 *Physical properties: Porosity accessible to water*

Porosity values constitute a criterion to determine the quality and durability of mortars, concretes, and rammed-earth walls. Results for the wall samples were 21.8% for REW1 and 22.2% for REW2.

The materials used for these rammed-earth walls tend to have high open porosity (30–50%, commonly over 35%), and are consequently classed as very porous materials. This high porosity can probably be accounted for by the presence of a fine fraction of Ø<0.063 mm (lime, calcite, clay minerals, etc.), all of which have a high specific surface with a high capacity for water absorption. Consequently, during batching they demand large amounts of water that, when eliminated by evaporation, leaves high open porosity in the rammed-earth wall structure. It is also a common practice to use large amounts of batching water for greater workability of the slurry during work.

REW1 and REW2 samples have porosity accessible to water values close to 22%, those values are very low. The origin of this low porosity level might be likely justified by the use of low water/lime ratio in order to obtain good workability, good compaction from the rammer, and adequate aggregate grain size.

4.1.3 *Mechanical properties: Compressive strength*

Empirical data obtained from rammed earth wall samples are shown on Table 2.

The compressive strength in REW1 and REW2 samples is similar 20.1 N/mm^2 and 20.3 N/mm^2, most likely due to the low porosity. Compressive strength depends on several factors, but one of the most influential is the material's open porosity (the lower the porosity, the greater the material's strength and vice-versa).

Table 2. Study of compressive strength (N/mm^2) of different rammed-earth walls at various sites in the province of Seville (Spain).

Place	Compressive strength
Fadrique's tower (Albaida)	20.1*
C/ Sol wall (Seville)	13.0
Maria de Pineda wall (Seville)	3.9
S.Antonio's Tower (Olivares)	3.7
San Juan de Aznalfarache's wall (Seville)	3.1
Marchena's wall (Marchena)	3.9
Villaverde`s wall (Villaverde del Río)	7.3

*Average of values from the two samples REW1 and REW2.

In addition, the lime content positively affects mechanical strength. In previous studies on rammed-earth walls (Martín-del-Río et al. 2008), an analysis of mechanical properties revealed the exceptional quality of these rammed-earth walls, with higher values than found in other studies on this material at different sites in the province of Sevilla (Spain).

5 CHARACTERIZATION OF PATHOLOGIES AND HAZARDS

The analysis and diagnosis of the tower's pathologies are based on the analysis methodology proposed by Canivell (2011) for the characterization of damages and hazard assessment in rammed-earth wall masonry.

5.1 *Damage characterization*

The tower is generally well preserved as a result of its recent intervention, although there is some damage (structural, material, and superficial) due no doubt to the minimal regular maintenance. This damage is generally scant or, at the most, of little importance and of low hazard.

Amongst the scarce and less significant damages are the vertical fissures visible in some courses due to the expansion and contraction of the infill due to drying shrinkage during manufacture of the walls.

Material damage is more evident and is due to erosion (especially bad in the topmost courses lacking adequate roofing). The surface loss of mass overall in the walls is significant, with a consequent exposure of the lime mortar layer between courses; however, it can be classified as of slight importance due only to the highly cohesive mortar resulting from the high-quality execution and the high proportion of lime.

The superficial damage is limited to adhered stains (no crust formation) arising from washing by rainwater which, upon filling the exterior network of pores and concavities with particles, slightly darkens the wall's surface and highlights its washed outer face.

5.2 *Hazard assessment*

The tower's hazard assessment has been carried out (applying the methodology proposed by Canivell, 2011) to facilitate the application and management of preventative strategies and actions and of maintenance in the medium and long term. The vulnerability and hazard status can be defined through the appropriate management of hazard factors and the assessment of hydric, physical, and structural hazards.

Three types of hazards have been evaluated: hydric, physical, and structural, corresponding to vulnerability to the action of water, erosion, and structural instability, respectively. Given the tower's small size and the homogeneity of the external hazard factors, we have applied the assessment methodology without distinction amongst the walls since differences are minimal in the global assessment.

The hazard factors associated to water vulnerability are mostly low to very low, with poor values found only in the scarcity of covering and roof, which are compensated for by the high cohesion and hardness of the rammed-earth wall. All this results in a very low hazard level to water and therefore there is no urgent need for applying specific preventative measures.

The structural instability has an even lower hazard level since none of its hazard levels reach high values; consequently, it has a very low hazard level. Therefore, we can assume that the probability of structural damage is low in the short term and, as a result, there is likewise no need for applying preventative measures.

However, there is a certain trend to higher hazard in material damage (erosion), evidenced by a somewhat higher hazard level due to the lack of protec-

Figure 4. NW face of the tower (detail) (A. Graciani).

tion (roof and covering), to the high exposure, and to the lack of regular maintenance. Therefore, it is advisable to apply certain preventative measures in the medium or short term to reduce the hazard of existing erosion progressing. Otherwise, what is currently superficial loss of mass and stains could degenerate with a certain degree of probability into more serious damage.

6 CONCLUSIONS

In addition to reconstructing the building process and phases, this technical-construction study (discussing the technical similarities and differences with other coeval buildings in the area, including the San Antonio de Olivares guard tower) has allowed us to establish construction guidelines to be followed in the tower intervention.

At the same time, based on a stratigraphic study, we have been able to resolve the historiographic doubts concerning its ascription (Islamic or Christian) by demonstrating it is an Islamic building remodeled in the Christian period by Prince Don Fadrique de Castilla (1224–1277).

The quality of the masonry and the material characteristics of the rammed-earth wall have been evidenced by the material characterization study performed based on the determination of carbonate content, the properties of the rammed-earth wall, and its mechanical strength. These characteristics not only confirm the hypotheses of temporal ascription put forth by the authors based on construction arguments, they can also be considered when establishing the features of future interventions.

This analysis of hydric, physical, and structural vulnerability of the masonry and their corresponding hazard levels has evidenced that the tower has no outstanding need for an intervention.

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Restoration of the rammed earth walls of the Poniente Tower and the Alafia wall in the fortified complex of Xivert (Castellón, Spain)

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ABSTRACT: This paper describes the restoration of the rammed earth walls of the Poniente Tower and the Alafia wall. Both historical constructions are located in the fortified complex of Xivert, (Castellón, Spain) which is situated on a mountaintop near the sea, in northern Castellón province, Sierra de Irta mountain range. In the Poniente Tower, the walls formed with masonry and rammed earth, reinforced with layers of lime mortar, were restored. In the Alafia Wall, the rammed earth walls reinforced with layers of lime mortar were restored and the culmination was restored with the same material. The works in both cases were done after large previous studies of the existing materials and history of the place.

1 INTRODUCCIÓN

1.1 *Situación geográfica*

Las dos construcciones, la torre Poniente y el muro de Alafia, forman parte del conjunto fortificado de Xivert, que está situado al norte de la provincia de Castellón y emplazado en los últimos estribos sudoeste de la sierra de Irta sobre una singular montaña en la proximidad del mar. Desde el recinto se tiene un control perfecto del territorio tanto inmediato, o sea del corredor de Alcalà a Santa Madalena, como distante, y eso a través de un sistema de atalayas y torres vigía.

El espacio construido total del conjunto, es decir castillo, albacar y poblado, se extiende sobre una superficie de unos 8000 m^2.

1.2 *Breve historia del conjunto*

El conjunto arquitectónico es de origen islámico, levantado sobre un asentamiento más antiguo. A pesar de la documentación antigua y de varios estudios recientes es difícil determinar con exactitud la fecha de la edificación, pero con seguridad al final de siglo XI y comienzo de siglo siguiente, o sea, en la época califal ya existía este hábitat fortificado. El conjunto posiblemente formaría parte de una red castral con función administrativa de un determinado territorio. A esta función se sumaba otra, que era la de ofrecer un refugio, en el albacar, a los habitantes y ganados del territorio perteneciente al castillo en tiempos de acontecimientos bélicos.

En el marco de la reconquista cristiana del país, concretamente en el año 1234 pasaron el castillo y el poblado a manos de la orden del Temple por un pacto de rendición pacífica. Este documento es la primera fuente escrita extensa referida a Xivert. Aquí, aparte de numerosas cláusulas de tipo jurídico, se especifica claramente la división del conjunto conquistado: los habitantes originales sarracenos permanecieron viviendo en el poblado (arravalum) y los nuevos amos, los cristianos, ocuparon el castillo (castrum) y el albacar (albacarum) contiguos. Gracias a la descripción de la separación y los límites de los dos dominios se deja una constancia del aljibe, la mezquita mayor y el albacar, entre otros, y su relación espacial.

El castillo-convento permaneció en poder de los Templarios hasta la extinción de la orden en la primera década del siglo XIV. Una vez disuelto el Temple, la mayoría de sus posesiones en el reino de Valencia pasó a la nueva orden de Montesa. La comunidad islámica, vivió en su poblado y cultivó las tierras hasta su definitiva expulsión en el año 1609. También parece que a partir de esta época la original fortaleza hispano-musulmana, sin más valor estratégico-militar después de la conquista, ya no se habitó de un modo estable.

1.3 *Estructuración del conjunto en sectores*

La extensa estructura del espacio construido de Xivert está conformada por la superposición de restos de edificaciones andalusíes con las del Temple y de Montesa. Esta compleja aglomeración está dividida, desde su origen islámico hasta la actualidad, en tres partes claramente reconocibles mencionadas en el documento de rendición. Es decir: el propio castillo fortificado emplazado en la parte alta, el albacar amurallado y finalmente, el poblado en la ladera de la montaña, también rodeado por una muralla.

2 TORRE PONIENTE

2.1 *Emplazamiento, descripción y materiales*

La torre está emplazada en el extremo oeste del recinto superior. Desde un punto de vista defensivo es la pieza clave de todo el espacio fortificado, ya que una persona situada en su terraza domina visualmente tanto el territorio inmediato, como el más alejado, y en los días de buena visibilidad, se llega a ver el golfo de Valencia.

La forma de la torre es ligeramente tronco piramidal, construida sobre una base rectangular de 4 × 5 m, asentada, como el resto del conjunto, directamente sobre la roca.

Los paramentos de los muros, de unos 10 m de altura están construidos en tapial de piedra, vale decir de mampostería encofrada, reforzada en las esquinas por piedras careadas de mayor tamaño. La excepción de esta técnica constructiva es el coronamiento de la torre, fabricado en tapial calicostrado. Según los restos materiales y la comparación con el lienzo adyacente, el coronamiento sería originalmente constituido por una franja seguida de 80 cm de altura, sobre la cual se sobreponían almenas, realizadas individualmente en encofrados especiales.

A la altura de unos 6 m existe una habitación a la cual se accede por una única entrada en el paramento sur. Al estudiar la torre, en base a la tipología usual de las torres árabo—bereberes de la península, se dedujo que la parte inferior de la torre está maciza. No obstante, después de retirar un considerable volumen de derribo del espacio interior, apareció en el pavimento una entrada a una nueva estancia. Esta estancia está concluida con una bóveda muy rebajada, de piedra colocada de canto. Puede conjeturarse que este espacio cumpliese la función de silo.

Los materiales y el modo de construir del muro adyacente son idénticos a los de la torre. Existen, pero, unos recrecidos del grueso y de la altura del muro, bien visible en la sección rota el paramento. Según los procesos constructivos y acabados la torre pertenece a la época musulmana.

2.2 *Estado de conservación*

Anteriormente a la intervención, el estado de conservación de la torre estaba próximo a una ruina. Era evidente que todas las lesiones que la afectaban estaban estrechamente relacionadas. Las causas directas del gran deterioro de la construcción estaban en la falta de un buen coronamiento, protector de la parte superior de los paramentos y en la falta del forjado de terraza que actuaría de unión y atado de la estructura edificada.

La falta de los citados elementos permitió considerables pérdidas de homogeneidad material, tanto en detalle -los morteros y tapiales desagregados- como a escala mayor -agrietamiento generalizado de paramentos. Las grietas más alarmantes eran las sensiblemente verticales, originadas en el coronamiento de los paramentos sur y norte. Estas grietas iban acompañadas de numerosas fisuras, bien visibles en los revocos interiores. A causa de estas grietas el lienzo oeste estaba prácticamente separado del resto de la edificación. La degradación material culminó con la caída parcial de una parte de volumen construido de paramento poniente.

Figura 1. Paramento oeste de la torre. Muro de mampostería encofrada reforzada en las esquinas por piedras careadas de mayor tamaño.

El paramento este era el más compacto, con menos lesiones de todo el volumen construido. Su firmeza estructural se debe en parte a la unión con el muro adyacente al noreste. Los daños destacables del paramento se reducían a la pérdida de grandes volúmenes de tapial en la zona del coronamiento.

2.3 *Intervenciones en los tapiales*

De los diversos trabajos de restauración describiré solo la restitución de tapiales.

La restitución de mampostería encofrada, esta vez armada para unirla al resto de la fábrica,

Figura 2. Restitución de tapial calicostrado, armado, para unirlo al resto de la fábrica.

se realizó en los paramentos S, N y sobre todo en el temible paramento O. El proceso se efectuó según la altura del encofrado en módulos de 80 cm (dos codos). Uno de los primeros pasos fue la colocación de varillas de acero. Puede parecer que el armado de fábricas es un hecho ajeno a la construcción antigua. Por este motivo buscábamos paralelos en la arquitectura preislámica, concretamente en el espacio geográfico del cercano oriente. Ya el tratadista griego Filón de Bizancio dedica unos escritos al armado de fábrica de murallas con madera o con parrilla metálica. Del mismo modo se armaban edificaciones en Siria preislámica, posterior sede del califato Omeya. En Xivert también tenemos ejemplos con zunchado y refuerzos con mader.

Los encofrados (colocados a una o dos caras, según las necesidades) se rellenaron con hiladas sucesivas de mampuestos y mortero mixto de cal y cemento blanco.

Un capítulo muy particular en la restauración de Xivert representa la restitución de los tapiales calicostrados del coronamiento. Para fabricar los nuevos tapiales hemos buscado la composición y coloración más parecidas posibles al tapial preexistente, haciendo varias pruebas a pie de obra con materiales del lugar.

El primer paso en la restauración fue la colocación de tapieras (encofrado), en las que se integraron los restos del tapial original para su unión con el nuevo. El trabajo de colocación fue complicado por la dificultad de acoplar las tapieras a la base original ya asentada.

Posteriormente las tapieras se revocaron interiormente con mortero de cal pigmentado con tierra del lugar (calicostrado) y se llenaron con una masa de conglomerado, compactada por capas de unos 10 cm de grueso. Los componentes de conglomerado eran la tierra cribada procedente de las excavaciones arqueológicas del recinto superior, cal grasa, grava, arena y trozos de cerámica que nos dejaron los arqueólogos.

3 MURO DE ALAFIA

3.1 *Emplazamiento y descripción*

Alafia es un lienzo de 12 m de largo, situado entre dos torres que forma parte de la muralla sur del albacar, es decir, de la única zona de fácil acceso a la fortaleza. La destacada posición del muro, desde el punto de vista estratégico, se refleja en su considerable grosor, que en realidad es la superposición de varios muros individuales definidos por distintas técnicas constructivas.

Aquí destacamos sólo el componente al exterior del recinto, o sea el muro de tapial calicostrado, decorado con una sillería fingida. Este tapial calicostrado, que por su composición material es auténtico hormigón medieval, se eleva sobre un zócalo de mampostería encofrada asentada directamente sobre la roca. El muro lleva una inscripción realizada, igual que las juntas de sillares fingidos, en fino mortero de cal y dice en letra arábica *al-fatih Allah*. La traducción es *La victoria la trae el Dios*, y la realizó durante la restauración la profesora

Figura 3. Muro de tapial calicostrado, decorado con sillería fingida, que se eleva sobre un zócalo de mampostería encofrada asentada directamente sobre la roca.

Carmen Barceló; según la profesora la inscripción se puede datar al final de siglo XII o principio de XIII, o sea en la época almohade y es única en su género en la península.

3.2 *Estado de conservación*

El estado de conservación del conjunto del muro y en especial del tapial, incluido el decorado y el calicostrado, mostraba una considerable degradación material. La mayoría de alteraciones estaba provocada por el gran deterioro del coronamiento. Las pérdidas de volumen de tapial favorecieron la formación de extensas superficies de escorrentías. El agua lavaba y arrastraba la tierra (componente del tapial), que se depositaba en el paramento decorado al mismo tiempo que ocasionaba numerosos desprendimientos y pérdidas de mortero de las juntas de la sillería fingida, la desagregación del calicostrado base y con ello filtraciones de agua hacia el interior de la fábrica. Cabe destacar también el biodeterioro superficial, es decir hongos, algas y líquenes.

3.3 *Intervenciones*

Las obras de conservación y restauración fueron un conjunto de intervenciones que tuvieron por objetivo principal devolver al volumen de la muralla su consistencia y permeabilidad natural originales y así evitar la penetración de agua y otros agentes naturales al interior del tapial y de la mampostería.

La primera actuación consistía en filtraciones de mortero para rellenar los vacíos, tanto en mampostería como en tapial. La finalidad de este proceso era la consolidación y homogeneización del volumen interior del muro. Al mismo tiempo se saneó el volumen interior de tapial de restos materiales desintegrados y se restituía con morteros de ca.

El siguiente trabajo, precedido por la aplicación con pinceles de varias capas de biocida para la neutralización de líquenes, se centró en la limpieza del tapial. El objetivo de este complejo proceso era la eliminación, con agua desionizada y cepillos finos, de la gruesa capa de tierra y de los restos de líquenes neutralizados, ambos depositados en la superfici.

Es interesante apuntar que durante las numerosas pruebas previas a la limpieza se descubrieron restos de color ocre claro y color amarillento sobre una finísima capa de estuco de yeso aplicado en juntas y sillares fingidos. La calidad del estuco es bonísima. Cuesta creer que esta decoración que debería con seguridad resaltar la importancia del muro, que dada la inscripción quizá fue parte de un oratorio al aire libre, permaneciera a la intemperie cerca de ochocientos años.

Figura 4. Limpieza de tapial calicostrado.

Figura 5. Sellado de sillares fingidos.

Figura 6. Desprendimiento de juntas en sillares fingidos.

Figura 7. Resultado final de la intervención.

Al terminar la limpieza del paramento se sellaron los desprendimientos de la sillería fingida. Otros trabajos complejos, realizados al mismo tiempo, fueron tres reintegraciones: de tapial, de calicostrado y de juntas ilusorias.

Aunque en los cuatro procesos citados se empleó mortero de cal, éste se diferencia por el tamaño de árido que lleva. Así con la selección y el tamizado especial de arena de río se logró un finísimo mortero para el sellado y restitución parcial de juntas, mientras que el del calicostrado llevaba arena de río lavada y al mortero de reintegración de tapial, además de arena, se añadió gravilla.

Último proceso era la entonación cromática de las partes restauradas.

Una vez restaurado el paramento exterior se procedió con el saneado del paramento orientado al albacar, creando una buena base para la restitución parcial del tapial calicostrado del coronamiento.

En la fabricación del tapial hemos aprovechado la buena experiencia adquirida durante la restauración de la torre de Poniente del recinto superior. También en este caso el componente principal era la tierra cribada procedente de las excavaciones arqueológicas: es la materia base del conglomerado formado además por cal, arena, gravilla y grava. El calicostrado, un revoco interior de las tapieras que al desencofrar se convierte en protección exterior del paramento, es mortero de cal. En el coronamiento se respetaron unos restos de tapial y unos mechinales, que son posibles vestigios del paso de ronda.

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Conservation of rammed earth works in the Islamic fortified complex of Calatayud (Spain)

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ABSTRACT: The Islamic Fortified Complex of Calatayud is one of the most singular examples of al-Andalus military architecture. The Complex has a perimeter of more than four kilometers and is defended by five castles. It was used and maintained as a military structure until the twentieth century. The chronology of its different works has been recently put into question. The Complex owes its singularity to the fact that it is primarily constructed out of gypsum ($SO_4Ca(2H_2O)$), obtained from the rock where the site is located. This fact sets is apart from most other examples of rammed architecture, where lime (CO_3Ca) is the main building material. This paper presents the results from two consolidation campaigns, dating from 2007 to 2011, which resulted in the first typological classification of not only the construction technologies found on-site, but also the conservation techniques used. This period also provided opportunity for testing the suitability of some of these techniques using historical material samples.

1 INTRODUCTION

1.1 *The site*

Calatayud is located at the intersection of two strategic peninsular border roads, one going from east to west connecting Castilla and Navarra and the other going from south to north joining Cordoba, Toledo and Zaragoza. The city stands where the rivers Jiloca and Jalón join each other, controlling a river basin one-hundred kilometers long and up-to twenty kilometers wide, in an intermediate position between the main tertiary basins of the Ebro and the Tajo Rivers.

A large fortified complex was built there over one-thousand years ago, during the al-Andalus period. With a perimeter of approximately four kilometers, it can accommodate not only space for housing but also land needed for farming. The site is composed of a large, hollow area crossed by two gullies that climb to the gypsum hill on the north side, which turns out to be the complex's strongest point.

The complex has five castles: "Castillo de Doña Martina", "Castillo Real", "Castillo de la Torre Mocha", "Castillo de la Peña" and "Castillo Mayor" o "de Ayyub". The last one faces north, overlooking the city, and must have been the "alcazaba" (citadel).

The ruins of Bilbilis, the town with which Calatayud was confronted in its early years, are located four kilometers away.

1.2 *Historiographical issues*

The settlement and the development of the Calatayud fortified complex have been the subject of numerous papers, all of which are based on analogies to other places in Aragón, such as Daroca, Molina de Aragón or even Albarracín.

The most common historiographical tradition claims that Calatayud was founded by Ayyub b. Habib, governor of al-Ándalus, in 716, as stated by Ximenez de Rada (1180–1247). Souto argues that this origin is very improbable (Souto 1989). As Souto explains, Ximenez de Rada wrote about the foundation of Calatayud in his "Historia Arabum" *ab isto dicitur* (meaning that what he describes is mere heresay and not fact). Souto

Figure 1. The north wall after conservation works.

doubts that "an al-Andalus governor could change his administrative seat from one city to another in only a few months' time, since it would entail very large movements in time and space, and it would be necessary for him to personally go to the frontier of what later would be the 'marca superior' and establish a 'qal'a' (fortress)..."

The oldest evidence of Calatayud date from 248/862–863, as shown in the documents of Ibn Hayyan (987–1075) and al-Udri (1002–1086), which recount the story of the renovation of the fortress' curtain walls in order to face the Bani Qase from Zaragoza, which was ordered by de Muhammad b.'Abdarrahman that Calatayud was transformed from a "qal'a" (fortress) to a "madina" (town).

Souto also refers to the evidence we have of Calatayud during the Umayyad period, pointing out its role in the Zaragoza rebellion against Cordoba between 934 and 937 (Souto 2005). Abderrahman III was forced to go out in campaign on the 28th of May of 937 and could only subdue the fortress after a very hard siege.

The most outstanding fact in Calatayud's history took place during the Taifa period, when Muhammad b. Sulayman, with the laqab 'Adud al-Dawla, turned the city into an independent kingdom, lasting from 1046 to 1051, and managed to mint its own currency.

Ibn Abi Zar (who died between 1310 and 1320) recounts the capture of the city by Alfonso I (1118) and speaks of Calatayud as "the strongest fortress of the Oriental al-Andalus".

This was the end of the Islamic period of the complex, which nevertheless continued having a military use until well into the 20th century. The complex has been transformed and renovated many times, making the many modifications hard to recognize, as gypsum was generally the only building material used, just as during the original construction process.

Figure 2. Tower number 2 showing formwork marks.

2 CALATAYUD'S RAMMED EARTH

2.1 *Gypsum as a building material*

One of the most remarkable singularities of the Calatayud fortified complex lies in the use of gypsum as the main building material, not only as mortar binder, but also as aggregate and as ashlars in the masonry. This is usual in places such as Aragón, Lleida and Teruel, all located in basins where there is an abundance of sulfates (Suárez Baldonedo 2006). Gypsum masonry works may use formwork moulds or not.

There are two types of materials known by the term gypsum that have different chemical and physical properties. One is the natural stone and the other is the result of applying heat to it. They have the following formulae respectively: CaSO4.2H2O and CaSO4.1/2H2O. The first one is known as natural gypsum stone or "aljez" and is a sedimentary rock that has a crystalline structure, formed by calcium sulfate with two water molecules (dihydrate). The second one is known as gypsum binder and is the gypsum stone that, after the firing cycle, looses one and a half molecules of its water and becomes calcium sulfate hemitidrateted; thus becoming a soft and powdery product that, when mixed with water, forms a moldable paste with a short setting time.

Throughout history masonry required a suitable binder to join pieces and coat walls. Gypsum was the ideal material for this because it is so easy to achieve its partial dehydration at low temperatures, becoming perhaps the first artificial material used for these purposes.

There are some places in Spain, such as the Ebro valley and parts of southern Aragón, where gypsum was extensively used, not only for coating but also as a binding material for masonry joints, flooring, massive walls, rammed earth reinforcements, etc. In the rest of the peninsula, gypsum was used mostly for coating walls and for ornamental plasterwork.

2.2 *Different products derived from the firing of gypsum*

From a scientific point of view, traditional gypsum is a multiphase product made by firing the natural gypsum stone (Villanueva 2004).

The firing of the gypsum stone in artisan ovens, also known in Spain as moorish or arab ovens, produces different phases of gypsum depending on the temperature reached. It is easy to reach 900 ºC at the surface of the stone, which results in anhydrous gypsum, also known as hydraulic gypsum for its ability to set underwater. Its traditional use is for flooring and is hence also known as flooring gypsum.

Inside the gypsum stone the temperature is lower (400–800 ºC), because gypsum has insulating properties, and the result of the firing is anhydrite II. Between 200 and 400 ºC we get anhydrite III, and below 200 ºC semihydrate beta. The non-porous structure of the stone which does not let the water get out allows for the production of semihydrate alpha and also results in some of the material not being transformed at all. This is precisely what is supposed to occur with a multiphase product, where size of the stone and the amount of heat applied determine the final product, covering the entire range of the calcium sulfate/water system.

There are three different kinds of traditional gypsum. The darker stones (over-fired) are stored and very finely ground to make hydraulic gypsum or flooring gypsum. The better looking pieces form the fine plaster and the rest of the stones, as well as the slag, form what in Spain is known as black plaster.

2.3 *Typologies of rammed earth in Calatayud fortified complex*

Souto distinguishes three types of rammed earth in Calatayud (Souto 2005):

Type 1 is rather a gypsum massive wall built with formwork with fragments of unfired gypsum stone. It is what Retuerce (2004) calls masonry built with formwork.

Type 2 is made of rammed earth only.

Type 3 is similar to type 2 but has small fragments of gypsum stone and occasionally also of straw. It is plastered with a strong gypsum mortar.

Bailliet proposes a chronological sequence for this typology in her face reading of the walls (Bailliet 2011).

Besides rammed earth, in Calatayud we sometimes find masonry works that are difficult to distinguish from examples of type 1 gypsum wall built with formwork, especially if they are damaged. These masonry works usually correspond to late medieval or moderns repairs. The "Castillo de Doña Martina" walls are made of special limestone masonry, sometimes with a header bond, that have four levels of wood reinforcement on their western side.

We also find gypsum stone masonry bonded with gypsum binder in the "Torre Mocha" and in the arch of the "Puerta Emiral".

3 CONSERVATION OF THE MAYOR CASTLE

3.1 *Recent works*

Since the middle of the 20th century, when the Castle stopped being used for military purposes, only the "Puerta Emiral" has been restored.

In 2007 there was a partial collapse in the north curtain walls of the "Castillo Mayor", requiring reparation work to be undertaken, first by the "Instituto de Patrimonio Cultural (IPC)" and afterwards by the "Diputación General de Aragón (DGA)".

The IPC carried out the first consolidation works campaign in 2008, cosidering the repair work an emergency. Its main goal was to reintegrate the collapsed walls. A second campaign was undertaken in 2010–2011 to end the consolidation works initiated in 2008 in the lower terrace area.

Also in 2008, the DGA undertook the restoration of the octagonal tower, west of the upper enclosure of the chateau, under the direction of Architect Javier Peña.

3.2 *Intervention criteria*

Since the first intervention in 2008, the aim of the IPC has been not only to achieve the best preservation conditions for the fortified complex walls, but also to study the ruins and share the resulting knowledge with the general public. The consolidation campaigns have been preceded by an archeological study and a stratigraphical analysis—face reading—of the structures.

Historical pictures show that since the complex was abandoned the curtain walls began to quickly deteriorate, due to the use of water soluble gypsum as the main building material. The Calatayud structures have two weak points: the base in contact with the ground and the coronation of the walls (in the case of the latter especially since the loss of the roofs).

Both throughout the 2008 emergency campaign as well as the 2010–2011 campaign, the IPC has invested in a system to drain the Castle terraces. The IPC has also experimented with various solutions to protect the upper part of the walls.

But the biggest effort has been given to preserve the different structures, some of which are very fragile, that show the diversity of building methods used in the complex in its more than a thousand year history.

3.3 *The gypsum used in the conservation of the fortified complex*

Albarracín traditional gypsum has been used for the conservation works in Calatayud. It is made of two types of gypsum stones found in the quarries surrounding Albarracín. One has a dark grey color containing clays rich in magnesium, and the other is red because of clays rich in iron. The two types have impurities of silica, both amorphous and crystallized.

The manufacturing method entails the dehydratation of the gypsum by applying heat continuously for 18 hours. A vault of about 30 cm in diameter is made with oblong stones and is placed over a stand made of sandstone where there are fewer red than grey stones. The material is mixed and ground after firing, after which it is screened to get the proper grain size.

Figure 3. Three types of walls built up with gypsum in different state (stone, binder) and proportion among them, in the northeast angle of the "Castillo Mayor".

The tests made in the Laboratory of Materials of the Madrid School of Architecture, with a mixing ratio water/gypsum of 0.45, show a compression strength value of 75 kp/cm^2 (7.5 Mpa) and bending resistance of 25 kp/cm^2 (2.5 Mpa) with an absorption coefficient of around 20%, which makes Albarracin gypsum one of the best gypsum-based materials for resisting water.

Albarracin gypsum properties have a close relation to the geological composition of the material that includes not only gypsum, but also clays (illite and chlorite), silica and detrital grains of quartz, hyacinths and amorphous silica. The proportion of carbonates, if they are present, is below 1%, and the red gypsum is rich in hematite.

3.4 *Drainage and protection against water*

The runoff water from the terraces has been collected with a drainage pipe located at the base of the foundation. The trench has been protected with a geotextile mesh fabric and is partially filled with gravel.

Various techniques have been used to protect the coronation of the walls. In 2008 a rounded coronation was made to cover various courses of stone that will protect the ruins and give the complex the safety conditions required for the public to be able to enter. This new stonework has been laid avoiding straight lines, as we do not have precise information on the parapet's height, and has been differentiated from the original stonework by including brass screws with the date of intervention. Lime mortar was used to form this coronation to give the walls a better durability.

However, after two winters, we saw that the condition of the surface layer of the lime mortar was very poor, and decided to use a traditional formula called "Loriot mix" (Gárate Rojas 2002).

This mortar is made mixing 2/3 sand with 1/3 slaked lime, together with a minimum amount of water in order to get a homogeneous mixture. Then quicklime is added to the mortar in a proportion of 1/5 of the total. When it is strongly mixed it gives off heat, caused by the lime hydration, and acquires improved properties against atmospheric agents. A hydraulic lime mortar has been also used for this purpose in order to test different methods.

3.5 *Reintegration of lost structures*

Three reintegration methods have been implemented during the two conservation campaigns undertaken by the IPC in Calatayud.

The first consists in filling the big holes with gypsum masonry, not only in masonry works, but also in type 1 gypsum wall works due to its very similar composition. These reintegration methods nevertheless had two different finishes in order to not confuse the different building methods. In the type 1 gypsum wall works the finish consists of a gypsum mortar laid several centimeters back from the original surface.

The second method is the reintegration with a true rammed earth construction made with wooden frames the same size as the original ones, filled with gypsum and gypsum stones in the same proportion found in the original type 1 walls. This method could be used in those places where the thickness of the reintegration volume was over 35 cm.

Theure third and more complicated procedure was the reintegration of the type 2 rammed earth. As there were no pieces of stone but only earth, the adherence between the new and the old material was not guaranteed. A gypsum mortar with pieces of unfired gypsum gravel between 5 and 20 mm thick was applied to the old structure after watering it down. In order to get the necessary cohesion, a set of PVC nails—known in Spain as mushrooms—were used to fix insulation and were nailed to the strongest parts near the rammed earth joints, and then reinforced with fiberglass fabric.

4 FACE READING

4.1 *Scope of the stratigraphical analysis*

The present study has been carried out during the process of the consolidation works around the area of the defensive wall of the Castillo Mayor, on the north side. This was done so we could verify the initial state of conservation, as well as to compare the documentation generated when certain areas are discover under sediments, deposits of collapses, and earth stuffed. Also, the use of face reading has turned out to be an important instrument in the documentation and evaluation of the real effects on each stratigraphic unit, including works of restoration as a final phase (Mileto 2003).

We had to be aware that the reading process was partial and the analysis was limited to a minimum part of the monumental complex.

The C14 analysis of a small amount of wooden samples has been used to establish the chronology. None of the samples went back the 11th century (Cebolla 2011).

4.2 *Periodicity hypothesis and constructive phases of the "Castillo Mayor"*

The analyzed results have produced 5 stages at the final periodicity:

Period I: The first period is divided in three initial stages, which make up the phases I, II and III, and it corresponds with the castle construction and expansion (Peña Gonzalvo 2009). Stage I is made up of common rammed earth. This kind of construction is present in the stretch of wall that we are studying and in the stretch of the "Torre Albarrana". Stage II corresponds with gypsum wall built with formwork, made with gypsum mortar and stones. In general, it had been used in the towers of the stretch of walls that we are studying. The use of this typology speeded up the construction process, the structures cohesion and endurance in the castle's most complicated area.

Period II: The second period covers a gap between the middle of 12th century and the beginning of 13th. From this period we can date the linked rammed earth on the eastern stretch of wall,

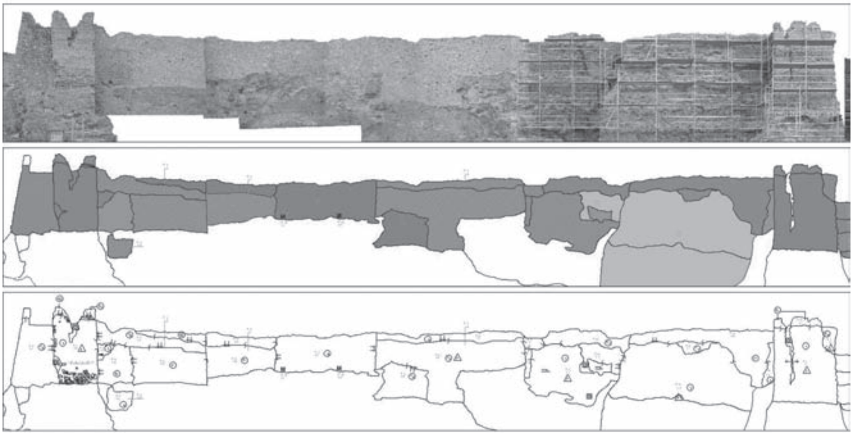

Figure 4. Face reading of the north wall.

between towers 2 and 3. The constructive, historical and bibliographical evidence all prove that its purpose was to reinforce the wall and was carried out at the beginning of Christian time (Graciani García 2008). It was probably done to paliate the effects of decay, but there isn't any trace owing to the consecutive processes of the reconstruction.

Period III: The original structure had suffered a long process of expansion since the 14th century. Especially during the reign of Pedro I, in which many changes and restorations took place (Almagro 1995, Souto 2005). Around this time the whole complex would be reinforced by reconstructions of large parts of the walls, where the reutilization of material abounds, by rebuilding the battlement, as well as by fixing blocked-up openings and hollows.

In the process of the face reading, we haven't identified elements belonging to activities developed between the 17th and 18th centuries. Therefore, we cannot determine the effects that positive or negative interventions may have produced during this period.

Period IV: The fourth period spreads from the 19th century, and is divided in three phases (VII, VIII and IX). During this stage there were adjustments made to adapt the enclosure into a fort prepared for the use of rifles (Peña Gonzalvo 2005). For this reason, there were modifications in the general aspect of the castle.

Then, the castle was abandoned and it suffered a systematic plunder, which added to the erosion and progressive collapse of several areas of the walls. Today there are numerous sectors in a situation of instable balance, which put the castle's conservation and the physical integrity of visitors in danger.

Period V: The works of conservation and restoration realized since 2008 not only consolidated the structures, but have increased the comprehension of this historical monument, which as has been explained is the result of a very long process of formation.

5 CONCLUSIONS

The conservation works in the Calatayud fortified complex has covered only a small part of its structures and cannot give definitive results. Nevertheless, they have shed some new light on the historiographical issues traditionally associated with the building and propose a relative chronology for the north walls of the "Castillo Mayor". Further interventions will be able to define this chronology more accurately.

After three conservation campaigns there is a small catalog of building methods than can be tested in the next few years in order to determine their suitability, and add information to the small amount of literature found on this specific type of walls.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)
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Rammed earth wall restoration method using the earth reintegration technique by ramming

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ABSTRACT: This article describes the rammed-earth wall restoration method using the earth reintegration technique by tamping. This technique is used in cases of severe material loss or when the superficial layer is seriously damaged. It is similar to the traditional system of tamping layers of earth laid down and confined within a wooden casing, except that here the wooden casing is only used for the outer face, the wall itself acting as the other face of the casing. As part of the preliminary study, it was necessary to carry out an analysis of the structural stability of the remaining wall's residual thickness, which allows the suitability of the method and the appropriate system for compacting to be determined. It is also necessary to carry out laboratory tests to determine the characteristics of the original historical material so that a material with similar characteristics can be used for the restoration.

1 INTRODUCTION

There is a great need to define the scientific and methodological bases for a correct intervention in the reconstruction and consolidation of the rammed-earth walls of our historic buildings. This article looks at the work carried out to restore the church of 'San Nicolás de Bari', which has involved the recuperation of the rammed-earth walls of the nave, in addition to carrying out important consolidation, restoration and appreciation work on the monument.

The restoration has been carried out using the material reintegration technique by tamping, i.e., using additional material of the same characteristics as the original, put in place with the traditional system of tamping down successive layers. The casing requires drill holes to pass through the entire thickness of the wall in order to fix the nails to the other side, since only one side has to have a casing, as the wall itself acts as the casing on the other side.

In order to obtain a good result, it is very important to carry out preparation work on the surface of the original wall. It is necessary to chip away at the damaged side of the wall to eliminate loose material. Then, the entire surface is scraped and the wall is given a final cleaning to eliminate dust and fine particles in order to achieve a clean contact surface. The internal binding between the existing earth and the new addition is guaranteed by the force of the compacting process and the lateral expansion of the newly added material, resulting in a single wall, called the wall of reintegration.

The technique described here has been carried out with fully satisfactory results and is suitable for cases of severe material loss or serious damage to the superficial layer of the wall.

2 BACKGROUND

2.1 *Current state*

The church of 'San Nicolás de Bari', in Sinovas (Burgos), was declared a National Monument in 1964. It is the result of many additions over a long period of time and it could be said that it is a "*collage*", made up of a 13th century Romanesque nave and facade, a 15th century tower, an apse and a Renaissance portico above the Romanesque facade, both from the16th century. Inside, the nave has a 15th century polychrome wooden coffered ceiling, belonging to the gothic-Mudejar school of Burgos, the artistic quality of which gives the monument an exceptional value.

The rammed-earth walls of the nave have undergone detailed research and consolidation work as part of the Monument's restoration process, the results of which are presented in this article. These walls were built in the 15th century on the foundations of the original 13th century stone walls. Historical documentation confirms the collapse of the ceiling of the nave of the Romanesque temple "*... taking part of the wall with it in its fall*". The exact causes are unknown, although there has been talked of a possible fire which, due to calcination of the stone, may have affected the solidity of the stonework. Whatever happened, those who performed the reconstruction work in the 15th century considered it best to rebuild the walls using earth instead of stone.

The rammed-earth walls were built using the remaining stone wall as support, once it had been levelled and assured. They also took advantage of the opportunity to make the nave higher, giving the church a greater presence, and putting in the abovementioned polychrome coffered ceiling. The new roof structure had to be trussed to eliminate the transmission of horizontal forces to the rammed-earth wall.

Throughout the contemporary era, the monument has been the object of several interventions, some of which have been unfortunate. Such was the intervention of 1965 to cover the rammed-earth walls. The north wall was rough-coated with cement mortar and chicken-wire meshing fixed to the facing; while the rammed-earth south wall was backed using *"... local stone imitating the original stone of the nave"*.

Thus, the monument's main facade seems to be made entirely of stone, although with a clear differentiation between the old and the new, producing a false impression of its historical evolution with a unified image of material that never existed.

Another unfortunate intervention was that of 1979, in which a new ceiling was installed above the existing one, throughout the nave *"… to protect the valuable wooden polychrome coffered ceiling"*. The ceiling is made up of a set of metallic braces resting on a concrete ring beam on top of the wall. At the same time, the roof of the Renaissance portico also probably disappeared, and was left without being rebuilt.

2.2 *The assignment*

At the end of 2008, the regional authorities (Dirección General de Patrimonio y Bienes Culturales de la Consejería de Cultura y Turismo de la Junta de Castilla y León) approved the project to restore the monument, which lasted until October 2010.

When the work began, the church was in a state of abandon, besides suffering from a lack of maintenance and the paucity of material with which the previous restorations of the 60s and 70s had been carried out. The monument also had problems associated with the wrong restoration criteria applied at that time, such as the stone facing of the main facade and the non-restoration of the roof above the entrance. Due to these facts, it was not possible to correctly interpret and evaluate the church.

The Restoration Project has allowed the church nave to be recuperated, first through a process of "*de-restoration*" and then a process of consolidation. Thus, today, the stone facing of the second half of the 20th century having been removed and the original wall recuperated, it is possible, through an adequate reading of the walls, to understand the vicissitudes of the monument's historical evolution.

Figure 1. Church of 'San Nicolas de Bari'. State before last intervention. The stone facing from 1965, covering the original rammed-earth wall, is visible. (Pinés & Jové-Architects).

3 METODOLOGY AND PRELIMINARY STUDIES

3.1 *Reading the walls through archaeological criteria*

In order to establish a clear scientific methodology, in which a complex intervention with *de-restoration* was foreseen, important preliminary studies were carried out.

The reading of the walls using archaeological criteria carried out by the enterprise "Estudios del Patrimonio Arqueológico e Histórico; Unoveinte", brought precision to the visual aspects. In the stratigraphic sequence of the south wall of the church, two different, superimposed stratigraphic units can be seen. The first, up to a height of 2.85 m from the altitude 0.00 of the entrance to the temple, corresponds to the base of the wall (specification UEM-10000), in which the construction material is specified as limestone masonry dating from the second half of the 13th century. The second corresponds to the upper part of the wall (specification UEM-70001), in which the presence of contemporary limestone slabs covering the exterior of the original wall is indicated.

In the north wall; two different, superimposed stratigraphic units are also visible. The first corresponds to the base of the wall (specification UEM-10003), with the same characteristics as those indicated for the abovementioned base of the south wall.

Figure 2. Restoration work. Recuperation of the rammed-earth wall built on top of the remnants of the 13th century wall (Pinés & Jové-Architects).

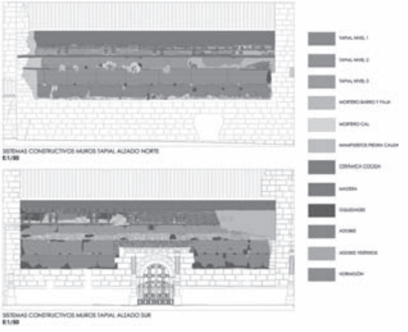

Figure 3. Wall face reading. (Félix Jové, GrupoTIERRA).

The second corresponds to the upper part of the wall (specification UEM-70003), in which contemporary cement mortar from 1965 is specified as the building material, covering the exterior part of the original wall. The presence of wooden nails is also noted (specification UEM-30000); these correspond to the coffered ceiling over the nave, dating from the beginning of the 15th century.

3.2 *Wall tasting*

A series of test samples were taken from the walls to know the thickness of the remaining original wall, its stratigraphy and the exact composition of its layers. Four samples were taken for this purpose, two from each of the walls, situated one above the other in each of the abovementioned stratigraphic units.

The samples were taken by means of drilling with a 50 mm diameter drill bit, perpendicular to the wall.

Cylindrical samples were extracted which literally showed the real wall section at the points of perforation, and which have allowed us to study the real composition of the walls. The lower part is, in both cases, a limestone wall with two unequal faces, filled up with smaller pieces of limestone, whose total thickness is 1.10 m. As for the upper part, there are two different solutions which are described below.

3.3 *Upper tasting of south wall*

On the outside of the wall there are sandstone slabs that try to imitate the base layers of masonry from the 13th century. These slabs, about seven centimetres thick, are held in place using cement mortar to one wall brick in contact with the original rammed-earth wall. This practice was typical at the time for restoring rammed-earth walls; first the outside face of the wall was scraped and cleaned, and then a facing of brick wall was raised which was then covered with cement mortar or stone slabs or other finishing material. This building system is fast, but is not correct because it stops the earth wall from transpiring, giving rise to a wall with two sides whose characteristics and behaviour are very different. In the upper part of the wall, the corbels of the eaves were eliminated and the heads of the braces of the coffered ceiling that stuck out were sawn off.

3.4 *Upper tasting of north wall*

In the north wall, in spite of what was indicated in the restoration project of 1965, the stone slabs and brickwork of the south wall were never done, cement mortar being applied with metallic wire nailed onto the original wall, so the total thickness of the wall would remain the same.

This cement rendering was affecting the wall's natural transpiration, which was in a very bad condition; hollow in places and with spalling that had left the wall itself exposed. The finish was extremely rough and with no surface treatment. It should not be forgotten that this wall is the rear wall of the monument, so the previous restoration here was a very superficial one, applying a simple exterior protection to the wall, ignoring aesthetic aspects.

Unlike the front wall, here it is possible to see the heads of the braces of the wooden coffered ceiling, as well as fragments of a sleeper, which was probably the support for the original cornice.

Loss of material is visible in the upper part of the wall due to rainfall, giving the sensation that the nave wall has lost the vertical with respect to the tower's stonework. The original corbels of the eaves were eliminated and substituted by a brick cornice, which was in very bad conditions, and generates a clearly insufficient distance from the plane of the facade.

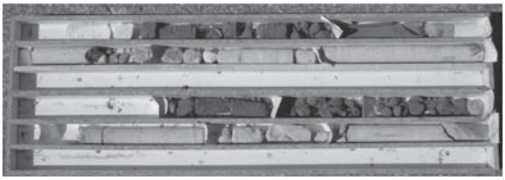

Figure 4. Church of 'San Nicolas de Bari'. Tasting from the south wall. The stratigraphy of the wall, each one of its layers and its real thickness, can be seen. Exterior slabs of stone on brickwork and interior body of wall, terminated inside with a rendering of lime (Pinés & Jové-Architects).

Inside, in the samples from both walls, the lime rendering, with a thickness of 5 cm, and showing no damage or damp, can be seen.

4 TRIALS AND CHARACTERIZATION OF THE MATERIALS

4.1 *Samples*

Using the material extracted in the sampling, ground characterization tests were carried out to determine the characteristics of the earth used in the original construction.

This source of data has allowed us to establish the characteristics of the earth used in the construction and to locate an "*earth quarry*" of similar characteristics to those of the original material used so as to be able to proceed with the restoration.

4.2 *Laboratory trials*

Size classification tests were carried out using a sieve and Atterberg's Limits (Spanish standards UNE-103.101:95, 103.103:94 and 103.104:93) to determine their characteristics and plasticity index. The two samples of the historic walls, south wall (sample 1) and north wall (sample 2), had similar characteristics. In both cases, they are brown sandy clays with low plasticity. The trials were carried out by the EPTISA Laboratory; the results are in Table 1.

This type of clay is found in the "*las barreras*" area of the village where, until the 1960s, material was still extracted by the villagers to make adobe. To make rammed-earth walls, this clay was mixed, according to the testimonies that have been gathered, with clean sand from the nearby River Duero. The first thought was to use exactly the same material for the restoration work; however, problems of access to the old quarry—now unused—led us to look for another source of material.

Finally, waste ground from the factory "GRUPO Gerardo de la Calle", situated in the nearby town of Aranda de Duero, was used. The tested samples, whose results can be seen in Table 2, showed dark brown sandy clays of low plasticity, with sporadic rounded silica gravel, appropriate for use.

Table 1. Trials with 15th century earth wall samples.

	Sample 1	Sample 2	Mean
Liquid limit	29.7	29.9	29.8
Plasticity limit	15.5	15.9	15.7
Plasticity index	14.2	14.0	14.1
Casagrande	CL	CL	CL
HRB	A-6	A-6	A-6

Table 2. Trials with restoration earth samples.

	Sample A	Sample B	Mean
Liquid limit	31.3	30.6	30.95
Plasticity limit	17.1	16.4	16.75
Plasticity index	14.2	14.2	14.2
Casagrande	CL	CL	CL
HRB	A-6	A-6	A-6

Table 3. Size classification analysis: % passing through sieve.

	20.0	12.5	10.0	5.0	2.0	1.25	0.4	0.16	0.08
M1				100	99.5	98.1	89.5	68.3	55.9
M2		100	98.9	98.2	98.0	97.8	90.0	69.6	58.5
MA	98.3	97.6	97.4	97.4	96.3	95.5	91.0	76.3	69.3
MB	100	99.5	99.4	99.3	97.7	97.0	92.2	76.9	69.5

The use of this earth guaranteed us a good, homogeneous supply of material, while also avoiding having to mix in sand in situ, thus making the work much easier.

As for the results of the size classification analysis (UNE 7.375:1975), the percentage that passed through the sieve for each of the samples tested can be seen in Table 3.

As can be seen, the selected earth (samples A and B) shows a greater percentage of fine particles than the historical (samples 1 and 2). In any case, all the tested samples show an adequate size classification curve for constructing walls, since the percentage of particles below 0.08 mm in all of them is over 20%, which is the recommended minimum.

4.3 *Results*

The selected earth has totally compatible Atterberg limits for use in building work, with characteristics that allow a sufficient range for the possible addition of other types of earth: large particles when there is a need to increase the resistance of wall's skeleton or fine particles when it is necessary to increase its plasticity.

It also has a suitable size classification curve, with an abundant content of fine particles. Thus, finally, it was adopted as the base material for carrying out the consolidation and restoration work on the original wall.

5 BUILDING PROCESS

5.1 *The preliminary work*

Given the south wall's state of conservation, the first job was to fill the many holes with earth material. To do this, the surfaces were dampened and then filled in manually using additional material, pushing the earth into the holes by hand or with a trowel. The cohesive properties of the earth material itself meant that such manual pressure was sufficient to stop it from crumbling before compacting.

On occasions, wooden splints or plugs were used in order to achieve the desired form. The material was applied in thin layers to allow a correct compression later on by means of horizontal tamping. It is extremely important to ensure that the hole is completely filled, thus guaranteeing the binding of the old wall and the new.

Once the holes had been filled in, we then proceeded to scrape the wall to make it all level, in such a way as to enable us to continue with the tamping process with a much more comfortable angle of 45º.

This scraping, which is done manually with a trowel, makes the surface rough, thus improving contact between the two materials. Next comes the filling of the gap using a circular compactor of small diameter which allows for the correct compacting of the edges against the existing wall, ensuring a complete and homogeneous filling of the gap.

After filling in the cavities, the new rammed-earth casing is then made from phenol boarding. The adopted solution is a single-face, rammed-earth wall strengthened with lime. Lime strengthening is a building method which directly provides the wall's final finish, ensuring high durability.

5.2 *The formwork*

The restoration wall was then built. To do so, the wooden formwork (casing) is fixed to the wall by means of metal nails that pass right through to the inside of the nave. The lateral *slabs* were made to measure for each casing, given the heterogeneity of the exterior form of the remaining original wall.

The building process was as follows: after placing and levelling the formwork, the first layer of limed mortar was laid down, with a volumetric proportion of one part lime to six parts sand and low humidity, equivalent to that of the earth mixture. Using the trowel, the mortar is pushed up against the casing so that the mixture generates a natural inclination that corresponds with the internal friction angle Ø of its components. Then the earth is laid down, levelling off the thickness of the layer up to an approximate height of about 15 cm. The level is obtained by inserting a trowel with a mark indicating the desired height. The layer of earth almost totally covers the previous layer of limed mortar, leaving 2–3 cm of lime in sight against the formwork.

Finally, the vertical manual tamping is performed with wooden and steel tampers.

5.3 *The tamping*

The tamping starts with a deep sound indicating that the mixture is not compacted at all, and ends with a high-pitched, almost metallic, sound,

Figure 5. Restoration work on the rammed-earth walls. Church of 'San Nicolas de Bari'. (Pinés & Jové-Architects).

Figure 6. New rammed-earth section. We can see the limed mortar line after ramming. Work of reintegration wall. Church of 'San Nicolas de Bari'. (Pinés & Jové-Architects).

Figure 7. Restoration work on the rammed-earth walls Church of 'San Nicolás de Bari'. (Pinés & Jové-Architects).

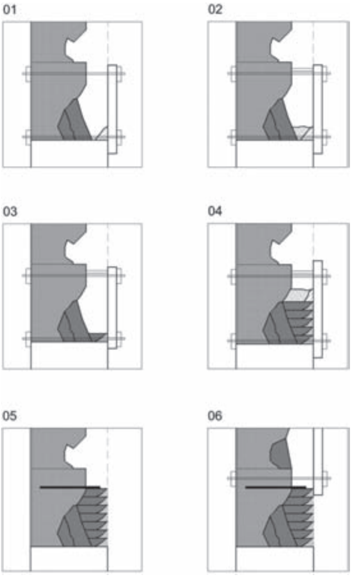

Figure 8. Building process applied in the material reintegration technique by tamping for the restoration of rammed-earth walls. (Félix Jové, GrupoTIERRA).

which indicates that the mixture has been totally compacted. The thickness of the layer is reduced to about 10 cm. As the tamping is done vertically, the mixture produces horizontal tensions; some of them act against the existing wall, so that the mixture once more pushes the earth with which the holes have been filled as well as the wall itself, ensuring a complete filling in of all the holes and guaranteeing a homogeneous behaviour of the entire thickness of the wall.

The laying down of layers continues with a similar process to that explained above. In each case, the correct compacting and levelling of the previous layer guarantees the correct structural behaviour of the whole. The formwork was constructed to a height of about 80 cm. The process is repeated in the upper levels, using the same drill-holes and upper nails as in the lower casing to secure it, in line with the traditional procedure.

Inside the church, all the drill holes in the wall for securing the casing are initially visible. The lime rendering and the final painting applied to the wall later hide all these marks.

6 CONCLUSIONS

The restoration method for rammed-earth walls using the material reintegration technique by tamping is very effective in cases of severe loss of material or serious damage to the superficial layer.

In order to guarantee good behaviour, it is necessary to select a compatible earth of similar characteristics to that of the rammed-earth wall to be restored, as well as carrying out meticulous preliminary work to prepare the surface of the wall; chipping, scraping and cleaning.

The result is a single wall in which the existing mass of earth and the new earth join together internally thanks to the force of the compression due to the tamping process. We have called the resulting element "rammed-earth of reintegration".

NOTE

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Restoration of rammed earth architecture: The projects funded by the Diputación Provincial de Valencia (Spain)

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ABSTRACT: The restoration of rammed earth architecture is included inside the series of interventions carried out on the architectural heritage sponsored by the Diputación Provincial de Valencia, during the period covering from 2000 to 2011. The research is intended primarily to analyze the type of intervention techniques applied and the materials used in the interventions on rammed earth and, at the same time, their execution, to find and determine the cases which are most adequate for and respectful of the historic building. This study intends to make them known, but, above all, contrast and analyze them as a whole to determine similarities, differences, side effects and their possible causes. The study has been carried out in the framework of the research project titled "The restoration of rammed earth architecture in the Iberian Peninsula." (Ref.: BIA 2010-18921) and financed by the Spanish Ministry of Science and Innovation.

1 FOREWORD

1.1 *The Diputación Provincial de Valencia: A brief explanation of its history and mission*

Spanish *diputaciones* are corporations chosen to lead and administer the interests of a province which have their origin in the Constitution of 1812, but were consolidated later on, after the provincial division of the State. In the case of the province of Valencia, which this article deals with, the *diputación* was created in the year 1836.

The Diputación Provincial de Valencia is therefore an institution which serves the municipalities of the province and acts as a "Council of Councils". Its main objective is to preserve the interterritorial equilibrium of the province and improve the administration of common interests in the scope of public health, social services, culture, education, public works and defense of the environment. It does so by cooperating with and advising the municipalities, and at the same time collaborating economically with those that have fewer resources. In this way, the Diputación distributes resources and services, paying special attention to the smallest villages, which do not for that reason lack important and abundant architectural heritage.

1.2 *The economic aid granted by the Diputación Provincial de Valencia*

The economic collaboration the Diputación Provincial de Valencia grants its' municipalities is reflected in the concession of specific aid linked to the areas they deal with. In the specific case of local architectural heritage, since the year 2000 the Diputación has given annual grants of economic aid destined to the works of restoration for the conservation of buildings in the province of Valencia which possess historic or artistic values, or are of local interest. The aid is given regardless of the ownership of the property, as long as it has public access. During the period covering from 2000 to 2004, this aid has been managed by the area of Heritage Administration and Maintenance of the Diputación Provincial de Valencia and after that, up to now, by the Department of Restoration of Cultural Property PIC and PID (Programas de Inversiones Culturales and Programas de Inversiones Deportivos [Cultural Investment Programs and Sport Investment Programs]). And the granting of aid is based on the artistic, architectural, ethnographic and typological value of each property and the severity of damage and level of risk of ruin or collapse that the buildings present, on the appropriateness of the proposals submitted, and finally, on the concession of aid granted in previous years. Moreover, it is necessary to point out that, prior to the creation of this specific aid, the different Provincial Plans of Works and Services and in some years the Cultural Facilities Plans have also contributed to the restoration of buildings with artistic value and even rammed earth architecture. This is the case of the Islamic tower of Albal, with a dossier of funded restoration in the year 1985 (ADPV, E.19.4, dossier 1, box 15029 year 1985).

2 THE RESEARCH: OBJECTIVES, METHODOLOGY, SCOPE AND LIMITATIONS

The main objective of the research was to examine in detail all the restoration projects of rammed earth buildings funded by the Diputación Provincial de Valencia between 2000 and 2011, given that precisely in this period the institution intended to enhance the conservation and protect the architectural heritage of the province, granting specific aid and allocating a part of the annual budget for this. Thus, the research is intended primarily to analyze the type of intervention techniques applied and the materials used in the interventions on rammed earth and, at the same time, their execution, to find and determine the cases which are most adequate for and respectful of the historic building. And in parallel, it aims to disclose the economic amounts the Diputación has destined to their restoration, as well as the typology and characteristics of the buildings and their restored walls.

Therefore, for each year, all the projects dealing with intervention on rammed earth architecture were selected, so we were able to consult the existing information in the records, and once they were analyzed, determine if they were actually interventions which affected rammed earth fabrics.

The only limitation of the study was precisely the information contained in the dossiers, as it can vary considerably in content and quantity. In general, the dossiers not only contain administrative but also architectural documentation, made up of not true restoration projects but mainly reports with brief estimates and historic-artistic studies, as they are part of the documentation required in the bases of the program for aid. In most of the records analyzed, there are few basic projects or execution projects which would provide detailed and comprehensive information, both written and graphic, of all the actions proposed. On the other hand, there are many reports without layouts, photographs or descriptions in which only the budgets provide some clue as to what has been done.

3 THE RESTORATION OF RAMMED EARTH ARCHITECTURE IN THE PROJECTS FUNDED BY THE DIPUTACIÓN PROVINCIAL DE VALENCIA

3.1 *The grants given by the Diputación Provincial de Valencia and the restoration of rammed earth architecture*

During the twelve years covered by the study, the Diputación Provincial de Valencia has funded a total number of 1,290 projects dealing with the restoration of properties of historical or artistic value or of local interest, which has meant approximately an average of 100 aids per year (except for the years 2001 and 2002, in which the number of projects funded amounts to 134 and 153 respectively, and the year 2008, in which the number is lower than 80). Without doubt, a great number of municipalities of the province have had the opportunity of restoring their heritage, if we take into account the fact that the province of Valencia is made up of a total of 226 municipalities (Table 1). However, on average, only five projects have been carried out on rammed earth architecture each year, regardless of the actions planned in each case. This number is further reduced if

Table 1. Summary of the economic aid granted by the Diputación Provincial de Valencia.

	Projects sponsored by the Diputación de Valencia		Projects on rammed earth		Interventions on rammed earth	
Year	Numb	Euros (€)	Numb	Euros (€)	Numb	Euros (€)
2000	117	3,005,000.00	2	84,142.00	2	84,142.00
2001	134	2,933,000.00	4	90,151.00	4	90,151.00
2002	153	3,005,054.00	3	70,151.00	3	70,151.00
2003	114	3,005,060.00	1	32,000.00	1	32,000.00
2004	112	3,005,060.00	4	180,100.00	2	120,000.00
2005	93	3,005,060.00	9	212,560.53	7	166,060.53
2006	94	3,005,060.00	5	143,000.00	4	119,000.00
2007	103	2,780,000.00	5	209,921.53	3	160,921.53
2008	78	2,900,000.00	7	312,945.79	4	170,645.44
2009	99	2,875,385.00	6	257,590.43	5	219,271.62
2010	97	2,235,000.00	7	207,526.00	6	187,526.73
2011	96	2,235,000.00	6	189,547.00	5	149,547.00
Total	1.290	33,988,679.00	59	1,989,635.28	45	1,551,386.85

restricted exclusively to the interventions carried out on foundations, walls, surfaces or copings the walls and elements with different material, such as floors, roofs or stairs, which can affect the rammed earth wall indirectly. To sum up, despite the fact that a total of 59 projects dealing with the restoration of rammed earth architecture were funded, we can only consider that on 45 occasions and on 27 different buildings this was actually carried out (Table 2). Without a doubt, this data should be valued positively because, nowadays, preserved constructions built with rammed earth are not very abundant in the province of Valencia.

Furthermore, from an economic point of view, during this period of time, out of a total of 33,988,679.00 Euros invested by the Diputación on the restoration of the local architectural heritage (which represents an annual sum of around 2,800,000.00 Euros), a total of 1,989,635.28 Euros has been specifically earmarked for the restoration of rammed earth architecture, unevenly distributed annually, since the amount varies depending on the number of projects and on the sum allocated in each case (Fig. 1).

Moreover, this does not imply that the amount granted by the Diputación is the only economic quantity used in the intervention on the buildings. Sometimes, there are considerable differences between the actual cost of the project, the aid requested and the aid granted, because major works of an elevated cost are proposed. This may entail that the budgets which were presented were later amended and, depending on the work to be done, the local entities may provide the difference or they may decide to divide the project into different execution phases, prolonging the interventions over time. In the latter case, the actions to be carried out are either changed from year to year to act on different elements or they are expanded due to the complexity of the intervention itself, as occurs with the Alfarp Castle and El Puig Hermitage in Xàtiva, which began phases number 7 and 8 respectively in 2011.

3.2 *The buildings with restored rammed earth architecture*

Geographically (Fig. 2), many of the buildings analyzed are located in the south of the province of Valencia, near the town of Xàtiva and close to the coast of Gandía and Oliva. On the other hand, there are few projects situated in the central and northern area of the province and in the proximities to the city of Valencia. The lack of projects

Table 2. Interventions on rammed earth sponsored by the Diputación Provincial de Valencia

Town	Building	Years
Aielo de Malferit	Palace	2005
Alaquás	Aguilar castle	2006
Alfarp	Tower of castle	2004/2005/2006/2007/2010/2011
Algemesí	Paret del Molinet	2002
Almoines	Arc del Trapig of Almoines sugar mill	2005
Ayora	Castle	2009/2010/2011
Bélgida	Tower of palace	2006
Benifaió	Mussa tower	2007
Bolbaite	Castle	2010
Chiva	Tower	2001
Chulilla	Castle	2008
Cofrentes	Castle	2000/2001
Cullera	Torre de la reina o Santa Ana	2002
El Palomar	Carrícola castle	2008
Estivella	Beselga castle	2005/2006
Genovés	Old church	2007
Gestalgar	Castle	2001/2010
Llutxent	Old palace	2001
Montroy	Castle	2005
Oliva	Palace of the Earls of Oliva	2010
Ontinyent	Palau de la Vila	2009
Simat de la Valldigna	Aqueduct	2009
Sot de Chera	Old castle	2005
Turis	El Castellet	2011
Xátiva	Hermitage of Santa María del Puig	2000/2002/2003/2004/2005/2008/2009/2010/2011
Xàtiva	Ardiaca Palace	2008/2009
Xeresa	Servana house	2011

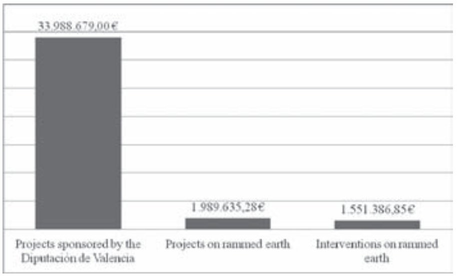

Figure 1. The economic aid granted by the Diputación Provincial de Valencia.

Figure 2. Map of the province of Valencia and the towns with restored rammed earth architecture.

in the interior area is remarkable, specifically near Chelva or Requena, where there are interesting examples of rammed earth architecture.

Furthermore, the majority of rammed earth buildings are defense structures, many of which are of Islamic origin. The interventions have been carried out mainly on towers, city walls, or on fortresses located not only on the outskirts of town centers (the donjon of the Cofrentes Castle, Chiva Tower or the Torre de la Reina in Cullera), but also inside the urban fabric (the tower of Alfarp Castle). Also, specific cases of manor houses were detected (Aielo de Malferit Palace, the palace of the Earls of Oliva and Llutxent Palace, among others), and churches (Genovés and the hermitage of Santa María del Puig de Xàtiva), farmsteads (the Arc del Trapig of Almoines sugar mill and the Servana house in Xeresa) and aqueducts (the one at Simat de la Valldigna).

Finally, it is worth emphasizing that it is complicated to pinpoint the type of wall in each building restored from the information analyzed in the records, because it only provides definitions and classifications given by the authors of the interventions or the editors of the historico-artistic studies. For this reason, in many of the projects it only states that the work is on rammed earth fabrics (tower of Belgida Palace, Ayora Castle, etc.) or concrete fabrics, as is the case of the documentation of the hermitage of Santa Maria del Puig in Xàtiva. However, it is also possible to find the following classifications and descriptions: rammed earth (Castellet de Turís, the Paret del Molinet in Algemesí, Cofrentes Castle and the palace of the Earls of Oliva); rammed earth with rubble (Turís Castle); rammed sand and clay earth with lime and gravel and a concrete crust, rammed earth with lime and sand, rammed earth reinforced with bonded layers of bricks (Aguilar Castle in Alaquás); brick- or stone-reinforced rammed earth (Cofrentes Castle, the Palau de la Vila in Ontinyent, Alaquás Palace); rammed earth reinforced with boulders and bonded layers of brick (Arc del Trapig of at Almoines sugar mill); lime-crusted rammed earth (Gestalgar Castle, Alfarp Tower, Ayora Castle, Bolbaite Castle and the palace of the Earls of Oliva); rammed earth with lime mortar and stones (Cofrentes Castle); rammed earth with gravel, sand and lime (Llutxent Palace); rammed earth of sand, gravel, lime and masonry (Llutxent Palace); rammed earth with lime mortar, gravel and sand (Aielo de Malferit Palace); rammed earth with lime mortar and masonry (Turís Castle); rammed earth with masonry (the Torreta in Chiva, Carricola Castle, the aqueduct of Simat de la Valldigna, Ayora Castle, Bolbaite Castle); rammed earth with lime and stone (Torre de la Reina or Santa Ana in Cullera) and rammed earth with stone or lime and masonry (Ayora Castle, Bolbaite Castle, the Castellet in Turís). Without doubt, we are dealing with definitions which sometimes coincide with one another and the type of existing walls, but it is also possible that many others lack scientific rigor and do not reflect the reality.

3.2.1 *The projects analyzed: intervention criteria, constructive techniques and materials used for the restoration of the walls*

Due to the variety of wall projects analyzed, different solutions are proposed depending on the necessities of the buildings themselves, the objectives pursued and the materials used. However, there are many aspects which coincide in the majority of interventions, both from a theoretical, technical and material perspective. While the intervention criteria are an aspect of great importance for any project of architectural restoration due to the fact that they define the main objectives of the interventions and how to reach them, in the great majority of the documentation analyzed, they are not mentioned. So the interventions proposed focus mainly on suggesting solutions to the existing problems, both for rammed earth walls and rammed earth architecture in general terms.

3.2.2 *Direct interventions on rammed earth walls*

The most direct interventions are included in this first group, i.e., those in which the intervention is made on the existing rammed earth walls, both in the foundation, its surfaces, walls and crowning.

According to the study, in Turís Castle only the foundation was intervened on by the addition of an inner filling with earth from the same works in order to consolidate it; in Gestalgar Castle, filling and compacting were performed around the foundation of the buttresses, and in the palace of the Earls of Oliva the foundations of structures on the ground were underpinned. The limited action carried out in this part of the architecture analyzed is probably due to either a good state of preservation or to a different materiality in comparison to the other walls.

On the other hand, the main part of the interventions focused on the walls and specifically on their reconstruction, repair and consolidation. Among the cases which go further than naming simply the reconstruction, it is possible to distinguish two different attitudes in their details and their relationship with the pre-existing walls. The first is the one adopted in Cofrentes Castle, in which the dangerous or more degraded parts were to be demolished to support the new sections of similar lime-crusted rammed earth wall, made with a paste made of natural soil containing cement by reproducing the traditional technique. The second posture is the one adopted in the Ayora Castle, where the original wall was conserved, so its consolidation and protection was necessary to ensure the reconstruction with rammed earth walls similar to the existing ones. Therefore, in both cases the reconstructions were carried out by means of original rammed earth techniques using mostly traditional materials, both in the walls and in the auxiliary items, using for example, timber formwork.

Also, the repair and sealing of cracks and large gaps usually requires sealing and injections. For this purpose, stainless steel staples and lime mortar are mainly used (Carricola Castle in El Palomar, Ayora Castle, Bolbaite Castle and the palace of the Earls of Oliva), but also fiberglass rods and epoxy resins (Turís Castle). However, a similar solution was not used for Montroy Castle, corners of the tower were repaired with ceramic brick of a similar color, made with mixed lime and white cement mortar.

Structural consolidation of the interior and the filling of cracks are also carried out by means of injections. The composition may vary from the use of lime mortars or lime and cement mortars in different dosages; the injection of lime mortar with consolidating products such as Paraloid and Xylene in Alfarp Castle, to the application of an expansive mortar of high initial resistance, like in Cofrentes Castle.

Several actions are carried out on the surfaces, mainly manual and non-abrasive surface cleaning to avoid damaging the original structure of the wall, and in this way to eliminate either the existing dirt and vegetation or the overlapping renderings that cover the rammed earth wall. This is the case of the Arc del Trapig at Almoines sugar mill, in which several manual techniques are combined, using small picks and brushes either with steel or synthetic and natural bristles. The superficial consolidation of the fabrics was also necessary in the majority of the interventions where either several hydraulic lime mortars should be applied, like in Sot de Chera Palace, or mixtures which contain cement. In Cullera Tower and the Cofrentes Castle, cement was combined with lime, sand, and natural pigments to retrieve some of the textures of the wall, whereas in Llutxent Palace, cement is simply mixed with sand and slaked lime in a dosage of 1:1:6. Also, to avoid differences of color on the surface, a hydraulic lime glaze was proposed in Ayora Castle, which contrasts with the silicate-based patina with mineral pigments of Sot de Chera Castle or a Fakolith product called Mixol in Alfarp Castle. And also water-resistant treatments with two components, diluted in toluene in a 15% up till rejection or saturation of the support, applied with a paintbrush (the Torre de la Reina or Santa Ana in Cullera), biocidal treatments, in order to protect the walls from vegetation, and water-resistant products of emulsion with a very diluted watery base of siloxane and alkosilan without the presence of organic solvents (Sot de Chera Castle) or even colourless water-resistant treatments without with Fakolith chemical products (Alfarp Castle).

Finally, the few interventions proposed for the crowning of rammed earth walls aimed, on the one hand, to protect the fabrics from erosion, which in Llutxent Palace was achieved by applying a mixed mortar with cement, slaked lime and river sand in a dosage of 1:1:6; and, on the other hand, to restore the missing volume, and for this reason, the same traditional techniques proposed for the reconstruction of the rammed earth walls with a curved crowning were used to evacuate the rainwater better. However, the intervention on Montroy Castle differs considerably from the former, because it entails "the restitution of the crowning of the tower up to its original height with a two-foot wall colored with ceramic brick similar to that of the tower, made with a mixed mortar of lime and white cement".

3.2.3 *Indirect interventions on rammed earth walls*

This second group includes interventions which affect elements of rammed earth architecture built with other techniques, as is the case of floors, domes, roofs or staircases connecting different levels, but whose restoration method can affect the rammed earth structure. In this case, it is necessary to highlight the intervention carried out on Montroy Castle, where the roof was repaired, waterproofed and paved on top of a layer of white reinforced concrete; the reconstruction of the ruined vaults was performed with white cement concrete and the reconstruction of two staircase wings was also carried out with white cement concrete, paving it successively with iroko wood planks fitted into place and screwed to the base. Without doubt, this is representative although not the only example of the frequent use of cellular concrete slabs (Carricola Castle in El Palomar, which was completed with a pavement of hydraulic lime mortar); the use of ground floor slabs of mass HM-15 concrete 10 cm thick paved with Ulldecona stone (Alfarp Castle) or wood (Cofrentes Castle); the filling of the extrados of the vaults with light expanded clay; the use of slabs of lightened Arlita F5 reinforced concrete (Beselga Castle in Estivella); and the building of concrete tie beams, both for floors, stairs and concrete lintels (Alfarp Castle and Cofrentes Castle). Only in Turís Castle were wooden lintels used and in Llutxent Palace the reconstruction of the floors was also performed with wood.

3.2.4 *Other interventions*

Finally, a third group includes projects which, due to the age of the buildings restored and to their historic role (defensive buildings of difficult access) were aimed primarily at improving access or their surroundings, and thus initiate their valorization and future use as museums. This is the case of the upgrading of the external access to Domeño Castle in 2005 and the second phase of the Carrícola Castle in El Palomar in 2010. Interventions were not made directly or indirectly on rammed earth structures, but benefited them as it made it possible to visit them.

3.2.5 *The materiality of the interventions*

In general, in the construction techniques described, traditional materials for rammed earth walls such as soil, lime, sand, gravel and masonry are combined with modern materials like cement, fiberglass, stainless steel or chemicals, in direct contact with the historic wall. Although traditional techniques are often used in an attempt to show respect for the rammed earth wall and concern for the chromatic finish in the majority of the cases analyzed, materials that are completely unrelated to this type of constructions are still used.

4 CONCLUSIONS

The interventions analyzed are very recent but they constitute a good example of the techniques and materials used nowadays. They mainly affect superficial and structural consolidation and partial reconstructions to complete missing volumes or fill in gaps in damaged buildings, due to the age of the buildings and the absolute lack of maintenance. Moreover, the cases analyzed are very similar regarding the type of intervention and materials used, because they generally seek to respect the original techniques and the use of traditional materials, although this is not always possible. Finally, we must point out that there may possibly be differences between what was intended and what was actually done, because changes in the materials or the solutions are frequent in any architectural project, and even more so in heritage buildings.

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In the Archivo General y Fotográfico of the Diputación Provincial de Valencia (ADPV) the following records of 1985 have been consulted and analyzed: 1 of box 15029 of section E.19.4; of the year 2000: 131, 037, 033, 013, 234, 153, 283, 093, 030, 035 y 123; of the year 2001: 151, 075, 051, 318, 206, 146, 078, 056, 117, 321 y 065; of the year 2002: 185, 118, 240, 105, 226, 238 y 176; of the year 2003: 185; and finally of the year 2004: 260, 057, 146, 177, 267, 114, 262, 225, 017, 293 y 153.

In the Department of Restoration of Cultural Property PIC and PID of the Diputación Provincial de Valencia the following records of the year 2005: 323, 066, 391, 172, 281, 329, 228, 266, 235, 154, 119 y 386; of the year 2006: 182, 032, 288, 116, 143, 311 y 266; of the year 2007: 035, 298, 126, 307, 127, 853, 864 y 243; of the year 2008: 550, 327, 103, 279, 333, 042, 041, 351, 238, y 579; of the year 2009: 381, 482, 380, 368, 184, 369, 220, 206, 356 y 466; of the year 2010: 453, 403, 452, 025, 387, 454, 440, 073, 379 y 380; and finally of the year 2011: 053, 375, 575, 172, 529, 538, 140, 360 y 037.

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Restoration of the Castle of Sot de Chera's Tower (Valencia, Spain)

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ABSTRACT: Moorish defensive towers are very common in the Valencia Region, (Spain) as they were part of the defensive system of the territory known as Al-Andalus. Those constructions were made mainly with mud walls; this traditional technique was very common, mainly because of its resistance, strength and economy. In this paper, the project and the works made to recover one of these defensive buildings are presented. This is the old Castle placed in a town called Sot de Chera. This paper shows the different phases of the restoration: the recollection of data, the archaeological tasks and its previous reports, the analysis of the materials and the study of solutions and its criteria, and the final construction. It emphasizes the mud wall technique as the most relevant part of the intervention. The process of restitution has employed the mud walls technique as it was made centuries ago, with its advantages and inconveniences. The paper also shows the difficulties found and the solutions implemented to recover the tower, as an example for future interventions.

1 INTRODUCCION

1.1 *Emplazamiento y del entorno*

Sot de Chera es actualmente un pequeño municipio de la provincia de Valencia, situado aproximadamente a 70 km al NO de la capital.

Geográficamente se localiza en la comarca de los Serranos, una zona muy montañosa entre las estribaciones de la sierra de Javalambre y la sierra del Negrete. Por su término discurre el río Sot o Reatillo, uno de los afluentes del río Turia.

Los restos del Castillo se sitúan sobre un promontorio rocoso junto al río, en el extremo SO del casco urbano actual. Esta ubicación, próxima a las escasas zonas llanas de cultivo de la zona en la vega del río, combina en este enclave estratégico el dominio sobre los caminos o pasos del valle, la disponibilidad de agua y un adecuado soleamiento.

1.2 *Antecedentes históricos*

En la zona se conoce la existencia de asentamientos de distintas épocas, con orígenes íberos y posterior colonización romana, esta última vinculada a la explotación del caolín, material utilizado habitualmente en la elaboración de cerámica.

El origen del Castillo es todavía incierto, pudiéndose deber a la sucesión de distintos asentamientos, con posible presencia visigótica, aunque los antecedentes más importantes y reconocibles son de la época árabe y después cristiana.

Durante los siglos XI y XII, los reyes taifas y los gobernadores almorávides y almohades formaron una red de castillos y fortalezas según la nueva distribución territorial en que se dividió el califato de Córdoba tras su abolición en el año 1031.

La mayoría de las hipótesis históricas planteadas hasta ahora suponen la existencia de una alquería árabe anterior al siglo XI, posiblemente sobre algún asentamiento previo, que pasó en este momento a convertirse en fortaleza.

Estos inicios y el emplazamiento seleccionado se repiten en muchas fortificaciones del sistema defensivo de Al-Andalus. En este caso, se corresponde con el modelo de una zona o elemento defensivo y militar, con un desarrollo urbano entorno al mismo.

Tras la conquista y formación del Reino de Valencia, el rey Jaime I donó la "alquería de Sot de Chera" (que incluía también el vecino lugar de Chera), al caballero Don Hurtado de Lihory, en donación reseñada en el "Llibre del Repartiment" en 1238.

La importancia estratégica del Castillo de Sot de Chera está relacionada con la situación fronteriza que tuvo en esta época. Fue un lugar de encuentro de varias rutas históricas entre los reinos de Castilla y Aragón, como punto de paso a poblaciones como Chulilla, Gestalgar, Chelva, Tuéjar y Alpuente.

En 1365 durante la guerra entre Pedro I el Cruel de Castilla y Pedro IV el Ceremonioso de Aragón, el castillo fue atacado y probablemente arrasado, como ocurrió en la vecina población de Chera. Un segundo ataque importante al castillo se produjo sobre 1429 en la guerra entre Juan II de Castilla y Alfonso V de Aragón. La población también sufrió episodios de epidemias y la expulsión de los moriscos, quedando casi despoblada en torno al año 1525.

La Carta Puebla de Sot de Chera se otorgó el 10 de enero de 1540 por Miguel Ángel de Mompalau, señor de la Baronía de Gestalgar y Sot de Chera, a favor de 12 nuevos moradores, que inician la repoblación y recuperación de la población.

Finalmente, cabe citar el apresamiento del Guerrillero Romeu durante la guerra de la Independencia en España. Se produjo en Sot de Chera el 7 de junio 1812, donde se había reunido con los jefes de varias partidas para planificar la estrategia militar en la lucha contra los franceses.

Se trata, por lo tanto, de una fortaleza y una población que sufrió varios ataques entre los siglos XIII y XVI, quedando huellas de los distintos hechos y avatares históricos en los restos de las construcciones que se han conservado hasta la actualidad.

Figura 1. Vista de la Torre del Castillo de Sot de Chera antes de su restauración (año 2002).

2 ESTADO INICIAL

2.1 *Situación urbana y accesos*

La parte más apreciable de los restos del Castillo es la Torre y su muralla próxima, que están rodeadas por las viviendas más antiguas del casco histórico de la población.

Estas viviendas y sus corrales, utilizan o aprovechan partes de las murallas y sus elementos defensivos. Por ello es bastante frecuente apreciar gruesos fragmentos de muro en las fachadas, medianeras e interiores de algunas viviendas. Los accesos al Castillo se encuentran protegidos y son reconocibles entre el trazado urbano, formado por calles estrechas, de forma sinuosa e intrincada, con mucha pendiente.

2.2 *Circunstancias iniciales*

Entre los años 1980–1985se produjo una grave agresión al Castillo, la demolición de una serie de construcciones anexas que incluso pudieron formar parte del mismo, y la construcción de dos viviendas unifamiliares. Desde ese momento, se detuvo cualquier intervención en el entorno del Castillo.

A partir de entonces (año 2001), se inició la redacción del nuevo PGOU del municipio, en el que se incluía el Catálogo de Bienes y Espacios Protegidos con una ficha específica sobre el Castillo. También se estableció la delimitación de su entorno y una normativa específica de protección.

Este proceso fue paralelo al nacimiento, y posterior desarrollo, de la normativa y legislación sobre patrimonio histórico que se produjo en España, y posteriormente en la Comunidad Valenciana, durante estos años.

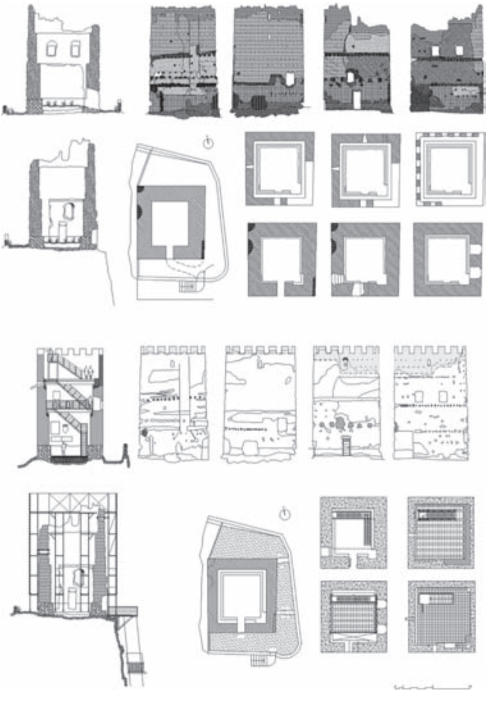

Figura 2. Planos del estudio previo y del Proyecto de ejecución.

2.3 *Los estudios previos*

Antes de iniciar el proceso de restauración se llevó a cabo un estudio completo. El proceso comenzó con la realización de una serie de levantamientos gráficos y fotográficos que sirvieron de base para el posterior tratamiento y elaboración de los datos con programas CAD.

Sobre estos datos se identificaron los distintos tipos de obras de fábrica, así como sus características fundamentales, evaluándose su estado y los daños más apreciables. En función de este estudio se preparó la primera propuesta de intervención.

Simultáneamente, se realizó el estudio arqueológico, en el que se recopilaron los datos históricos, y se establecieron las zonas de intervención de mayor interés y el seguimiento de las actuaciones a realizar.

Estos trabajos de campo se complementaron con análisis en laboratorio de granulometría y composición del tapial, obtenidos a partir de muestras disgregadas de la parte inferior de los muros interiores que resultaban poco visibles. La granulometría original de esta tapia resultó ser muy compacta.

2.4 *Características de la construcción y del tapial*

Según estos estudios previos la Torre fue construida con gruesos muros de tapial, cuya sección va disminuyendo desde la base hacia la parte superior debido a los apoyos intermedios de los forjados.

La torre tiene una planta aproximadamente cuadrada, de 9.20×9.80 m y una altura de 14.40 m. Se aprecia la realización de 15 módulos de tapial con un módulo de dos codos árabes y la altura de los cajones correspondía con 92 cm.

La base y apoyo sobre el promontorio son de muro de mampostería. Este elemento, más resistente ante posibles ataques, era utilizado comúnmente como cimentación y elemento de transición, permitiendo la nivelación necesaria para la ejecución del tapial.

3 LA PLANIFICACION DE LAS OBRAS

3.1 *Los proyectos de obras*

En agosto de 2003se redactó el primer Proyecto de Rehabilitación gracias a los convenios y acuerdos de colaboración entre el Ayuntamiento de Sot de Chera, el Servicio de Asistencia Técnica a Municipios de la Diputación de Valencia y la Dirección General de Patrimonio de la Conselleria de Cultura.

El primer proyecto contemplaba dos fases, en correspondencia con los dos aspectos fundamentales de la intervención: la consolidación exterior y el acondicionamiento interior. Así se adaptaba a los costes previstos de las obras y a las posibilidades de financiación, ya que los recursos eran limitados. Esto permitió solicitar ayudas y subvenciones de distintos organismos, como los fondos FEDER y LEADER.

Figura 3. Vista del andamio y del montacargas en el inicio de las obras.

Posteriormente, en noviembre de 2008, se redactó un Reformado de Proyecto que modificaba la segunda fase, que incluía las obras acceso, acondicionamiento interior, recuperación y mejora del entorno.

Este desarrollo del proyecto en varias fases permitió adaptar y mejorar la realización de las obras, ajustando los trabajos y las soluciones constructivas al mejor conocimiento de la torre, estado y circunstancias, por la colocación de los medios auxiliares.

3.2 *Los criterios de intervención*

Entre los criterios de intervención adoptados pueden distinguirse dos tipos: los teóricos o proyectuales y los constructivos. Estos criterios estuvieron en continuo diálogo durante la realización de la obra y se adaptaron a la realidad material de la Torre, lo que generó una paleta específica de recursos para resolver los distintos problemas.

3.2.1 *Criterios de proyecto*

El criterio fundamental fue la recuperación de las distintas fases o circunstancias históricas que había sufrido la Torre, siguiendo el principio del máximo respeto hacia la evolución de las construcciones históricas.

Siguiendo este principio de la restauración arquitectónica, se han mantenido, e incluso consolidado, las huellas de todos los avatares que han sufrido los muros de la Torre: apertura de huecos, vaciados parciales, huellas de elementos constructivos adosados (una chimenea y varios niveles exteriores de forjados) y los impactos de proyectiles de distinto tipo.

Asimismo, se eliminaron estrictamente aquellos elementos que perjudicaban la conservación de la torre: restos de escombros, vegetación silvestre, antiguas instalaciones y morteros de relleno utilizados en reparaciones anteriores no documentadas.

Otro criterio de intervención fue la utilización de técnicas constructivas tradicionales, realizando un tapial de tierras (o gravas) y cal. También se emplearon la menor cantidad posible de elementos y materiales diferentes, ajenos a la construcción inicial.

Como último criterio de proyecto se diferenció la obra nueva de la existente, empleando varios recursos: pequeños elementos de separación como una fina malla de polietileno, y la realización del tapial, con una modulación similar al preexistente, pero no idéntica. En la realización de los muros perimetrales de mampostería también se mantuvo este criterio, utilizando el mismo tipo de material o solución constructiva, con una disposición de los elementos ligeramente diferente.

No obstante, se procuró que todas las intervenciones y las fábricas siguieran un criterio de integración, de modo que las diferencias entre las partes o elementos originales y los restaurados o repuestos fueran apreciables a media o corta distancia, pero sin perder la visión de conjunto a nivel volumétrico y de apreciación general.

3.2.2 *Criterios constructivos*

La sustitución de aquellos elementos o partes de fábrica que estaban en muy mal estado. Para ello fue determinante el nivel de disgregación o fragmentación de la fábrica (o los elementos que la constituyen), que impedía su consolidación o compactación y, por lo tanto, la transmisión adecuada de cargas al resto de las fábricas, lo que comprometía la estabilidad del conjunto.

Se establecieron bases de apoyo que fueran firmes y estables, así como unas adecuadas uniones de los tapiales nuevos con los existentes y de estos últimos entre sí. Esto se consiguió realizando encuentros con la rugosidad adecuada y aprovechando o, en su caso, realizando llaves de unión entre las distintas partes.

Por ello, fue preciso retirar la parte superior de algunos tramos de muros reconstruidos tras las ocupación cristiana, hasta alcanzar un apoyo suficiente y estable. Esto coincidía con los inicios de un módulo de tapia y permitía el atado con el resto de la obra.

La intervención en huecos o faltantes de menores dimensiones también siguió criterios constructivos, ya que estos huecos, situados generalmente en la parte exterior de los muros, podían generar un deterioro progresivo de la torre.

Dada la dimensión de estos elementos, no era posible realizarlos con tapial, por la dificultad de compactación. Se rellenaron con fábrica de mampostería, de manera similar a lo que se realizaba en su época, de lo cual se han encontrado ejemplos en la Torre.

El relleno de estos huecos, así como el resto de los muros recompuestos, se retranquearon ligeramente (entre 1 y 2 cm) respecto al plano original de referencia, diferenciando la parte restaurada.

3.3 *Medios auxiliares*

La dificultad de acceso al Castillo fue un aspecto fundamental, ya que por un lado se encontraba el promontorio rocoso prácticamente vertical (un desnivel de 40 m sobre la base) y, por otro lado, el abigarrado caserío y las calles tortuosas de acceso, que hacían muy compleja la llegada por esta zona.

Este fue uno de los principales inconvenientes para el estudio y la posterior intervención. Por lo tanto, en fase previa a la formalización del proyecto se tuvo que estudiar con varias empresas constructoras cómo se podían hacer llegar todos los materiales, medios auxiliares y elementos complementarios hasta la parte superior según los medios que cada empresa disponía.

Finalmente, se optó por una solución novedosa, considerada como la más sencilla, viable y segura, que consistió en la instalación de un montacargas inclinado hasta la plataforma auxiliar en voladizo ubicada al pie de torre. Esto permitió un suministro sencillo y constante de materiales y elementos auxiliares de la obra.

Figura 4. Compactación de la masa de la tapia.

3.4 *Zona de acopios, ensayos y pruebas*

Un aspecto que también resultó fundamental fue establecer la zona de acopio de materiales, de fácil acceso a pie y rodado, con todos los servicios y suministros necesarios, obligatoriamente próxima al montacargas.

En esta zona se realizaron con facilidad pruebas de ejecución de los primeros tapiales, se comprobó la dosificación, se realizaron las muestras, ensayos de los tratamientos que posteriormente se aplicarían en las fábricas. Esto supuso ahorro de tiempo en la ejecución, ya que se trabajaba con el entrenamiento previo de los operarios y la verificación de los materiales a emplear.

En esta zona se procedió posteriormente a realizar las amasadas periódicas de la mezcla de la cal y los áridos para la masa del tapial, así como para realizar los morteros de las obras complementarias.

4 EL DESARROLLO DE LAS OBRAS

4.1 *Revisión, actuaciones y tratamientos iniciales*

Las obras comenzaron en julio de 2004 con el acopio de materiales y el montaje de los andamios del montacargas. Seguidamente se realizó la limpieza y el desbroce interior y del recinto próximo a la Torre.

Previamente se había llevado a cabo la intervención arqueológica, que supuso el vaciado interior y exterior de escombros. Tras realizar un aporte de rellenos de gravas para nivelación de las superficies de apoyo, se montaron dos andamios tubulares, uno exterior rodeando el perímetro y otro interior. Estos elementos auxiliares disponían de plataformas horizontales situadas a las distintas alturas de trabajo para facilitar el acceso a todas las zonas.

Estos andamios permitieron revisar y completar el análisis de las condiciones iniciales de la Torre en los niveles superiores y en el remate de la misma antes de inicio de las obras, lo cual no se habían podido realizar por resultar inaccesibles.

Seguidamente, se procedió a la pulverización de un biocida de amplio espectro que permitiese eliminar tanto la vegetación.

4.2 *Ejecución del tapial*

La intervención proyectada contemplaba la recomposición de las zonas degradadas siguiendo los criterios expuestos en el apartado anterior.

Se consideró fundamental recomponer aquellas partes de las fábricas que identificaran las cotas de forjados, completaran los muros en altura y anchura, y finalmente recuperaran las almenas. En todos los casos, y especialmente en este último elemento, se conservaron los restos de arranques dejando la mayor parte del testimonio de los elementos originales.

Siguiendo esta forma de proceder, los primeros tapiales se realizaron siempre sobre los restos saneados de los existentes, de forma que repitiese la elaboración original de la fábrica de tapia.

Previamente se confeccionaron seis pruebas con dosificaciones diferentes que permitieron decidir la dosificación final elegida, así como el proceso de compactación a seguir en la confección del tapial.

Durante el proceso de montaje se acodalaron los restos a conservar de forma que se integraran en la nueva fábrica del tapial. Para la disposición de las agujas se utilizaron varillas de acero roscadas pasantes, que permitiesen el encofrado y desencofrado, su reutilización y una mayor rapidez durante el proceso de elaboración. Era necesario conseguir el suficiente confinamiento de la masa y una adecuada sujeción, evitando el desplazamiento de las tablas.

Los tapiales se construyeron con 4 tablas de 22 cm de anchura y 4 cm de grosor colocando los costales cada metro y medio aproximadamente.

La masa del tapial se formó utilizando los áridos de la zona, de modo que se conseguía una mayor integración con los restos de la tapia existente. La dosificación empleada fue la siguiente: 4 partes de arena amarilla, 4 de arena blanca, 8 de grava de río, 3 partes de hidróxido de cal y 1 de cal hidráulica.

El amasado se realizó mediante hormigonera eléctrica, lo que permitió obtener una masa muy homogénea. La proporción de agua fue mínima,

Figura 5. Resultado del tapial empleado en la recomposición de la zona superior de las almenas.

generando una masa muy seca, que por la acción de la compactación manual, se obtuvo una fábrica muy compacta. La masa fue vertida en tongadas de 8 cm aproximadamente, que después del apisonado se redujeron a unos 5 cm. Esta compactación se reforzó puntalmente en las zonas próximas al encofrado.

En los remates de las almenas y de los antepechos se finalizó la última tongada de forma convexa para facilitar la evacuación del agua de lluvia y evitar encharcamientos y erosiones por acción de las heladas.

4.3 *Procesos complementarios de reparación*

En la tapia existente se realizó una consolidación con lechadas de cal de las zonas exteriores y de las zonas que iban a conectarse con las nuevas fábricas. Se procedió al sellado de las grietas mediante la inyección de varias lechadas de cal hidráulica de forma ascendente, hasta la colmatación de las mismas.

Las grietas y huecos de mayores dimensiones se rellenaron con mampostería y un mortero con la misma dosificación que la masa utilizada para la tapia, pero en este caso sin el árido grueso de río.

4.4 *Acabados*

Una vez finalizada la nueva fábrica de tapia se procedió a un patinado muy superficial en aquellas zonas en las que el color del tapial ejecutado difería de la tonalidad existente en el resto de la fábrica. Para tal fin se utilizo una base de pinturas al silicato con pigmentos minerales de forma que se creaba una veladura superficial.

Se optó por esta solución frente a una posible coloración inicial de la masa del tapial, debido a las considerables diferencias de tono, textura y cromatismo que presentaban las distintas zonas de la Torre. Estas eran debidas a la distinta orientación, recomposiciones o fases de ejecución, y presencia en alguna de ellas de líquenes.

No obstante, esta pátina irá desapareciendo con el paso del tiempo, por los procesos de carbonatación de la cal y de erosión ambiental, dando lugar a una integración más natural, como ya se puede apreciar.

Finalmente se aplicó un tratamiento preventivo de biocida de amplio espectro y un hidrofugado en toda la torre mediante una emulsión en base acuosa muy diluida de siloxanos y alkosilanos sin presencia de disolventes orgánicos.

5 CONCLUSIONES

La rehabilitación de la Torre del Castillo de Sot de Chera se ha realizado recuperando la misma técnica constructiva que se empleó en su construcción original, lo que la ha hecho perdurar durante más de 900 años: la técnica del tapial.

En obras de intervención sobre construcciones históricas realizadas con tapia es fundamental conocer previamente sus características y peculiaridades.

Tras los estudios previos, debidamente documentados y contrastados, que deben servir de base para establecer los criterios de intervención, es necesario abordar un cuidadoso diseño de las soluciones constructivas y un seguimiento y control de las obras que permitan recuperar adecuadamente esta técnica tradicional.

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Restoration of rammed earth architecture in the Iberian Peninsula: Ongoing research

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ABSTRACT: The Iberian Peninsula represents the geographic area of Europe with the largest amount of architecture built out of rammed earth. For some time now, all the variants of this building method have been studied and yielded very important results. On the other hand, quite a few interventions have been carried out on historic rammed earth buildings. We can affirm that since the nineteen eighties, more and more interventions have been carried out on rammed earth constructions, both monumental and vernacular, all over the Peninsula. The interventions performed on this historic heritage have been different as regards reconstruction, conservation, repairs, substitution, structural consolidation, etc. The criteria, techniques, materials and actions put into practice have also been different. The research presented here strives to pool the experiences of restoring the monumental architectonic heritage in the Iberian Peninsula in order to learn from these interventions and draw conclusions and perspectives for the future.

1 FOREWORD

The research presented below is being carried out thanks to the project "La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas" (The restoration of rammed earth architecture in the Iberian Peninsula. Criteria, techniques, results and perspectives, ref. BIA 2010-18921), granted by the Spanish Ministry of Science and Innovation under the National Grant Scheme for the year 2010. The research put into practice aims to analyze the restoration works carried out from the eighties until the present in order to evaluate the criteria and techniques used and the results obtained over the years, along with the evolution these criteria and techniques have undergone over the years. The initial date is in the eighties, since it coincides with the arrival of democracy in both Spain and Portugal and the political and administrative changes that came about and the different intervention policy on monuments that ensued regarding the criteria and the professionals involved. The analysis has been carried out from a multidisciplinary point of view, involving researchers and collaborators from different fields: architects, quantity surveyors, archaeologists, historians, art historians, restorers, engineers, petrologists, etc. The research team also relied on the important collaboration of scientists, whose mission was to oversee the project at all times.

2 GROUNDS AND REASONS FOR THE RESEARCH

In the last thirty years, many interventions have been carried out in the Iberian Peninsula on our monumental rammed earth architectonic heritage. Thirty years ago, when the first actions were carried out (Niebla City walls, 1979), there was a scant corpus of knowledge about building techniques, but still less was known about the sort of interventions to carry out. In time, the professionals and technicians who took part in this type of architecture experimented with criteria and techniques related with their knowledge and experience to achieve the best possible results.

The intervention criteria, the techniques used and the results obtained have been diverse, but in many cases it was not possible to consult the experience of other technicians because knowledge and experiences were fragmented by the geographic distance between professionals. At the present time, the conservation of rammed earth architecture from the point of view of the criteria and techniques used has hardly been studied at all from a general point of view (Viñuales 1981, Odul 1993, Warren 1999; Warren 2001, Pignal 2005, AA. VV. 2004, AA.VV. 2008, Boussalh 2005, Correia 2007, CRATerre 1993, Guillaud 2001, Graciani 2008), although there are many publications about the restoration of several concrete examples of intervention on certain monuments (Niebla City Walls, Toral de los Guzmanes, Granada City Walls, Sevilla City Walls, Bétera Castle, Murcia City Wall, etc.), addressing the reasons for the intervention, the criteria followed and the techniques used (Guarner 1982, Guarner 1987, Jurado 1987, Guarner 1991, Jurado 1991, Algorri 1994, Gallego 1993, Gallego 1996, Cabeza 1996, López Martínez 1998, López Martínez 2001).

Therefore, the original hypothesis of this research consists in sharing experience to generate knowledge within reach of everybody, both regarding the specific criteria to follow in the restoration of rammed earth architecture and the techniques used and the difficulties involved in their use. The idea is to provide valuable information for the technicians who have to work on this sort of architecture based on the experience of others, where we can learn from both successes and errors.

3 AIMS OF THE PROJECT

Any sort of study, however in-depth and multidisciplinary, or any intervention methodology, however serious and rigorous it may seem, is no guarantee of a correct intervention in the architectonic restoration process. Preliminary studies of a building with an enormous amount of detail sometimes result in interventions that distort its essence or character. This occurs because the discipline of restoration is not an exact science and the restoration project belongs in another disciplinary sphere that lacks the credibility and impartiality of science. At this point, it is necessary to address the intervention criteria that must be based on the principles of the discipline of restoration and guide the actions of the project designer (Vegas 2011).

The definition of the basic principles of the discipline of restoration can be found in several authors (Carbonara 1997: 451–51, Jokilehto 1999: 295–304, Earl 1996: 80–118, Doglioni 2008: 85–103), who coincide on important issues. These general disciplinary principles make it possible to control the impact of the intervention regarding the conservation of the building, that is, to control the degree of change and therefore the relationship between the situation before and after the intervention (Doglioni 2008: 89). Among these general principles we can include: the conservation of the authenticity of the historic-cultural document; the minimal intervention; the reversibility of the intervention; the compatibility of the intervention in all its aspects (material, structural, functional, aesthetic, etc.); the durability of the intervention; current expressiveness and distinguishability. The relative importance attached to these principles involves different kinds of intervention, leading to different criteria, regardless of the specific case study addressed. The criteria that lie at the basis of the reflection about the project also influence or should influence the choice of actions in the intervention (protection of the coping of a wall, underpinning, opening up of a new bay, etc.) and the execution modalities or techniques employed.

The general and principal aim of the proposed research is to define, based on general intervention principles, specific criteria for the restoration of rammed earth architecture and the analysis of the techniques used in order to obtain guidelines for future interventions.

Furthermore, this research aims to obtain a series of specific objectives that could be summarized in the following categories: (a) a comprehensive database of interventions performed in the Iberian Peninsula in the last thirty years on historic monumental buildings and sites built partially or entirely out of rammed earth; (b) a comprehensive compilation of unpublished information about the state prior to restoration, the project, the works and the state after the works of a selection of interventions carried out in the Iberian Peninsula in the last thirty years on historic monumental buildings and sites built partially or entirely out of rammed earth; (c) the drawing up of a methodology for the analysis of the intervention criteria and techniques useful for the study and analysis of the cases selected but that can also be used in any other geographic and architectonic context where intervention criteria are to be evaluated; (d) the drawing up of guidelines for intervention on monumental rammed earth architecture in the Iberian Peninsula through the knowledge gleaned during research and directly applicable in future interventions; (e) the transmission of the knowledge acquired and training of professionals and future professionals through the actions of the program and other actions arising from it (seminars in master's degrees, talks in professional associations and schools connected with the exhibition, lectures in courses, congresses, conferences, publication of articles and chapters of books, promotions of research work and doctoral theses, etc.).

When all is said and done, the ultimate objective consists in contributing by means of the knowledge learned and the reflections made to the conservation of the abundant monumental and other rammed earth architectonic heritage in the Iberian Peninsula. Thanks to the knowledge acquired by shared observation, new interventions can be planned on the basis of past experience, by perfect familiarity with the successes and failures and the durability of the possible options.

4 METHODOLOGY USED IN THE RESEARCH AND THE FIRST RESULTS OBTAINED IN 2011

The methodology chosen for the research is founded on the analysis of case studies with a qualitative method on the basis of abundant information gleaned from different primary sources (interviews and information directly provided by the agents involved in the restoration of the buildings) and secondary sources (other possible sources of information), both direct (the restored buildings themselves) and indirect (bibliography, documentation in archives, project documentation, etc.).

From this point of view, the research is based on three fundamental stages, divided in turn into different tasks that define all the sections of the research in detail, each of which corresponds to the development over a one-year period approximately:

1. Compilation of information (preparation of a database with the most complete list possible of works carried out; a list of a selection of interesting cases; compilation of as much information as possible; visits to the buildings restored; physicochemical analyses; material characterization testing and treatment evaluation testing).
2. Case analysis, reflection and experience sharing (analysis and evaluation of cases with a multidisciplinary method; compilation of a detailed data sheet of each intervention; a comparative analysis of the interventions; organization and holding of meetings for reflection; publication of the minutes of the meetings).
3. Production and diffusion of the corpus of knowledge (drawing up of the general guidelines for the restoration of monumental rammed earth architecture in the Iberian Peninsula; publication of the results of the research; setting up of a website to permit the diffusion and implementation of the results of the project; organization and setting up of an exhibition). Below we shall address the stages of methodology and the first results found in 2011, based mainly on stage 1 of the research.

4.1 *Compilation of information*

In the first place, at this stage of the research, a database has been created containing a file designed in a specific manner with fields in which to classify the works completely. The fields are divided into three sections: general data about the building (name of the building, address, autonomous community, GPS coordinates, ownership, type of building, description, building technique(s), photographs), general data about the intervention (author(s), title of the project, funding agency, estimated cost), intervention techniques used (foundations, structure/walls, cladding, coping, other elements), current state of the intervention (presence of damp, presence of salts, loss of mass, cracks, etc.); intervention criteria. So far 230 buildings located all over the Iberian Peninsula have been recorded (Fig. 1). This number may increase during the course of the research. To compile the files in the database we have drawn from different types of sources, depending on the type of information sought. In the first place, the aim was to identify restored rammed earth buildings scattered all around the peninsula, and, in the second place, to compile a minimum amount of information in the database files so as to be collect the data necessary to catalogue them. All the researchers in the project and the group of scientific collaborators participated, as well as all possible contacts of researchers, professionals, administrations, associations, etc. that could be reached. Furthermore, the lists of the following archives were consulted: the Institute of the Cultural Heritage of Spain, the Ministry of Culture and the Ministry of Development (1% Cultural Plan and the so-called Plan E). At the following stage of the research planned for 2012, the databases of the autonomic administrations will be consulted (Generalitat Valenciana, Junta de Andalucía, Gobierno de Aragón, etc.).

On the other hand, using the database previously created, a first selection of interesting cases was drawn up, which may increase in the future depending on the interest that may be aroused by the new cases introduced in the database. The selection of the first approximately 50 cases was based on: the interest of the building, the interest and importance of the restoration works, the variety of building techniques used, the presence of different interventions carried out at different times, etc. For the buildings selected, a detailed file was drawn up to contain the information necessary to analyse the intervention criteria and techniques and the results of these. The files were drawn up by the architects,

Figure 1. Location of the buildings catalogued up to date and introduced in the data base.

architectural technicians, restorers, companies involved in the restoration process or researchers who had participated in the cases or studied them in detail. In order to compile information in a satisfactory fashion for both the database and for the cases selected, some of the buildings were visited.

4.2 *Analysis of the cases, reflection and experience sharing*

As regards the second stage of the research, most of which will be carried out in 2012, analysis and evaluation of the cases are already under way. This task has been informed as a multidisciplinary analysis (history, archaeology of architecture, construction, chemistry and petrology, architectonic restoration and conservation, restoration and conservation of materials, etc.) aimed at identifying the intervention criteria and techniques used and evaluating the results. In this first year, a rough draught has been made of the analysis and evaluation methodology of the cases of intervention, based, after a general study of the case (intervention dates, budget, funding institution, architects and agents taking part in the intervention etc.), on the study of five main sections that define the study of the building and the intervention on it.

On the one hand, the plan is to study the parameters related with the building itself. In the first place, the architectonic and construction characteristics of the building and especially the building technique (rammed earth, lime washed, with *brencas*-undulated reinforcement-, in Valencian style -brick- or stone-reinforced rammed earth-, with added stones, etc), since, depending on the basic building technique, a series of specific problems and pathologies arise and consequently specific intervention criteria and techniques are required (Fig. 2).

In the second place, it is necessary to identify the needs of the building itself (structural, material, functional, cultural, etc.) and especially the degradation phenomena that affect the buildings divided into structural pathologies (cracks, collapse, overloading, etc.), material pathologies (erosion, disintegration, salts, etc.), pathologies caused by vulnerability to atmospheric agents (missing coping, rising damp, etc.), anthropic pathologies (plundering, partial demolitions, etc.).

On the other hand, it is necessary to study the parameters that define the intervention on the building, which in turn can be divided into three sections. In the first place, identifying the use of a clear methodology for the intervention that makes it possible to establish a relationship between the building and its characteristics, the requirements involved in its physical, symbolic, cultural, etc. conservation and the criteria and techniques to be put into practice. In the second place, the intervention techniques used in the restoration (interventions on the foundations, walls/structure,

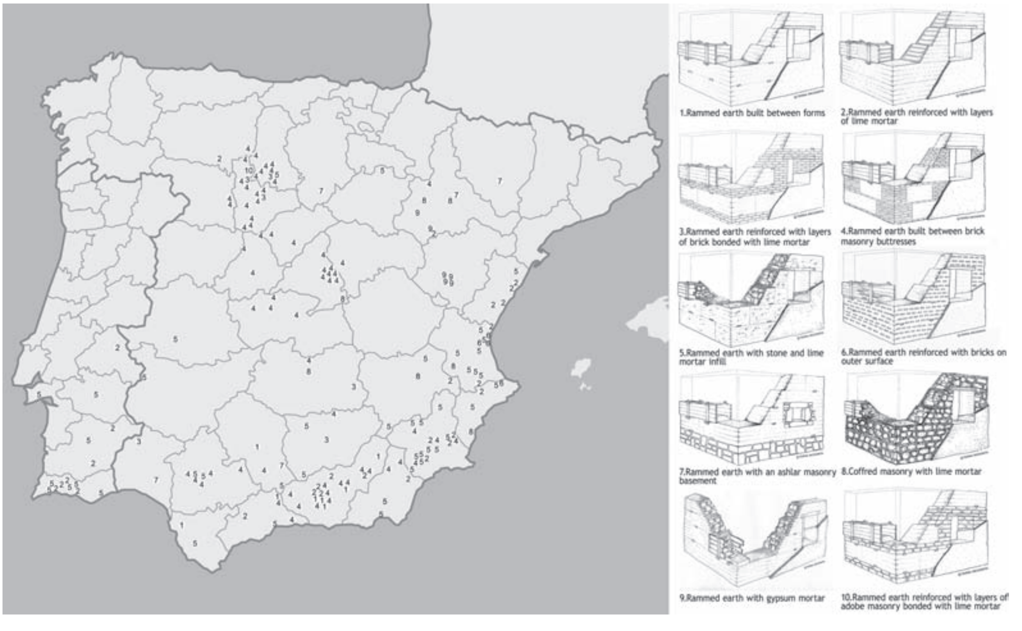

Figure 2. Variants of the rammed earth constructive techniques that appear in the case studies of the data base. (Drawings: García, Cristini, Tibor).

cladding, coping) analyzed according to the aim of the method used (structural consolidation, protection from atmospheric agents or damp, geometric or volumetric recuperation, typology, preparing the building for a new function, etc.), the materials used (traditional materials, new materials, a mixture of traditional and new materials, materials similar to the existing ones, etc.), the type of action (conservation, transformation, elimination, substitution, partial or total reproduction of the existing material, etc.), type of contact relationship (physical connection, mechanical connection, adherence or physicochemical adhesion, etc.). (Fig. 3).

In the third place, the intervention criteria, based on both the general principles of the restoration discipline (conservation of authenticity, minimum intervention, reversibility, compatibility, durability, current expressiveness and distinguishability, neutrality) and on specific criteria for intervention on rammed earth: volumetric recuperation (recuperation of the upper profile according to the original level or the erosion level, recuperation of missing volumes, etc.), substitution or recuperation of the surface, conservation of existing remains both at a volumetric and a material and surface level. These criteria are analyzed in the first place on the basis of the criteria mentioned in the primary sources (projects, interviews, files, etc.) and, in the second place, on the basis of the intervention works carried out and the techniques used. In this sense, in order to measure the criteria of reversibility, compatibility and durability respectively, the following

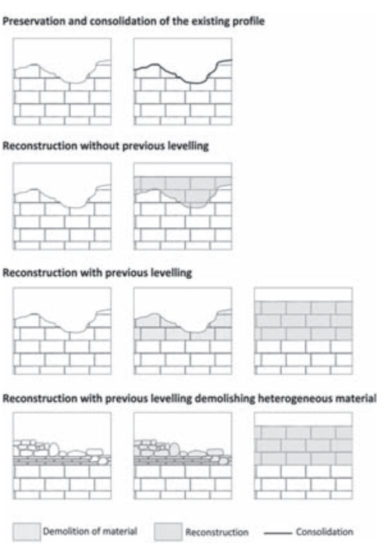

Figure 3. Example of the different constructive techniques found in the studied cases related to the different intervention criteria while building with rammed earth on top of the existing rammed earth wall.

parameters are used: conservation of the existing material, addition of new elements without removing the existing ones, etc.; the use of materials similar to the existing ones, traditional materials; maintenance of the structural conception, etc.; lack of damage caused by the passage of time; behavior of the intervention over time), etc.

Finally, the organization of the International Conference on Rammed Earth Conservation—ResTAPIA 2012 belongs in this section, since it was created from the outset as an opportunity to meet and share experiences.

4.3 *Production and diffusion of the corpus of knowledge*

As regards the third stage of the methodology, a website has been designed (www.restapia.es) as part of the production and diffusion stage of the corpus of knowledge. This website will facilitate the diffusion and implementation of the results of the project. It is a website that contains the aims of the project and the most relevant results but that also puts at the disposal of society (professionals, companies, researchers, etc.) not only the knowledge gleaned but also the possibility of consulting a forum of experts. The site was designed and structured with the following sections: introduction, objectives of the project and research team and team of collaborators; complete database of the monumental rammed earth architectures restored in the last thirty years in the Iberian Peninsula; an explanation of the building techniques for the variants of rammed earth constructions (drawings of details and explanations); intervention criteria and techniques (guide or protocol for intervention, details of the intervention techniques); virtual bibliography; specific bibliography with downloadable pdf texts; useful links; news blog related to the subject; an interactive space or forum for the exchange of information.

5 CONCLUSIONS AND PLANS FOR THE FUTURE

Now that the first year of this research has come to an end, we can conclude that all the interventions on monumental buildings in the Iberian Peninsula constructed in any possible variant of rammed earth building technique are being abundantly catalogued. Efforts are also being made to create a methodology for the analysis of the interventions based on objectivable and measurable parameters. Furthermore, we are attempting to keep the research open and participative so that any researcher or professional who so wishes can share his own experience to broaden the common knowledge. On the other hand, in the two remaining years, we intend to increase the case studies and study in greater depth the cases that present characteristics of special interest in order to make a profound and concrete comparative analysis of the criteria and techniques used and results obtained over time. The final product of this broad study and analysis will allow us to draw up some guidelines for intervention on monumental rammed earth buildings as regards both criteria and intervention techniques.

NOTE

The team of the project "La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas" (The restoration of rammed earth architecture in the Iberian peninsula. Criteria, techniques, results and perspectives, ref. BIA 2010-18921), granted by the Spanish Ministry of Science and Innovation under the National Grant Scheme for the year 2010, is composed by: Camilla Mileto, Fernando Vegas (head researchers), Valentina Cristini, Maria Diodato, Paolo Privitera, Lidia García Soriano, all from Universitat Politècnica de València; Francisco Javier López Martínez, Universidad Católica de Murcia; Vincenzina La Spina, Universidad Politécnica de Cartagena; Francisco Javier Castilla Pascual, Universidad de Castilla La Mancha; José Manuel López Osorio, Universidad de Málaga; Amparo Graciani García, Universidad de Sevilla; José Antonio Martínez, Instituto de Historia Naval; Esther de Vega García, former member of the Instituto del Patrimonio Cultural de España; Mariana Correia, Escola Superior Gallaecia; Maria Fernandes, University of Coimbra; Hubert Guillaud, CRATerre—University of Grenoble.

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Reflections about the restoration of a rammed earth Islamic tower

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ABSTRACT: Torre Bofilla is an Islamic watchtower built at the beginning of the 13th century by the dwellers of the underlying farmstead of the same name. It is a tower made out of rammed earth filled with a small amount of lime and stone filling, with a square 6 by 6 m plan and about 18 m high. This article addresses the research carried out on the tower during the restoration works, with the preliminary reflections intended to make the restoration respect to the greatest possible degree the old fabrics and all the traces accumulated upon it both during the building stage and later, when it was plundered, abandoned and manipulated. The text will deal with the specific details of the restoration of the tower with the different systems applied in order to address the criteria and reflections made beforehand.

1 RESTORATION OF THE RAMMED EARTH: STATE OF REPAIR AND PROBLEMS

The restoration of rammed earth walls, whatever their type and materiality, represents a technical and conceptual problem that is hard to solve (Warren 1999, Mileto 2011). In the first place, the amount of mass missing from the walls tends to determine the type of intervention in most cases. If the loss of mass is limited to the external surfaces and adopts the form of a patina or superficial erosion, the structure will not be compromised and the restoration can leave these surfaces as they are so as to emphasize the age of the wall. On the other hand, if the loss of mass involves serious erosion or a lack of volume and particularly if this occurs in the lower part of the construction, the structure may be compromised to such an extent that the restoration works cannot ignore its presence and must take steps to guarantee the survival of the building.

A fairly common example of the latter situation is the loss of volume in the coping of the building, which does not usually affect the structure directly because it is at the top, although it may lead to the progressive degradation of the rest of the building, so it is necessary to deal with it in some way. Behind the wish to alleviate this degradation, we often find a desire to replace the missing volume of the building, using solutions that involve restoring old forms and crowns that attempt to satisfy both requirements at the same time.

In all cases of serious erosion and loss of volume, a question arises regarding how to act on a wall, whose cohesion, compactness and structural resistance depend, at the end of the day, not on the material itself—the earth mixed with binder or degreasing agents—but on the specific way it is applied while it is built. If the loss of volume is at the base or lateral surface of the wall, this gap can in no case be filled in using the original building technique employed when the building was erected, since it would be impossible to compact the mass added to it vertically. If the loss of volume is at the top of the wall, rammed earth may be used as the building method to fill in the gaps as long as the wall underneath is in a good state of repair.

In any case, this second option can have several consequences. In the first place, it means that the original shape of the building must be restored, although this is not strictly necessary in most cases from a structural and construction point of view, but responds rather to a desire to restore it aesthetically. In the second place, it is necessary to know the original height of the crown of the building, which is not always readily apparent. In the third place, it inevitably involves a clear contrast between the original rammed earth surface, whose patina is a token of its age, and the new surface, with its smooth, even appearance and the signs of the new formwork.

This latter consequence responds to other important criteria, such as distinguishability in restoration, as defended by Camillo Boito since 1883 (Boito 1988) and later advocated by successive theoreticians and restoration charters; the fitness and advisability of using the original building methods in restoration works; and the recuperation of these abandoned or no longer used building techniques as part of the defense of a cultural identity lost or reviled in the 20th century, and the use of possible tools to create a more sustainable and ecological new architecture.

Let us take it one step at a time. The distinguishability endorsed by Boito was a concept that arose in the context of romantic restoration, concerned with the replacement of missing parts of the building as though they were original. Distinguishability is a term with great semantic flexibility, since it covers from total contrast to the slightest subtlety (Carbonara 1997). A lot of water has flowed under the bridge since Boito's time, and new concepts have arisen such as concinnity, involving harmony between historic construction and additions during restoration, just as the gaps in a historic painting are filled in with *rigatino* technique, seeking to enhance the total reading of the painting without renouncing the distinguishability of the details added. At the present time, suitable restoration works, architectonic stratigraphy, our current knowledge of materials, the patina provided by age, the possibility of chemical characterization and, above all, our difficulty in reproducing exactly the original techniques, are a guarantee of always necessary but, in many cases, obvious distinguishability in order to ensure that our restoration is correct without being too explicit (Vegas 2011).

On the other hand, in our opinion, the use of the original building methods in the restoration—but not necessarily the reconstruction—of a historic building is always commendable and predictable, but not at the expense of contrast or an increase of distinguishability. Indeed restoration does not imply volumetric restitution or reconstruction of the building, but rather repairs at certain places, where the original techniques may and at times should be used in order to guarantee physical, chemical, structural, construction, and other kinds of compatibility. Nevertheless, as we pointed out above, on the one hand, this procedure is impossible in the restoration of rammed earth walls because it cannot be applied in a lateral direction and, on the other hand, it is feasible but produces many aesthetic side effects in the coping. The only way to guarantee the integration of additions in the upper part of a wall would be by artificially eroding the new crust, taking it into account that the destruction of the crust will inevitably trigger the degradation process of the wall.

Given this situation, the first piece of advice would be not to fill in missing parts or crusts of the rammed earth wall unless it is absolutely essential to ensure its structural conservation. If it is, given that it is not possible to reproduce the same techniques in the restoration of rammed earth walls, specific intervention methods must be created to guarantee compatibility between the historic wall and the added parts. To begin with, there are two possibilities, with their respective variations. If it is not possible to achieve a mixture of the same composition as the historic rammed earth wall with identical structural features because of the lack of good compaction, in the first place, the binder in the mixture would need to be increased to enhance the structural features of the uncompacted mixture. There is a limit to this procedure: if the rigidity of the addition mixture is increased too much, making it lose the elasticity of the historic rammed earth wall, it may become detached in the short or medium term. In the second place, there is the complex and hard-to-apply option of lateral compaction, which in any case must be carried out in very thin coats and the amount of binder should probably be augmented, as we pointed out in the first case.

2 BOFILLA TOWER

Bofilla Tower is an Islamic watchtower (Rodríguez 2008) that was erected in a hurry at the beginning of the 13th century, when the inhabitants of the area were aware of the advance of the Christians in the Reconquista, which ended in 1238 with the conquest of the town and the nearby city of Valencia (Bazzana 1978). The carbon 14 test performed on samples of timber from the putlogs and rests of the joists of the tower date it around 1210 or 1220, and this is confirmed by ceramic pieces found in the filling at the base of the tower (Fig. 1).

On the other hand, we know its construction was rather hasty because home-made formwork was used to build it—probably the planks used to build the farmstead at the foot of the tower—which were connected by means of nailed posts. The planks available were insufficient to cover the whole perimeter of the tower, so that the tower was built with a U-shaped formwork that was moved after the earth had been compacted to complete the perimeter, thus avoiding any joints at the corners that might weaken them (Fig. 2).

But the joint at the middle of the tower might also have weakened the whole structure, so they took the precaution of alternating the joints in

Figure 1. Bofilla Tower in the surrounding landscape before its restoration (Vegas & Mileto).

Figure 2. Corner of the tower that shows the continuity of the rammed earth wall (Vegas & Mileto).

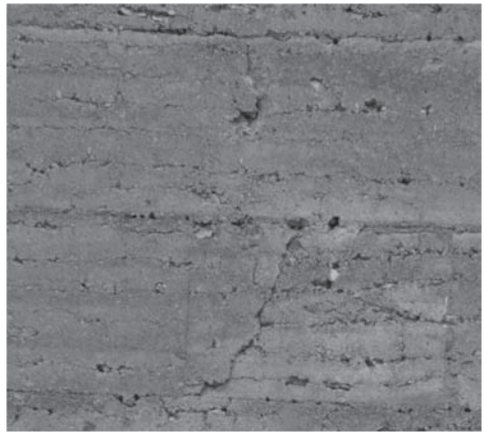

Figure 4. Successive courses showing alternatively inclined joints (Vegas & Mileto).

Figure 3. Building system used alternating the available U-shaped formwork (Vegas & Mileto).

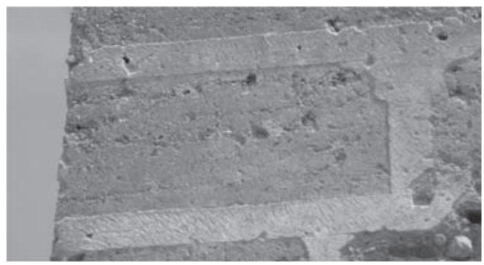

Figure 5. Strips of lime mortar sealing the joints at the top and the bottom of the tower (Vegas & Mileto).

the successive courses so that the entire ensemble would look well bonded, not only at the corners but all over (Figs. 3 and 4). The horizontal joints in the rammed earth were sealed *al fresco* at the top and bottom of the tower with 15 cm strips of mortar with a large lime content, which, combined with vertical strips, had the appearance of false ashlars (Fig. 5).

The three intermediate floors and the thin floor of the parapet walk (Fig. 6) were made with central girders and a large number of joists made of olive wood (Macchioni 2009), probably taken from the neighboring countryside and supplied by the local families.

In our days it is hard to think of olive wood used for joists and girders over 2 and 4 meters long, because we tend to prune olive trees to make it easier to beat them with poles when harvesting the olives. But medieval olive growing allowed the trees to grow freely, and they grew to be 8 m tall and more, and tending flocks and plant farming were combined and olives were gathered directly from the ground when they had fallen freely. The tower was used until the early 15th century, as documented by the archaeological remains found, and from that time onwards both the tower and the farmstead underneath were abandoned while the neighboring town of Bétera grew in importance (López Elum 1994).

Before the restoration (Fig. 7), the state of conservation of its walls was relatively good, despite the loss of the roof and floors and the neglect to which the tower was condemned for some five centuries. The wooden floors had disappeared completely, probably due to a fire, of which traces could be seen. However, the intervention was urgently required mainly for two reasons: the pillaging of the stone voussoirs of the double arch at the entrance that had caused the partial collapse of the interior surface over it and the hole at the entrance to the tower at the southwest corner, which had left it suspended in the air instead

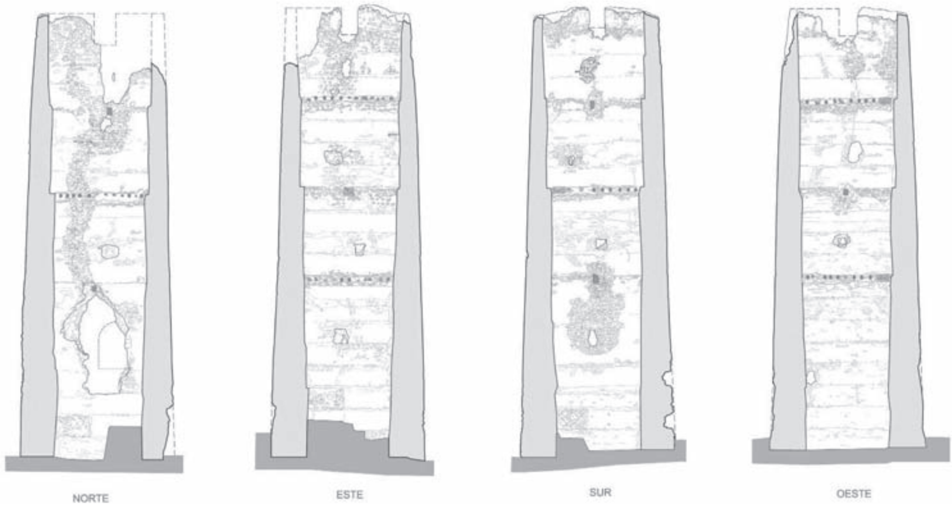

Figure 6. Traces of the disappeared wooden floors in the interior of the tower (Vegas & Mileto).

Figure 7. State of the tower before the intervention (Vegas & Mileto).

of resting on the ground. On the other hand, the south façade of the tower had lost its surface and the stone filling of the wall could be seen at the top and bottom of the tower.

3 OPTIONS ADOPTED IN THE RESTORATION

In the first place, the surfaces of the tower in a good state of repair were hand-cleaned with brushes, without attempting to leave the surface immaculate, since that would have involved unnecessary erosion of the historic surfaces. These well-conserved walls did not need further interventions, due to their healthy appearance after no fewer than eight centuries. The gaps in the rammed earth mass were another matter, and did require repairs and reintegration. Following the initial reflection, given that it was impossible to provide the historic mixture of nine parts of earth and gravel and one of lime (Kröner 2009) with a stone filling arranged in courses with the same structural features as the existing building, it was decided to improve the mixture by increasing the binder. The gaps at the southwest corner and the hole inside the north façade were filled with stone masonry bonded with mortar comprising 3 parts of earth and gravel and one of NHL-3 hydraulic lime (Fig. 8). As much local earth and gravel as possible were used, and were collected and sieved at the foot of the tower, so that the resulting mixture would not suffer from using gravel from a different place. In all the cases where it was deemed necessary, corrugated fiberglass rods were introduced to act as connectors. Perforations were drilled with the utmost care to avoid percussion, because despite the romantic appearance of the tower, several areas were found to be in danger of immediate collapse.

The stones that had fallen from the tower were used again, placed inside the wall and bonded in five successive layers that corresponded to the five historic building strata of each rammed earth module, not out of romanticism but in order to adjust the filling in of the gaps to the adjacent horizontal historic joints. Once one section of the surface was completed, it was rendered with the same mortar up to the next joint of the rammed earth module in the historic wall. The rendering lime-water in the surface was absorbed with a sponge and was brushed afterwards to show up the local gravel in the mixture. Then the next module of the rammed earth wall was treated in the same way, so as to mark the natural horizontal joints between modules, corresponding to the horizontal joints between the historic modules of the wall.

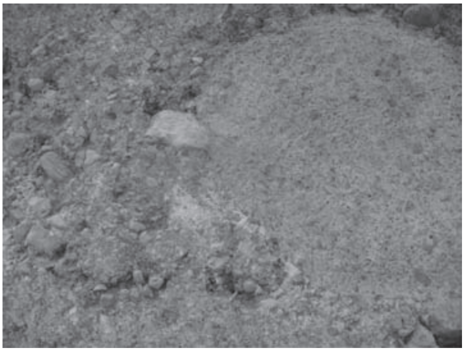

Figure 8. Integration of the gaps in the rammed earth wall (Vegas & Mileto).

Figure 9. Tower crown with consolidation and reintegration treatments (Vegas & Mileto).

As determined in the preliminary tests, once the rendering had set, the added masses slightly tinted with natural soils were the same color as the paler shade of the binder in the historic wall, not darker. From this moment on, a restorer set about giving a patina to the added mass, by splashing on with a brush natural soils with a lime base in order to guarantee good integration.

At the crown, in order to secure the surfaces in danger of immediate collapse in the north side and the merlons in the east and west sides that had lost stability due to erosion at the base, several possibilities were considered. Finally, it was decided to use the same procedure as to fill in the gaps because it ensured bonding and adherence, instead of more theoretical methods, which did not offer so much durability. The intention was not to restore the tower to its original shape, so these gaps were filled in up to the adjacent historic level and the degraded crest of the coping was respected in the areas where material did not need to be added to secure or stabilize the fabric (Fig. 9). Any attempt to outline the original shape of the upper edge was avoided at all costs, even where it was clearly the original coping, in an attempt to achieve the appearance of a hypothetical second-last course.

On the south side, in spite of the apparent seriousness of the naked appearance of the surface, the wall was deemed stable enough and it was believed it would not have conservation problems in the short and medium term unless water was retained or seeped into the fabric. In this way, the rubble that could be seen through gaps in the fabric was partially repointed only in the spots where it was necessary to drain out water. This partial repointing was carried out with the same mortar used to fill in the large gaps on the surface described above, and a final patina was applied so as to achieve greater integration.

The roof and interior frameworks of the tower were built with pine girders and joists, according to the rhythm marked by the traces on the historic walls, like the staircase (Fig. 10). It would have been logical to look for olive girders or joists or girders and joists from some wild tree like holm oak to imitate them if any of them were missing. In this case, as there were no remains, the framework was fashioned out of traditional materials like timber but with contemporary grammar.

Figure 10. New floors and ladder in the interior of the tower (Baeza).

Figure 11. Bofilla Tower before and after the intervention (Vegas & Mileto/Baeza).

On the other hand, as described above, contextual integration was performed on the exterior, seeking to harmonize with the degree of degradation, patina and color of the preexisting adjacent areas to better guarantee the integration of the parts added to the building, which the authors have always given the central role in the intervention. When examined in detail, the additions have the appearance of *rigatino* in a historic painting, so that distinguishability had been guaranteed at the same time as the historic image and the value of the age of the building have been safeguarded.

NOTE

This paper is a part of the scientific research project "La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas" (The restoration of rammed earth architecture in the Iberian Peninsula. Criteria, techniques, results and perspectives, ref. BIA 2010-18921) granted by the Ministry of Science and Innovation under the National Grant Scheme for the year 2010.

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Restoration of two rammed earth walls at Sagunto's castle (Valencia, Spain)

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ABSTRACT: In 2010 a phase of restoration works at the Castle of Sagunto began. It was promoted by the Institute of Cultural Heritage of Spain. The action required the assessment of the varying degrees of conservation of the rammed earth construction in two of the walls. Following the intervention criteria, one of the walls needed to recover the closing function of the Castle. The complete or partial demolition of the wall would have represented a significant loss in the complete understanding of the building and even the defense elements as battlements and loopholes. The second wall contained information about the medieval Islamic plan. Regarding the intervention of technical implementation, it was taken into consideration the dimensions that were possible to identify. The work included earth, mortar and lime concrete as characteristic elements.

El castillo de Sagunto ha sido utilizado como enclave militar de forma prácticamente ininterrumpida desde sus orígenes, que pueden datarse en el siglo V a. C., hasta bien entrado el s. XIX e incluso con ubicación de casamatas para baterías de ametralladoras en la Guerra Civil española en el siglo XX. Como consecuencia de ello, ha sufrido numerosas modificaciones, ampliaciones y reformas aunque hay que señalar que el perímetro de la actual fortaleza coincide prácticamente con la construcción de época islámica (Andreu, E. & Sánchez, M.V. 2000).

En la actualidad el castillo es una gran construcción de predominante trazado y fábricas medievales donde se superponen etapas constructivas desde época romana reutilizando materiales y ámbitos. Está conformado por ocho recintos o plazas. El sector 2, objeto de esta intervención (Moliner, M.E. & Almena, L.M. & Camps, C. 2008), se sitúa al oeste de la plaza de San Fernando y el sector 3 en el lado sureste de la denominada plaza del Dos de Mayo (Fig. 1).

1 ESTADO PREVIO A LAS ACTUACIONES

El sector 2 es un tramo de muralla en cremallera que se adapta a la topografía de la montaña en dirección sureste-noroeste salvando un desnivel de 17 metros de altura en una distancia de 22 metros. Este sector comprende en si mismo dos fábricas murarias distintas. El primer tipo es un lienzo de muralla como cierre de la plaza de San Fernando, ejecutado con fábrica de mampostería de la época de la Guerra de la Independencia. De la misma época y factura, se hallan dos lienzos en la zona superior del sector formando dos brazos en forma de uve. El segundo tipo, de fábrica de tapial de tierra calicostrado, corresponde al lienzo del trazado medieval de la muralla.

Cuando se acometió el proyecto, se tenía algunas evidencias de lo que podría ser el trazado medieval del Castillo de Sagunto en el sector 2. Una de las evidencias era el propio lienzo sur cuya traza de dirección este-oeste pasa por delante del muro de mampostería, comentado en primer lugar, no teniendo ninguna vinculación estructural, constructiva y formal entre ellos y que avanza por delante de éste unos 5 metros hasta que su trazado gira 90º para comenzar el ascenso de la montaña. Su estado en la zona que nos ocupa era de ruina completa, grandes pérdidas de volumen de tapial, erosión de costras y los restos de algunas en situación de equilibrio inestable con peligro de caída. Las otras evidencias eran la fábrica de mampostería como base del lienzo de tapial y

Figure 1. Planta del Castillo de Sagunto. Emplazamiento de los sectores 2 y 3.

un pequeño resto de la costra de la cara interior, ambas en la zona inferior del sector 2. La última pista la daba la huella de la sección de un muro de tapia de gran potencia que se podía apreciar entre las fábricas de mampostería en forma de uve, en la parte alta del sector (Fig. 2).

Tras las excavaciones arqueológicas programadas en la fase inicial de ejecución de las obras, se confirmó la hipótesis de que el trazado medieval de la muralla rebasaba el límite actual, dando

Figure 2. Estado previo. Alzados exteriores del sector 2.

sentido a las partes discontinuas de los lienzos de la zona superior del sector. Los restos encontrados correspondían a una fábrica de tapial de tierras calicostrado sobre un basamento de fábrica de mampostería tomada con mortero de cal. En cuanto a los restos de la zona inferior, estos se encontraban bastante alterados y contaminados, con pérdidas volumétricas importantes en la mampostería, y desplomes de costras e invasión de vegetación en el volumen del tapial de tierras.

En la zona superior, se encontraron los núcleos de tierra de las fábricas de tapial, con pérdida volumétrica importante, ausencia de costras longitudinales, y con permanencia de tres costras transversales correspondientes a testeros de cajón. En algunos casos la inexistencia de restos de las costras del tapial en los alzados exteriores e interiores del muro, ya había sido reparada y reforzada con una potente hoja de fábrica de mampostería y ladrillo cerámico macizo de factura tardomedieval, de anchura variable entre 60 y 70 cm.

El sector 3 se trata de un tramo de muralla con la base ubicada sobre una cresta rocosa cuya cara sur se encuentra a 12 metros del suelo y el alzado norte (interior) a 3 metros de un suelo de cantera resultado de la extracción de roca. Es un tramo zigzagueante en planta, de unos 42 metros de longitud que comienza en el extremo oeste de la plaza de la Ciudadela y finaliza en los restos de un cubo o torre maciza. Se trata de un lienzo muy complejo dadas las distintas fases constructivas que se han ido superponiendo en cada época (Fig. 3).

El estado de ruina del lienzo construido con fábrica de tapial superaba el 50% en cuanto a pérdida volumétrica se refiere. Dos grandes faltantes aparecían en el mismo. De este a oeste, y dividiendo la longitud el sector en cuatro tramos más o menos iguales, en el segundo tramo se presentaba una pérdida completa de la costra de tapial y consecuentemente del núcleo de tierra por su alzado sur. La otra gran pérdida volumétrica en este caso

Figure 3. Estado previo. Alzado norte, interior, del sector 3.

Figure 4 Lienzo de la muralla

integral, se localizaba en el último tramo de lienzo que acometía contra la torre. En esta zona, el único indicio de que allí hubo una fábrica de tapial era la presencia del derrumbe encontrados a los pies con tierra y restos de costras.

Los otros dos tramos no es que estuvieran en mejores condiciones. El primero de ellos, de época francesa, es un tramo de muralla con tipología de defensa con aspilleras ejecutado con fábrica de mampostería y ladrillo macizo cerámico sobre la fábrica medieval existente de tapia calicostrado de tierra, que tenía faltantes volumétricas en sus elementos de defensa en ambos extremos. El tercer tramo -correspondiente a una zona reparada de la muralla medieval que se trasdosa por el exterior con una fábrica de mampostería- podría describirse en buen estado y, aunque incompletas, incluso conservaba restos de las almenas; sin embargo la parte superior se estaba separando de la fábrica de tapial a la que trasdosaba. Por tanto, hasta la zona de lienzo, en teoría mejor conservado, tenía su estabilidad cuestionada (Fig. 4). En cuanto a la torre del extremo, le faltaba la mitad de la fábrica de tapial calicostrada, permaneciendo en pie el trasdosado interior de fábrica de mampostería que se hizo para reforzar o reutilizar la torre.

2 ANALISIS DE LAS FÁBRICAS DE TAPIAL

En el sector 2, la fotografía, cartografía histórica y la investigación arqueológica durante la fase de ejecución de obras ha permitido recuperar el trazado de la muralla islámica en esta zona del castillo (Fig. 5). Sobre este lienzo de tapial, de un espesor notable de 1.60 m, no ha sido posible detectar ni la longitud ni la altura del cajón debido a las fuertes alteraciones que ha sufrido la estructura y los materiales cerámicos hallados en el relleno interior de tierra remiten a finales del siglo XII o principios del siglo XIII como fecha más probable de su construcción.

El deterioro de la costra del tapial a lo largo de los años, sobre todo en el paramento exterior, obligó a reparaciones históricas consistentes en la eliminación de las superficies de costra en mal estado y su sustitución por muros de mampostería y sillarejos reutilizados. Estas reformas que se dan en el sector 2, también pueden observarse en gran parte de las murallas del castillo.

Si bien el mejor de los datos de lectura histórico-constructiva en el sector 2 ha sido el alumbramiento de una traza desconocida hasta este momento en esa zona, en cambio en el sector 3 -con más volumen conservado de las fábricas de tapial- el análisis del

Figure 5. Alumbramiento del trazado medieval en el sector 2.

lienzo muestra al menos cuatro fases constructivas aportando muchos más datos de la muralla. Hay que señalar que la altura de la roca en el lado sur del sector 3 es de 12 metros, representando por sí misma una magnífica defensa natural, siendo la primera construcción una torre de planta ligeramente rectangular construida con muros de tapial calicostrado y núcleo de tierra apisonada y cuyo paramento exterior aparece revestido por un estuco de color blanco. Se asienta sobre una base de mampostería y los muros tienen un ancho de 0.47 m y una altura de cajón de 0.94 m. La distancia entre agujas oscila entre los 0.70 m y los 0.90 m. La torre no era maciza ya que se detectó en el lado norte una puerta de acceso al interior de la misma. No se puede concretar la cronología de construcción aunque se la debe situar en época islámica.

En una segunda fase se construyó un muro a modo de parapeto en el límite exterior de la roca. Con la misma técnica constructiva de la torre, tiene un ancho de 0.55 m. En su parte superior se encontraba rematado por una capa de mortero ligeramente curvada. No se detectaron restos de merlones. A este parapeto se le adosa en una fase posterior, ya a finales del siglo XII probablemente, un nuevo muro de tapial calicostrado. Con una anchura de 0.70 m y una altura de cajón de 1.10 m. Se pudo documentar únicamente una longitud de cajón de 2.40 m. Las transformaciones posteriores impidieron conocer la altura total que tendría este nuevo lienzo.

Ya en época tardomedieval se superpone un nuevo muro de tapial calicostrado. Esta nueva construcción tiene un adarve de mayor anchura que la muralla islámica subyacente, salvándose esta diferencia mediante la colocación de losas de piedra en voladizo. El ancho del muro es de 0.80 m, identificando dos cajones, el inferior con una altura de 0.90 m y el superior de 0.60 m. Muy probablemente esta segunda caja fue rebajada por las reparaciones y reformas que sufrió este tramo durante el siglo XVI y posteriores.

3 TRABAJOS DE RESTAURACIÓN

El mal estado de conservación del sector 3 afectaba a los principales elementos de valor identificativo de una muralla. En primer lugar, la falta volumétrica hacía evidente la pérdida del valor del lienzo como elemento de límite, y por tanto de la muralla de la que forma parte, que además en este caso tiene el carácter defensivo necesario de la tipología del "todo" al que pertenece y de manera más propia conformando una de las plazas del castillo de Sagunto que, de manera característica, se distingue por la suma o comunicación entre recintos; y por tanto, debido la misma causa, otro de los valores tipológicos que quedaba diluido con la pérdida volumétrica del lienzo en cuestión era la configuración del espacio arquitectónico: al interior como recinto del castillo y hacia el exterior como perfil paisajístico. En segundo lugar, la parte del volumen desaparecido tenía como consecuencia la pérdida de elementos propios como los merlones, aspilleras y adarve.

El objetivo de la recuperación volumétrica y de la identidad de almenas y adarve era conservar la lectura de la superposición de las distintas etapas constructivas identificadas en el lienzo.

Con la misión de consolidar las preexistencias y sumarlas a las fábricas rehechas, se procedió a distintas labores previas: desde la inyección de lechada de cal entre hojas de mampostería que reparaban trasdosando fábricas de tapial; la preconsolidación con pulverización de agua-cal de los tapiales -que habían perdido costra y volumen- labor que ayudó a realizar los trabajos de compactación manual de los volúmenes a recuperar minimizando la erosión accidental de forma temporal; e incluso la estabilización de una importante superficie de costra rebajando el trasdós de tierras, manteniendo las lenguas internas de la costra para facilitar el agarre a la nueva fábrica, esta vez únicamente, formada con hormigón de cal vertido y no compactado manual.

A continuación, se montaron las tapialeras siguiendo la métrica que correspondía a cada tramo: métrica medieval islámica antigua, islámica moderna o medieval cristiana según la fase del tapial preexistente. También se tuvo en cuenta la distancia de la disposición de agujas, el largo y alto de la caja, así como las alturas de las tablas reproduciendo las dimensiones de la fábrica original. La mayor dificultad radicó en la definición de las alineaciones del lienzo del sector 3, que al ir quebrándose siguiendo la base formado por el cortado de roca natural, fue necesario un importante esfuerzo de replanteo y revisión de la disposición de lienzas superando el vacio de las zonas derrumbadas para conseguir la continuidad con los extremos. Otra característica de los trabajos de restauración fue la superación de los desplomes que no debía reproducir la obra nueva, cuestión que generó cejas y franjas de transición que ayudaron a la diferenciación de los trabajos de restauración.

En el caso del lienzo de fábrica de tapial del denominado sector 2, el valor histórico y constructivo a restaurar principalmente era el de testimoniar la presencia de un trazado que rebasa el límite del lienzo actual. Los trabajos de restauración se enfocaron hacia la consolidación de los restos de ese nuevo trazado hallado, alcanzando mayor sentido la propuesta del proyecto que ya planteaba recuperar con una materialidad distinta la zona de intersección entre el muro medieval islámico y el muro de mampostería del siglo XIX, con el propósito de dar a entender la lectura de la adición posterior del segundo de los muros a la planimetría medieval del conjunto (Figs. 6 and 7).

Figure 6. Alzados exteriores del sector 2. Consolidación de los restos del trazado exterior de la muralla medieval de castillo.

Figure 7. Alzados exteriores del sector 2. Cambio de materialidad en la zona que conecta los dos muros.

La ejecución ha empleado los mismos técnicas de elaboración de la fábrica original descritos en el sector 3 para la elaboración de nuevas fábricas de tapial, también empleando como materia prima el resultado del amasado de árido, arena y cal formando en realidad un hormigón de cal cuya mayor cualidad es la variable de tonalidad distinguiendo las tongadas de material compactado manualmente que, junto con las juntas de las tapialeras, mejor evoca la fábrica de tapial preexistente.

4 DETALLES DE LA EJECUCIÓN

Después de la aplicación de un biocida de amplio espectro que permitiera eliminar tanto la vegetación superior como líquenes y hongos, se realizó la limpieza de la costra de forma que permitiera conocer el estado de la capa exterior de la tapia y conseguir una lectura de continuidad con la nueva fábrica que se iba a realizar para consolidar y completar los faltantes.

Completadas las operaciones de preconsolidación descritas en el anterior apartado, se realizó un replanteo de las hiladas de tapial definiendo dosificaciones, alturas y anchuras para cada una de las distintas tapias encontradas.

Se realizaron varias pruebas, un total de trece, para decidir tanto el aspecto como los procedimientos a emplear en la elaboración de las nuevas fábricas de tapial. La muestra de tapial elegida para la restauración de los lienzos en zonas con importantes pérdidas volumétrica, contaba con una dosificación de una parte de cal hidráulica NHL5, una de hidróxido de cal, dos de arena amarilla de mina, y nueve partes de zahorras de río o grava gorda, que en realidad consistía en una hormigón de cal que sería colocado en obra por tongadas dentro de una tapialera con una humectación muy baja y compactado manualmente con un pisón dejando el aspecto final de líneas de ejecución de 8–10 cm (Fig. 8).

Tras los trabajos de definición de dosificación y lectura de las métricas preexistentes, y de forma previa inmediata a la ejecución de las nuevas fábricas de tapial, se desarrollaron los trabajos de saneado de los núcleos de tierra de las fábricas de tapial. Estos trabajos se llevaron a cabo con seguimiento arqueológico, con objeto de identificar nuevos elementos de lectura de las fábricas históricas, tanto por la recuperación de material cerámico de datación de las fábricas como por la aparición de agujas o costras de cajón que cotejaran las métricas halladas hasta ese momento. El saneado de las fábricas rebajó de forma escalonada las tierras, eliminando las franjas afectadas por la erosión y la contaminación biológica, de manera que la profundidad mínima conformada tuviera una dimensión de 25 cm con objeto de tener una entidad estable suficiente.

Una vez que la fábrica existente presentaba estabilidad, se empezaron a montar las tapialeras de forma que prolongasen la lectura de las hiladas que marcaban las agujas de montaje en las fábricas preexistentes. Para permitir dicha lectura se optó por dejar embebidos en la fábrica unos tacos de madera de 7 × 7 cm. con una muesca en la parte inferior de forma que permitiese la extracción de la varilla roscada que se utilizaba para apretar los costales, abandonando en el interior del tapial, la aguja de madera (Fig. 9). Posteriormente estas agujas de madera, al estar seccionadas en los extremos, eran extraídas de la fábrica sellando dicho alojamiento de la aguja con un mortero de cal de forma que, de cerca, pudiera evidenciar la situación de la aguja, o bien reconocerse cuando pasado un tiempo se desprenda ese sellado como ocurre, sin ninguna intención estética original, en las fábricas de tapial antiguas otorgándoles ese aspecto tan característico.

Las hiladas de tapial se realizaron de dos formas según la tipología de la tapia preexistente. La primera de ellas fue ejecutada mediante tablones de 22 cm de forma que repitiese la disposición con la que se fabricó la tapia de referencia. En el segundo de los casos se colocó un tablero contrachapado marino de forma que la lectura era uniforme sin dejar la marca de los tablones, cuya altura en la fábrica original no se pudo determinar.

El apisonado de la masa se realizó mediante una primera pasada con pisones de madera y metálicos y posteriormente con una compresión mayor en las zonas exteriores mediante una madera de 5 cm y un apisonado directo con el martillo. De esta forma se conseguía una mayor compresión en las zonas exteriores que estarán a mayor exposición de las condiciones atmosféricas adversas

Figure 8. Compactación manual de la nueva fábrica de tapial.

Figure 9. Agujas de madera y varillas roscadas necesarias para apretar los costales de las tapialeras.

como el viento y la lluvia. El remate horizontal de los tapiales que conforman las nuevas almenas de algunos tramos, se ejecutó con una forma cóncava de manera que permitiese la evacuación del agua de lluvia más rápidamente.

5 CONCLUSIONES Y REFLEXIÓN

La ejecución de fábricas nuevas de tapial es un trabajo sencillo si se dispone de las herramientas, medios y la dosificación adecuada al contexto en el que deban integrarse. Es importante la formación en la técnica de las personas que compongan el equipo de trabajo, no siendo necesaria la experiencia previa pero si la comprensión de todas las instrucciones particulares para lo cual resulta muy útil la realización a pie de andamio de una muestra real de montaje de tapialeras, costales y agujas, su relleno y compactación. El ritmo de compactación del tapial optimo para el esfuerzo manual establece una "melodía" de tres impactos consecutivos, un intervalo de silencio y, de nuevo otros tres impactos que se aplican siempre sobre el mismo punto de la masa a compactar. La reparación y restauración de los lienzos con pérdida volumétrica parcial es un trabajo complejo por la dificultad en el montaje de las tapialeras debido a que, casi siempre, no se puede reutilizar los pasos de las agujas originales. Para evitar el deterioro de los nuevos volúmenes formados y la rotura de las aristas, es importante insistir en que debe evitarse el trasiego de materiales y personas sobre ellos.

El objetivo de esta intervención en varios tramos de la muralla del castillo de Sagunto, ha sido la recuperación de la entidad de los lienzos para devolver la identidad de límite a la muralla y su presencia como perfil paisajístico, integrando las fábricas nuevas e históricas desde la distancia; desde cerca, mejorar todas las lecturas constructivas características de los tramos preexistentes para restaurar su valor histórico. Solo el paso del tiempo tras la ejecución otorgará las auténticas conclusiones sobre la durabilidad y la integración de estas obras.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Restoration of the Andalusí wall of the Alcazaba Antigua (Ancient Citadel) of Granada (Spain)

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ABSTRACT: The primitive Andalusí wall of the Alcazaba Antigua of Granada in Cuesta de Alhacaba area was strengthened on the northern side by means of the construction of further outer wall, parallel to the existing one, in the area just next to the Cuesta de Alhacaba. This new wall, of a larger size than the inner one, was 350 m long, stretching between Puerta del Ensanche (*Bab al-Ziyada*) and Puerta Monaita (*Bab al-Unaydar*), with fourteen intermediate towers. It was built by means of *tapia calicostrada* (lime-crusted rammed earth) walls. In some towers and panels the original parapets and crenellations have been maintained. This part of the wall was subjected to consolidation and restoration in the period 2002–2006. The purpose of this work was to recover the structural safety and to facilitate observation of the original elements that have been preserved, and of contributions of previous interventions, while undergoing minimum changes in the visual image of the walls.

1 BACKGROUND

1.1 *Historical introduction*

The hill situated on the right-hand bank of the River Darro was a settlement of the Iberian-Roman *Iliberri*. The limits must have coincided with those of the first *Madina Garnata* Andalusí on the northern and western sides, where there are steep escarpments. The fact that the capital of the new Taifa kingdom of the Ziri dynasty was established in Granada at the beginning of the 11th century led to the strengthening of the old walls. A few decades afterwards the city expanded towards the plain and the walled precincts were considerably enlarged; the first precincts became the centre of power under the name of *Alcazaba Antigua* (Ancient Citadel). At a later date the fortification on the northern side was reinforced, in the area just close to the Cuesta de Alhacaba, with the construction of another exterior wall parallel to the existing one, with gates at both ends (Fig. 1). This must have been built in the period of the Almoravids (1090–1157) (Torres 1952, Marcos 2010), or maybe in the Almohad period (1157-1232) according to other authors (Márquez & Gurriarán 2008). The fact that Granada was chosen as capital of the Nasrid dynasty in 1237 led to the construction of a new palatine city on the Alhambra hill, and therefore the Ancient Citadel lost both political and military interest. Half way through the 14th century this area was left intramural, as the northern suburb of the city, called the Albaicín, was surrounded by the outer city walls (Orihuela 2001).

1.2 *Restorations*

In this sector there is evidence recorded of seven interventions of consolidation and restoration. With the exception of the last one, they were all directed by Francisco Prieto-Moreno Pardo, who was the conservation architect of the 7th area. The three projects of the 1950s were based on urgent tasks of underpinning of foundations and consolidation of wall faces, by means of concreted rubblework and ordinary rubblework respectively. In 1962 there was an additional repair job of the wall faces with a minor loss of mass, by means of solid masonry brickwork rough rendered with lime mortar and clayey earth, and an effort to find a similar tone to that of the well-preserved rammed earth wall or *tapias*. However, in 1963 the decision was taken to leave the repairs with solid masonry brickwork exposed, although in areas with superficial crust decomposition they continued to apply the same aforementioned rendering. This new criterion, justified by the convenience of distinguishing the new (brickwork) from the original (*tapias*)

Figure 1. View of the western section before the restoration.

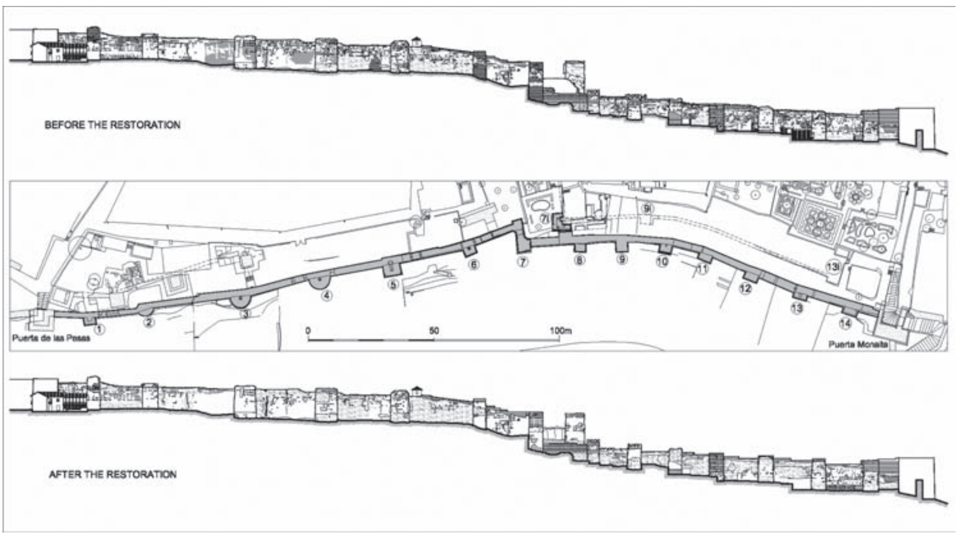

Figure 2. Plan and elevations before and after the restoration.

continued to be applied in the 1968 project. There may also have been influence in the change of criterion, although this is not indicated in the written records, due to the poor adherence of the lime mortar used on the masonry brickwork grouted with mortar from Portland cement.

Following the 1982 project, the architect Ana Iglesias took action on the intramural wall face between the *Bab al-Ziyada* and tower 5. She changed the criteria and the previous constructive techniques, because she was intending to achieve mimesis with *the existing tapias by means of shuttered pseudo-tapias*. White cement was used as agglomerate, but on applying it laterally and not from above, it lacked the necessary rammed action. The inner strengthening with bars of corrugated steel and electro-soldered mesh has contributed to the considerable deterioration of this intervention, even after a period of less than thirty years.

2 DESCRIPTION OF THE WALL

The stretch of wall subject to intervention is 350 m long, between Puerta del Ensanche or de las Pesas (*Bab al-Ziyada*) and Puerta Monaita (*Bab al-Unaydar*), with fourteen intermediate towers, and it can be divided into two areas (Fig. 2). In the centre of the eastern one, beginning in the first aforementioned door, there are three semi-cylindrical towers and another prismatic one, all of a large size and considerably separated. When we reach tower 7, which was initially built as an *albarrana* (a flanking tower linked to the wall by a brick vault), there is a turn in direction and a break in the parapet walk, and the 150 m of the western area runs on to a plateau at a lower level than the previous one. The seven towers of this sector have a rectangular layout, are fairly near each other and stand out only a little from the wall. Towers 8 and 9 and the panel between

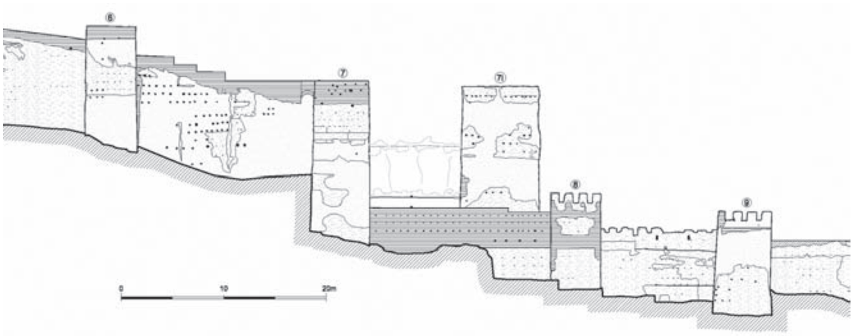

Figure 3. Elevation of the central section after the restoration.

them have maintained the parapet and the crenellation, with two loopholes carved in the parapet. The average height of these stretches is about 10 m, and reaches a height of 15 m in some towers; the width varies between 2.70–3.60 m. The towers stand out two courses of *tapias* above the panels and they can be reached from the parapet walk by very high steps, shuttered in the *tapias* of the towers. They were built by means of greyish *tapias calicostradas* (rammed earth with a hard lime crusted surface) with courses of 71–84 cm in height. They had *agujas* (pieces of wood for sustaining the shuttering) of boards of 8×2.5 cm that were set inside, except in the parapets, where they could be retrieved. In almost all the towers and panels we can see various impressions left by the esparto grass rope on the surface of the wall, and situated horizontally at the height of the *agujas.* Possibly these ropes were used to control the horizontal level of the construction, as they utilized several plank moulds at the same time (Fig. 8).

This sector of the wall was submitted to consolidation and restoration work during the period of 2002–2006, under the direction of one of the authors of this paper (J.M.C.), with separate advice from the other author (A.O.). One of the two towers preserved above ground level of the inner wall was also restored, and this we have referred to as 7I. Both this tower and the stretch 5–6, and particularly tower 7 of the outer wall, retain on their outer face decorative traces of white band 4.5 cm wide, to accentuate the courses there (Fig. 3). This type of adornment has been considered in other Andalusí fortifications as specific of the Almohad dynasty (Azuar 1996).

3 PATHOLOGIES DETECTED IN THE WALL

3.1 *Natural pathologies*

Problems of stability of banks of the natural conglomerate of the hill where the Ancient Citadel is situated in the proximity of towers 2, 3, 5 and 6, as well as in the panel between towers 2–3; deterioration due to atmospheric conditions, particularly winter frosts; the presence of parasite vegetation rooted into the wall and its immediate surroundings, as well as lichen and dirt on the wall faces; the existence of nests of insects, birds and rodents, which had made their breeding and resting place here in these *agujas* holes.

3.2 *Anthropic pathologies*

The presence of insignificant attached buildings of no interest, brackets of television aerials and electric cables; cavities made in the wall faces by people who used them as store rooms, wood sheds, etc; the excavation of caves under the foundations of some panels of the outer wall; elevation of the original height of the wall, filling up on top of towers and panels, to achieve horizontal surfaces in the gardens of properties that were previously intramural.

4 RESTORATION CRITERIA

After consolidating everything that was deemed necessary for restoration, the main objective is that it should be unnoticeable from a distance, but that it can be observed by those who wish to investigate and appreciate the remains under conservation. Our aim has been to respect as far as possible the previous actions of restoration without detriment to the security and protection of the restoration and the original materials.

All the accessible wall faces of towers and panels were restored as well as their upper parts so the conditions for draining away rainwater were improved. No work was done on the intramural wall face situated between the Puerta de las Pesas and tower 5, which had undergone intense restoration in the 1980s.

Figure 4. View of the central section after the restoration.

Figure 5. View from tower 8 to tower 14 before the restoration.

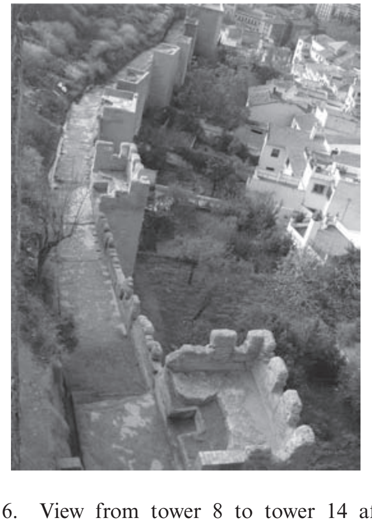

Figure 6. View from tower 8 to tower 14 after the restoration.

The small agujas holes that had grown larger due to the action of groups of animals, as mentioned previously, were filled up sufficiently to hinder them nesting, but not completely, to avoid any radical change in the previous image of the wall. Nevertheless, the large anthropic cavities in the wall faces were totally blocked up. The caves excavated under some panels were also filled in using heavy stone lime concrete (Figs. 4–6).

5 RESTORATION TECHNIQUES

Stabilization of banks and underpinning of foundations was carried out using masonry walls.

5.1 *Selection of the type of mortar for reintegration*

The type of mortar used for reintegration of vertical and superior wall faces was established after analyzing the Study of Characterization of Materials and a series of trials carried out in situ, with monitoring during a winter period. Three different compositions of the agglomerate were experimented with: aerial lime only, a mixture of aerial lime and hydraulic lime, or a mixture of both types of lime and white cement with the same proportion of the three products. The best results were obtained with the latter formula and a proportion of aggregate/sand of 1:2. It cannot be forgotten that the implementation work is itself a coating applied laterally to a wall and not the traditional one of rammed earth from above. The climatology of Granada also influences the result of the initial mixtures, as the enormous variations in temperature and winter frosts cause rapid deterioration of the upper layers, since they are exposed to the water and inevitably this is manifest in the freezability of the material. It has been proved that this effect is lesser with the chosen composition, although precaution must be taken not to damp proof until the water of the mixture has completely evaporated.

Filling the fissures and cracks was carried out with the system of putting in plugs from the bottom upwards, therefore guaranteeing the greatest possible filling of the cracks with mortar or lime slurry. To do this the crack was sealed in stretches of 50 cm and the mortar was poured in until it flowed out of the top, in order to avoid pockets or empty areas.

5.2 *Cleaning of the wall faces with preserved tapia crust*

Cleaning of the wall faces was done using a jet of high pressure water, whether the coating was in good condition or deteriorated or almost inexistent. Further to this a consolidation treatment was given, with lime water in the case of partially eroded courses, and finally a damp-proof product (Tegosivín). These joint actions have given the best result in the curves of absorption-desorption, as it reduced the speed of absorption of water and its capacity of retention, and at the same time it doesn't produce any significant alteration in the degree of drying out. There were positive effects of cleaning the surface on the degree of hardness; with this treatment the superficial area that was most modified was eliminated, therefore improving the properties of the material. The aesthetic result is correct, since this treatment cleans the wall faces without changing the colour or its texture. The permeability to the water vapour was also tested.

5.3 *Areas with eroded tapia crust*

In the areas where the *tapia* crust was eroded to a depth of about 4 cm from the original surface, a mechanical cleaning was carried out to eliminate loose or degraded elements, until it became a good base on which to place the later treatment. Further to this, an impregnation was applied with 20 coats of lime water, in order to achieve a correct consolidation of the material. The process was completed by damp-proofing the surface. Also in this section we include the inner consolidation of cavities of crumbled fragments that should be maintained, and therefore consolidated, which was done by means of cleaning with high pressure water, followed by consolidation with lime water then sealed with hydraulic lime mortar.

5.4 *Areas with loss of mass*

In this project three levels of loss of mass in the wall surfaces were considered: a superficial one, loss of medium depth and large cavities. The reason for this distinction was that of applying in the reintegration of each level slightly different material, which could facilitate and accelerate the implementation of the work.

The first level included deterioration between the crust and about 8 cm of depth. The material applied was the mortar described in section 5.1, with semi-coarse aggregate, i.e. aggregate up to nº 6 in the whole mass.

The second level included deterioration with loss of mass between the crust and about 20 cm. In this case the same mortar was used in the superficial levels, but in the deeper ones mortar with coarse aggregate. In the third level, foreseen only in the existing cavities, an aerial lime concrete with stone aggregate was used in depths greater than 20 cm, changing to the previous material on reaching the corresponding levels.

The aggregate of the restitution material used on the most superficial layer, which should remain uncovered, was selected with adequate soil texture and aggregates of different origin were mixed to achieve heterogeneity similar to material of the existing mass.

The exposed surface was left at a level −3 cm from the original finished surface, and a combed treatment was applied, consisting of combing to achieve a rough surface on which the aggregate could be observed. Afterwards, a series of horizontal lines of small depth were drawn, imitating the indication of the internal beds or strata of *tapias* with the purpose of avoiding a superficial homogeneity which was not desired. Using rather thicker lines, and equally superficial as the previous ones, the impression was made of the different courses of the *tapia*.

It was important that the thickness of the coats of reintegration mortar was not more than 1 cm, since due to the characteristics of this material a greater thickness would mean its cracking and becoming detached because of lacking sufficient air for carbonization. These coats were laid by throwing them gate would stick on to it. The edge of each of the coats was gate would stick on to it. The edge of each of the coats was well closed on top of the previous one and on the base of the material (Fig. 7).

5.5 *Treatment of cracks*

The cracks were joined up using stainless steel staples after cleaning up the area and discovering the strong material in which to place the staple legs

Figure 7. View of towers 2 and 3 after the restoration.

Figure 8. Detail of *aguja* and esparto grass trace on the *tapia*.

with resin. This resin was never less than 50 cm from the ultimate surface, to avoid producing any change in it. After this joining up operation, the important cracks and cavities existing in the walls were cleaned and filled up with mortar of the same characteristics as the aforementioned ones.

5.6 *Treatment of "agujas" and their holes*

It is well-known that the holes we refer to as *mechinales* are not associated with the original image of a wall like this one, built with set in *agujas* of wooden boards. They become manifest with the first deterioration and are the origin of a lot more. However, we consider that the presence of these holes has created a characteristic image of the ancient *tapia* walls, and that it should not be modified. Any steps regarding them were therefore taken according to the area where they were placed. Those situated in areas of crust in good condition or deteriorated were left as they were, cleaning them up and damp-proofing them. In the cases where their dimensions were disproportionate, their inner mixture was remade with mortar of a slightly darker tone, to simulate greater depth, and giving a slightly concave finish to the surface. The new depth of the hole was not more than 7 cm with regard to the surrounding surface. In the areas where wall mass was remade, no *mechinales* were presented on the surface. In those where the wooden *agujas* existed, the disintegrated material was cleaned and fumigated by injecting insecticide-fungicide (Xylazel). In the case of much deteriorated ones the latter was substituted by a consolidating material (Paraloid).

6 CONCLUSIONS

Consolidation and restoration have been carried out with due respect to part of the previous interventions and there have been minimum chromatic and volumetric changes in the existing Andalusí city walls. Almost a decade after commencing the work, the state of conservation is satisfactory.

NOTE

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Historical rammed-earth structures in Eastern Andalusia: (Spain) The restoration philosophy of the architect Prieto-Moreno

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ABSTRACT: Southeastern Spain presents a wide range of rammed earth forts and city walls built during the al-Andalus historical period. Taking this architectural heritage as a starting point, the paper will explore the working methods of the architect Francisco Prieto-Moreno, who during the Francoist era directed various interventions on the historical rammed earth buildings of Almería, Granada, Jaén, Málaga and Ceuta. Using a reasoned approach to these intervention projects, the paper reflect on how Prieto-Moreno saw the problem of restoring historic buildings. His interventions on historical architecture show a wide range of criteria, from actions strictly limited to underpinning and consolidation to the reconstruction of volumes with the goal of recovering some of the lost profiles. This study analyses the interventions of the architect, taking into account the technical, economic and cultural context of his work. The paper is related with the scientific research project *"La restauración de la arquitectura de tapia en la Península Ibérica. Criterios, técnicas, resultados y perspectivas"* (ref. BIA 2010-18921) granted by the Spanish Ministry of Science and Innovation".

1 INTRODUCTION

Francisco Prieto-Moreno y Pardo (1907–1985) was the subject of the doctoral thesis of one of the present authors, and was one of the leading representatives of the restoration of Spanish architectural heritage during the Francoist era. In the early 1940s he was appointed to head the Seventh Zone of the Servicio de Defensa del Patrimonio Artístico Nacional (Service for the Defence of National Artistic Heritage), directing the restoration of many buildings in south-eastern Spain and the cities of Ceuta and Melilla. The state initiative of dividing Spanish territory into reconstruction zones to repair the destruction of the Civil War, and in later years to supervise the conservation of heritage, meant Prieto-Moreno worked at the same time as other leading professionals of the period, such as Francisco Pons-Sorolla, Luis Menéndez-Pidal and Alejandro Ferrant. His long career in the field of architectural restoration would be completed by his work as Architect-Curator of the Alhambra and Generalife for over four decades, beginning in 1936 when he inherited the post from Leopoldo Torres Balbás, with whom he developed a close personal and professional relationship. Although the main theme of this work is analysis of Prieto-Moreno' interventions on rammed earth architecture, we have considered the importance of their context in a turbulent historical sometimes led towards riskier methodological positions.

After the plethora of theoretical discussion on the restoration of historical buildings in the first third of the 20th century, during the Francoist era these theoretical currents became sluggish, although this was counterbalanced by a great many heritage interventions, largely subject to the new conditions imposed by the Civil War. Although it is a complex task to untangle, in these short pages, the theoretical and methodological directives of architectural restoration during the Francoist era, it can be said that in the post-war period, until the end of the 1950s, urgent architectural reconstruction was considered less important than other activities responding to the complexity and singularity of each historical monument. Thus, there was an extensive field for experimentation among the various needs and sensitivities accompanying the evolution of restoration in those four decades.

2 THE MAIN ACTIONS OF PRIETO-MORENO ON FORTIFICATIONS

The development of this research was based on important archive work, gathering the projects drawn up by Prieto-Moreno referring to fortified architecture. We sometimes find projects on stone buildings with little presence of rammed-earth walls, such as the Alcazaba at Loja and Salobreña Castle, in the province of Granada; Mota Castle in Alcalá la Real and the Castle of Santa Catalina in Jaén, the city walls of Úbeda and Sabiote, and the fortified city centre of Melilla. Similarly, we have worked on other interventions by the architect on civil monuments where the percentage of rammed earth structures is lower, leading us to omit these from this study.

In interventions on rammed earth fortifications, the first approach examined the Alcazaba of Almería and the towers surrounding the district of La Chanca, the castle of Baños de la Encina (Jaén), the Alcazaba of Málaga and the castle of Fuengirola, the Alhambra and the walls of the Albaicín in Granada, the tower of the Fort in the Granada town of Las Gabias, and finally, the city walls of Ceuta. These numerous elements attest the enormous experience of Francisco Prieto-Moreno as an architect-curator in this field.

The research begins with the analysis of numerous intervention projects drawn up by the architect, and the interesting historical graphic documentation enabling us to establish a critical review of his programme of work. Of the many photographs studied, due to the limited scope of this work, we include only the most representative, some illustrating the physical reality of the constructions, and others showing the precarious state of conservation before the restoration work (Fig. 1).

Figure 1. Walls of the San Cristóbal, Almería (1958) Fuente: Ministerio de Cultura. Archivo General de la Administración. Fondo Cultura, IDD (03)116, Caja 26/160.

It should be pointed out that in this examination of the documentation, mainly the holdings of the Archivo General de la Administración (General Government Archive, AGA, Alcalá de Henares), a great many monuments and projects were studied, as in many cases the project descriptions are brief and written for administrative use. Thus, their contents cannot be considered definitive, and occasionally the work carried out would really be determined by the needs of the monument on site.

3 AN ANALYSIS OF THE MOST IMPORTANT RAMMED-EARTH RESTORATION PROJECTS

We analyse in detail some of the architect's interventions on rammed-earth fortifications which from our point of view are more significant in relation to the subject of the Congress. The projects date from 1950 to 1969 and we have studied them in chronological order.

3.1 *Walls of the San Cristóbal, Almería (1950–1960)*

This building is directly connected to the Alcazaba of Almería, where Prieto-Moreno carried out an important campimg of intervention from the early 1940s. Beginning in 1950, he drew up various projects referring to the walls of San Cristóbal, and we examine here one from 1958, where he considers intervening on one of the towers of the covered walkway from the Alcazaba to the fortified walls. The photographs of the period show large cracks suggesting severe deterioration (Fig. 2). The work to consolidate the walls continued in 1959–1960, the case we analyse here. The towers connected by curtain walls were built using the lime reinforced rammed-earth technique: a compacted earth wall reinforced on the outside by a crust of lime rammed in layers at the same time as the earth mixture, a procedure that gives the wall greater surface strength.

The project description indicates the technique planned for the intervention, which was to use "*the same earth the wall was made from, so that the restoration is not a different colour.*" Special care was to be given to the buttressing of the base, which was to be done in slipform stone in concrete formwork: "*Both the construction of the rammed earth wall and the stone and brickwork will use local earth in order to have the colour blend with the old wall.*" (AGA, Sección Cultura 26/148).

The result of the intervention would be a slipform stone wall, flush with the original, with concrete formwork over irregularly spaced wooden planks, period, in which the discipline of restoration was

Figure 2. Walls of the San Cristóbal, Almería (2012).

clearly visible on the wall surface, with the intention of conserving the structure of the building reproducing here and there the holes that housed the temporary stays used to support the formwork during ramming. The surface color blended with the existing aged wall color more than the interior of the earth wall, as the original finish of the lime-reinforced rammed earth used was a whitish lime mortar.

3.2 *Nasrid wall of the Albaicín of Granada (1953–1968)*

This city wall, also known as Cerca de Don Gonzalo, was erected in the mid 14th century, and consists of a set of towers connected by curtain walls 130 cm thick, built of lime-reinforced rammed earth. Prieto-Moreno's interventions took place from 1953 to 1968 in a total of eleven projects. This was an ambitious programme, executed in different stages and embracing different intervention criteria and techniques, and was one of the most important of the architect's activities in Granada, as it meant a significant reconstruction of the profile of the wall, which had partly disappeared in this sector.

In the 1958 project, the action was limited to the part of the wall from the chapel of San Miguel Alto to the east, the sector known as "Vereda de Enmedio". At that time, according to the architect, the heavy winter rain of previous years had caused substantial loss of material, making urgent measures necessary to prevent more serious damage.

The project description proposed reinforcing the foundations and buttressing the wall with rubble stone and concrete, lime, sand and *alpañata* (the red earth of the Alhambra hill), and rebuilding part of the wall. The 1960 project specifies that the work should follow the same criteria in the Cerca de Don Gonzalo sector, mainly carrying out buttressing. The project description of 1963 refers again to this area, although in this case the intervention technique is specified: *"The sectors affected by consolidation will be visible from outside, made of solid brick with thick joints, a system which enables colour matching in the wall as a whole, while the restored areas can be distinguished from the old walls, some of which retain their original plaster."* (AGA, Sección Cultura 26/367). The last project referring to the Cerca de Don Gonzalo sector is from 1968, and for the first time mentions the need to integrate the supervision of the archaeologist: *"… under the direct command of the Architect and the supervision of specialist archaeologists, as even when the work is easy to do, it is important to achieve a particular aesthetic in relation to the setting"* (AGA, Sección Cultura 26/134).

The scope of the work varied according to the state of conservation of the sectors. In some cases, where large cracks appeared in the bases of the walls, threatening collapse, they were buttressed using a brick mixture, brick pillars and stone infill. In other cases, where sections of the structures were completely lost, the action consisted of reconstructing the profile up to the height of the battlement walkway, the intervention, as indicated in the project, consisting of two rows of solid brick flush with the wall surface, with an inner filling of cyclopean concrete. The recovery of the stepped profile of the wall was intended to reproduce the steps of the original wall, with modules of an average height of 80 cm according to the size of the original rammed-earth wall sections, although these modules are not conserved in some of the steps made.

3.3 *Torre de Baltasar de la Cruz in the Alhambra, Granada (1964)*

There were many interventions by Prieto-Moreno on this Nasrid building from 1936 to 1978. One of the most important campaigns was carried out on the southern wall of the site, including the Agua, Arce, Siete Suelos and Baltasar de la Cruz towers. We examine this last case in detail.

The Baltasar de la Cruz tower, built in the 14th century of lime-reinforced rammed earth, was bombarded by Napoleon's troops in 1812 and almost completely destroyed. In 1935, Leopoldo Torres Balbás partly rebuilt the tower using brick pillars and stone up to the level of the battlement

Figure 3. Forefront: Nasrid wall of the Albaicín of Granada Bottom: Alhambra of Granada (2011).

walkway. During our research in the Archivo General de la Administración we were unable to find any report or description of the intervention on this tower written by Prieto-Moreno. However, the Archive of the Alhambra conserves plans of the project, enabling us to document that the work by Prieto-Moreno would complete the reconstruction of the tower begun by Torres Balbás, raising it to about what must have been its original height. The new work allowed the use of the battlement walkway, leaving the top level room unroofed and avoiding the difficult question of discerning where the upper vault which must have closed the tower would have been located (Espinar & López 2004). Prieto-Moreno would choose brickwork with a broken whitish cladding, which let the brick show through and marked the holes of the temporary stays originally used during ramming of the wall, a typical feature of eroded rammed-earth walls. To integrate the colour of the cladding, a patina was applied of *alpañata* dissolved in water.

In 2000 new restoration work was carried out on the tower due to its poor state of conservation. The work was directed by the architect Antonio Luis Espinar Moreno, who consolidated the structure of the building, giving it a flat roof and renewing the cladding (Espinar & López 2004).

3.4 *Fortified walls of Ceuta (1967)*

The project would affect the Marinid towers and walls surrounding the Afrag, a sector where the architect specifies that "enough remains of the original for a complete restoration, although we run the risk of losing it, as there are sections of the tower or merlons which are completely destabilised." (AGA, Sección Cultura 26/113). Prieto-Moreno based the urgent need to consolidate the walls on the historical value of the site and also on "its archaeological importance, as these are the last remains of the city limits."

The interventions would be carried out on the walls and towers in poor condition, with the following notable actions: on the towers of the Puerta de Fez gate, the lost merlons were rebuilt with cyclopean concrete, filling in the cracks and fissures of the walls and sectors with loss of the original crust with lime and cement mortar. Finally, the bases of the towers were buttressed with concrete with sections of brick.

The first of the towers to the north of Puerta de Fez was buttressed in the same way, while for the second a fallen section was reconstructed in cyclopean concrete. In one of the towers in the southern sector of the wall, the most deteriorated, a new concrete lining was laid between the walls, sealing the cracks and fissures with stone and then plastering with lime and cement mortar. At the top of the tower a reinforced concrete tie beam and brick merlons were also added. In some cases the concrete elements conserve the courses of the original rammed-earth wall sections and display the holes of the temporary stays. The concrete and mortars used present a rough textured finish and are designed to blend with the present earthy colour of the fortifications.

In 2012 restoration work was carried out on the wall, concentrating on the southern sector,

Figure 4. Fortified walls of Ceuta (1967) Fuente: Ministerio de Cultura. Archivo General de la Administración. Fondo Cultura, IDD (03)116, Caja 26/113.

Figure 5. Tower in the district of La Chanca, Almería (1967) Fuente: Ministerio de Cultura. Archivo General de la Administración. Fondo Cultura, IDD (03)116, Caja 26/111.

where the walls were restored and the brick merlons added by Prieto-Moreno were removed. The work was directed by the architect Pedro Gurriarán Daza.

3.5 *Towers in the district of La Chanca, Almería (1967)*

In the project description, the architect proposes the consolidation and partial reconstruction of the sections of wall still standing, explaining that "*the part of the wall itself which supported the battlement walkway is practically all lost, with the part which stood out still standing. As the breakage was a single event, we find that part of the remains of the tower lacks a foundation, and thus is uns*table." (AGA, Sección Cultura 26/111). Prieto-Moreno suggests underpinning the foundations with cyclopean concrete and "*the walls will be built using the technique of filling with concrete layers, so that the current formwork coincides horizontally with the height of the formwork the Arabs used for each wall section. We will then plaster with lime mortar, using sand, so it blends with the existing finish.*" The work carried out indeed shows underpinning with concrete and wooden formwork, in some cases conserving the position of the holes of the original temporary stays.

This underpinning also fills in a cave which had been hollowed out at the base of the tower. The wall abutting the lost section, as it did not have a surface crust, was badly damaged and irregular in texture, and was plastered, using a well-chosen rough finish, applying a mortar probably made of lime, cement and rough sand.

4 DEFINITION OF HIS CRITERIA AND ANALYSIS OF HIS RESATORATION PHILOSOFY

Most of Prieto-Moreno's restoration work on rammed-earth architecture was done, as remarked above, on lime-reinforced rammed earth walls, which originally presented a hard earth wall reinforced on the outside with a crust of lime. It is not always possible to recover the original material aspect of these structures, as the resulting wall is a direct consequence of its construction technique (Mileto et al. 2011).

The fact that many of the buildings analysed were in a ruinous state when Prieto-Moreno took charge of their restoration justifies, as the architect would point out, the urgent nature of the interventions. We should not forget that during the closed economy, architects and restorers were faced with a great scarcity of technicians and materials, as we gather from the words of Prieto-Moreno as he began work on the castle of Salobreña. The project description, which is outside the scope of this study, includes this especially significant comment regarding the amount assigned for the restoration: "*it is really insignificant and hardly enough to begin work on a symbolic plan. Because of this the items needed to repair the most pressing damage have been consigned.*" (AGA, Sección Cultura 26/291).

In general, the written projects should be understood as the instrument used to make the conservation of the historical building viable, without expecting exact and precise descriptions of the planned interventions. Reading the project descriptions and later analysis of the work actually carried out also reveals the concern of Prieto-Moreno that the volumes and elements he was trying to restore should respect the original materials and that these in turn would integrate well in the new work. Another aspect which can be seen now that years have passed is that the interventions are reversible. We can see that the poor materials used to carry out the work, whether or not this was intentional, mean that some of the more recent restoration projects were able to "un-restore" or remove previous restoration work, in accordance with the increasingly accepted conservation theory of "de-restoration".

While it is outside the scope of this study to analyse the theories and international treaties which might have been the reference points of

Figure 6. Tower in the district of La Chanca, Almería (2012).

Prieto-Moreno, we should not forget that the architect's criteria for intervention are in agreement with the principles of the Athens Charter (1931) and the Venice Charter (1964). The recognition of the double artistic and historical value of the building and the use of modern materials and techniques were aspects which the architect took into account in his interventions. We can point to the special attention shown in the projects to conserving structural and constructive value through underpinning and consolidation. This is the case in the work on the wall of San Cristóbal and the towers of La Chanca in Almería, or the fortified walls of Ceuta. In contrast, we can see in other interventions that the architect opted to restore the volumetric lines and basic profiles of towers and city walls. This is the case with the tower of Baltasar de la Cruz in the Alhambra, and some sectors of the wall of the Albaicín of Granada.

5 CONCLUSIONS

We should not forget that the actions of the Spanish government in these decades of the 20th century led to a considerable transformation of the state of Spanish architectural heritage. It is also necessary to point out that the buildings analysed in this study are a tiny percentage of the huge volume of work which Francisco Prieto-Moreno had to undertake as the architect of the 7th Zone. This situation would make the exhaustive control of these complex works more difficult, especially as, with a few exceptions, they were carried out without the help of archaeologists aware of the material aspect of the original construction.

Therefore, we should understand the interventions of the architect as the result of the correct application of the restoration criteria of the period, in a geographical context of a high density of heritage, and carried out with technical and budgetary limitations. From our point of view, it would not be viable to interpret these interventions without putting them in their historical, social and cultural context, while their study is crucial to the present reading of the building. These interventions ensured the survival of many rammed-earth fortifications which would undoubtedly have disappeared or deteriorated badly if not for the action of the architect appointed by the government as head technician.

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Restoration of the stone *tapia* of *hsin al-Qala* (Castell d'Alcalà de Gallinera), Alicante, Spain

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ABSTRACT: The fortress of Alcalà de Gallinera is recognised as a monument of great historic and architectural value. The stone *tapias* (rammed earth walls with stone in-fill) of this Almohad construction, in their current ruinous condition, constitute a material document of exceptional interest. This paper details the restoration methodology, understood as a unified process which includes phases of prior study, project and execution of the work. Previous research carried out has provided information on the materials, techniques and trades of the original wall, crucial matter to drawing up the restoration plan. Archaeological study provides valuable information and makes it possible to establish a precise chronology of the different elements of the monument. This paper describes the restoration criteria and interventions, without losing sight of the knowledge of and respect towards this architecture, encouraging a greater appreciation of these walls that are almost a thousand years old.

1 INTRODUCTION

The Almohad is strategically situated on a bluff surrounded by cliffs. The whole valley can be seen from its summit and the sea can be glimpsed in the distance, with its extremely complex and long defensive walls blending into the crags on which they stand. The name Alcalà comes from the Arabic *qalaça,* meaning a fortress city, and the Castell d'Alcalà de Gallinera has witnessed many historic events. This *hsin* is a representative monument of a group of fortress with immense value that constitutes a unique episode in the islamic defensive architecture. The fortress enclosure is made up of three areas staggered in height: the lower and upper *albacar* and the *celoquia*, combining with a Christian *castrum* (Fig. 1). It is an enclave in a mountain massif of the northern foothills of the Prebaetic mountain system, north of the Marina Alta region in the present municipality of Vall de Gallinera (Alicante, Spain).

Figure 1. General plan of the fortress.

2 METHODOLOGY

The methodology applied shares a series of principles and criteria based on the international charters for the restoration of monuments. Architecture as a document of material culture requires respect not only towards its space, form and composition, but also towards methods of construction and materials. We should not forget, as Brandi (1988) states, that "*only the materiality of artwork is restored*".

2.1 *Historical study*

Documents dating back to the thirteenth century (Guinot 1991), relate significant historical events and provide extremely precise chronological data which, unfortunately, are barely relevant to an understanding of the architecture of the fortress. In addition, research on the architecture of Sharq al-Andalus by renowned experts providing unanimously accepted theoretical reference models has been studied (Bazzana 1992, Bazzana et al. 1988), as have several monographs on the castles of the region (Segura 1984), all yielding data highly relevant to the study of these constructions.

2.2 *Architectural survey*

In keeping with the *Dichiarazione sul relievo archittectonico* (Almagro 2004), documentation, mainly graphic, is elaborated to enable an in-depth study of the monument. Gathering onsite data is an extremely important part of this process, since in this phase repeated and prolonged contact with the construction is established, reflecting the current conditions, both of the original work and later additions. The survey was conducted without neglecting traditional systems, but incorporating new technologies that provide three-dimensional coordinates and photogrammetric techniques. Given the large size of the fortification and the complexity of the mountain location, general plans were drawn up initially to assess its morphology and dimensions. These plans were then used as reference in carrying out monographic studies of different issues such as measurements, composition, construction, dating, stratigraphy (Mileto & Vegas 2003), materials used, state of decay, etc.

In this case it is necessary to highlight the importance of the studies carried out on the construction technique of the *tapia*. By carefully examining the wall faces it was possible to identify the surviving traces of the construction process of the wall: heights, lengths, putlogs, bars, wooden boards, corners, openings, flooring, or any other relevant data. Information tended to be scarce and incomplete (Fig. 2). The key to the interpretation is to establish equations between the different variables knowing the general laws of the process, some data can be used to obtain other information which has left no physical trace (Soler 200902).

2.3 *Study of materials*

The aim of this study is to reveal the secrets of the extraordinary longevity of this stone *tapia* wall, which has no doubt been helped by the material used: a mix of sand, gravel and lime bonding the rough stone (Fig. 3). Certainly further knowledge of this is highly relevant, and convenient, since new walls had to be built. What materials had been used? What were their characteristics, their dosages? What where their properties? For the purpose

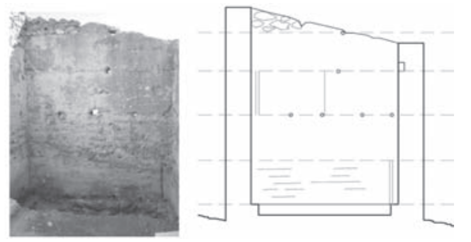

Figure 2. Surviving traces of the construction process.

Figure 3. Lime mortar and rough stone with the trace of a putlog in a ruined *tapia*.

of durability it is important to know the resistance, which also bears relation to other properties such as cohesion. Knowledge on absorption is also important since it is a determining factor when establishing the superficial behaviour of the wall face.

In order to establish these characteristics, sample fragments which had fallen off the *tapias* were collected, carefully noting where they were collected and carrying out a series of analyses and tests in a laboratory.

As regards the results obtained from the rough stone, the characterisation of materials matched carbonated rock, with a composition of 0.949 $CaCO_3$ and 0.017 SiO_2, according to the reading provided by the diffractometer. Other tests established density as 2.280 kg/m^3 and absorption as 4.64%. It was confirmed that aggregates and sand are limey and that the bonding material was lime, given the great purity of the rocks, 95% calcium carbonate, the lime is non-hydraulic, high-calcium lime (Arredondo 1967).

In addition, the lime mortars tested provided their density and absorption properties. Moreover, when these were broken up they were classified into three levels of consistency. The next step was to determine the size of the grains and compare with the Bolomey ideal curves. Given the impossibility of chemical discrimination for the components of these samples, it was not possible to establish with certainty the dosages used. However, by analysing the percentages remaining in the 0.063 sieve and using reasoned hypotheses regarding the size of the grains of lime and sand, it was possible to deduce dosage values. These values range between 1:2.3 and 1:1, with an average of 1:1.7, and are within the usual values for restoration. The dispersion from an ideal theoretical dosage can be explained by the construction conditions, bearing in mind that in real circumstances, these dosages would be applied in volume, and therefore these approximations can be considered valid. As regards mechanical resistance, tests were carried out using reference samples of mortars with similar characteristics to those analysed, and a correlation was established between the cohesion obtained and the breaking up of the samples.

The results of the breaking of the mortar samples were 5.00–6.00 N/mm^2. In addition, the characterisation of the rough stone made it possible to state that the compressive strength exceeded 50 N/mm^2. The resistance reached by walls depends mostly on the shape and positioning of the stone and the thickness and resistance of the joints. In any case, an exact approximation is not needed when calculating wall resistances, which without doubt are much greater than the tensions they are subjected to, ranging between 0.3 and 0.5 N/mm^2.

2.4 *Archaeological work*

The cross-disciplinary reading of the archaeological strata and the wall units was carried out jointly by architects and archaeologists. Knowledge on the use of spaces through the study of the ceramics found in relation to the period provided a new analysis of the architecture and contributed to a better interpretation of the wall remains for the purposes of the intervention.

Archaeological work focussed on the areas that were to be defined, since they were partially underground, as in the case of some accesses to the walled enclosure, towers, water tanks or dwellings. This made it possible to reach floor level and analyse the total height of the walls. Once this flooring, with its characteristic thin layer of lime mortar, had been documented archaeologically, it was protected with geotextile sheets and a layer of gravel to prevent deterioration.

The excavation strategy and the process were based on the Harris-Barker method and the revisions carried out by Steve Roskams (2001). The complete recording of data was classified into the following fields: spatial, stratigraphic, graphic, movable archaeological material and computerisation. The open area excavation strategy with no intermediate baulks could be carried out in specific rooms and helped establish the origin of these constructions, dating back mostly to the Almohad period, between the late twelfth century and the thirteenth century, although most of the structures date back to the first half of the thirteenth century. Constructions dating back to the time of transition to feudalism in the second half of the thirteenth century were also documented, for instance one of the towers or the double wall system of the defensive walls, which must have been part of a process of refortification of the entire castle.

3 RESTORATION OF THE TAPIA

The restoration project (Soler 2007) was conditioned by the location of the fortress and by financial limitations. All of this meant the decision was made to carry out a minimal intervention, which in the case of most *tapias* meant cleaning and strengthening the upper sections while respecting the existing silhouette. Sections of wall were only reconstructed selectively after careful consideration.

The aim was to transmit the image resulting from the passing of time, preserving all the imprints and patina, but healing wounds and only replacing specific points for conceptual or technical reasons (Fig. 4)

Although interventions on roofs, vaults or roof timber which had practically disappeared were planned for a later phase, the architecture is the object of an in-depth study and careful reading of the remains, ensuring the intervention on the walls was not to the detriment of any future restoration work. This is the case of the traces of the missing vaults or the spaces left by corbels, or of roofs that no longer exist. All these remains, which should be respected, require provisional protection or shoring up.

3.1 *Architectural type*

The current state of ruin prompted some questions on what the original construction was like. The typological study identified the different constructions of the ensemble and established a relation

Figure 4. View of the lower *albacar* after restoration.

between the remains still existing and the parts that no longer exist, thanks to information on the original architecture.

In this sense the aim is to avoid losing elements that help understand the configuration of the spaces, and for this reason an intervention was carried out to recover individual points such as jambs and corners. Equally, another aim is to preserve significant elements of its image, such as the defensive walls.

In various sections the battlements have disappeared completely while in others there are impressions which make it possible to define their size and position. This was helpful in the intervention as it made it possible to recover a minimum sequence of battlements, bearing in mind that these transmit the meaning of defensive architecture (Fig. 5).

3.2 *Stability*

The disappearance of roofs and intermediate floors has worryingly decreased the safety and stability of the walls. This situation is made worse by the pressure of earth accumulated as a result of the collapse and the fragmentation of the defensive walls. The worst examples occur when the wall is extremely long and the upper edge is free, functioning as a cantilever. Orthogonal walls create a new rigid edge which significantly improves stability.

The intervention has managed to improve these aspects mainly through the following operations: recovering corner joints, transforming the shape of the wall faces by staggering the *tapia* walls in order to lower the centre of gravity and eliminating wall fillings to relieve the pressure from earth.

3.3 *Interfaces*

One of the greatest conceptual and technical problems in the restoration is the dialogue between existing work and new work: defining limits, edges, transition surfaces.

Decay attacked the layers closest to the crumbling surfaces. It was crucial to carry out a cleaning operation, repairing the remains and strengthening them with washes of lime. Where necessary, toother were shaped to improve the bond between the original and the new tapia walls. Filling by

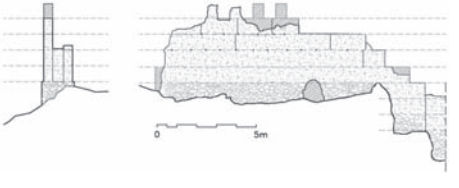

Figure 5. Restoration project: defensive *tapia* in the lower *albacar.*

vertical sections was complicated since it required special compacting techniques. As a general rule, the contact surface between the new building work and the existing construction has a mesh incorporated to improve adhesion and to allow the original work and the intervention to be told apart.

For the crowning of the existing tapias, a solution of little aesthetic effect was adopted, maintaining the unfinished silhouette of the wall. The surface was covered with a layer of lime mortar strengthened with a mesh and incorporating ground ceramic whose durability is vouched for by centuries of use.

In addition, a chromatic study was carried out on the ensemble of wall faces for intervention which had previously been cleaned. Samples were manufactured using a mortar of lime, different types of sand, and a small proportion of natural pigments to create the different colours of the colour chart. The aim is for the new *tapia* walls to blend in harmoniously with the other walls. In a way this is like the treatment of gaps when restoring a painting (Brandi 1988). The integration has to combat the dirt covering the existing walls which have masked their colour, and the deterioration of the outer layer, which have altered their texture.

3.4 *The basic units of tapia walls*

The construction process by means of the successive shifting of formwork, filling and compacting, makes it possible to come up with theories regarding the units built each time, with the formwork ensemble, known as *tapiada*. For the purpose of a specific action, references to unit dimensions based on the islamic system of measurament, which are at best theoretical but do not correspond with the lengths built, are of no use. Taking this into account, to complete the intervention the studies carried out on the traces of the *tapia* wall faces are of vital importance. After the process explained below it was possible to establish the measurements of the formwork used. Thus, the *tapiadas* carried out in the restoration were built with compatible dimensions that cause no conflict and favour the interpretation of the technique used (Fig. 6)

In the *tapia* walls preserved it is relatively easy to determine the thickness by directly measuring the remains and the result is approximately 45 cm. Walls of this thickness are of use when resolving the interior divisions of the walled enclosure, while the defensive walls themselves are finished with a very thick wall formed by 45 cm leaves connected with a central filling. The height of each lift can also clearly be deduced from the vertical distance between the putlogs of consecutive lifts. The height may vary but the average is 80 cm.

However, the measurement that is most difficult to establish is the length of the *tapiadas*, as the

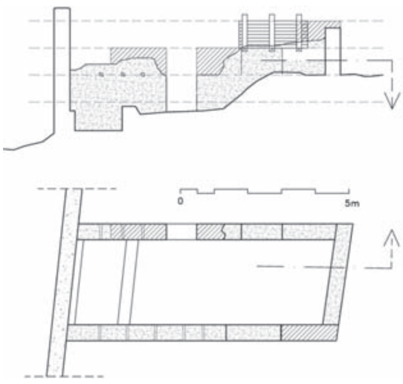

Figure 6. Restoration project: dwelling in the lower *albacar.*

vertical joints are seldom visible. Nevertheless, knowing the construction process this measurement can be obtained using other data. Following close observation it could be stated that each board rested on three putlogs, and the last one of each *tapia* unit is the first of the next one. This means that the length of each tapia unit corresponds to that of the distance between the three putlogs of the same unit of formwork. If it is not possible to determine this information so precisely this means that the approximate length will be double the average distance between putlogs. Given the data obtained in the surveys the average theoretical value of each built length is 160 cm.

The use of formwork provides a base unit for the walls, but we must also recognise the great flexibility of the system which uses overlapping to allow the construction of variable lengths in each *tapiada*, allowing for great variations in size.

The more common measurements for walls that have already been mentioned, correspond with the Almohad period of the fortification, twelfth and thirteenth century (Ortega & Tejerina 2008), but it is interesting to note that in some cases other measurements have been observed for *tapiadas*: approximately 260 cm long, 110 cm high and 45 cm wide, with four putlogs per formwork crate. These date back to the later stages of the Almohad period, at the time of the transition towards feudalism.

3.5 *Formwork ensemble*

Knowledge of formwork should not be limited to the side boards and the whole ensemble should be considered along with the rest of the elements allowing its implementation. After the careful examination of numerous wall faces and the search for imprints, since the process of execution was known it was possible to define the size and positioning of the elements which make up the formwork. This data made it possible to manufacture the formwork used for restoration, guaranteeing measurements compatible with the existing walls.

The intervention included the selective reconstruction of sections of *tapia* wall following the criteria regarding stability and architectural types explained above. Avoiding a return to pristine condition, an unfinished outline is maintained with the reconstruction of entire *tapia* units. In addition, it was decided that formwork crates should be left beside the last section of reconstructed *tapia*, as if the work had been frozen at the moment of construction (Fig. 7). This reinforces the idea of an unfinished outline, but also shows how *tapia* walls were built and encourages appreciation of this thousand-year-old technique, linked to the period the fortress was built in, given that its use in the region fits it with *Andalusí* culture, which was abandoned following the expulsion of the *Moriscos, (1609).*

3.6 *Materials*

The difficulties in accessing the fortress, which could only be reached via a narrow path or by helicopter, made it necessary to use materials from the location as far as possible. Fortunately, water was available from a spring inside the fortress itself and there was an abundance of rough stone scattered beside the buildings. The historic location from which sand and aggregates were extracted was not known, and although there were rudimentary lime kilns abandoned nearby the only viable solution was the commercial supply of lime, sand and aggregates.

For technical and conceptual reasons the new stone tapia walls had to be compatible with the existing ones. Should they last a thousand more years? Minimal, yet sophisticated variations inspired in laboratory studies were introduced. In the dosages of mortars, aggregate with a maximum size of 20 mm and sands with a carefully-selected grain size were used, as stipulated in regulations. During the observation of the samples of the historic tapia walls it was detected that some nodules of lime had barely

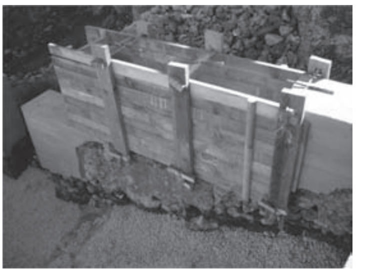

Figure 7. *Tapia* formwork used for restoration.

carbonated. To avoid this problem hydraulic lime incorporating a small proportion of white BL32.5 N cement was used to improve the initial resistance. Ground ceramic was also used for crowning the walls. Following the studies, the bonding mix for rough stone had a dosage of 1:2, that is to say, one measure of bonding agent to two of sand and aggregate.

In order to overcome the limitations of the laboratory tests, various lengths of *tapia* were constructed on site using rough stone, gravel, sand and lime. Instructions were given regarding the process of compacting and removing from the mould. Careful attention was paid to the way in which they were broken, the positioning and union of the rough stone, behaviour of the mortar joints, thickness of the outer layer, marks of the boards and texture and colour of wall faces. In addition, some fragments from the breakages were collected and used to create test samples. These were tested for breakage by compression and the results at 8 days were above 4.2 N/mm^2. With the variety of information obtained from the test tapia walls, small corrections were implemented in order to carry out the final execution. During the intervention controls were carried out on the execution of the tapia walls and breakage by compression tests were carried out with satisfactory results. It should be remembered that the hardening process of lime mortars is extremely slow compared with cement mortars, but on completion of the process the resistance is almost the same.

4 CONCLUSIONS

4.1 *Restoration methodology*

The methodology which began with a process of historic documentation, architectural survey and monographic studies, provides scientific knowledge and a global overview of the monument. This information was of use when drafting the restoration project which combined them all. This set the guidelines for the construction work so that in all the phases the same values and criteria were shared following an uninterrupted and unified plan.

Repeated and conscientious visits and direct contact with the monument were essential from the initial prior studies to the completion of the building work. This made it possible to obtain information on every minute detail of the material aspects and provided a context for theoretical studies.

The restoration of the stone *tapia* wall is an act of construction which is not strictly-speaking technical. This is an open field where there are many factors such as labour, materials, costs, equipment, which transform it into a cultural action. There are rules for construction which have to be known since they define the intervention. Restoration must be something more than constructing, but never less.

4.2 *Stone tapia walls*

Stone *tapia* walls are a very specific type of tapia, that can be found, within the Islamic culture, in Mediterranean mountains where stone is abundant. The technique shares all the elements of formwork, but cannot be considered to be rammed earth. Instead of the characteristic process of tamping, it follows a specific procedure for filling, positioning rough stones and compacting, with certain similarities to the *opus*. Mechanical resistance of stone tapia walls can be compared to that of masonry ones. Unlike rammed earth walls the values for mechanical resistance are high.

The state of ruin is due to an abandonment spanning centuries and for this reason the buildings have lost roofs, floors, lintels... Despite this, the thick *tapias*, invaded by vegetation, remain standing resisting the passage of time. Their survival is due to the mastery of the technique and materials employed to build them, which should be studied as well as admired.

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The valencian rammed-earth wall ("tapia valenciana") in the restoration of Alaquàs Castle (Valencia, Spain)

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ABSTRACT: The Alaquás Castle, declared as historical heritage, is one of the best examples of renaissance manor palaces in the valencian area. It has suffered different interventions throughout its history, and even came close to being demolished in the early 20th Century. Yet despite this, its walls, coffered ceilings and other architectural elements have been preserved and had been put in value in the last intervention completed in 2007. Ashlar walls, made of limestone, frames the rest of the walls built with the so-called valencian rammed-earth wall, formed basically of sand-clay soil with lime and medium size gravel, a crust rich in lime and sand, and a brick reinforcement forming courses separate about 10 cm height. Its thickness is between 45 and 90 cm. The valencian rammed-earth wall interventions have been: consolidation or replacement of damaged areas, and rebuilt of nonexistent elements.

1 THE ALAQUÀS CASTLE-PALACE

1.1 *Castle or Palace: A brief description*

The Alaquàs Castle-Palace constitutes one of the most remarkable examples of isolated Renaissance manor palace typology of all the valencian territory. It is a square plan building with central courtyard and four battlemented towers in the corners.

The courtyard is delimited by a stone arches system allowing a very clear opening to the gallery that communicates the different rooms. The four aisles have in some of their galleries up to four different levels delimiting different rooms with different heights. The main floor houses have large noble rooms with invaluable Renaissance coffered ceilings and singular ceramic pavements decorated and dated in the 16th Century. It occupies approximately 1500 m^2 in plant and its battlements reach a height of 24 metres.

The building we can see today was built at the beginning of the 16th Century by the García de Aguilar family, that occupied important political positions and with a relevant implication in the valencian high society of the time. Although it was a new plant building it was built over remnants of the Vilaragut family former palace that had the Alaquàs lordship from 1373 during almost a hundred years.

During the 17th Century, the castle lived one of the most international episodes by the hand of Pardo de la Casta, keeping a very deep-rooted link with the Manfredi family and, by extension, with the city of Cremona. Afterwards, the building suffered an important decadency until the beginning of the 20th Century, when the ownership of the castle passed on to Julio Giménez Lorca, announcing in 1918 the demolition of the castle to take benefit of its building materials, mainly wood as a mere commercial element. Thanks to the important and quick civic answer, it was achieved that on the 26th of April, the king Alfonso XIII signed a Royal Order according to which the building was declared Historical and Artistic Monument.

During the following years large studies were prepared by architects concerned with the enormous value of the building, gathering plenty information about its artistic importance (In 1922 the Valencian Culture Centre published the book "El Palacio señorial de Alaquàs" by José Manuel Cortina Pérez and Vicente Ferrán Salvador that gather the first multidisciplinary study that symbolizes the attainment of the declaration of the castle as a Historical and Artistic Monument).

Even so, in 1928 and in a clandestine way, there took place the partial demolition of the northwest tower, whose reconstruction is described in this article.

Finally, after several transfers in inheritance the property passed into the hands of the Lassala family that used it as private residence and exploited it for other business and diverse uses. The first democratic Town Hall in April 1979 promoted and started a long process to recover the castle as a public space that finished in 2003 with the monument expropriation being completely managed since then by the Town Hall.

1.2 *Its most recent history*

Nowadays, the building is declared as Property of Cultural Interest since 1999 and it creates a complex

Figure 1. View of the castle in the final processes of the restoration works. In this image we can notice the extension of the of the valencian rammed-earth in the walls.

Figure 2. Air view of the castle before starting the restoration works, where can be noticed the northwest tower inexistence.

Figure 3. Plan of the previous study included in the Master plan.

with the Church of the Assumption to which it is joined by a covered gallery over an arch.

During 2003 to 2005 a Master plan was prepared under the direction of the architect Vicent García Martínez, with the collaboration of important scholars and researches (García 2005) that provided it with a common criterion at the time of studying the building, its pathology and the intervention to be prepared. After this analysis and defining the programmatic necessities the Alaquàs Town Hall decided to dedicate the building to an educative-cultural use according to the possibilities that the building presented.

In November 2005 started the restoration works according to the guidelines described in the Master plan. In March 2005 the building was inaugurated with a cultural exhibition that occupied all the ground floor, the noble floor, continuing later the works to adapt the chamber as educational space.

2 VALENCIAN RAMMED-EARTH WALL IN THE ALAQUÀS CASTLE

2.1 *Valencian rammed-earth wall technique description*

With the exception of the tower corners and the inner courtyard arches all the brickwork of the castle is done by means of the valencian rammed-earth wall. Essentially it is a reinforced wall with brick to courses separated from approximately five to ten centimeters and in all its thickness. The importance of this building system lies in the fact that achieves greater resistance and it ties up the valencian rammed-earth as a whole without eliminating its most important advantages such as the easiness of its construction, the little specialization required if its labour, speed of execution and, maybe the most important one, its least economic cost regarding to another type of walls such as stonework.

However, one of the attributed properties and that optimizes its use for defensive architecture would be the projectiles impacts good absorption; although it should be appointed as a disadvantage regarding other type of walls construction system, the need of greater thickness walls for its stability and to decrease buckling effects.

It is very well known and extended the building technique and its materiality, as its use became widespread as much for defensive architecture, as it has been said before, and for its civil and domestic use. Although its use goes back to the almohade period, it was generalized from the 14th Century in which flourished the construction of palaces and convents. A good example of defensive architecture is the Christian wall in Valencia dated in 1356.

Figure 4. Xàtiva's Almudín façade, in which the valencian rammed-earth wall can be seen, built on the ashlar brickwork.

Figure 5. Hollow horizontal section done in the rammed-earth wall of the Alaquàs castle where can be seen the traces of the bricks internal disposition.

The proper Alaquàs castle is another example, where both, domestic and defensive architecture are present.

In subsequent centuries this kind of construction has also been used for the domestic architecture, finding examples of rural architecture like in the façade of Mas de la Cova in Manises (Valencia), Property of Local Relevancy, or in the Ribera and the Costera areas in several examples of public or residential buildings such us the Almudín in Xàtiva.

Fray Lorenzo de San Nicolás (de San Nicolás 1633) described in 1633: "*Valencian rammed-earth walls faith make with sand, half bricks and lime, adding layers of one and the other; is very strong work*".

Making an extension to the above description of this Hispanic writer, the valencian rammed-earth wall differs from the other rammed-earth walls in its constructive genesis and aesthetical aspect.

This technique, based on archaeological studies carried out in the Alaquàs castle, consist of the construction of brick courses lying on the rammed-earth arranged lightly separated from the façade surface, so that once the different layers of lime and clay are poured, the bricks remain sunk of the superficial crust, giving it such a characteristic image.

The use of the bricks provides greater resistance because it regularizes somehow the different courses giving major monolithic nature. This technique can remind us the "opus testaceum" being the difference that the lost formwork was the brickwork in which the different layers were poured.

2.2 *Characterization of the rammed-earth wall*

The structural walls of the Alaquàs castle obeyed to a logical distribution according to the structural scope to be resisted. Generally speaking, they followed the disposition of placing ashlars at the four corners in such a way that the most exposed points to the changing weather conditions and even to the enemy's attack were made with a more resistant material. This stonework, usually, is composed of two sheets of regular ashlars placed in courses from between 25 and 45 cm height. Inside, there's a mortar rich in lime and arid completing the space in between the two sheets in such a way that consolidated enormously the corner giving to it an eminently structural function.

The studies carried out in the Master plan indicate that the valencian rammed-earth structural walls are the most generalized ones in the castle:

"The rammed-earth wall is composed of a sand-clayish body with lime and gravels, a crust of mortar, made of lime and sand with reinforcing brick courses on which we can noticed certain homogeneity in the materials, in the formwork measures and in the reinforcing brick courses separation". (García 2005).

The approach in the intervention was mainly based on addressing three basics concepts that affected the valencian rammed-earth wall. The first one was related to superficial aspects of cleaning and punctual replacement of some eroded or damaged bricks due to different reasons. The second one was based in blocking up the areas that had been open or that presented considerable lacks of material integrating them with the rest of the antique brickwork. Finally, the third one made reference to the valencian rammed-earth to be reconstructed in the tower demolished in 1928.

2.3 *Rammed-earth wall's cleaning and consolidation techniques*

As stated in the intervention project the general state of the rammed-earth walls was quite acceptable presenting several areas with pathology proper of this kind of walls like vertical cracks in coincidence with the limits of the formworks position. Besides, in certain points the bricks layout changed and there appeared many hollows and grooves to lodge facilities.

The approach when intervening was to correct these faults detected in the preliminary study and some others not previously detected but that followed the same typology. The first task in the intervention was responsible for removing a layer of acrylic painting present in the whole building. The method used for this cleaning up works was aluminium silicate projection at low pressure to remove the painting without damaging the appearance of the rammed-earth wall.

Once this work was done, it was proceeded to consolidate the surface by means of a spraying of potassium silicate so that it achieved a greater superficial resistance in those areas that presented superficial degradation.

2.4 *Rammed-earth wall's reintegration*

Former interventions in the castle's walls and the readjustment that some of the areas that suffered throughout history, showed in some façades lack of homogeneity in the rammed-earth walls. The intervention project identified these areas and planned the works necessary to recover the original aspect of the rammed-earth walls.

Independently of the established concept for the volumetric recovery of the fourth tower that will occupy the third area of intervention, we refer to the rammed-earth wall's recovery to complete those hollows that had been open in previous stages, work that impelled an architectural recovery of the original spaces that had been distorted after several refurbishments and adjustments adding brickworks of another nature, that although it was not passing for a mimetic copy of the rammed-earth wall, it was necessary to give a superficial unique aspect to the rest of the rammed-earth wall. It is here where the execution and finishing techniques might be questioned but not the intention of recovering the rammed-earth wall aspect to unify wall faces.

Making a small reflexion about the restoration philosophy, for Roberto Pane (Carbonara 1976), "*every monument must be seen as a unique case, because it is such as a work of art and such must be its restoration*". On the other hand, in Cesare Brandi's words (Brandi 2003), "*only the work of art's matter is restored*", clearly alluding to the image and making sure its transmission making the intervention to remain as intact as possible over the course of time.

It is not a way to justify the work carried out but conceptual criteria that guarantee the works done at the Castle.

In this particular case, the main difficulty was the practical impossibility to carry out the original rammed-earth wall technique as we were dealing with walls' hollows to be completed, with a great mobility limitation on their upper part to be able to close the rammed-earth wall. Besides, other

Figure 6. Cleaning tests to remove the existent painting by means of aluminium silicate projection.

Figure 7. Reintegration of the rammed-earth wall in those areas with hollows of the former supports of the wooden beams.

difficulties arisen from the execution of the aforementioned Valencia rammed-earth wall need to be added, as that of the optimization of the resources due to the great amount of wall repair works to carry out and, above all, that of leaving a superficial aspect alike to the rest of the historical rammed-earth wall.

To do that, an exhaustive study of different faces of the castle walls was carried out, with a particular emphasis in the composition of the bricks' jointing grid where the brick's faces are slightly in the background and in the colour and superficial texture of the rammed-earth wall; this last aspect will be based on the dosage of the lime mortar crust. To do so, different samples of a composition of thin arid and lime grout adding the use of mineral pigments were carried out.

The proposal raised as suitable for this kind of intervention was to build up a brickwork wall with solid brick courses measuring 28 × 14 × 3 cm and a lime mortar with dosage 1:4, using the arids of the area to get a good integration with the existing brickwork. According to the location of the face to recompose, the different courses followed a cadence alternating 3 or 4 header courses and one stretcher course. The horizontal joints were about 6 to 10 cm thick, being the horizontal joint from 2 to 3 cm thick.

Figure 8. Tests carried out to build the valencian rammed-earth wall.

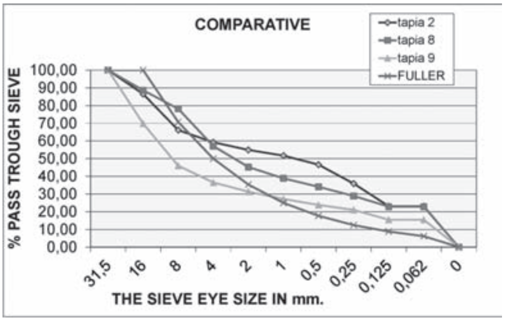

Figure 9. Granulometry of three rammed-earth walls samples compared with Fuller.

Figure 10. Image of the fourth tower during the reconstruction process.

Later, the outer plaster layer was made with lime mortar of dosage 1:3 with the same arids and pigments dosages that integrated with the annex brickwork. In some cases a superficial patina for a suitable chromatic reintegration was used.

2.5 *The reconstruction of the fourth tower*

The reconstruction of the fourth tower was, with no doubt, the work to which more time was devoted to the decision of the carrying out and the selection of the materials. The decision adopted was to use bricks with similar dimensions to the existing ones and rounded arid for the lime mortars. The rhythms of the bricks disposition were studied and a template to be used as a model was prepared. Over the existing rammed-earth wall a brick course was placed marking the difference between the intervention done and the existing wall.

Obviously, as it can be deduced, in this works the valencian rammed-earth building process of

Figure 11. Image of the process of placement of the brick course in the brickwork of the fourth tower during the reconstruction process.

Figure 12. Image from the courtyard during the reintegration and reconstruction works of the fourth tower.

the walls was not followed as we lacked the proper formwork of this technique that formworked the front parts of the wall faces in such a way that when tamping, the mass would flow around the bricks giving them their characteristic aspect. Due to this, the adopted solution in the reconstruction of the fourth tower can be considerate as a brickwork to the image of the valencian rammed-earth wall.

The final result of this method aimed at a visual integration of one of the most used techniques in historic buildings of the Levante area.

NOTE

Architectural study: Vicent García, Miguel Monteagudo, Albert García, Marina Saura, J. Carlos Calderón, Soledad Caparró. Archeological study: Víctor Algarra, Paloma Berrocal, Alejandro Vila and Virginia Berrocal. Ceramics study: Jaume Coll, Victoria Domínguez and Isabel Caruana. Wood structures' study: Liliana Palaia, Santiago Tormo, Marina Saura.

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Xàtiva's Castle (Spain)—constructive analysis of rammed-earth walls and its interventions

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ABSTRACT: Along its extensive history, Xàtiva Castle (Valencia, Spain) has suffered numerous and systematic destructions. These destructions have been followed by a more or less intense reconstruction. The final result is an overlapping of Iberian, Roman, Moslem, and Christian structural walls and, more recent reconstruction, of the XVII, XVIII and XIX century. The extensions of these walls, and the remains of the towers and defensive elements, give a valuable constructive interest, due to the quantity and quality of examples of different types of structural walls. In general, a strong rammed earth was used in both the inner and outer core. During the last years, the interest in restoring the historical walls, has allowed many interventions on sections with greater necessity. This recovery has added value to very important sectors of the castle.

Setabenses muros,
Célicas almenas,
Por hercúleas manos
Sobre riscos puestas:
Belveder excelso,
Cerco de la Ametlla,
Gruta del granado,
Alcazaba regia:
Fértiles colinas
De arroyuelos llenas,
Que besais las plantas
A encumbradas sierras:
Decidle a Vernisa
Si de mi se acuerda.

(Villanueva 1833)

1 EL CASTILLO DE XÀTIVA

Al sur de la provincia de Valencia, en la comarca de la Costera, en la cresta de la sierra del mismo nombre se encuentra edificado el Castillo de Xàtiva, igualando en largo a la misma ciudad, aproximadamente un kilómetro. Se halla repartido en dos castillos, el Mayor hacia poniente y el Menor hacia levante. La parte central es común a ambos, y por la misma puerta se entra a los dos, a través del patio de armas. Tanto en levante como en poniente, sendas murallas bajan por la falda de la sierra hasta confundirse con la zona urbana, donde la ciudad histórica ha evolucionado urbanística y paisajísticamente.

A lo largo de su dilatada historia como fortificación militar, el Castillo de Xàtiva ha sufrido numerosas y sistemáticas destrucciones seguidas, cada una de ellas, por reconstrucciones más o menos intensas. El resultado final es, hoy, un cúmulo de fábricas iberas, romanas, musulmanas, cristianas y, más recientes, de los siglos XVII, XVIII y XIX. Incluso en el siglo XX se realiza un chalet. Son de destacar las actuaciones realizadas en los primeros tiempos de la época cristiana, siglo XIV, traducidas en la cuidadosa labra y estereotomía de los sillares de los muros y dovelas de las puertas y torres que la fortifican, destacando la Puerta del Socorro, la Capilla Gótica, la Cárcel… Acabadas las guerras carlistas, en 1864, con motivo de las leyes desamortizadoras se subasta el Castillo, pasando a manos privadas. Por el hecho de ser uno de los conjuntos históricos más representativos de la Comunidad Valenciana, junto con la necesidad de acometer seriamente los trabajos de recuperación del monumento, la Generalitat Valenciana adquiere el Castillo de Xàtiva con su entorno el 21 de diciembre de 1989.

En abril de 1990, adscrita la gestión del monumento a la Dirección General de Patrimonio Cultural, a cargo del Servicio de Patrimonio Artístico Inmueble, como en otros castillos de la Comunidad, la Generalitat, a los efectos de la tutela de los mismos y con el fin de favorecer la atención técnica y su mantenimiento, nombra los arquitectos conservadores respectivos.

Esta circunstancia ha permitido centralizar la documentación de las diferentes intervenciones en cada monumento en el arquitecto conservador respectivo.

Figura 1. Plano del Castillo de Xàtiva donde se indican los puntos de intervención entre los años 1990–2011.

Figura 2. Cartel conmemorativo del 2010 en el que se recuerda la destrucción de la ciudad por Felipe V el 25 de abril de 1707 dentro del contexto socio-cultural del castigo no asumido.

A primeros de 1992, queda redactada la Fase Previa del Plan Director, que viene a ser el primer Plan Director del Castillo de Xàtiva, dado que contiene, no solamente la recopilación de documentos y obras realizadas hasta la fecha, sino que, además, contiene exhaustivas propuestas de elaboración de estudios e intervenciones con un plan de prioridades de urgencia, dado el estado ruinoso de numerosos elementos y murallas (65 puntos con necesidad de intervención urgente), quedando todos ellos codificados e identificados.

2 OBJETIVOS Y MÉTODO

Desde que la Generalitat Valenciana adquirió la propiedad sobre el castillo hasta hoy, se han venido realizando una serie de intervenciones (alrededor de 20) en las murallas del Castillo de Xàtiva de las que existe abundante información, pero no una sistematización operativa para su consulta. Con ello, el objetivo principal del trabajo consiste en el estudio y sistematización de las fábricas intervenidas, a partir de la documentación y recopilación gráfica y escrita de los respectivos procesos constructivos y finales de obra de las intervenciones citadas.

Se parte de los conceptos generales y simples de: tapial, sillería, mampostería..., dejando claras y establecidas cuestiones tales como materiales, dimensiones y disposición de los mismos y sistemas constructivos, a través de una codificación lo más intuitiva posible. Llegando al establecimiento de una ficha tipo que recoge los siguientes temas: elemento tratado, codificación de fábricas, datación entendida como indispensable orientación histórica (el antes y el después), descripción de la fábrica y pormenores dimensionales-constructivos, esquemas tipológicos, fotografías y observaciones finales. Seguidamente, para cada intervención se van rellenando las fichas según las fábricas que corresponda. Además, se añaden descripciones,

Figura 3. Tramo E11 de las murallas de levante antes de la intervención.

fotografías y la planimetría necesaria para su localización e identificación. Finalmente, se tratará de establecer conclusiones a partir de coincidencias o constatar la disparidad de fábricas o soluciones constructivas, todo ello filtrado por el contexto socio-cultural concreto del objeto de estudio y la consciencia de los que suscriben.

3 LAS INTERVENCIONES

En el conjunto del Castillo, la primera intervención por parte de la Generalitat Valenciana se realiza entre abril y octubre de 1991, correspondiendo a las obras de emergencia en la Torre y Tramo de Muralla (S6) adosados a la Puerta del Socorro. Seguidamente, en diciembre de 1991, como continuación de la anterior, se interviene en una serie de puntos ruinosos (tramos MA4, S9 y MA1) situados en el Castillo Mayor. En la segunda mitad del año 1992 se consolida el tramo de muralla S8, situado en el recinto central del Castillo Mayor. Siguiendo este proceso de intervenciones, en el año 1993 queda redactado un nuevo proyecto de reparación de desprendimientos en puntos del Castillo Mayor (tramo S11) y Murallas de Poniente (Torreón entre tramos O7 y O8).

Estas obras se contratan y ejecutan en al año 1996. En el año 1997–1998se ejecutan las obras de reparación del tramo O7 de la muralla de poniente. Entre los años 1998 y 2001se realizan las obras de consolidación y reconstrucción de la Torre del Sol y tramo de muralla adyacente E10. También, entre los años 1998 y 2001se realizan las obras de consolidación de la bóveda y muros exteriores de la Nevera, completadas con las obras de adecuación del túnel de acceso. En noviembre de 2008 finalizan las obras de restauración del torreón-escalera del tramo E11 de las murallas de levante.

Recientemente, junio de 2010 y agosto de 2011, finalizan las obras de restauración del tramo de muralla S4, y reposición del lienzo y torreón primitivos del mismo tramo situado en el patio de armas. También recientemente, por parte del Ajuntament de Xàtiva, en el año 2009, el desarrollo de un Taller de Ocupación ha permitido restaurar los aljibes situados en la Devesa del Castillo Mayor. En la actualidad, existen dos proyectos pendientes de actuación, la restauración del tramo E12 de las murallas de levante, y la restauración del tramo E1, extremo este del Castillo Menor (Torre de l'Esperó).

Figura 4. Tramo E11 de las murallas de levante después de la intervención.

Figura 5. Tramo S4 de las murallas del patio de armas antes de la intervención.

Figura 6. Tramo S4 de las murallas del patio de armas después de la intervención.

4 LA SIMPLICIDAD DE LOS CONCEPTOS. CODIFICACIÓN INTERVENCIONES

El estudio y sistematización de las fábricas intervenidas, se resume en una serie de fichas que se presentan como avance del trabajo final de evaluación académica del máster en conservación en el patrimonio arquitectónico que se está realizando y cuyo objetivo final es el estudio y sistematización de las fábricas del Castillo de Xàtiva a partir de las intervenciones recientes (1990–2011).

En el marco de este estudio, se ha clasificado las fábricas de mampostería como sigue:

Se entiende como obra de fábrica el elemento constructivo compuesto de piedras, de ladrillos, de adobes, de tapial o mixtos, aparejados y trabados de acuerdo con unas determinadas leyes.

La fábrica de mampostería (FM) es la obra hecha de mampuestos colocados y ajustados unos con otros sin sujeción a determinado orden de hiladas y tamaños, recibidos con argamasa, mampostería ordinaria (MO). Se distingue la mampostería por la disposición y grado de preparación de los mampuestos, concertada, careada o, sobre todo, aquella en la que los mampuestos se disponen en hiladas (HM).

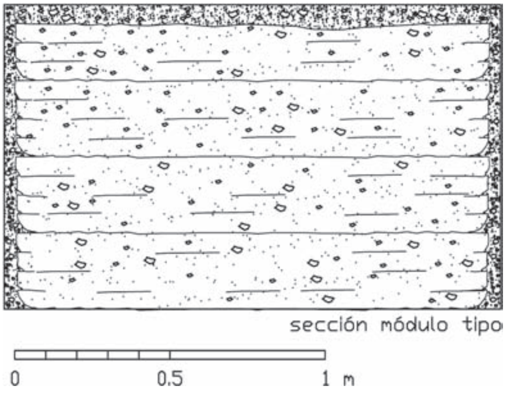

Figura 7. Sección transversal del modulo tipo FT/TT/CC correspondiente al primer momento constructivo, siglos XIII-XIV hasta el siglo XIX.

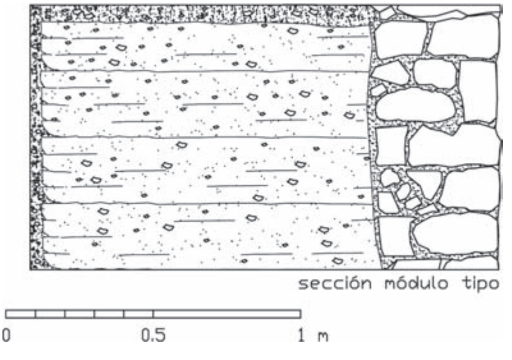

Figura 8. Sección transversal del modulo tipo FT/TT/CC correspondiente al segundo momento constructivo siglo XIX.

La fábrica de sillería (FS) es la obra hecha de sillares, y en especial cuando éstos están bien labrados o aparejados. En general, en el Castillo de Xàtiva, los sillares que aparecen en sus fábricas son reutilizados, pertenecientes a construcciones anteriores, romanas, visigodas… En muchos casos, en las diferentes fábricas de mampostería aparecerán sillares utilizados como mampuestos, esquinas.

En cuanto a la fábrica de tapial o tapia (FT) se precisa la consideración de que es tapia (pared) toda aquella fábrica que está realizada con tapiales (encofrado). Por tanto, en el interior del muro, núcleo, emplecton, podremos encontrar tierra (TT), mampuestos (MM), hormigón de cal (CC), opus cementicium… En cuanto a la superficie externa o costra, la tapia podrá ser calicostrada (CC), con costra reforzada con mampuestos (CM)… o, simplemente, será patente la impronta, textura, de la tabla del encofrado sobre el hormigón.

Clarifican los conceptos las consideraciones de Basilio Pavón Maldonado en su Tratado de Arquitectura Hispano-Musulmana (PAVÓN, 1999). Las construcciones islámicas de al-Andalus vienen diferenciadas de las antiguas "… *por el empleo de varios materiales en una misma muralla, puerta o torre…*" los materiales protagonistas fueron los mampuestos "…*sillares y tapial hormigonado…*". En Xàtiva se mantiene la "… *dictadura del tapial, con ausencia del ladrillo que es sustituido por la mampostería pero con carácter auxiliar y a título de zócalos…*". En el estudio de los tapiales "…*se puede distinguir el tapial normal de tierra o arena, canto y cal y otro más consistente, propiamente hormigón de la apariencia de la*

Figura 9. Vista frontal del sector derrumbado descrito en la ficha. Se aprecia el núcleo terroso y solera de coronación del primer módulo, FT/TT/CC. También se aprecia y señala la hoja exterior de mampostería ordinaria, FT/TT/MO.

Figura 10. Vista frontal del tramo intervenido.

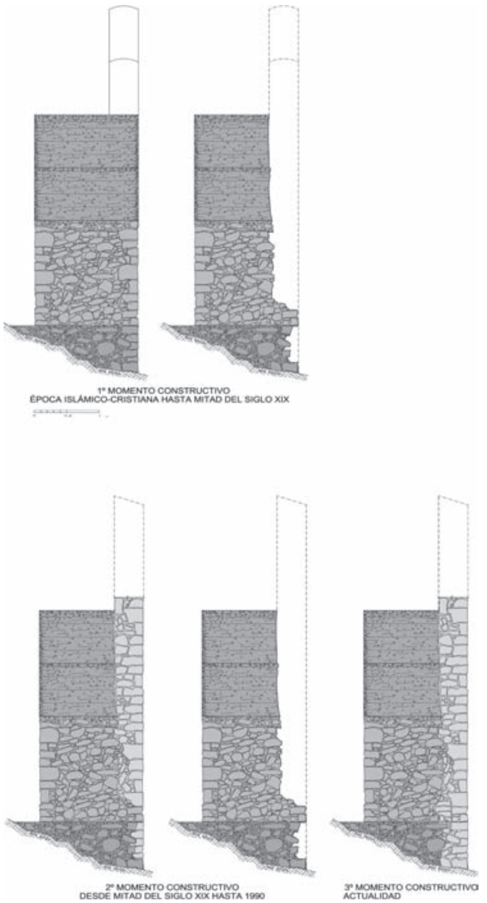

Figura 11. Secciones transversales del lienzo en cada momento constructivo.

mampostería, ambos con la huella de los mechinales y encofrado…”. “… Lógicamente los materiales predominantes en cada región durante la dominación islámica marcarán el rumbo a seguir por la arquitectura cristiana…”.

5 EL ESTUDIO DE LAS FÁBRICAS INTERVENIDAS

Por otro lado, el trabajo pretende estudiar las fábricas intervenidas y se centra especialmente en aquellas zonas que se han producido derrumbamientos y que la información recogida en las intervenciones realizadas han puesto al descubierto datos desconocidos hasta el momento, quedando plenamente identificadas y definidas. Como ejemplo se transcribe la ficha número 3 en la que se describen los conceptos precedentes, situando el elemento estudiando y dibujando las secciones transversales con la hipótesis constructiva dependiendo de las épocas en las que se ha construido.

Ficha 3.

P01. Emergencia en torre y tramo de murallas en el castillo mayor de Xàtiva (1990).

Elemento: Lienzo de muralla, nivel, por encima del zócalo. La altura en el sector derrumbado es de 1.80 m, en el punto más bajo del lienzo.

Codificación: FT/TT/CC → FT/TT/MO.

Datación: Por la modulación del tapial que constituye el vuelo y calidad de la fábrica del zócalo, podemos considerar que su origen es cristiano. La hoja externa se repuso con fábrica de mampostería, posiblemente en la primera mitad del siglo XIX, que es la que se vuelve a derrumbar en la actualidad (1990).

Figura 12. Tapia del siglo XII.

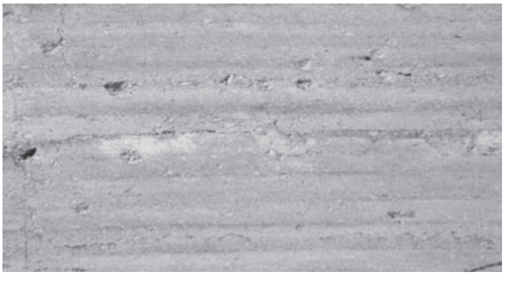

Figura 13. Tapia del siglo XXI.

Descripción: Fábrica de tapial de núcleo terroso calicostrada. La modulación es de 90 cm de altura. La coronación de cada módulo aparece reforzada con una solera de hormigón de cal, de 5 a 10 cm de espesor. En el módulo superior, dicha solera aumenta de espesor, constituyendo el adarve o paso de ronda. En el siglo XIX, se repone como hoja exterior la cara externa de la tapia, con fábrica de mampostería ordinaria recibida con mortero de baja calidad y espesor medio de 45 cm, alcanzando en algunos sectores los 60 cm.

En la ficha 5 se continúa la descripción del mismo elemento, en la que aparece la evolución de la construcción. Se trata de un lienzo de 1.60 m de espesor y una altura media entre 6 y 7 m según la pendiente. La longitud media es de unos 22 m La datación de la base es posiblemente islámica, el zócalo y el vuelo, de época cristiana. La hoja externa se repone en el siglo XIX y, por segunda vez, en 1990.

6 CONCLUSIONES

Como ya se ha citado, no se olvide que cualquier conclusión pasará por el filtro del contexto sociocultural concreto del objeto de estudio y la consciencia de los que suscriben. Estamos hablando de "*setabenses muros*", bombardeados, saqueados, y desterradas aquellas "*hercúleas manos*" que los levantaron. En el año de 1707 por el tirano rey Borbón Felipe V, Xàtiva se borra de los mapas, de los archivos y se la estigmatiza con el insulso nombre de Colonia Nueva de San Felipe. En el año de 1812, el ilustre diputado Don Joaquín Lorenzo Villanueva, nacido en Xàtiva en 1757, consigue que las Cortes de Cádiz restablezcan el secular nombre de su ciudad natal, Xàtiva (en el año 2012se celebra el bicentenario de la restitución).

Restituido el nombre, falta restituir los "*setabenses muros*". Tenemos los mismos materiales, sillares, piedras y tierras. También, el sistema constructivo para colocarlos, el tapial. Y, sobre todo, el mismo árido-argamasa que da consistencia a aquellos materiales: se trata del árido que de los ríos Cányoles y Albaida suministran a la comarca desde hace miles de años.

Tenemos, por suerte, el trazado de los diferentes lienzos, ya que las bases persisten. Tenemos la rígida modulación que proporcionan los tapiales. Y sabemos cómo se coronan, con "*célicas almenas*", definidas por aquella misma modulación.

Cualquier cosa que se haga con la autenticidad de estos ingredientes, no puede considerarse como nueva, aunque lo hagas ahora, es antigua. Son los materiales, con formas simples adquiridas a través del sistema constructivo, tapial, los que poseen la expresividad, la plasticidad o artisticidad requerida.

Ramón Gaya, pintor que escribe, acierta plenamente en estos temas (Gaya 2010).

"El arte grande no tiene nunca estilo, pero sí fisionomía, rostro, y tiene, claro está, forma; pero su forma es única, intransferible, y no puede, pues, convertirse en estilo, ya que el estilo está fundado en un juego sutil y muy ocioso de repetición, en un ingenioso artefacto mecánico de repetición".

"*El arte es realidad, el arte es vida él mismo y no puede, por lo tanto, separarse de ella para contemplarla; el arte no es otra cosa, no puede ser otra cosa que vida, carne viva, aunque, claro, no sea nunca mundo*", es decir, naturaleza.

"*Cuando el crítico, por ejemplo, se planta delante de una obra, no lo hace como hombre –con su compuesto natural de ignorancia y saber-, sino como perito; deja, pues, de ser alguien para ser algo y, a partir de ese momento, todo lo que sucede no sucede ya dentro de un espacio vivo y entre seres vivos, sino entre cosas, entre simples cosas inanimadas. ¿Qué puede, pues, importarnos, que tales cultivadores se llamen Burckhardt, o Winckelmann, o Ruskin, autores, sin duda, eminentes, si todo aquello que nos digan será siempre el fruto de una relación, no ya equivocada –eso no sería tan grave-, sino de una relación que no ha tenido lugar, que no se ha efectuado, que no ha sido? Y no ha sido porque ese algo que es el crítico no puede acercarse a una obra con naturalidad de hombre, con simpleza de hombre, sino armado, avisado, conocedor, se enfrentará con ella, se plantará delante de ella como un… policía, como esa cosa que es un policía…*"

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Earthen architecture and construction

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Ksar of Timinoun—a Saharan traditional earthen architecture heritage

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ABSTRACT: This contribution is presented under a global context on the reflection of the preservation and the promotion of the earthen architectural heritage in the region of Gourrara, southern Algeria.

The Ksours hold testimonies of the history of an architecture in which the earthen material contains a set of economic, ecological and durability characteristics. Today, this architecture is facing serious threats which depend on the vulnerability of rammed earthen material and on social, economic and political factors. To prevent its degradation, a thorough knowledge of the constructive systems adopted in this earthen architecture is required as well as a detailed diagnosis of the various phenomena of degradation. Through the case study of the Ksar de Timimoun, the authors have listed the various constructive systems built with earth and have tried to develop a process of conservation and promotion of this earthen architecture.

1 PRESENTATION OF GOURARA SITE

1.1 *Location and boundaries*

The region of Gourara is located south-western Algeria, northern Adrar, it is part of the Western Sahara region, formed by the Tuat, and Gourara Tidikelt. This region is located in a triangular shaped location (S. Haoui, 2002) that makes the western erg, and the plateau of Tadmait and Saoura Oued, thus marking the boundaries of a large area of 500 km^2 at an altitude of 300 m (Fig. 1).

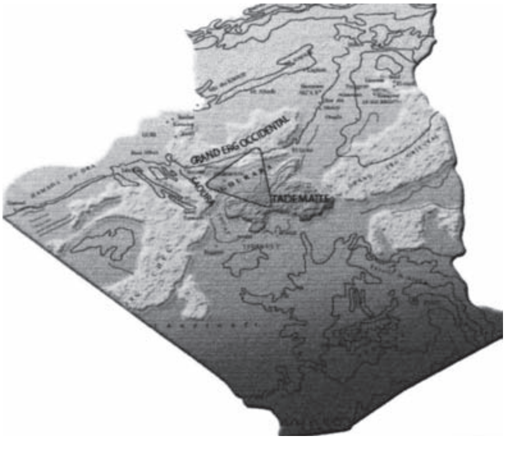

Figure 1. Localization of Gourrara. J. Bisson in "The gourrara. Study of human geography, research institute, D.E.S, Algiers,1956".

Ksours and oases such as Tabelkoza, Sidi Mansour and Taghouzi form the northern boundary of the Gourara region, to the west, the last oasis in Gourara, Bahamou, can be considered as an ethnic boundary (J. Bisson,1956), while Meslila is part of the Saoura. To the South, the physical boundary is erg Echech and a succession of palm groves, Ksours and Sebkhas.

1.2 *The climate*

The climate of this region is arid and hot. It is characterized by a very hot and long season and another very cold and short season. Rains are rare and devastating.

This region is exposed to East, North East winds with major sandstorms.

1.3 *Irrigation system and logical layout*

In an area with very low rainfall, water gathering and sharing are essential for any human settlement.

The area topography allows water extraction and its transport through underground tunnels "The Foggaras" to supply palm groves. This method of irrigation has allowed the establishment of Ksars at the outpouring point of foggaras near palm groves (Fig. 2).

To cope with such very hostile environment and the domestication of territory, the first kinds of settlement were the fortresses with their high and strong walls built to resist harsh climatic conditions and attacks of other tribes: These are the "Ighamawens" or Kassabah.

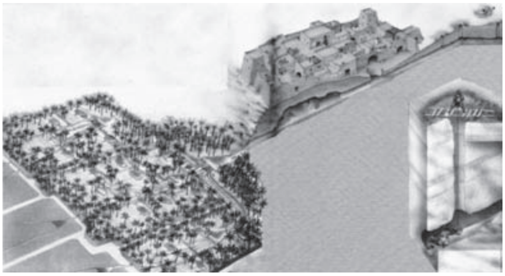

Figure 2. System of irrigation “The Foggaras”. A. Foufa and N.Abderrahim Mahindad with a group; students: Abderrazek, Bahria, Benzina, Loua Gbamou, Zerrougui within the framework of workshop MATEC in 5th year.

They are located on a rocky outcrop along the ridge which is overlooking the Sabkha, according to the locations of fouggaras (A. Cornet.1952).

Figure 3. Ksar of Timimoun: Localization. J. Bisson in “The gourrara. Study of human geography, research institute, D.E.S, Algiers,1956”.

2 PRESENTATION OF TIMIMOUN KSAR

2.1 *Location and morphological data*

Timimoun, also called the “Red Oasis” because of the color of its buildings, is the main Ksar of Gourara area. Timimoun City is located 189 km northern Adrar and about 1258 km from Algiers.

Timimoun region has two morphological advantages (Fig. 3) which are:

- The M’guiden Plain: A vast plain lined with a 70 km wide Erg which represents a huge water storage tank for the region;
- The Sebkha of Timimmoun: is a kind of salt clay depression ranging in size from 2 km to 15 km wide, over 80 km long.

2.2 *The formation and evolution of ksar*

Timimoun included all geo-morphological data that favored its emergence and evolution: The settlement being that of a sabkha, and the Mguiden plain reaching its greatest width, the water supply is secured and groundwater allows its regularity.

New ideologies were introduced by the Saints “The Walis” (S. Haoui. 2002) that lived in Gourara starting from the 15th century such as the merging of different social groups.

A Timimoun, seen as the first homogeneous core that can be considered the first urban center of the Ksar, exists thanks to a unifying desire of wali Sidi Moussa, the founder of Timimoun. He marked the site of the Ksar, between Agham Akbour and Aghem Amellal, he set up the new market of “Souk Sidi Moussa” and annexed the palm grove located in the Ait El MehdiKsar.

The Ksar is formed by the aghems and their extensions in the center of the territory of Timimoun it is: Aghem Akbour, Aghem Amellal, Aghem Sidi Brahim, Aghem Ait el Mehdi and Tadmait.

The Ksar is structured by the pathways connecting the various access routes which are punctuated by “rahbet” locations such as rahbet Tadmait to the North/East, and erhoubet to the South and El Hadhra, at the intersection of the caravan trail coming from the Doudan and inter—Ksour track going north/west towards the Tell.

These pathways converge in “El-Mijour”, a structural axis along the Ksar, to the Southwest/Northeast. This is the growth axis of the Ksar through which the core is connected to the entire city.

Timimoun City will undergo major changes because of the French occupation in the 20th century, such as the construction of a military fort and the creation of a village.

This village is located in the Southeast and across from the Ksar and on higher grounds in order to control it and it is strongly distinguished by its orthogonal landscaping. The two urban systems are separated by a large street that was set on the old caravan trail and where major buildings by their functions and their a Architectures could be found: a Town Hall, a Military Fort, a Hotel, a Church.

This linear area along one side of the Ksar and across the village caused the separation and differentiation between two urban settlements logics, two social groups and even two types of construction techniques and know-how. This was the first major break in the homogeneity of the city.

Nowadays, “building plots housing” and facilities are located on the outskirts of the city, juxtaposed and with no overall structure, in front of a pre-existing historic core that is in a condition of neglect and degradation.

This historical development of Timimoun resulted in the emergence and the juxtaposition of three kinds of settlements:

– The Ksar: historic core which is the realization of the continuous adaptation of the form to the location.
– The village: reflects a culture and a method of area appropriation corresponding to the different colonial vision.
– The contemporary operations: results of a centralized planning.

This situation creates a break in the morphology, function and architectural language of Timimoun and particularly at the Ksar.

In fact, across the Ksar, this break is seen in an overall image that disappears, revealing formal and architectural discontinuities, caused by the introduction of new type of buildings and materials which are different, and indifferent to the environment.

The break extends to the functional, symbolic and social levels:

– The Ksar, once autonomous and capable of providing for daily needs can no longer find this balance and survives today in the absence of any project that would support its contemporary needs (sanitation, lighting, access roads, services. ...).
– The Ksar had great symbolic and social value which is now devoid of public spaces that are places of collective memory such as rahbates, mosques, and ighamawens which have either disappeared or are in an advanced condition of deterioration.

3 THE MATERIALS AND CONSTRUCTION TECHNIQUES IN THE KSAR OF TIMIMOUN

3.1 *Building materials*

As in any Gourara, the inhabitants of Timimoun Ksar have always built with materials available on site: earth and palm trees.

In Timimoun, local know how has created a real city with forts, houses and mosques.

Easily maliable, clay or "Tine" (mud) is the most widely used material in Timimoun and Southern Algeria in general.

3.1.1 *Earth*

The architecture of Timimoun is an earthen architecture par excellence. This earth is used in all structural components as well as mortars and plasters.

It is also used in the manufacture of earthen bricks or "Touba" (adobe): This is the first element of prefabricated building used by man.

The technique involves molding adobe bricks without compaction with a mixture of earth and vegetable fibers (straw). The resulting mixture is then introduced by quantity into molds of (15 × 12 × 30) cm. The blocks thus obtained are left to dry in the sun for 4 to 5 days in summer and 15 to 20 days in winter (Fig. 4).

Earth is also used in filling in the floors and in the mixing of mortars and plasters.

3.1.2 *"Tafza" stones*

The used stone is uncut stone. The blocks are of variable sizes and undergo squaring before being used. It is of sand and is used for the construction of walls, floors and stairs. The stones used in the foundation are extracted from the sabkha (Fig. 5).

3.1.3 *The palm tree*

The palm tree is the wood used in the region. All its components are used in construction; the only

Figure 4. Manufacture of earthen bricks or "Touba" (adobe). N. Abderrahim Mahindad.

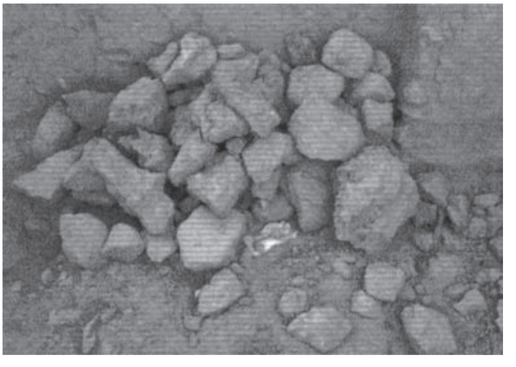

Figure 5. The stones "tafzas". S. Haoui in "For the preservation of the architectures Ksouriennes in raw earth. Example ksar of Timimoun, Algeries".

condition is that the tree must be dead before it can be used as it is the main wealth of Ksours.

- The Trunk “Stipe”: also known as “khechba”, it can be used as thick beams, it can be sawn lengthwise in two, three or four parts then left to dry for several days. They will deliver beams having a 12 to 15 cm flat face over 2 to 3 m in length. It can also be cut into quite rough planks from 30 to 40 cm long with 3 cm thickness for woodworking purposes (Fig. 6).
- The palm “Djerid”: This is the palm leaves used as support layer in the floors.
- The grip of the palm tree “Kernaf”: triangular and relatively resistant, is used for the roof. With its flat shape, it is used above the beams “Khechbates” and separated at 25 cm from each other. Laid on top of the joists, they form a more or less light floor.

3.2 *The constructive typologies (building techniques)*

As part of this work, we will look at three types of structure, namely: The foundations, walls and floors against materials, components and their construction techniques.

3.2.1 *Foundations*

The walls are generally built straight on rocks. In some cases holes of uniform widths are dug to a depth of 50–80 cm. Foundations are built with large stones or blocks of stone with lime mortar (Fig. 7).

3.2.2 *Walls*

The walls are bearing walls and can vary be 40 to 60 cm thick. There are two types of walls according to materials: Adobe walls (mud brick) and stone walls (Fig. 8).

- The adobe walls (Toube): must be built when it is not raining to allow their drying. They are made of mud bricks (15 × 12 × 30 cm) and are completed in two stages: the preparation of materials including sorting and cleaning the earth and the making of bricks and the building of the walls.

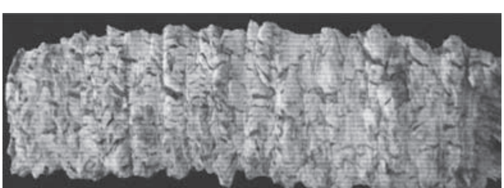

Figure 6. The trunk “Stipe”. S. Haoui in “For the preservation of the architectures Ksouriennes in raw earth. Example ksar of Timimoun, Algeries”.

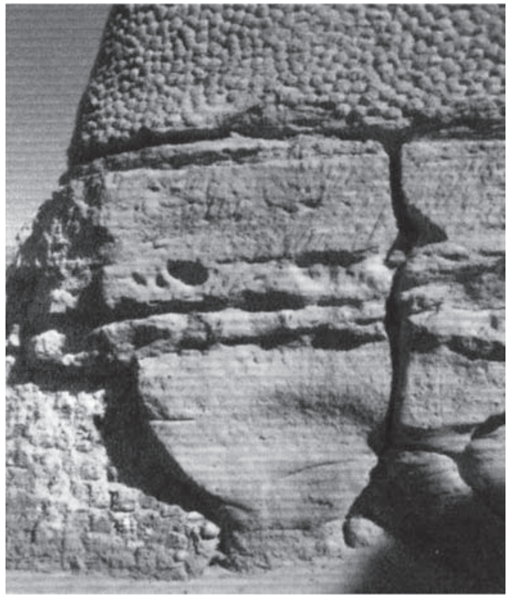

Figure 7. View of foundations. N. Abderrahim Mahindad and A. Foufa with a group; students: Abderrazek, Bahria, Benzina, Loua Gbamou, Zerrougui within the framework of workshop MATEC in 5th year).

Figure 8. The adobe walls. N. Abderrahim Mahindad.

- The stone walls: They are made of stones of different sizes placed on a bed of mud mortar. There are two types of stone walls according to their fitting: stone walls of sand (Tafsa) placed on fields revealing the polygonal face and walls of stones laid in fish bone shapes at 45°.
- The builder starts with the outer walls and then those inside independently from previous ones, this is why the interior walls are never harped to the outer walls.
- The clay used as a binding material is kneaded with the feet. It is then used to coat the walls to get a smooth finish.

Once completed, the walls are coated with slurry of clay, used to seal joints in order to avoid the water infiltration into the structures in case of rain.

The finish coat can be smooth and applied and smoothed with the palm of the hand as it may be streaked with fingers as a comb as it can be applied as a small flattened balls giving a very decorative rather special feature of the region (Fig. 9).

These walls and especially the earthen walls have high thermal performance: They allow the regulation of indoor temperature, slowing the penetration of heat at night and usefully retroceding at night. An advantage reinforced by the thickness and mass of the wall which gives it great thermal inertia.

3.2.3 *Floors*

These are wooden floors with vegetal support. They are made up of:

- Beams palm "Khechbates", formed by ¼ to ½ of palm tree trunk, 2 to 3 m long, taking support at their ends on bearing walls or pillars.
- A support layer, laid over the beams, it may be the grip of palm trees "Kernafs" which are light and strong and offer beautiful decorative patterns or "Tafza" rubbles.

Figure 9. The finish coat. S.Haoui in "For the preservation of the architectures Ksouriennes in raw earth. Example ksar of Timimoun, Algeries".

- A layer of palms "Djerrid" that will be the support of the final coat of filler (Fig. 10).
- A filler layer: Made up of clay mortar 15 to 20 cm thick to consolidate the whole structure.

Given the large thickness of such floor, the inertia of the structure provides good thermal and acoustic insulation.

3.3 *Degradation and constructive pathologies*

Degradation of the Ksar is due in part to the vulnerability of buildings and damage found in buildings preservation of which requires considerable financial and technical resources.

These damages are due to two main causes: the physical characteristics of the earthen materials and some adopted construction techniques, in fact:

- Erosion due to sand and rainfalls damage on the walls and especially in the base and foundations, causing differential stacking resulting in collapsing and severe cracking.
- The walls are poorly or not harped on the corners and the interior walls just go up against the outer walls because they are built after them. A phenomenon which can cause the separation of the structures above the latter, especially as it is neither chained nor braced.
- The expansion stress of the materials due to changes in ambient air humidity causing its disintegration.
- The bending of beams of palm trees due to the undersizing of the structure or the quality of the wood because the palm tree is a second quality wood or overload.

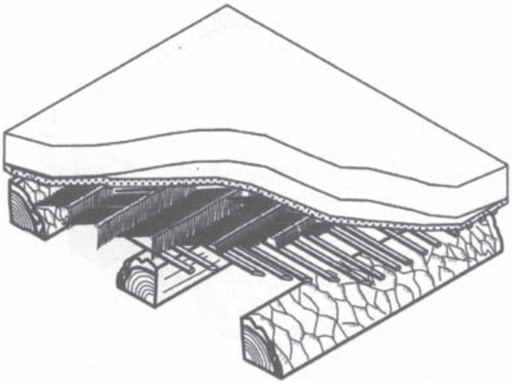

Figure 10. Type of floor. N. Abderrahim Mahindad and A. Foufa with a group; students: Abderrazek, Bahria, Benzina, Loua Gbamou, Zerrougui within the framework of workshop MATEC in 5th year.

- Dislocation of the beams from their anchoring surface given the lack of embeddedness, especially since there is a risk of separation of walls in the absence of Harping and chaining.
- Sealing problem due to the absence of slope and the quality of application of the clay resulting in ponding of water on the terrace and water infiltration into the structures.
- Rot and decay of wooden structures of aging materials and attacks by insects and fungi.

These constructive earthen architecture pathologies in Timimoun have encouraged the brutal introduction of new materials in a Ksour environment such as:

- Substitution of palm tree beams by prefabricated reinforced concrete "slabs" of and corrugated iron.
- Using mortar cements and then paint it with red paint in an attempt to mimic the original material.

All these deterioration factors cause the Ksar Timimoun to be a dilapidated structure, lacking hygiene and comfort, rejected by the population, condemning it to ruin.

Physical preservation of the Ksar as a witness of ancestral knowledge induces the urgency of building operations and reinforcement of structures built to prevent any further disintegration, such as:

- Strengthening the foundations and wall bases.
- Strengthening the masonry works by percolation.
- Chaining the walls to stabilize them to prevent their separation.
- Strengthening of palm tree beams at floor level and enlargement of anchoring surfaces.
- The treatment of bearing components in palm tree wood by oil impregnation.
- The discharge of floors.
- Setting up seals on the terrace.

4 CONCLUSION

The Timimoun Ksar is now marginalized and degraded because of its abandonment by the population. A precarious situation threatens an ancient heritage with a great historical, cultural, architectural and even constructive value.

The Timimoun Ksar condition is not restricted to it but to all the earthen ksours in the Tuat, Gourara Tidikelt and Saoura areas.

Conservation and preservation of these sites, requires urgent treatment at different levels: Technical for the conservation of earthen architecture and physical preservation of Ksours and Strategic by the establishment of a rehabilitation and integration policy of these sites and their promotion.

This is about establishing "a clear and appropriate heritage strategy" for Ksours which is based on their promotion and rehabilitation.

Conservation of buildings and the sustainability of the earthen architecture of ksours must be done in conjunction with the economic and social development of the regions. This is to define actions based on a holistic and participatory approach to save and preserve the ksours that involve their physical, cultural, social and economic environment.

Knowledge of local and ancestral know-how in such earthen architecture is critical to any action intended for its preservation and consolidation. The choice of methods and techniques of conservation and restoration should be consistent with the materials to safeguard their image and material authenticity during the restoration works.

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Cob, a handy technique for a new self-builder

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ABSTRACT: The project here presented has been a very special worksite experience where the authors have tried to share everyday solutions due to the lack of experienced labor, the limited economy, and the sourcing of local and good quality raw materials. Compared to regular building technologies, using cob has shown to bring out totally new labor/material and time/money ratios. From the very beginning it was clear that, for once, monetary law wouldn't guide the whole building process. Somehow it had some similarities with a cooperative project concerned with the distribution of benefits within the worksite rather than to the big goods suppliers. Although the authors had some experience in traditional rammed earth, cob was chosen because of its simplicity. Since this was their first self-build project, the authors had to find for ourselves the right way of working out each solution.

1 WHY US?

Before addressing how the project has been done and every worksite incident we went through, there is an important question to be answered: why use cob? This requires first, to identify two variables that determined the choice. On the one hand, is the raw material and on the other hand, is the execution. No one can understand the one without the other. The method of cob execution requires a certain composition of silt, clay, sand, straw and water, to allow the material to be worked manually, to create round pieces of the size of a handball.

Also unlike other earthen techniques, cob is the only western tradition that does not require any kind of form or mold. The only molding is done when the mass is dry and smoothed, using a machete to get the desired shape. Although this is a technique developed in the British Isles and Normandy since ancient times, it became well known in the media drive of the 60's thanks to the counterculture movement on the West Coast of the USA (Fontaine, L. & Anger, R. 2009). This alternative movement appropriated this technique because it did not require high capacity and allowed an independent craft economy for the construction of their homes. This explains the great freedom of expression that has defined today's cob architectural style, as opposed to the traditional style of older cob houses in Europe. This principle of ease of implementation also led our clients to decide on this technique. But, sensitive to the unique environment from which they originated in the Empordà and where the project was located, they sought our advice to ensure a harmonious integration with the existing architectural environment. Our experience as architects was focused on the use of traditional techniques in both new construction and the renovation of traditional heritage buildings. The young couple intended to build their home themselves near the historic center of La Pera, integrating the foreign technique of cob with the local architectural language.

Despite the ease of implementation, which qualified this technique as appropriate for self-construction, there were three other priorities that cob also allowed and were part of the starting requirements of the owners. First of all, earth was a safe material with a high degree of breathability—the ability to regulate humidity and capture pollutants in the indoor environment. Secondly, cob also generated high comfort passive spaces, with high thermal inertia, very suitable for the Mediterranean bioclimatic architecture (Serra, R. & Coch, H. 1995). Finally, it exhibited optimum acoustic and insulation properties, as an absorbent. Finally, cob maximizes the use of local materials as the earth comes mostly from the same excavation and the straw is readily available in the rural area.

2 GETTING FAMILIAR WITH COB

Often in our practice, we first come up with the design and only then, we determine the materials. In this case, taking the cob as a premise, the project plan was designed after, considering the chosen material and technique. As the material cob was unknown to us, we needed to acquire experience with the technique. The physical limits of the material were not a disadvantage: moderate span, evenly distributed load and generally obvious transmission of gravity loads, which did not reduce the possibility of obtaining relevant results in our particular architectural conception. As a result of this, we proposed two separate architectural volumes, the workshop and the house. Since the workshop had no specific function, it was less subject to building codes. Therefore, the workshop served as a test pilot project. Later, for the execution of the house and already with this previous experience, we had to meet strict regulatory requirements.

The building is L-shaped, adapted to the geometry of the plot and situated for an optimum solar orientation. The 40 m² workshop stand in the foreground on the access road. The 215 m² house has a high degree of privacy regarding access. The distribution of the different parts of the house reflects both the desire to integrate the preexisting environment and to enhance bioclimatic criteria. Concerning the interior space, the sleeping area in the southeastern end has a more intimate atmosphere. The kitchen on the opposite side has a generous connection with the existing fruit orchard. It is also at the center of the volume. The living room is closely connected with the presiding terrace and centers the whole house. Private spaces occupy the northern perimeter, while collective spaces enjoy the south side by a gallery. This element responds to both passive criteria of comfort in summer and winter, and to reduce the visual impact of the elevation with greater architectural perspective (Fig. 1). Having defined the proposal on paper it was time to put our hands into the mud.

The first step was to characterize the soil from the plot. We made a series of tests not covered by any

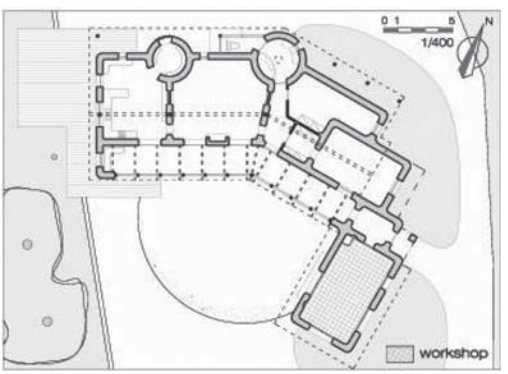

Figure 1. Floor plan (www.bangolo.com).

official legislation but very simple recommendations taken out from cob handbook (Bee, B. 1997). We focused on the granulometry knowing that the ideal would be 30% silty clay and 70% sand. We first performed a settling test, in which by the way the layers were deposited, we could observe the ratio of gravel, sand and silty clay. This test showed the need of sand, but a more accurate granulometry curve confirmed 68.5% of silty clay and 31.5% of sand-gravel. There was no advantage to determine the silt and clay percentage, since sand was the only corrective element possible to add. In order to use cob, we carefully control two variables: cohesion, since it determines the success of the mixture application; and retraction, because once dried, excessive shrinking should be avoid. For this reason, we carried out cohesion tests on samples with different proportions of sand and determined the proportion for satisfactory retraction. The cohesion tests consisted of shaping strips of 3 cm in diameter and then, they were placed in cantilever. Those samples that allowed an overhang of 12 cm before breaking ensured the cohesion necessary for our purpose. Shrinkage tests consisted of introducing the sample in a wooden mold and leaving it to dry, and then measuring the gap. The best sample resulted in a 2.3% decrease, less than the 3% allowable retraction. This characterization revealed the proper mix of 4 parts of our earth with 2 of introduced sand. In order to achieve the proper cob mix straw must be used. By adding straw, we increased the cohesion thanks to the reinforcing effect and the natural glue contained in the cellulose while reducing the final shrinkage. From all the available straw nearby, barley was chosen for its great length and flexibility. To determine the necessary amount we add the maximum permitted without loss of workability. The proportions that met our goal were 2 parts of earth with sand already added and 1 part of straw. At this point, we quit with home-made tests and we made up cob samples in order to determine at the laboratory the compressive and flexo-tension strength within the UNE regulation. Breaking four test pieces resulted in each case in compressive stress results of about 2 N/mm² and torsion flexion fractures at 0.7 N/mm². Values were comparable to lime mortar on compression while the flexo-tension values show its low suitability to support specific loads.

3 BUILDING YOUR OWN HOME

With all the trials and tests completed, the commissioning work could really begin. As we said, we started with the workshop, as a pilot program and from this experience two fundamental contributions subsequently emerged for the house worksite. First of all, forget any technological fundamentalism and second, demand the same degree of professionalism, as you would for any other gainful activity, even in the case of self-construction. So, we chose to introduce the advantages of machinery to assist in the process of kneading the mixture. During the workshop construction everything was manually done and the production of 1 m^3 of cob, required 32 hours and 4 people. Even for this self-construction site, those figures take to pieces economic variable and confirm what Nicola Sinopoli says about this invisible technology: *"Many of these activities not directly constructive, in the course of history have often constituted the feasibility conditions of all the works composed by man, could extend the promotion of a war of conquest to capture slaves needed the construction of a tomb or a temple, build fleets needed to transport materials to a distant shore in the case of a monumental work, but we could see only the mobilization of family and friends to graze bricks and place them one above the other for a farmer who built his own house"* (Sinopoli, N. 1997). We therefore acquired a kneading blade excavator, which reduced the time exactly in half. To build the same cubic meter of cob required 2 operators for 16 hours. During the building of the workshop, the social and community aspect were prioritized over the purely executive. But, the results also showed the need to maintain a small human group in order to achieve the minimum skills needed. After this rehearsal, we finally started building the house. To explain all the processes and decisions we went through, hereby follows the main sections of the construction.

3.1 *Foundation and wood framed structure*

There should be some precautions with the ground in which cob is built. First, you should avoid direct contact of the cob to the ground to avoid problems of capillarity, runoff and splash, which accelerate wall erosion. One should also look closely at the uniformity of the ground resistance under the proposed foundation, in part because the success of this technique is the slow and equal settlement of all the walls. That is why we chose a cyclopean type foundation with stones quarried from Girona and lime mortar as the binder. This system allows for a slow and progressive settlement while lifting the cob walls. Also, capillary action is less harmful compared to concrete because of its great breathability. The usual moisture barrier for capillarity is not appropriate here since we must ensure good cob adherence to the base by the irregular surface of the foundation stones. But not all precautions end here, since for proper behavior of the cob, the height of the foundation wall must be 90 cm above ground level. To build this bench, a ceramic enclosure was used, due to the lack of skill that masonry wall construction demands. The basement serves to place the cross ventilation window located on pavement level. Once finished the basement and before carrying out the cob walls, a new convergence between low-tech and high-tech took place. Carpenters just using dovetail joinery and stainless steel pins installed a solid wood framed structure with a numeric robot. The purpose of this structure responded mainly to three reasons: To control the elevations, cylindrical volumes and rounded corners of the earthen walls. To facilitate the building of the walls, this structure allowed awning covering when raining and it maintained a secure grip of the operators. Finally, due to the failure to fix the wooden beams on the cob walls, the roof was too weak for the wind suction and therefore, the outer pillars provided the needed anchorage.

3.2 *Lintels, carpentry and ring-beam*

It is in the execution of the walls that the cob technique is presented in full force and where it takes more time to build. When raising cob, one must build 30 cm layers by continuously applying 3 kilos boluses. You cannot place the next layer until the bottom is dry enough to support the weight of the worker. In our case, because it was necessary to complete one course in six days, there was no need to wait for drying. Another peculiarity of the cob that had to be taken into account when erecting the walls was the need for a slight slope to prevent erosion. For the formation of lintels, we also chose different solutions in the workshop and house. In the workshop we used the local traditional triple wooden lintel with the outside slightly depressed for greater protection of the future window. With the intention of using bamboo that grew nearby, we built lintels by using four segments of bamboo along a slight incline to help promote wider dissemination of natural light. Later we lined it with jute cloth for better adherence of the earth plaster. In the gallery, lintels were used mixed with bamboo inside and outside to improve the consistency of the final elevations. All doors and windows were installed in a final phase of the work through a few slots on both jambs without any prior framework. This simplicity of the carpentry installation is due to the great plasticity of the cob plasters, which allows the movement of the wood without cracking. Due to having raised the roof structure prior to erecting the walls, there was not enough space between the roof and the last cob layer to through the cob bowling with equal ease. To ensure that the beams were put under stress, we placed a wooden wedge on top of the ring-beam. In this case and unlike the workshop, it was not necessary to tie it to the cob wall, as the wooden structure with the base of the pillars and the foundation anchors fulfilled this task. During the execution of the cob walls, adobe was also used for building arches, in order to avoid complex cob formwork and to have the bearing capacity straight after finishing. We cannot end this section without a comment on cob furniture that this technique allows to elaborate. Solid benches next to windows to increase the thermal inertia, elegant carved niches in the wall or thin cob shelves reinforced with bamboo. These elements show the great sculptural possibilities of this technique, either by adding or removing cob on the finished walls (Evans, I. at al. 2002).

3.3 *Finishing the roof*

Concerning the infill and the aim of using the most of local raw material, bamboo and reeds were applied to cover the bedroom area and the gallery. In the living room, kitchen and workshop, to avoid an excessively exotic appearance, we used the same Douglas fir wood, as in the frame structure. All these materials were part of different architectural earthen construction cultures since ancient times.

To finish the roof, we considered the breathability of the entire cob volume and how important this quality was in the roof surface. First, a layer of earth mortar of about 5 cm was laid to homogenize different infillings. Then, we laid a thermal mortar made of lime and rice hulls of 25 cm thick and the last layer of lime and "cocciopesto" mortar to improve waterproofing. Local ceramic tiles were placed raised at 5 cm so, cross ventilation would occur before heat reached the actual roof. The two circular spaces, pantry and kitchen, were covered with weaved technique ceiling, where the main veins were twisted with split bamboo and wicker, and the rest was made of woven reeds. This decision was based on the availability of material on hand, as the local basket maker had the ambition to solve new challenges with this ancient technique.

There were two domes for the bath with opens at the top, forming an open neck protruding above the tiles, as well as a suggestive lantern (Fig. 2). Once both wicker frames were fixed on the top of the walls we applied the cob mix as a render giving the space an elegant continuity between walls and false dome. From the beginning of human settlement, basketry has always played a central role in vernacular architecture (Kuoni, B. 1981).

3.4 *Partitions, facilities and finishes*

The few non-bearing walls were made with a kind of balloon frame built with bamboo and later filled with cob. Later, a reed fabric was fixed on each side in order to apply the last earth rendering. The owners learned this traditional technique at a cob workshop in Normandy and chose touse this solution. We had preferred to use adobe walls, but after a comparison of time needed for both techniques, the reed fabric was chosen.

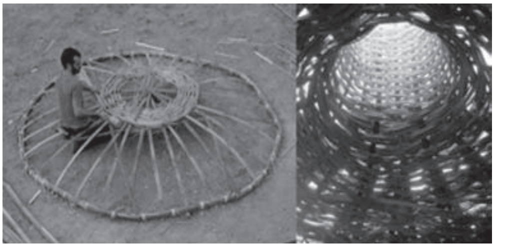

Figure 2. Basketwork structure and traditional lantern (Photo Oriol Roselló).

The electrical wiring, mechanisms boxes and tubes were embedded within the walls and were fixed using cob mortar. Initially, surface boxes and tubes were planned, since there was uncertainty about securing them using cob as mortar. But after several years of worksite experience, we confirmed the cob's reliability to attach carpentry or facilities. For heating, a biomass boiler was proposed connected to radiant tubes set into the walls. By doing so, a better heat distribution on the body is achieved compared with radiant floors. Before fixing the tube clips, extra rice husk and cob thermal render were applied. With the facilities already finished, we started the floor with a 25 cm thick gravel sub-base and a series of consecutive cob layers, based on a reduction of the granulometry and a more finely chopped straw. This was a last minute decision because we always considered the possibility of using a limestone mortar slab and ceramic tiles typical of the local tradition. This choice responds to two different natural factors. First, this would allow a higher breathability that could prevent possible capillarity humidity, so the walls would remain drier.

The last section is about the interior and exteriorplasters. On the interior walls it was clear to apply cob plastered using the same method as in the floors (Snell, C. 2004). In rooms where extra light is required, a final coating of lime paint should be used. On special surfaces, like the bath and kitchen, lime stucco is appropriate thanks to its impermeability. In many traditions all over, the use of non-hydraulic techniques has proven suitable for earthen architecture (Houben, H. & Guillaud, H. 1994).

It was on the façades, where the choice of plaster was debated the most, among architects

Figure 3. View of the house within the historical environment (Photo Oriol Roselló).

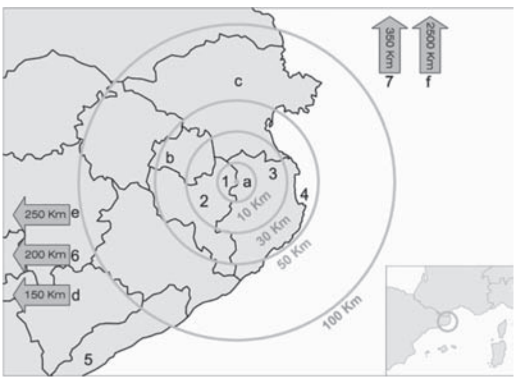

Figure 4. Materials that made up a large percentage of the total volume (www.bangolo.com):

1. Soil from the site itself: La Pera, Baix Empordà.
2. Foundation stone quarry: Pont Major, Gironés.
3. Sand for cob mix: Ventalló, Alt Empordà.
4. Douglas fir, structure and partition: Rodez, Midi-Pyrenees.
5. Drain and base pavements gravel: Ventalló, Alt Empordà.
6. Rice husk for insulation mortar: Pals, Baix Empordà.
7. Bamboo for basketry and roof: La Pera, Baix Empordà.
8. Ceramic walls at basement: Alpicat, The Segrià.
9. Barley straw for mixing cob: La Pera, Baix Empordà.

Materials that made up a little percentage of total volume:

a. Cane for walls, dome and cover: Vilabertran, Alt Empordà.
b. Flanders pine woodworking: Scandinavian area.
c. Non-hydraulic lime: Pont Major, Girona
d. Hydraulic lime mortars: Cervera, Segarra.
e. “Cocciopesto” ceramic dust: Porqueres, Pla de l’Estany.

and developers. While we preferred a non-hydraulic lime plaster using local sand and pigment, as the buildings around, the owners opted for earthen plaster. Likewise, in our rehabilitation practice, lime plasters loose the battle against nostalgic “petrophilia”, that is to say, the fashion of leaving stone masonry with no rendering at all. Here, we were trying to prevent for the volume finished with earthen plaster to excessively impact the landscape (Alcindor, M. 2011). In this case, the choice was reached with the desire to spread this new technique. Since this decision came at the very end of the works, we had to add generous eaves around the roof perimeter, as earth plaster does not endure without having this “big hat”. The same project with more modest eaves and the lime plaster that we usually use in our works would have had much greater affinity with the architectural tradition of the region.

4 CONCLUSIONS

For any project it is important to consider which values one intends to promote, as they often come into conflict and one is forced to choose between them. In this particular case, it has been even more important to prioritize due to the divergent directions of the starting values.

The first requirement seemed to have been to avoid a too unusual formal result due to the distinctive historic environment, where it was located. Despite using a technique originating in northern latitudes and with technical limitations inherent to self-building, the house fits in the landscape without too much impact (Fig. 3). Trying to combine architectural elements of the local identity, such as the roof, chimneys, porches, courtyards and vegetation with the more relaxed style of the traditional cob seems to have been a successful strategy. It was also important to be aware that in this case, the integration was not total, but one can see a path towards its beginning, especially when compared to contemporary cob houses, where the final result responds exclusively to alternative architecture patterns. The fact of purposely leaving the walls bare with the intention of encouraging this new technique, contradicts the will to harmonize with the preexisting architecture. Self-building is a very valid option for this type of traditional building where the ratio of labor and materials is contrary to contemporary worksites. It is appropriate to emphasize our feeling that self-building seemed a quite reckless choice.

Now, five years later, it actually looks like a good way to avoid the effects of the global financial crisis we are suffering (Jackson, T., 2011). Perhaps the most sobering value has been maximizing local resources (Fig. 4).

Under this self imposed restraint, we seemed at times to be recovering the true values of preindustrial techniques. How to build with what we have on hand and minimize the variety of materials are strategies that extrapolated, and would help recover some land management and social cohesion that are now lost. This would avoid the protectionist and nostalgic heritage strategies prevalent today, while encouraging a return to values and strategies of maximizing resources. It is curious to see how, under such strategies, holistic links between agriculture *(rice husk and barley straw)*, housing *(local artisans and self-building)*, landscape (bamboo and reeds) and community *(workshops and celebrations)* are recovered.

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Analysis and characterization of earthen architecture as a structural material: The corbelled course domes in Syria

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ABSTRACT: When investigating earthen buildings to analyze their resistant behaviour, the structural design and the methods under which they were designed and built should be taken into account. In the case of adobe or Sun-dried mud, the most important property that characterizes these materials is their low capacity to develop traction tensions. The structural behaviour under the hypothesis of gravitational and dynamic loads is analyzed. After that, an isotropic damage model is done to be implemented in a finite element program in order to get a tensional state and an index of damage to contrast the results with the real model.

1 INTRODUCTION

For knowledge of historical monuments and in order to be able to thoroughly approach a restoration project, the use of precise diagnostic methodologies and techniques is essential to be able to ascertain the actual materials and causes of degradation, and then arrive at a diagnosis and determine possible solutions.

The advanced structural calculation procedures developed by Continuous Medium Mechanics have recently provided very powerful tools for the analysis of increasingly more complex structures.

Among these methods, the Finite Element Method (FEM) (Zienkiewicz & Taylor 1994) has been most developed. However applying the FEM to analyse the condition and behaviour of historical structures is rather more complex, since in order for the results to be reliable certain conditions relating to its application are required in the analysis, and fundamentally the use of non-linear models.

To approach the analysis of these structures, the structural concept and the methods under which the domes were designed and built must be taken into account. These structures were conceived and built using unknown parameters, since concepts such as strain, strength and deformability, which are judged as essential for the understanding of structural behaviour, were then unknown.

The mechanical behaviour of fabrics is far removed from that which is assumed in the lineal analysis (Lourenço 1998). The joints and possible fissures cause a loss of material continuity; the mechanical properties depend on the tension forces applied; there is no linear relationship between tensions and deformations, etc. These effects emphasize the fact that the lineal analysis does not correctly reproduce the behaviour of historical buildings; we can only expect for an approximation to structural reality that will be divergent to varying degrees according to the conditions of deformation, tensions and deterioration of the fabric itself, besides that of the mortar and its components.

Thus appears the non-linear analysis, which attempts to evaluate the behaviour of structures using the properties of materials that are variable. To make a model of this variability makes the analysis extremely complex. In the FEM this involves an evaluation of the constitutive matrix according to the concepts of the theory of plasticity and the mechanics of fractures. This process is necessarily non-linear, and therefore repetitive, which involves an increase both in complexity and in computational time.

The appearance of fissures in the fabric, and the variation in the tension-deformation conditions which they cause, make necessary the inclusion of fissurisation modes in the applied analytical models in order to obtain realistic structural results in the study.

There are three basic procedures of non-linear analysis (Oñate & Hanganu 1999) on which to model this non-linear behaviour of structures, calculating the appearance and evolution of fissures and the maximum structural loads. The so-called isotropic damage model was used in this study (Oller 2001), which was utilised within the CID programme (Alonso 2003) of finite elements for the study and analysis of various historical domes, and of which we give an abbreviated description.

Damage mechanics is a branch of Continuum Mechanics, which, by means of internal variables introduces micro-structural changes into material behaviour. These variables model the influence of the behaviour history of the material in the evolution of tensions.

The emergence of fissures and their evolution over time in materials such as concrete and masonry can be described as the course followed by several points of damage.

If a damage function is defined representing correctly the response of the material, both in compression and traction, then the non-linear behaviour of the masonry can be represented in a model.

Cracking is represented in this case as an effect of local damage that can be defined according to the known parameters of the material and to functions that control the evolution of the damage with the successive tension loads at each point. In the CID programme, an application of the isotropic damage model developed in the last decade was used (Barbat & Oñate 1997).

The model used takes into account the three assumptions necessary to correctly model the non-linear behaviour of concrete and masonry; the different behaviour in compression and traction; the deterioration of rigidity through mechanical causes (tension loads) and the effect on the response of the size of the mesh of finite elements.

2 CONCEPT OF ISOTROPIC DAMAGE

A point in the material with a certain degree of damage is considered, the deterioration being represented as hollows in the fabric. The damage variable "*d*" is defined thus:

$$d = \frac{S - \overline{S}}{S}$$

where S = total surface under consideration; $\overline{S}$ = the effective resistant area; and $S - \overline{S}$ = the hollowed surface. This index expresses the degree of deterioration of the material. The zero value represents the undamaged state, while 1 is the total damage of the resistant area.

The relationship between Cauchy's standard tension and the actual tension acting on the part of the effective resistant section is derived from the condition of equilibrium:

$$\sigma = (1-d)\overline{\sigma} = (1-d)E\varepsilon$$

This scalar index is sufficient to adequately represent the behaviour of materials such as concrete, brick and stone (Fig. 1).

The effect on the mechanical behaviour of the material is a reduction of rigidity proportional to $(1 - d)$.

In the repeated FEM process the constitutive matrix $\overline{D}$ is calculated as:

$$\overline{D} = (1-d)D$$

where D is the elastic constitutive matrix.

The scalar variable of damage is:

$$d = 1 - \frac{r^o}{r}\exp\left\{A\left(1 - \frac{r}{r^o}\right)\right\}$$

The values r, r^o, A are obtained as in reference (Hanganu 1997).

An important advantage of the damage formulation is its simplicity of calculation compared to other cracking models, since a special algorithm is not required to integrate the constitutive equations of the elasto-plastic models.

In the case of the Syrian domes studied, the material used was adobe or sun-dried clay bricks. The property characterising these materials is their low tensile stress capacity. Compared to acceptable compression strength, tensile strength is much lower. Different researches (Huerta 1990) (Martín-Caro et al. 2001) coincide in attributing mechanical values to clay fabric and materials, depending on those established for the foundation base material, which in the case of adobe, were estimated to range from 1 to 1.5 N/ mm^2 of compression strength. The values for tensile strength were 100 times lower, averaging around 0.01 N/mm^2.

The domes studied are representative of a common habitat in the region (Fig. 2), with only

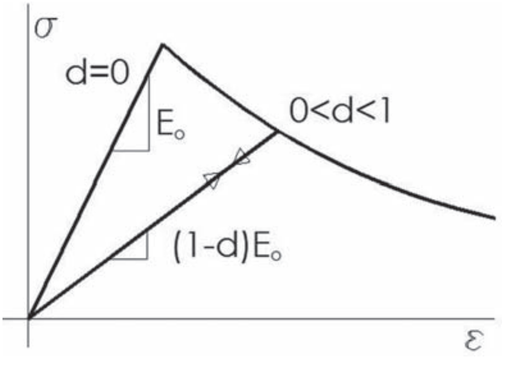

Figure 1. The effect on the mechanical behaviour of the material is a reduction of rigidity proportional to (1 – d). Alonso A. (2009).

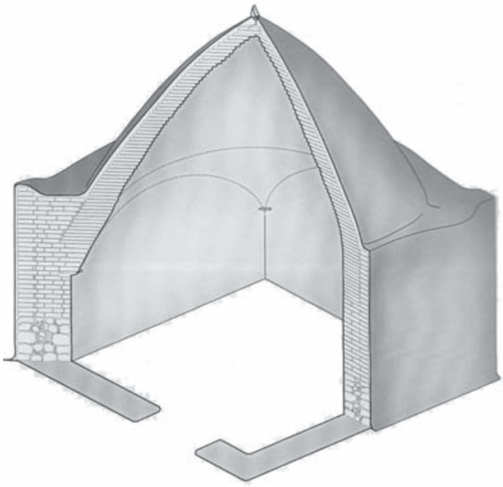

Figure 2. Axonometric view of a simple dome. Dipasquale L., Mileto C., Vegas F. (2009).

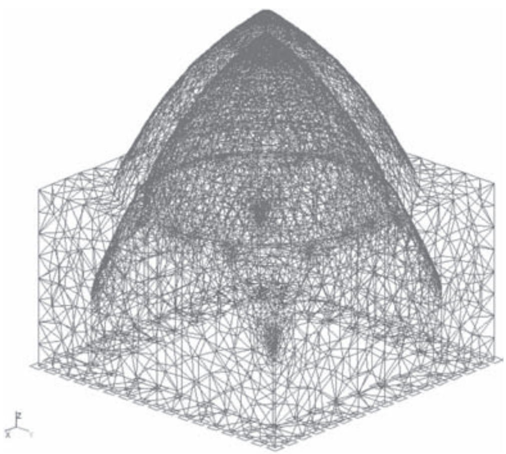

Figure 3. Analysis model. Alonso A. (2009).

one small sized living space, a value geometry comprising dome diameters ranging from 4 to 7 metres, approximate wall thicknesses of 60 cm. and approximate dome thicknesses of 30 cm.

The dome was modelled in combination with the walls using mesh of volumetric finite elements in the intrados and batter (Fig. 3), resulting in a model with 18,370 nodes, 82,180 solid tetrahedron elements and 54,762 degrees of freedom (gdl).

Initially, analysis assumes that the structure is formed by a continuous material of lineal-elastic behaviour, and the parameters are specified through the constitutive matrix. It requires comprehensive information of the mechanical properties, which, as we have pointed out before, can be an area of conflict.

The mechanical characteristics of adobe as material used in the model were as follows:

From the study of structural behaviour under the gravitational load hypothesis, with a non-linear calculation procedure (Alonso 2003), following an isotropic damage model (Hanganu 1997) and implementing it in the CID program (Alonso & Pérez 2002) of finite elements, a stress state and damage rate are obtained showing excellent structural behaviour.

The state resulting from the calculation under tensional gravitational actions shown in Figures 4 and 5, shows that the tensional state Sx (Fig. 4) in the direction of the parallels, ranging from a compression stress of –0.014 N/mm^2, very far from the allowable strength of the material, and tensile stresses, concentrated in a very low value items of 0.029 N/mm^2, values are also very low and perfectly acceptable for the material of construction, including traction.

Likewise, the tensional state Sy in the direction of the meridians (Fig. 5), it only varies between

Table 1. The mechanical characteristics of adobe.

Modulus of deformation (E)	4000	N/mm^2
Poisson ratio	0.2	
Density	1900	Kg/m^3
Compression strength	1.5	N/mm^2
Tensile strength	0.01	N/mm^2
Fracture energy	0.01	Nmm/mm^2

OMAR et al. 2009. The earthen in-scale model and the mechanical tests, *Earthen Domes et Habitats*: 370.

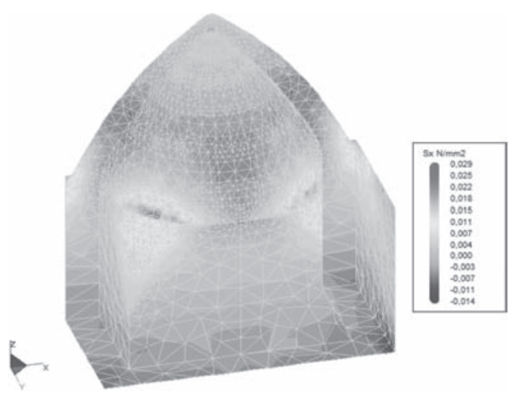

Figure 4. Stress state. Sx in the direction of parallels. Alonso A. (2009).

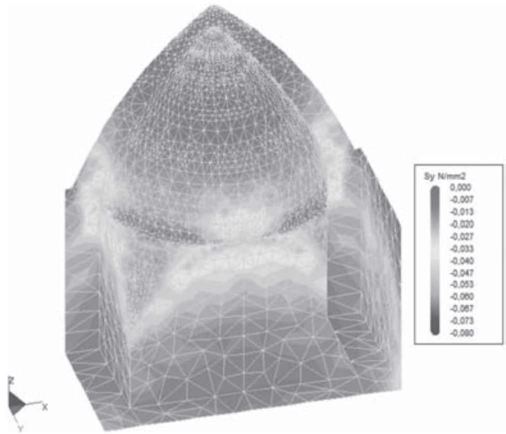

Figure 5. Stress state. Sy in the direction of parallels. Alonso A. (2009).

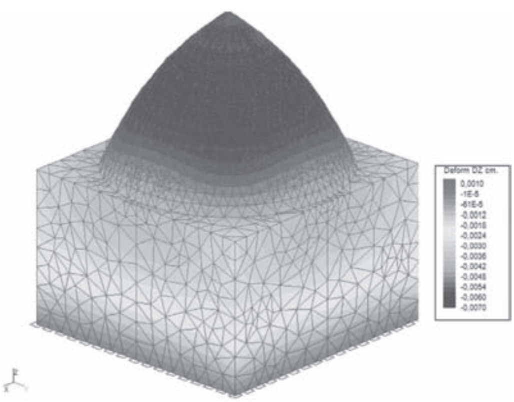

Figure 6. Deformation as a result of own weight load. Alonso A. (2009).

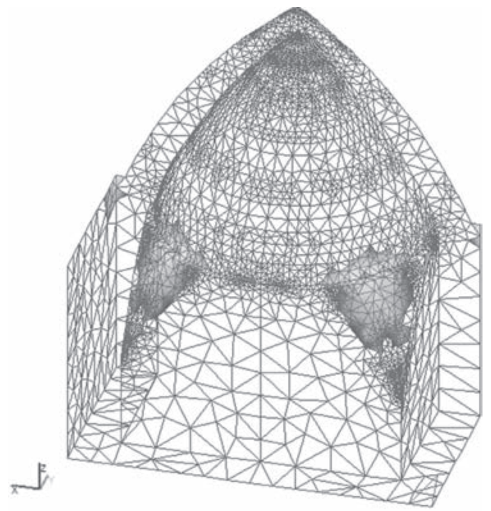

Figure 7. Model of damage resulting from own weigth load. Alonso A. (2009).

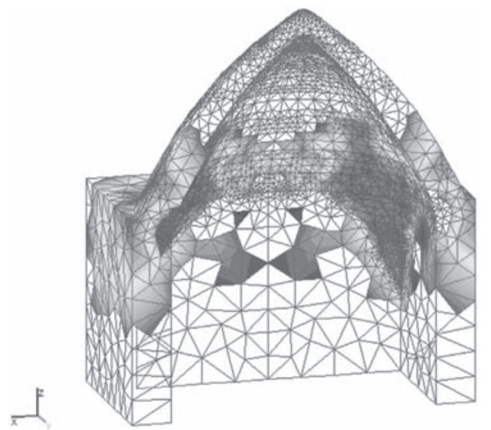

Figure 8. Model of damage at the point of collapse for 2.5 times the dome's own weight load. Alonso A. (2009).

compression and values of –0.08 N/mm² and –0.007 N/mm².

Similarly, the displacements that occur in the dome, under gravitational loading, are also very low. In Figure 6, shows the map of vertical displacement, which in the upper part range between 0.07 and 0.01 mm (Fig. 6).

In this analysis, non-linear damage model, described above, is seen under gravitational loads, an almost total absence of the level of damage (Fig. 7), with a damage index between 0.2 and 0.6. The collapse occurs in a hypothesis of 2.5 times the gravity load that is subject to the dome (Fig. 8), which shows the high safety of this type.

This conclusion is also supported by the actual model given that no relevant cracks was found therein.

3 MODEL RESPONSE TO SEISMIC ACTION

In order to evaluate de structure behaviour at the time of an earthquake of a certain intensity (Fig. 9), it is required a model dynamic analysis by using the seismic action of a registered earthquake suffered in Turk in 1999, with a 2.33 m/s² maximum acceleration.

The first five modals frequencies show how extremely rigid the dome is.

The spectrum in accelerations (Fig. 10) that is applied has a 0.56 g maximum acceleration.

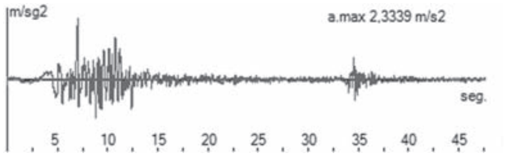

Figure 9. Deformation as a result of own weight load. Alonso A. (2011).

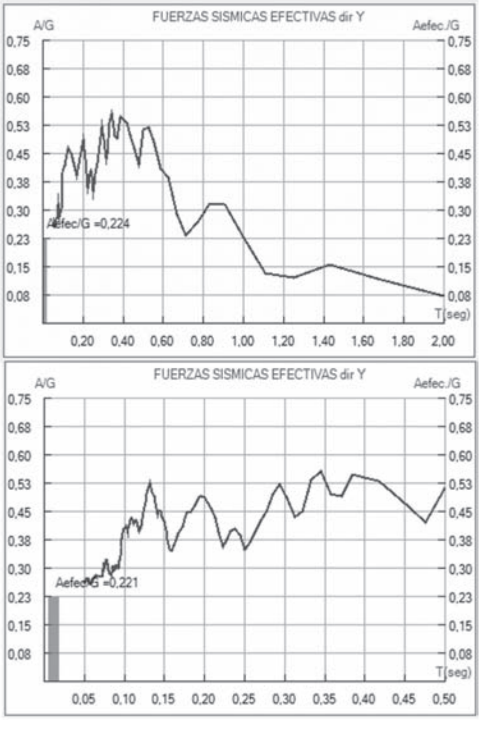

Figure 10. Effective spectral acceleration. Alonso A. (2011).

Table 2. The first five modals frequencies.

Mode	Frequency (cps)	Period (seg.)
1	50.76	0.019
2	50.98	0.019
3	83.16	0.012
4	87.69	0.011
5	88.05	0.011

The different periods of vibration of the structure are very low so the effective spectral acceleration acting on the model is 0.22 g.

It has been developed a modal spectral calculation and seismic time-stepping methods. When the damage model is applied to seismic actions (Fig. 11), the analysis shows that the crack level originated is low. This shows that the structure offers a good resistance capacity against the dynamic actions of the earthquakes.

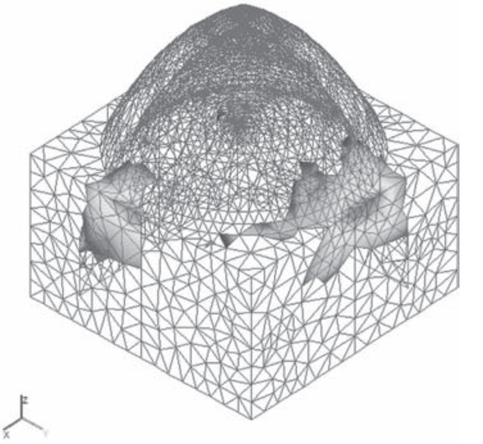

Figure 11. Effective spectral acceleration damage model. Alonso A. (2011).

4 CONCLUSIONS

Although the material of this type of construction is of very low resistance, the shape, size and thickness of the dome and the walls, justify the low value of the tension that is subject to both compression and in traction.

The inexistence of any set of real cracks in the domes is consistent with the stress state shown in Figures 4 and 5, both in the direction of the meridians and parallels.

Additionally, the shape and dimensions of this type of construction, provides a high level of stiffness, so the gravitational vertical displacement under load are not significant, consistent with the low stress state. The vertical displacements are not significant. For this reason, the influence of elastic constants in the analysis, since their values are very low or insignificant, is irrelevant.

The map of damage obtained in the calculation of the effect of the gravitational loads is inexistent, and to reach a collapse it would be necessary to increase these gravitational loads by up to 2.5 times their current value, which guarantees the high security of these buildings.

NOTE

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ABSTRACT: The following is the earth construction for the bioconstructive and bioclimatic public school in Santa Eulalia de Ronçana, near Barcelona. This was the winning proposal among twelve others in a tender. In addition, the project has been recognized in European Awards and has won two prizes for sustainability and environmental quality: the Ecoviure and the Endesa Awards 2010.The green brick, BIOTERRE CEB (compressed earth block), is the material used in walls and domes for its high thermal inertia and low environmental impact. It meets all the requirements of the Spanish standard UNE 41410. The classrooms roof was constructed using elliptical Nubian domes, with the brick showing on the inside. The CEB, made with raw earth, has excellent absorption, plasticity characteristics, high thermal inertia and low environmental impact for a construction material. The construction project sets a good precedent that optimizes the development of more public projects at a European level.

1 INTRODUCTION

We have been implementing earth-based solutions to improve the quality of our buildings, to respect nature and to use environmentally low-impact materials, considering at the same time the maximum comfort, welfare and health of users. Working with this type of construction is also an opportunity to use earth as a structural material, primarily CEBs (Compressed Earth Blocks), in both vertical and horizontal surfaces. This material was chosen for its qualities and is perfectly suitable for the compression typical of domes and walls. In addition to their many advantages, these technologies and materials also influence the perceptions of users. According to the teachers, feelings inside the building are very positive. The many different types of people visiting the building express a general sense of well-being, peace and tranquility, proving that it's an architecture meant to be felt and visited, not photographed. It's designed in harmony with nature for the benefit of the people who live in it.

2 THE PROJECT

2.1 *Shape and distribution*

The school entrance, located in a corner, is framed by a large arched wooden girder. The building's low height with reference to the access road makes visible a roof garden full of autochthonous species and classrooms decorated with mosaics of broken ceramic tile, called "trencadís" in Catalan, a distinguishing characteristic of the architectural movement called Modernism.

The classrooms have their own colors, both inside and outside, to help children recognize and differentiate each one. On the inside the school is organized around a central oval courtyard, inspired in the shape of a uterus and providing a microclimate and a better view of the rooms. The courtyard is more public than the entryway and the multipurpose room. In its northeast corner it opens out onto the only bit of nature in the area: a park, a creek and views of the massif of the Montseny Natural Park in the background. Wooden beams radiate from the center of the courtyard, which is presided by a fountain and a noble oak tree, as if it were a sacred place. They are the symbols around which school life is organized and give rise to its name, "La Font del Rieral".

Beyond the entryway and the hall the building is divided into two parts: to the north, an administration and service area, and to the south, an arc formed by five domed hexagonal classrooms, facing the green area, and by another one further down the hallway at the eastern end, made intentionally in the shape of a heart. The classrooms are arranged

Figure 1. Santa Eulalia of Ronçana School, exterior view.

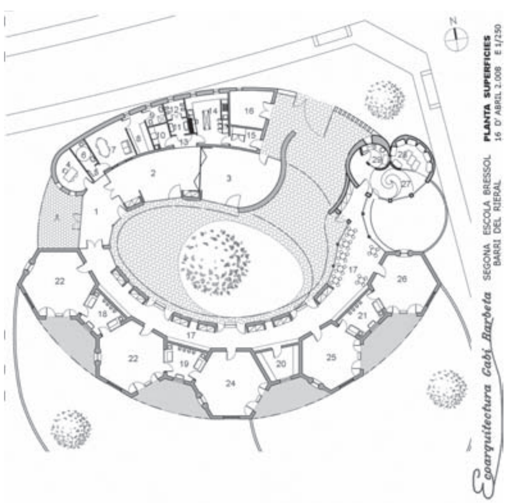

Figure 2. General Floor Plan, functional.

so that older children are near the entrance and the lunch room, and the smallest are at the end, where they have the peace of mind they need. The shape of the classrooms promotes work in a circle, typical of group dynamics. The area, radius and height of each one changes subtly, depending on the age of the children, with areas ranging from 39 to 31 square meters. The hexagonal-shaped perimeter CEB wall is 30 cm thick and 208 cm tall. Over it is a 25 cm concrete hexagonal perimeter hoop and Nubian domes between 1.5 and 1.65 m high, depending on the section and based on the golden ratio. The radius of the circular path of the domes is 3.3 meters, and the heart shape is formed by working with three radiuses: 3.69, 2.25 and 1.38 meters.

Figure 3. Middle School in Santa Eulalia of Ronçana. Exterior view of the entrance and the courtyard fountain.

Lavatories and changing rooms are found between the classrooms to give teachers greater versatility and more support. The access corridor is especially wide to make room for side cabinets, to open up the classrooms, and to promote complementary activities such as snacking and game playing.

The northern part contains the services (bathrooms, kitchen, and administrative offices) and the building is separated from the busy street by a CEB wall 45 cm thick with small controlled apertures to minimize heat loss. The multipurpose/dining room is open to and perfectly illuminated by the central courtyard, and when subdivided by a folding wall it is independent of the nursery thanks to the northern access. A curved rammed earth wall reusing clay soil from the excavation of the foundations provides the backdrop for the room.

2.2 *Bio-construction technologies*

Since the beginning of the creative process, the project has been integrating natural materials such as the CEB (Block Compressed Earth), earth walls (rammed earth), finished with lime mortar and ground insulation, cork, natural fibers, wood, eco-friendly paints, flooring cork based linoleum and tree bark façade finishes, working with a

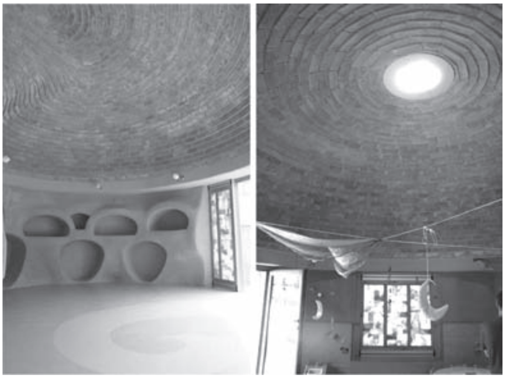

Figure 4. Bio-construction materials in the classroom.

great environmental awareness and minimizing the presence of metals and steel structures. From this awareness derives the solution of sustainable building elements for covering by working directly in compression. One way is to design with common sense, which for millennia, man has used and the Nature manifested in many forms organic effective and efficient. The design process includes concepts of bioclimatic architecture:

"Trombe" walls made of salt ionizing bricks and green pergolas for sun protection in the classrooms of the south facade, roof garden with native species, recovery systems for rain and waist waters, cross ventilation systems, biomass boiler, and solar panels for underfloor heating.

2.3 *The ease of building with CEB*

We must demonstrate to other technicians, insurance companies, organizations and professional associations that earth as a building material, a millennium material, is safe and easy to control in comparison with the other construction technologies. For that it is essential to ensure comparable compressive strength, durability against water and salt, predominantly, and control of the architectural benefits obtained.

Based on the wide experimentation and the methods outlined in the doctoral thesis of Gabriel Barbeta, we can say that it is now feasible to have quality standardized material made of earth. CEB is the technology that obtains these objectives most easily. The reasons for this are:

1. The technology is comparable to traditional ceramic brick, in terms of both the type of equipment needed and the way to work with it.
2. Workers do not need to be highly qualified; any builder can carry out work with this material.
3. It is easily industrializable, which implies a more homogeneous and controllable material.
4. In turn, it allows the use of hydraulic compression machines, which give greater compactness and strength.
5. As the pieces are small, problems caused by shrinkage due to drying or the expansiveness of clay are not an issue and do not affect the proper functioning of the walls.
6. Transportation within a 70 km radius of the Bioterre manufacturing plant was affordable. That meant only a 10% energy impact increase in the cost of the material, making it better than using the expansive earth taken from the same place.

2.4 *Technical characteristics of the CEB used*

The weight-bearing walls of the school were built with double walls of Bioterre CEB, most with a thickness of 30 cm. They stand on a reinforced concrete foundation of hexagonal paving stone interconnected by braces because the ground was at risk of settling and expanding. The wall alternates thicknesses of 15 cm indoor and outdoor 30 cm expanding to 45 cm on the north side that borders to the bustling main street. Inside view shows a wall with earthy color CEB transparent water-repellent treatment on the basis of latex, silicone resin or potassium silicate.

It has also been used with stabilized earth walls (rammed earth), adobe clays own the place and finished with lime mortar and soil cover mechanically projected.

Despite seeking a uniform distribution of loads, the small differences in tension generated by sills, openings and corners led to the adoption of a micromesh type Murfor of 3 mm, located every meter in horizontal bed joints.

- The BIOTERRA CEB is a block type 5, standardized by the Spanish UNE 41410 structural material with great flexibility: it can be one of the best anti-seismic and allows it to withstand traction. (ININVI regulations, Peru). Overcome resistance to the collapse of reinforced concrete structures. For concrete floor according to E = 55,000 to 90,000 K/m^2 at 7 days and 100,000 175,000 K/m^2 to 90 days. The dynamic modulus of elasticity is 30–25% higher than E. compression. Young's modulus E = 25,409.37. Compressive strength N/mm^2 σc = 7–10, exceeding 5 N/mm^2 block marks the CTE F. Traction 10%. Shear $\tau = 1/8$
  Compression $\leq 3,442 \pm 0.057$ N/mm^2
  Bending $\sigma f = 3.57\ (\sqrt{\sigma c'}/7)$. 0.88 (1).
- The compressive strength when wet goes down by almost half, this largely depend on the type and degree of stabilization employed.

– The breakdown in the press is never instantaneous it breaks gradually rearranging its molecules, compressing. Even when it is stabilized, retains its plastic state.
– The Poisson's ratio (according to FELT) is 0.2 to 0.3, at compression of 0.08 to 0.24.
– Fire Resistance >240 min TIPE M0.
– Thermal insulation. e = 30 cms. Standards UNE-92-001-90/91 UNE 92-201-89 UNE-92-202-89 ISO/DIS 8990
$\lambda = 0.415$ W/m °C at 0 °C K = 1.06 W/m² °C
$\lambda = 0.546$ W/m °C at 35 °C K = 1.30 W/m² °C
$\mu_{(\text{damping factor})} = \exp(-e.V\pi c\delta/\lambda T)$ (2)
$\phi_{\text{termal lag}} = T/2.e/\lambda.V\lambda c\delta/\pi$ T = 7.99 hours
– Acustic insulation e = 30 cm F 500 Hz
Rg en dB (A) = 54.0

Figure 5. Rammed earth with reserve for a hole.

2.5 *Other outstanding properties of CEB*

– Great thermal inertia, heat buildup in summer and/or during the day for winter and/or night. Specific heat: 0.27 kcal/kg.
– No radioactive or toxic particles, other than the very nature of the place.
– Resistance to climate change. The coefficient of thermal expansion is 0.012 mm/m °C.
– Volumetric stability, from the stabilization of the clays that compose it. Coefficient of linear shrinkage of 3 mm/m (unstabilized).
– Permeability and regulation of water vapor. Water absorption coefficient of 5 to 8% (dry weight).
– Adherence to wood and organic materials.

2.6 *Generic Parameters for the construction of a CEB wall*

– Mortars: Faster natural cement or mortar M-2.5 with the addition of 50% prepared earth TMA < 5 mm.
– Joints: 15 mm.
– Rig: From perforated brick are valid and solid brick with labyrinth seal. Chases Max: 25 mm in segments <1.5 m.
– Expansion joints: <40 m y <20 m In morphology L o U. Hollow: Width >2.1 m.
– D. between holes, hole—encounter walls >0.5 m.

Figure 6. A linear shrinkage test with different dosages.
a) 10% lime.
b) 12% cement, 7% perlite and 24% brown fibers.
c) 12% cement and 7% perlite.

2.7 *The rammed earth*

Despite the ease of construction with CEB, and even greater ease for curved walls (Fig. 5), it was decided to also use earth from the site as an ecological gesture. Using earth from the excavation site to build walls is certainly one way to minimize the impact of construction. Also, reviving the rammed earth technique seemed like a good option given the local traditions and the type of wall that was to be built. To carry out this task it was essential to check the properties of the earth and of the stabilization system used. Although linear shrinkage is a major handicap, it also provides water protection.

The results obtained in the specimens (Fig. 6) were: retraction of 1 cm on the longitudinal test

60 × 7 × 4 cm (1.67% of the total). The fiber dosage compensated the content of expansive clays to obtain an excellent compressive strength of 192.11 Kp/cm^2.

3 CTB DOMES

The construction system of the elliptical Nubian domes is based on the path from the fixed centre and radius variation in each of the different courses. To do this we used something new: a rotary telescopic metal ruler, functioning as a compass (Fig. 7). This technique results in a stepped, irregular and absorbent surface when block is left in the exposed, significantly improving the acoustic performance. The dome is 15 cm of Bioterre complete with a cover of 7 cm of concrete reinforced with polypropylene fibers and the isolation of two layers of natural cork bound with cement glue. The exterior finish is made of mosaic, called in Catalan "trencadís".

The design and calculation of the domes were made from a radius of 3.3 meters and a point or height of 1.75 meters, although among them were small dimensional variations. The loads considered were of 2.92 KN/m^2 for blocks of land, 0.08 for cork isolation thickness of 6 cm and 1.3 KN/m^2 for the final layer of mortar with waterproofing and multi-colored ceramic recycled tiles. At the same time we considered the variables of wind loads, earthquake and snow and follow the mandatory requirements established by the Technical Code for Construction in Spain (CTE-SE-DB-AE). The design values were 0.4 KN/m^2 for wind and 0.5 KN/m^2 for snow because the altitude is below the 300 meters above the sea level. Transiting use loads were not taken into consideration because the shape of the domes slopes and the finishings materials were considered not passable. The calculation of the seismic force resulting from the own loads in relation to the height was made on the basis of Spanish rule NCSE-02.

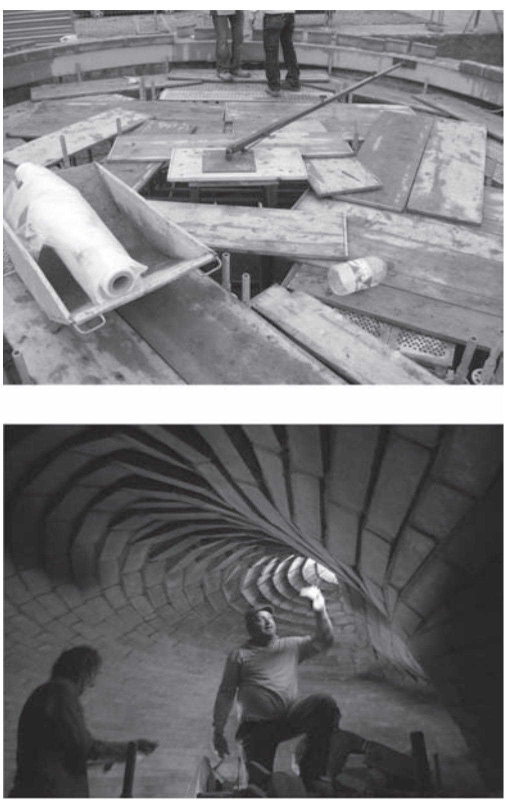

Figure 7. Building Nubian domes without formwork.

To study the stability of the section used the static method by funicular polygon graphic computer drawing. We analyzed the average worst section of the domes, using the following assumptions:

- The dome is similar to an infinite continuum of circular sections. We analyzed a circular area of the dome's horizontal sliced section.
- The scale of the graph lines is proportional to the real thrusts.
- The balance of the dome is achieved by containing the different thrusts lines obtained within the central third of the cross section of the different segments. The horizontal thrust must be counterbalanced at its base by a perimeter concrete ring beam.
- At the top of the dome the reaction there is a horizontal force equal and opposite to the thrust at the base. We place it situated in a third of the most external section.
- The axis lines of the reactions and the total charge of the section run through the center of gravity of the section, which is directly determined by the command "massproperties" in the AutoCAD drawing, having previously assigned "volume" to the AutoCAD object. If the traced polygonal axis lines of the reaction fall outside the middle third center.

The axis-force line must be relocated inside the middle third center changing the inclination and tracing back the force polygon.

The resulting polygon conditioned us to increase the section in the lower area of the dome, filling it with concrete to prevent tractions and the use of steel reinforcement.

The linear thrust obtained was 634 Kp to be added to the seismic thrust in order to determine the amount of steel reinforcement in the hexagonal perimeter hoop. During the construction of the domes, due to the great flatness of the last rows of CEB and, despite using the construction system block Nubian offset to the radius of the track, decided to use a fast natural cement brand named "Marfil" from the local company "Cementos Collet".

These domes also offer us many advantages such as providing a greater volume compared to flat ceilings, enhancing the sensation and perception of space, allowing a better climate pattern during summer, thanks to the possibility to allow hot air to go up to be evacuated through the practicable skylight, minimize the area covered affected by solar radiation thanks to the geometry of the dome, compared to a flat roof, and finally offer a natural finish with multi-tonal BIOTERRA seen without the need for any lining.

4 CONCLUSIONS

Finally, once exposed the costs and time spent in the execution, we can conclude that they are competitive and perfectly acceptable in the construction of contemporary buildings in highly developed areas, although prevalent social concept intrinsic to the technology of the self construction. It is an open path that offers options and hope to a large crowd of people on this planet.

The technological aspect of solidarity in the use of low tech is to find a common path to all humanity; should not be forgotten and must be present in our consciousness as technicians.

In turn the duality between economy and time should not condition the increase of the quality of our buildings, respecting the environment using materials and technologies with low environmental impact and to think in the maximum comfort, convenience and health of the users.

This is reflected in the opinion of the educators who work in the center and parents of children, their feelings inside the building are very positive, characterized by a general feeling of well being, calm and loving place. An architecture to be felt and accessed, not to be seen from afar, designed in harmony with nature and for the benefit of people who use it.

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Earthen and water architecture: University workshop in Ksar of Tamnougalt, Drâa valley (Morocco)

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ABSTRACT: Tamnougalt is situated in the Drâa Valley, in the south of the Great Atlas, a few kilometres away from the Sahara Desert. Nowadays, Tamnougalt is divided into three districts or villages, among which is the old Ksar; the focus of this study. The progressive neglect and abandonment of the old village by its native inhabitants has brought instability to this architecture of noble materials, mainly earth. The preservation and survival of this architecture has always required a periodical maintenance, which nowadays almost no longer exists. The decline of these buildings, which make up a great cultural inheritance, is hastening on. For this reason, the authors decided to move to Tamnougalt, in order to learn the techniques and actions that constitute the knowledge of this vernacular architecture.

1 INTRODUCCIÓN

1.1 *Antecedentes*

En septiembre de 2003, un grupo de profesores y alumnos de la Escuela Universitaria de Arquitectura Técnica de Granada, en cuanto sede local de Forum UNESCO, Universidad y Patrimonio, participaron en un primer Taller Internacional sobre la Arquitectura de Tierra, "Learnig from Tamnougalt", que tuvo lugar, asimismo, en el Ksar de Tamnougalt, desarrollado en colaboración con profesores, doctorandos y estudiantes de la Facoltà di Architettura de la Universitá degli Studi di Firenze, la Facoltá di Architettura di Torino y la Scuola Professionale Edile di Firenze. Aquel proyecto tuvo su origen en el Departamento de Tecnología de la Arquitectura y el Diseño de la Facultad de Arquitectura de Florencia.

Lo positivo de aquella primera experiencia animaba a que no quedara en un hecho aislado y, desde el principio se creyó necesario repetirla, ampliarla, y además establecer relaciones de colaboración con entidades locales, para que el resultado de estos trabajos repercutiera asimismo, sobre el propio ámbito de estudio, sobradamente necesitado de iniciativas que contribuyan a divulgar, primero y a conservar un patrimonio excepcional, y que en consecuencia, incidan en la deprimida economía de la zona.

Estos objetivos llevan a un grupo de profesores y alumnos de la Escuela Universitaria de Arquitectura Técnica de la Universidad de Granada, a organizar y participar en un Taller con doble enfoque; por un lado, experimentar otras estrategias pedagógicas, -diferentes caminos hacia la formación integral de los estudiantes-, incidiendo en la actitud para la comprensión y el respeto de una cultura "ajena" a través del conocimiento que se obtiene del contacto directo con ella.

Por otra parte, indagar acerca de la oportunidad de abrir y desarrollar nuevas vías para la investigación, sobre la base de la cooperación universitaria, y desde la perspectiva de la salvaguarda de una arquitectura y tecnología tradicionales, de alto valor patrimonial pero también muy frágiles, de modo que los trabajos a realizar a partir del Taller den lugar a iniciativas que contribuyan a un cierto desarrollo sostenible en un área geográfica de recursos limitados y fuertemente condicionados al ciclo del agua.

Asimismo se pretende iniciar un camino de colaboración en esta materia con entidades públicas locales como la Universidad de Marrakech, la Oficina del Inspector de Monumentos de esta misma ciudad y el CERKAS (Centre de Restauration et de Réhabilitation des zones atlasiques et Sub-atlasiques) en Ouarzazate.

1.2 *Situación*

Los talleres tuvieron lugar durante los días 22, 23 y 24 del mes de septiembre de 2010, en el Ksar de Tamnougalt, que se encuentra situado en el valle del Drâa, al sur del Gran Atlas Marroquí, entre los macizos del Antiatlas y Yebel Saghro, a unos pocos kilómetros del desierto del Sahara.

Entre las montañas y el desierto queda una franja de terreno llamado presahariano, atravesada, entre otros, por el río Drâa, que se nutre de las aguas procedentes de las montañas.

2 TALLERES EXPERIMENTALES DE LA ARQUITECTURA DE TIERRA

2.1 *Preparación*

Al ser el objeto del Taller un campo de conocimiento muy específicos o cuando menos nuevo para la mayoría de los participantes, se considera necesaria una cierta preparación previa a su realización. Se comienza con la recopilación y distribución entre los participantes de información y documentación básica sobre el tema y la zona, con búsqueda bibliográfica en distintos fondos bibliotecarios, o a través de Internet. Asimismo, se contacta con el asesoramiento de personas expertas, tanto en el país de destino, como en la Arquitectura de tierra y su Tecnología.

2.2 *Talleres*

2.2.1 *Taller de tapia*

Este taller conlleva la intervención directa en la construcción del muro o tapia, esencia de la arquitectura de tierra, participando, bajo la dirección y supervisión de los alarifes locales, en la preparación previa de la tapiada o unidad de trabajo, colaborando en el amasado de la tierra y el agua, en su transporte hasta la tapiada, y finalmente en el apisonado. El aprendizaje de la técnica del amasado y el apisonado se complementa con la preparación previa y el avance del encofrado de la tapiada.

La tapia se suele construir sobre un zócalo de otra fábrica, que le protege de la humedad, generalmente de mampostería. Sobre este zócalo se montan los moldes (tabiyyas o tapiales), siendo la separación entre los tableros el espesor que va a tener el muro.

Además los listones de la base que unen los tableros verticales, son cubiertos con piedras sin dejar que la tierra los oprima y una vez terminada la ejecución del cajón de tapial, se puedan retirar con facilidad.

Los encofrados de madera que se utilizan en esta zona son de 0.50 × 1.70 × 0.70 m y en ellos se vierte la tierra por tongadas de unos 10 cm. y se compacta con un pisón de mano. La tierra tiene que estar húmeda, sin llegar a ser barro y limpia de piedras excesivamente grandes, solo la gravilla.

2.2.2 *Taller de forjados*

Se participo en la preparación completa de la estructura del suelo, desde la elección del árbol en el palmeral para la elaboración de las viguetas, hasta la elaboración de las bases de cañas que reciben los suelos de tierra apisonada.

El cañizo es un conjunto de cañas dispuestas paralelamente y amarradas entre sí formando una estructura plana y rígida. Se utiliza como parte de la composición de los forjados de las edificaciones de Tamnougalt.

El uso de la caña es apropiado pues resulta ser un material longevo, resistente a la humedad y con una estructura de fibras largas y laminadas que trabajan bien la flexión dentro de los límites de coherencia que el material puede llegar a tener.

Para la construcción del cañizo las cañas se disponen en paralelo y mediante una hilera de nudos en perpendicular cada 50 cm aproximadamente se van anudando simultáneamente hasta conformar la estructura plana final.

2.2.3 *Taller de revestimientos*

Este taller tal vez era, a priori, el menos interesante por la simplicidad de las operaciones y de la técnica a utilizar, pero al final fue el que más reminiscencias de carácter lúdico pudo despertar en los participantes.

El revoco está compuesto por arena, paja triturada y agua (2 de arena, 1 de agua y 1 de paja). Siendo éste de una consistencia plástica con el que

Figura 1. Apisonado de tierra.

Figura 2. Ejecución del cañizo.

se revisten paredes. Este revestimiento es ideal para encalados a posteriori.

El revestimiento que se aplica una vez hechos los muros de tapial se realiza mediante esta el revoco.

Además de revestimiento, la tierra del revoco sirve para la fabricación del ladrillo de adobe. Estos ladrillos se utilizan para la continuación de muros donde el tapial resulta muy difícil de ejecutar o para aligerar el muro en los puntos más altos donde la carga es mucho menor.

Figura 3. Ejecución de revoco.

Figura 4. Haciendo adobes.

Para obtener la forma de prisma rectangular se utilizaron moldes de madera de $10 \times 11.5 \times 30$ cm que se rellenan y se dejan secar.

3 TOMA DE DATOS Y LEVANTAMIENTO DE LA GRAN KASBAH

Se seleccionó una serie de Qasba u otros edificios que respondían a diferentes tipologías, accesibles y, a ser posible, sin un elevado grado de deterioro. Asimismo se levantó la estructura urbana de la fortaleza, distinguiendo la topografía de los distintos barrios. Ya sobre el terreno se opto también por comprobar el grado de deterioro causado por el agua en los elementos más sobresalientes de esta frágil arquitectura.

El trabajo se centró en una de las edificaciones más importantes de la aldea, a la que se tenía acceso por una impresionante portada, la cuál era su única fachada exterior, puesto que el resto eran medianerías. La vivienda se distribuye en torno a cuatro patios y tiene 2 plantas de altura casi en su totalidad.

Debido a las grandes dimensiones de la Gran Qasba tuvimos que dividirnos en varios grupos de trabajo, dentro de los cuales había personas dedicadas a croquizar las plantas y los detalles de fachadas y puertas, a la toma de medidas con cinta métrica y láser y a la realización del reportaje fotográfico necesario para los trabajos posteriores.

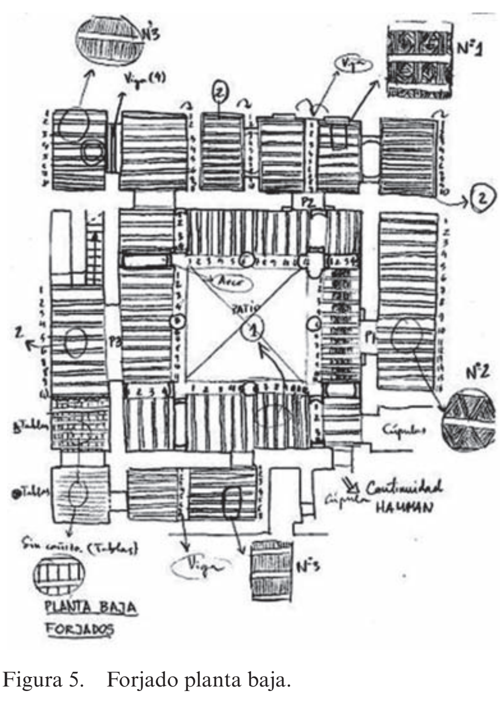

Figura 5. Forjado planta baja.

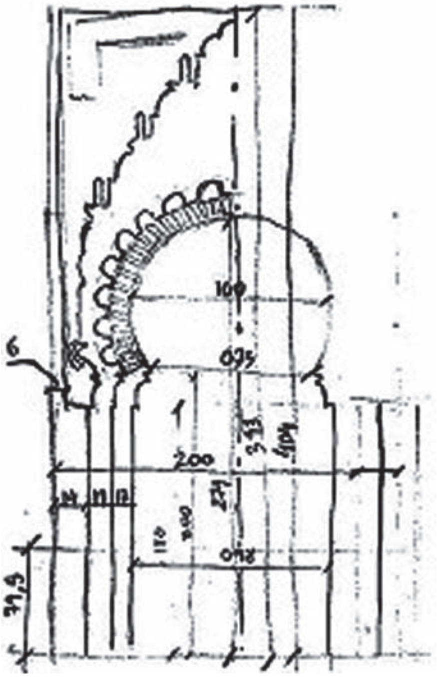

Figura 6. Croquis arco principal.

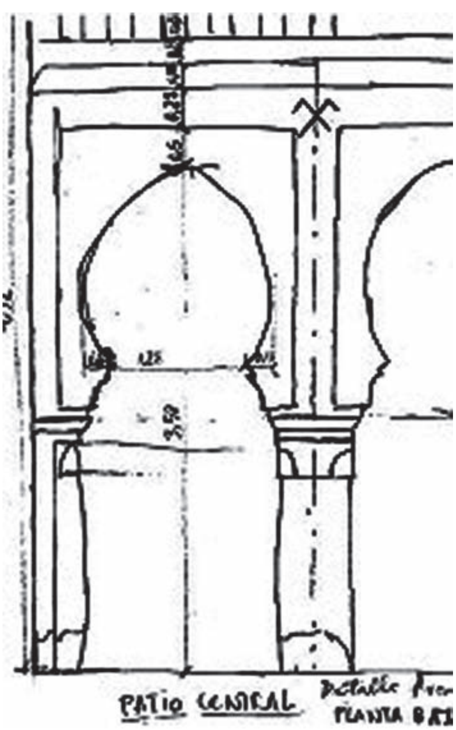

Figura 7. Croquis arco patio central.

4 OBJETIVOS Y LOGROS PEDAGÓGICOS DEL PROYECTO

La realización de un proyecto de tal envergadura no se puede decidir banalmente, sino que se busca que el entorno, el itinerario, las actividades planteadas, etc. puedan transmitir y sean capaces de enseñar algo interesante, a título tanto personal como colectivo. En este, en particular, el interés de los participantes y organizadores en los temas de construcción tradicional y ecológica es más que manifiesto. Algunos de los objetivos principales que se perseguían con la realización del proyecto son los siguientes:

– Acercamiento progresivo a la cultura, el ambiente, y la vida social de Marruecos: para ello el viaje no se planteó de forma directa origen-destino, sino que se planificó un viaje en autobús desde Granada hasta el destino principal en Tamnougalt (Agdz). De este modo el impacto por las diferencias culturales entre nuestro país y el país vecino se disminuyó, pues el norte de Marruecos es bastante parecido a algunas zonas de España, y la inmersión en el Marruecos profundo se hizo de forma progresiva.
– Aprendizaje y estudio de las tipologías constructivas empleadas tradicionalmente en la zona: con tal fin se llevaron a cabo una serie de tres talleres como reflejo de los principales elementos de los edificios. Todos los alumnos participaron en todos los talleres de forma directa, siendo los encargados de elaborar cada elemento, y aprendiendo de forma empírica los pasos a seguir en cada caso.
– Comprensión de los sistemas de regadío y aprovechamiento del agua en la zona: en casi todo Marruecos el agua es un bien escaso, pero en la zona sur, próxima al Sahara, lo es aún más. Partiendo de esa idea, era interesante ver de que forma se distribuye el agua para los regadíos en la zona del palmeral y comprender la importancia que el líquido elemento tiene en el desarrollo de la vida cotidiana en la zona. Para ello se realizó una visita guiada a las huertas del palmeral más cercanas a Tamnougalt, en la que un habitante de la aldea fue explicando el sistema de acequias y la distribución de estas a través del entramado de huertos privados, todos ellos cercados por sendos muros de tapial.
– Realización sobre el terreno del levantamiento de una de las Qasbas del poblado de Tamnougalt: esta fue una de las actividades más interesantes, ya que nos ponía a todos en una situación real de trabajo como técnicos.
– Trazado y ejecución de un proyecto de rehabilitación para el edificio: una vez de vuelta se procede a la ejecución de un proyecto de reha-

bilitación del edificio sobre el que se trabajó en Tamnougalt. Con ese objeto, los datos tomados en campo se informatizan con la ayuda de diferentes soportes informáticos, como por ejemplo programas de CAD, y se lleva a cabo el trabajo de gabinete necesario.

Además de todo lo enumerado anteriormente, otro logro implícito en el viaje fue el aprender a utilizar los recursos de los que se dispone en el lugar para el desarrollo de las comunidades, en todos los ámbitos. En el de la arquitectura y construcción de edificios, el uso de la propia tierra en la construcción de los muros, y los troncos de palmera y las cañas, obtenidos ambos del cercano palmeral para los techos.

El viaje y las actividades realizadas durante él nos sirvieron a todos como experiencia y para enriquecernos tanto en el ámbito técnico y pedagógico, como en el ámbito personal. El hecho de que resultase tan productivo fue gracias al modo de enseñanza y aprendizaje, que se basó en la elaboración "por uno mismo" de las cosas, para retenerlas en la memoria y comprenderlas a fondo, pues no hay mejor forma de aprender que por la propia experiencia.

5 CONCLUSIONES

Entendemos cubiertos los objetivos propuestos en el taller, y por otra parte se quiere indagar acerca de la oportunidad de abrir y desarrollar nuevas vías para la investigación, sobre la base de la cooperación universitaria, y desde la perspectiva de la salvaguarda de una arquitectura y tecnología tradicionales, de alto valor patrimonial pero también muy frágiles, de modo que los trabajos a realizar a partir del Taller pudieran dar lugar a iniciativas que contribuyeran a un cierto desarrollo sostenible en un área geográfica de recursos limitados y fuertemente condicionados al ciclo del agua.

NOTA

Los autores de las imágenes y croquis que aparecen son los participantes en el workshop.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)
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Infomes de la Construcción, Nº 523 Monograph *Earth as building material*, a contemporary approach

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ABSTRACT: This paper presents a reflection on the contents of the monograph *Earth as building material* (La tierra, material de construcción) for the volume 63, number 523 of the Informes de la Construcción reports, published in July 2011 by the Instituto Eduardo Torroja de Ciencias de la Construcción IETcc—CSIC. This document contains current news about earth architecture, incorporating technological innovations into the sector, the latest research in universities in several countries and the major referral centers in the study of this field. The publication has been coordinated in the Polytechnic University of Catalonia by the authors of this communication.

1 INTRODUCTION

In January 1986 the Instituto de Ciencias de la Construcción Eduardo Torroja published the monograph *Earth as building material* in the volume 37, number 377 of the Infomes de la Construcción journal. This first monograph on earth building, coordinated by Dr. Engineer Julian Serrano Salas, wondered whether it was possible to build with earth. Building with earth? Earth as a building material? Earth as a subject of investigation?

That document brought back the memory of the past to open the future's doors, being in advance of one's time in criteria of sustainability and social environment that we consider absolute nowadays. This document submitted scientific and technical analytical treports on earth as a building material. It also brought pilot projects forward like Le Domaine de la Terre, a colletion of experimental social housing built in Isle d'Abeau, near Lyon (France). Earth had a future.

Years have passed, and earth is already part of the present. That is why the Informes de la Construcción scientific journal, and specially on its director Ignacio Oteiza's initiative, it is promoted a new monograph journal to reflect the progress and experiences that occurred worldwide in the use of the earth as a building material. It is thanks to this impulse that we can consult this monograph on the link:

http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion.

This paper analyzes the document here referenced. The foreword by Dr. Engineer Julian Salas connects the previous with the present monograph, contextualizing the *earth* core values to achieve true development of all peoples.

2 PURPOSE OF THE COMMUNICATION

Firstly, this paper's aim is to present the art's state relative to raw earth as a building material and its presence in contemporary architecture. That's why the criteria used in authors selection are described, as well as the contents of the several articles published in the Informes de la Construcción Monograph number 523 are analyzed. The intention is to draw conclusions added to the conclusions of each of the authors involved in the publication.

3 STATE OF THE ART

Since the monograph's coordination, the will has been to provide a tool to promote the use of earth as a building material among architectural professionals. For this purpose an international vision covering all continents has been sought with emphasis on the deep knowledge of the last building and laboratory experiences. So it has been prioritized those articles that incorporate referenced technical information enabling to understand the behavior differences between the different techniques as well as their specific potential.

In order to complete the pragmatic willingness of the edited document, it has some end attachments incorporating an important amount of world research centers. It is also of particular importance the listing of construction companies experienced in earthen built projects implementation, as well their contact data.

Following up on the above outlined criteria, the published information is meant to be a living document where new research centers and new construction companies can be incorporated to create a database providing work to those developers, technicians and builders willing to incorporate the earth into their projects with the greatest knowledge and rigor.

In order to define the script content of the journal, a desk research was executed prior to selecting the authors and articles. This process consisted of identifying those national and international entities working with earth as a material, from colleges or universities to architects that nowadays are using it in their projects.

The journal index is divided into 5 thematic areas:

- New earthen built buildings.
- Restoration of earthen constructed buildings.
- Characterization by laboratory tests.
- Claddings.
- Regulations currently in force in different countries.

We found it important to add a technical note (1) to the proposed index, in order to take stock of CRATerre's experience on the eighties social housing project at Domaine de la Terre, Isle d'Abeau. This paper links directly to the 1986 earth monograph and let us evaluate its behaviour in this time period.

From the editorial board of Informes de la Construcción scientific journal it is also been done an editing effort to include as many authors as possible. While a conventional number of Informes de la Construcción consists of 8 articles, 16 articles have been included in the earth monograph, 7 of whom are written by Spanish authors and the rest by European, Latin American and Australian authors, fulfilling one of the initial intentions which was to gather international news about the earth as a material.

Despite this editing effort, we are aware that the published articles represent a small list of all of the people currently working on the earthen construction study. That is why we want to acknowledge and encourage them to publish their work in future issues of the Informes de la Construcción journal, as a mechanism to regularly update the knowledge around the earthen building.

4 CONSTRUCTION TECHNIQUES AND CONTEMPORARY EXAMPLES OF EARTH BUILDING

The articles focused on reporting recent experiences in the earthen building field, show favorable future prospects.

Overall, 71 current earthen buildings are mentioned, as a representative sample of the countless contemporary cases. 48 of the mentioned buildings provide examples of new work. 69% of new constructed buildings outlined in the monograph are located outside the Spanish territory (Fig. 1).

These examples are mainly cited in the two items heading the publication. The first article (2), by the authors of this paper, has been looking at the international scope and at the experiences of recent years, including examples of both high and other not so high-tech societies. The second article (3), by Fermín Font and Pere Hidalgo, extensive experienced authors both in construction and publication, focuses on the examples that can be found on Spanish territory in recent years.

Efforts have been made in order to show in the examples that different techniques may include various uses buildings, pushing away the idea of material solely linked to the single-family home. That is why we found that 50% of new buildings appearing in the monograph refer to public facilities. Most of these public buildings presented in the monograph have achieved numerous national and international awards.

The construction techniques here presented collect those most common practices in the areas under study. We recognize the existence of many more projects, especially of housing in Latin America and Africa, as well as the use of other techniques and practices which must be taken into account in future works.

In new building, the monograph presents 26 rammed earth works, which represent 54% of the explained cases (Fig. 2). This technique, either

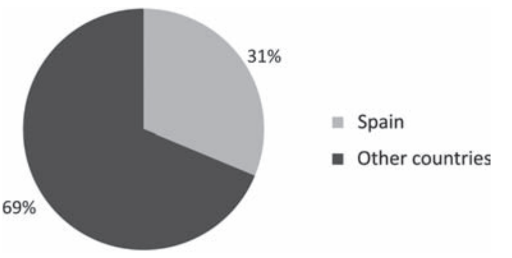

Figure 1. Percentage of new constructed buildings appearing in the IC 523 Earth as a building material. Case by location. Source: Own elaboration.

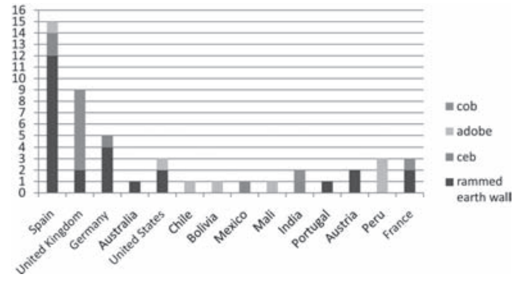

Figure 2. Number of new constructed buildings appearing in the IC 523 Case according to location and technique. Source: Own elaboration.

for its certain similarities with concrete or for its industrialization potential, as well as for its aesthetic value, is achieving reliability for technicians worldwide. It is demonstrated in the proliferation of new rammed earth buildings, both housing and public facilities.

Rammed earth's modernization can be appreciated not just at a technical but also at an aesthetic and formal level (Figs. 3 and 4). Most of these innovations arise from Lehm Ton Erde study, led by Martin Rauch in Austria. At a formal and aesthetic level, many different realizations can be found, such as sloped elements, large openings, large clear height walls and curved lines, among others.

Since its inception, innovation focuses towards stabilization and compression with mechanical means. Aesthetically, the most widespreaded has been the addition of colored earth that provides a huge tectonic strength vibration. Technically, their latest researches on prefabricated rammed earth wall panels (4), represent an approach to this technique's industrialization, although low demand does not yet guarantee economic viability out of the Austrian territory (Figs. 5 and 6).

Similar percentages ranging 10 to 20% are represented in the monograph examples of buildings made of cob, adobe and compressed earth block (Figs. 7 and 8).

The adobe buildings' update, from a technical point of view, has been first of all to achieve improved buildings stability against horizontal forces in seismic risk areas (Figs. 9 and 10). Parallel experiences by Marcial Blondet (5) and his team at the Pontificia Universidad Católica, and Raquel Barrionuevo (6) and his team at the Universidad Nacional de Ingeniería, both in Peru, reflect vertical structure and decks progress, considering a minimum economic cost need.

Regarding the cob technique, new works by Linda Watson and Kevin McCabe (7) from the University of Plymouth, United Kingdom, and the cooperation experiences in India by the Linz

Figures 3 and 4. (Left) National Wine Centre, Adelaide, Australia. Source: University of Adelaid. (Right) Sublette County Library, Pinedale, Wyoming. EEUU. Source: Carney Architects.

Figures 5 and 6. Prefabricated rammed earth building wall. Printing Gugler. Melk, Austria. Source: Martin Rauch.

Figures 7 and 8. (Left) Bodega Los Robles, San Fernando, Chile. Source: José Cruz Ovalle. Sandra Bestraten and Emilio Hormias USF. (Right) Universidad Indígena de la Chiquitanía, Bolivia. Source: Sandra Bestraten and Emilio Hormias USF.

Figures 9 and 10. Reinforced module for seismic simulation tests. Lima, Peru. Source: Marcial Blondet. Domocaña ceiling on Housing in Humay, Peru. Source: Raquel Barrionuevo.

University of Art, Austria (Figs. 11 and 12) invites to experiment with this technique's plasticity to create buildings with organic shapes which combine tradition and future.

Figures 11 and 12. Eden Project Service Pavillion, Cornwall, United Kingdom. Source: Abey Smallcombe. Handmade School in Rudrapur, India. Source: BASE-habitat.

Figures 13 and 14. Care Center for Blind People, México city, México. Source: Mauricio Rocha. Deep-anam School multipurpose room, Auroville, India. Source: Auroville Earth Institute.

In the case of compressed earth blocks (Figs. 13 and 14), thanks to the easiness of its industrialization, the greatest progress is found in the worldwide big amount of regulations, as reflected in Jaime Cid and his team's article (8) at the Universidad Politécnica de Madrid, related to these blocks' specifications, explaining their geometrical, dimensional and composition features.

Since it is a masonry material, the compressed earth block also permits its usage in roofs. We take Auroville's impressive dome as example, executed by Auroville Earth Institute, a reference center in performing this technique in India since 1989.

5 RESTORATION, CRITERIA AND INTERVENTION TECHNIQUES

In order to approach the present intervention techniques on the earthen built architectural heritage, Luis Maldonado and Fernando Vela-Cossio, from the Universidad Politécnica de Madrid, introduce us to the existing historiography as a first step for valuing the distinctive conservation and restoration features of the earthen architecture (9).

Even though the journal has an international will, 74% of cases shown in the articles expounded in this section are in Spain. From the Universidad Politécnica de Valencia, Camilla Mileto and Fernando Vegas stress the study on criteria and intervention techniques (10), with not only technical but also integration solutions of the monument action itself (Figs. 15 and 16).

Figures 15 and 16. Restoration of the Nogalte castle. Murcia, Spain. Source: J.M. López Osorio. Restoration of the Bofilla tower in Bétera. Valencia, Spain. Source: Mileto & Vegas.

The third article in this block refers to a methodology for the injuries analysis as well as to intervention recommendations on the earthen built heritage. Miguel Angel Rodriguez's team, from the Universidad de Oviedo, contributes to the specific knowledge of the lesions identification in earthen buildings from Havana's historic city centre (11), in order to get an optimal intervention based on the characterized pathology.

6 CHARACTERIZATION OF BUILDINGS THROUGH TESTS

The importance of characterization in earthen building techniques tests lies in the need to check traditional knowledge opposite to the scientific community, to provide data that may come to certify the materials properties and thus, to gain technicians and professionals' confidence. In turn, it enables to progress in the introduction of composition innovations of materials which may mean a technical optimization.

In scientific research field, three articles dealing with complementary subject areas are presented.

The first article refers to the connection between the drying process and the rammed earth walls' resistance acquisition. From the Bauhaus University in Weimar, Germany, Horst Schroeder discusses the importance of initial moisture content of different test-tube tested as well as the disparity in results according to the mixtures composition, underlining the heterogeneity of earth as a building material. The article obtains, among other conclusions, that in the rammed earth wall case, the characteristic strength is obtained after 90 days of drying time, unlike the 28 days need for concrete (12).

The rammed earth walls' thermal behavior is the subject under study in the second article of this block. We find this matter to be particularly relevant, as the Spanish Building Technical Code requires, on the energy efficiency provisions, very difficult to fulfill thermal transfer values for vertical surfaces without adding specific insulation layers to earthen walls.

From the University of Technology in Sydney, Australia, Kevin Heathcote analyzes the different procedures that affect the indoor comfort. He is also very critical on the thermal values of the earthen buildings. He concludes that a good passive design together with the benefits of thermal inertia can compensate the lack of thermal insulation, as they achieve better comfort conditions in summer than those of conventional buildings (13). Still, he recognizes the deficiencies of thermal transmittance level as a disadvantage during winter.

Finally, concerning the mechanical characterization of adobe buildings, we find a new study by Humberto Varum team, at the Universidade of Aveiro, Portugal, offering an analysis methodology for obtaining mechanical characteristic values in a very rigorous way (14). Furthermore, this study also complements the seismic investigations in Europe.

7 CLADDING TECHNIQUES

The most significant new features included in the monograph within the scope of consolidation and cladding of earth walls consist of the description of Francisco Javier Castilla, from the Universidad deCastilla la Mancha, about the proliferation of new industrial products for protection against erosive agents (15). The author focuses on the importance of the fact that these new products are based on the criteria of compatibility with the support and breathability.

We must also mention the contribution of one of the most prestigious authors in the field of earth construction. Gernot Minke, from the Universität Kassel, Germany. He presents one of his latest researchs, in this case, about loam plasters (16) where he analyzes the critical properties for choosing an earth coating: abrasion, erosion and moisture absorption. He also corroborates, in a study of more than 30 samples with different compositions, that plasters with straw particles show minimal shrinkage and abrasion, as well as the fact that linseed oil is as effective as lime or cement to protect against rain erosion.

8 RESEARCH INSTITUTIONS, FORMATION AND CONSTRUCTION AROUND THE EARTHEN ARCHITECTURE

Aiming to bring technical expertise to all professionals interested in building with earth, it was decided to incorporate a list that includes 148 associations, institutions and formation centers on the subject, 73 of them in Europe.

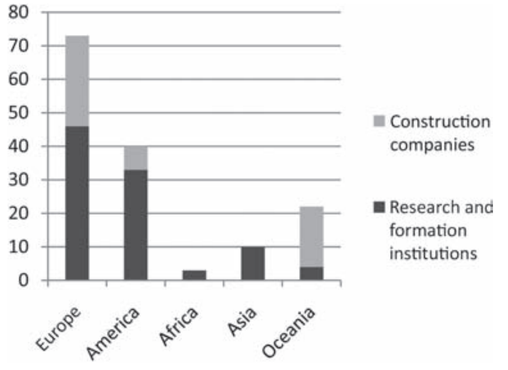

Figure 17. Number of construction companies and research and formation institutions listed in the monograph IC 523 by location. Source: Own elaboration.

Oceania is a clear example of the growth of contemporary earth building. It has 18 firms specialized in rammed earth construction, associated in 3 professional institutions. They are one of the emerging organized groups on the subject of earth construction.

This list, although probably several not detected groups and companies are still missing to incorporate, serves to raise awareness of the state of the art and especially establish links between practitioners and agencies experienced in this field. As a matter of proximity, this search has focused on our territory (Fig. 17).

In America, Africa and Asia we are aware of the existence of companies with experience in earth construction, but they generally belong to the informal sector, which makes it difficult to be included in this publication.

9 CONCLUSIONS

After the analysis of the published articles in the volume 63 number 523 of Informes de la Construcción, monograph "La tierra, material de construction", the first conclusion we observe is that the generous amount of buildings found show expressive freedom, like current architectural compositions, beyond the vernacular mimesis. This fact alone demonstrates the technical but also aesthetic solvency of *earth* as a building material in the first decade of the 21st century.

There has been a great progress since that first monograph we mentioned in the introduction. The information provided in this new monograph is a reference to the possibilities offered by these techniques nowadays.

This resurgence as a material is not located in a particular geographical area, and we note that its use is in a clear expansion in developed countries, driven by the need to seek for alternatives that allow us an approach to a really sustainable architecture. From this point of view, the earth can give us some answers. This fact can promote the recovery of the constructive identity in developing countries, so influenced by what happens in technically advanced countries.

Although some standard processes have been consolidated, these are almost exclusively for the CEB compressed earth block. We must continue working to achieve the regulation of other techniques currently in use. It is basic to carry out research to establish protocols for execution work control and quality control of the resulting material, made on site or prefabricated.

In the restoration case, it is common to find earth material in the interventions. It is therefore essential to establish criteria for analysis, expertise and intervention. It would be interesting to incorporate tools for mechanical characterization through non-destructive testing, similar to those used in the analysis of other materials such as concrete or wood. Whether for determining the strength of masonry in a patrimonial building to restore, as in a new rammed earth wall, this characterization would improve intervention decisions and ensure the quality of the performed work.

It is necessary to examine the feasibility of industrial production to help improve product quality and reduce implementation costs.

It is required to quantify the contribution of earth building techniques in sustainable building, from CO^2 emissions during the performance or the lack of pollutants, to their unexplored virtues like thermal inertia.

The continuity in the ongoing process of constructive and material innovation, will help finding solutions that are close to the living and environmental needs of the human habitat. Many of these conclusions are shared by the published articles in the monograph *Earth as a building material.* That is why as a final conclusion we want to encourage all those who look at the earth as a material for the future, to continue the research from universities and research centers, and expand the horizons of knowledge about building with earth by presenting their results in the open scientific and technical knowledge media in this field, such as the *Informes de la Construcción* scientific journal.

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The first Italian experience of industrialized earthen products for the building trade

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ABSTRACT: In the last years, the green building techniques and the new rules about saving energy have strongly influenced the market, supplying products specifically designed to this aspect. In this scenario earthen architecture too seems to have been crucially rediscovered. On this basis and in accordance to a particular market area (the green architecture one), it seemed the right moment to reintroduce earthen products (and its derivatives) into the contemporary economic cycle. This was the starting point of the innovative experience carried out by Fornace Brioni in Gonzaga (Mantua, Italy). Through a collaborative partnership, this kiln has developed specific adobe and unfired clay products (extruded bricks, mortar, plasters and paintings). The main innovation has concerned the testing and controls carried out to define the core products and to guarantee their quality, according to the ecological and biocompatible rules, including the adobe life cycle.

1 INTRODUCTION

Over the last few years, building has increased dramatically and is, a factor which is seriously affecting the general pollution of the atmosphere: 1/3 of the CO_2 emissions of these last 50–60 years can be attributed to bad building management. (Bollini 2006a).

At the present time, 50% of the total global consumption of natural resources can be ascribed to the building process; in addition, it accounts for 40% of electricity consumption and 16% of water consumption (Bollini, 2006). The reasons for this are to be found in the current way of considering the building process as an open linear system in which resources are used extensively for building but the waste material generated rarely becomes a recyclable new source.

Given this scenario, the biggest expense in the energy budget is still building management in particular winter heating and summer cooling: if building a flat on average implies an energy cost of 5/6 toe, with heating 1 toe/year, over a 50 year period of time, a building that takes 5/6 toe to put up costs 50 just to heat in winter, 10 fold higher than its basic cost. (Bollini 2011b).

So it is important to point out that this *modus operandi* most of all involves a waste of *energy*; in other words, we waste and inefficiently use the intrinsic quality of the energy sources of the planet (especially non-renewable ones). The most striking paradigm is the use of oil (or electricity) to keep an indoor environment at 20°C in winter and 26°–27°C in summer.

Recently there has been a growing sense of awareness of this dramatic situation, an awareness which is increasingly involving the building process. Given the current state of affairs, the reintegration of an ancient material, such as earth, represents a new beginning in the technological innovation and development of products in the sphere of green architecture. However, in order for this type of building to become popular, there has to be a set of regulations in place.

This is what a small Italian brick–kiln company (Fornace Brioni from Gonzaga, Mantua) has been doing since 2005, manufacturing and producing earthen bricks (adobes), mortar and plastering on a large scale. The company's core business is terracotta floor tiles, made by soft paste molding. The term *soft paste* refers to a brick-kiln production line that provides a soft clayey mix to mould both by hand and mechanically falling into molds. This facilitates and boosts business expansion into a wide range of very low cost earthen products, offering great variety and access to a new niche in the marketplace. The author of this article has been involved in this project as a consultant and principal scientific advisor.

Since 2011 the specific earth brand has been Since 2011 the specific earth brand is referred to "matteobrioni srl" (www.matteobrioni.it or www.interra.it) as specific business unit of Fornace Brioni, exclusively engaged in the production of earthen elements.

2 THE OBJECTIVE OF THE RESEARCH AND DEVELOPMENT PROJECT

The aim of the study was to analyze a wide range of clay-based building products in order to minimize the environmental impact during manufacturing and to improve their performance quality so that they can be used in the energy re-qualification process, indoor rehabilitation and new building (green building/architecture).

The first questions were: what kind of earthen bricks would be better to produce? For what kind of use? And moreover, does it make to propose a new load-bearing earthen brick in Italy nowadays? Although there's an interesting earthen heritage in Italy, the earth isn't a recognized building material. People don't know it and have all the typical prejudice against the use of earth in (new) buildings.

Professionals don't trust it, while craftsmen are not able to use it. So, which is the best criterion to propose industrialized earthen products and make them accepted by people?

The idea was to focus on the specific characteristics and performance of earth as a green building material.

The specific relevance of the clay-based products in energy redevelopment lies in the versatile potential of earth to become a fundamental, basic element for indoor micro environmental regulation; this can be done both by the handling of thermal flow (we note that the earthen elements mainly work in terms of heat accumulation, rather than insulation) or of moisture flow. Normally the construction of highly energy-efficient enclosures implies the need to adjust the humidity; this is usually carried out by a specific installation.

The final goal, therefore, was to create a product range suitable for use, together or independently, in plug and partition facilities, indoor protective covering, wood ceilings, attics and storage heaters.

Load bearing performance has been omitted as the Italian building code makes it too difficult to use; testing the mechanical performance (compression and bending) was carried out simply in order to make a further check on the material and guarantee its movement without risk of breakage.

3 DEFINITION OF MIXTURES AND THE PHYSICAL-MECHANICAL CHARACTERISATION

The first step was to define the right mix for the adobe. The inputs were the different uses for which it was designed: thermal and acoustic mass, thermal insulation (partially) and inside moisture regulation. The different components to analyse were: earth, vegetable fibres and sometimes sand.

The brick samples were hand-made using a small kneading machine to prepare the mix (Fig. 1); 4 different kinds of fibres (straw, rice hull, wood powder and kenaf husks), added in 7 different percentages (from 20% to 80% in volume) were tested.

The silty-clayey earth did not require the further addition of sand; in each sample the physiological shrinkage occurred without cracks. The second step was the evaluation and quality comparison of the different samples using a specific testing protocol.

This protocol is the result of previous experience gained during the restoration of an earthen quarter in the Marche Region where the setting up a load bearing adobe production highlighted the need for such a protocol for the acceptance and quality control of the adobes produced, this was necessary due to the absence of regulations governing earth building in Italy. (For further details please see Bollini, G. 2007a and Conti, A.P. 2007. Villa Ficana in Macerata: the restoration of a raw earth quarter. In Q. Wilson (ed), *Proceedings of 4th Adobe Conference of the Adobe Association of the South-west: AdobeUSA 2007, May 18–21 El Rito NM*: 98–104. El Rito: El Rito Northern College Ed.).

The normative references that were analysed, compared and used in this first checking phase of testing at the brick-kiln company were Standards New Zealand, New Mexico Adobe and Rammed earth Building Code, and Standards CRATerre. The testing protocol provides as follows:

Dimensional characterization and acceptance: view and tactile analysis (Standard CRATerre); size and shrinkage evaluation (New Mexico Adobe and

Figure 1. The kneading machine used to prepare the first hand-made samples (photo: G. Bollini).

Rammed earth Building Code 1991); medium dry weight and density; modulus of rupture test and determination of compressive strength (Fig. 2), drop, impact and penetration tests (Standard CRATerre and Standard New Zealand—Committee BD/83: DZ 4298 *Materials and workmanship for earth buildings)*.

Performance characterization: erosion, abrasion (Fig. 3) and water absorption (partial dipping, Fig. 4) (Standard CRATerre, Standard CRATerre—*Blocs de terre comprimée: normes,* New Zealand—Committee BD/83: DZ 4298 *Materials and workmanship for earth buildings*).

This first part of experimentation allowed us to select the best vegetable fibre for the mix (in terms of type, percentage and length) and also the type of earth. The evaluation criterion was not the mechanical strength of the adobe samples, which is often (and wrongly) the main performance requested for an unfired clay brick, but its overall durability and its real behaviour in use. These analyses led us to define 3 kinds of bricks which have the same fibre added, but in 3 different percentages.

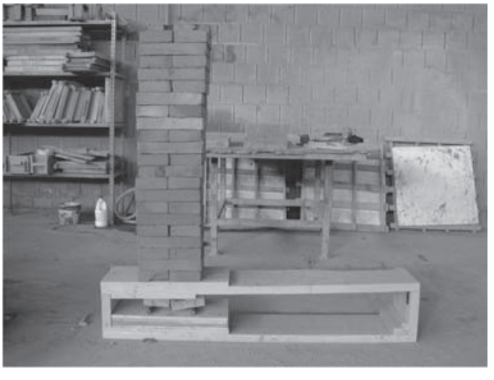

Figure 2. Modulus of rupture test (photo: G. Bollini).

Figure 3. Abrasion test (photo: G. Bollini).

Figure 4. Water absorption test.

Figure 5. The industrialized adobe production line (photo: M. Brioni).

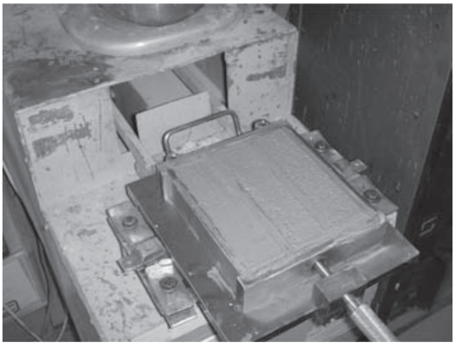

Figure 6. Mortar tests at LTM (photo: G. Bollini).

The next stage was to verify the actual possibility of production on an industrial scale, employing the firm's standard kiln production line (obviously stopping before the furnace stage) (Fig. 5). To be sure of the results, the 3 kinds of brick (now industrially made) were tested again, employing

Table 1. Bricks moisture absorption.

	Bricks moisture absorption W% (average value after 45 days; % of dry weight)		
U_w increase	Heavy (1450 kg/m^3)	Medium (1200 kg/m^3)	Light (800 kg/m^3)
45% to 55%	7.8%	8.9%	10.8%
Over 90%	32.5%	33.8%	54.4%

the afore-mentioned testing protocol; the goal was to verify possible differences and inconsistencies between the hand-made adobes and those made industrially. Once this point was reached, it was essential to be able to provide all the performances that are standard in the technical folder of (green) building materials: thermal conductivity, specific heat, acoustic performance, permeability, absorption and regulation of humidity, absence of radioactivity, as well as a minimum mechanical performance. The problem is that to determine all the foregoing data there is a normative apparatus that could not always be applied uncritically to earth.

Finding an accredited material testing Lab that would agree to study with us and define an adobe testing protocol to provide and certify the physical and mechanical performance of the adobes was not very simple; these scientific facilities often do not have the required elasticity to deal with earth building. As they have to abide by a codified and recognised testing method, they usually follow specific *Product Standards*, but nothing exists on the subject for earthen materials (in Italy).

An option, in the adobe case, is to refer to what is prescribed for fired clay bricks, even if some tests risk leading to erroneous or superficial verdicts, because they are incompatible with the characteristics of earth as a building material (Bollini, 2008). Neither the development nor the definition of the testing protocol itself were easy; even in this case each normative reference was analysed, evaluated and, when necessary, calibrated *ad hoc*, so that it was both reliable and repeatable (Fig. 6).

After extensive research, the tests were carried out at the Laboratorio Tecnologico Mantovano—LTM (www.labtecman.com) (Mantuan Technological Lab), duly authorized pursuant to L. 1086/71. The testing protocol was drawn up based on the requirements of the (Italian) UNI EN 771-1 for (fired) brick (UNI 771-1:2005 Specifiche per elementi per muratura—Parte 1: Elementi per muratura di laterizio). In the case that a specific testing method was not convincing or suitable, equivalents were looked for in international earth building codes currently in force. The references were the New Mexico Building Code for Adobe 1982—New Mexico Adobe and Rammed earth Building Code 1991 and the German Lehmbau Regeln developed by Dachverband Lehm e.V. (www.dachverbandlehm.de).

When even these testing methods gave negative results, we studied ways in which "to force" the testing criteria to analyse the performance of the specific product correctly, a process which involved many attempts, retrials and methodological corrections.

One such example was the decision to omit the test for water absorption by imbibition as required by UNI 771-1 but to continue with the most significant test of absorption of atmospheric moisture, conducted in accordance with the internal procedure defined by LTM technical; this made it possible to see (Table 1) the quality of our earth bricks against high fluctuations of moisture in the long term.

4 RESULTS

The final outcome of nearly three years' work, which was extended to include earth mortar and plasters, was the input into the Italian marketplace (in 2008) of a clay-based range of products (named *Linea inTerra*™), industrially made with both technical and environmental as well as controlled and certified performances.

There are 3 types of adobes (30 × 15 × 5.5 cm), varying in density and thermal behavior (ρ 1450 Kg/m^3, λ 0.47 W/mK and μ 8; ρ 1200 Kg/m^3, λ 0.40 W/mK and μ 7; ρ 800 Kg/m^3, λ 0.18 W/mK and μ 5), earth mortar (ρ 1500 Kg/m^3, 1.57 N/mm^2 as compressive strength and 2,8% as shrinkage) and earth plasters (Fig. 7). The performance of all the in Terra™ products are downloadable from the website www.matteobrioni.it, *Products* section, along with building and item specifications.

The building solutions identified by the range of products are based on the coupling of different materials (such as timber, fired clay bricks, stone or concrete), designed and laid out so that each of them, within the walls, floor or roof stratigraphy, expresses the maximum of its inner peculiarities,

Figure 7. The inTerra™ range of products (folder).

with the earthen elements compensating for any performance gap. In this way earth too can play a significant and innovative role as regards the European Directive 2002/91 on EPB (Energy Performance in Buildings) requirements. This is also borne out by the recent LCA study.

5 LCA (LIFE CYCLE) ASSESSMENT

In order to truly offer a product with low environmental impact, we are currently engaged in the definition of Life Cycle Assessment (LCA) of the brick at higher density (1450 Kg/m^3). The study, conducted with the guidance of 2B Studio—Consulenza Ambientale (2B Environmental Consultancy: www.to-be.it.), aims to quantify through the LCA method the environmental impacts associated with the production and extraction of raw materials, the phases of packaging, use and end of life of the brick.

The boundaries of the system start with the supply of raw materials and their transport to the brick-kiln, continuing with the production and packaging phases, finally ending with the distribution of the product to customers and the end of life of earth bricks and the packaging itself. Given the inherent variability, the use of brick is excluded from the boundaries of the system. These boundaries specifically include supply of raw materials, transportation to the brick-kiln company, storage and handling of materials; pre-processing of mix; forming bricks, drying of the bricks; recovery of waste (green bricks, mix, sawdust and water), packaging, distribution to customers, brick and packaging end of life. The raw materials are: clay, vegetable fibre and water, with the clear predominance of the material earth (clay). The latter is supplied by the quarry located in the flood bed of the River Po. All materials are locally sourced, and the fibre is the result of a waste processing company located approx. 20 km from the factory. Water is drawn directly from the well, both the quantity necessary for the mix, and that used to wash the moulds, which is then recovered and reused.

The survey, conducted through a series of meetings and discussions aimed at collecting data for input, was developed by SimaPro7 software; the reference was the database Ecoinvent, when consistent. The outcome of the LCA evaluation was checked by ITC-CNR (Istituto Tecnico per le Costruzioni del Consiglio Nazionale delle Ricerche).

For earthen plasters the LCA was analysed by some students of the Polytechnic of Milan as a thesis degree (the tutor was arch. Sergio Sabbadini, BEST Department). The referring database was Ecoinvent the same.

Next steps in this field should be the application submission for the EPD trademark (Environmental Product Declaration) and LEED acknowledgement.

6 NEXT STEPS

Six years have passed since the start of this project and it is now beginning to see results.

The market is responding quite well; several interventions have been made including a public one, which is a school in Novi Ligure (AL), where the clay bricks were used as accumulation walls in the greenhouse. The structure is reinforced concrete) and is attracting growing interest around the project.

The 2012 goal is to further proceed with the performance control of the product, expanding the range of tests to be conducted. In some cases it will be an updating of past results, due to product improvements, in others it will aim to better understand its limits and potentials as well.

In 2011 we planned a series of tests on the full range of products, with particular attention to new ones such as clay-based paints.

Some of them concern the determination of the clay bricks specific heat, plaster and paint resistance to abrasion and dirt etc. The tests, for which I obviously checked the protocol, will be conducted in collaboration with the Polytechnic of Milan and a private lab (Istituto Giordano, www.istitutogiordano.it).

7 CONCLUSION

All the work that has been done up to now is based on the belief that the re-entry of earth into the building process today will certainly help (as has already partially occurred) to develop a more meaningful and widespread use of natural materials for building healthy (indoor) environments and move in the direction of both sustainable development and energy saving.

These are the particularities, the challenge and satisfaction inherent in this project, which led a (small) national company to offer the market a building product so old and yet so simple, but which has been updated and performance-checked through research and contemporary technology. Specific technical folders for all the clay products have been provided to guarantee professionals and craftsmen as well. I think that this is one of the main results.

The hope is that by similar actions, earth will finally emerge from the self-building vernacular ambient to increasingly become a reliable and affordable material. Another step to pass from zero energy building to zero impact building!

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Earthen building: A comparative analysis of three texts

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ABSTRACT: An analysis is carried out of the differences and analogies existing between three works: the first one is *El arte de albañilería by Juan de Villanueva*; the second is the booklet *Dell'Economica costruzione delle case di terra*, published by the Georgofili Academy of Florence; the third work to be analyzed is the *Traité théorique et pratique de l'art di bâtir* by Jean-Baptiste Rondelet. In the comparative analysis of these three texts the technical aspects are considered, like the composition of the mortar, the type of earth used, modalities, time and building instruments. This enables one to acquire further knowledge on earth, aimed also at the conservation of the existing buildings constructed with this construction technique.

Between the XVIII and XIX centuries, earth construction was the subject of scientific studies; the treatise writing and manuals of this period are not just limited to mentioning this technique among existing ones, but represent a real 'education' in realizing works with this building technique (Cacciavillani 1998 and 2000). The subject of this study is a comparative analysis of three works in particular: the first is *El arte de albañilería* (1827) by Juan de Villanueva (1739–1811); the second is the booklet *Dell'Economica costruzione delle case di terra* (1793), published by the Georgofili Academy of Florence; the third work analyzed is the *Traité théorique et pratique de l'art de bâtir* (1803), by Jean-Baptiste Rondelet (1743–1829).

An analysis is carried out of the differences and analogies existing between the three works, considering the technical aspects, like the composition of the mortar, the type of earth used, modalities, time and construction tools. Such comparison, carried out starting from the original graphics of the three texts being analyzed, makes it possible to acquire further knowledge on earth, aimed also at the conservation of existing buildings.

The treatise *El arte de la Albañilería* by Juan de Villanueva is presented as a description of both the theoretical and practical knowledge needed by a builder. It is made up of twenty chapters and deals with different subjects, such as the characteristics of the materials used in masonry, the tools necessary for the various types of works and the different building techniques for the realization of masonry, explained with extreme precision both with regard to the order of the most elementary stages, and in the definition of more specific elements such as arches, vaults and everything concerning a building. One long chapter, as well as other short references, is dedicated to earth walls.

The booklet *Dell'Economica costruzione delle case di terra* published by the Georgofili Academy of Florence, is by an anonymous author, a member of the Academy, but from the preface it can be supposed that it is a non-literal translation of the French text by Francois Cointeraux of 1792. The small Italian manual is completely dedicated to the subject in question; besides giving explanations for the realization of works in earth, it very enthusiastically proposes the diffusion of the same, listing their considerable advantages. The third work examined is the *Traité théorique et pratique de l'art de bâtir*, by Jean-Baptiste Rondelet, which analyses in particular the construction of the 'formed wall', that is, 'cast into a formwork': this is undoubtedly economical, allows the construction of solid houses, safe from fires, ideal for rural buildings. The author stresses that, when the walls are well made, they constitute a single piece that can last for centuries, if covered with good plaster on the outside.

These texts explain the characteristics of the material: the external aspect and the quality of the earth to be used, as well as the questions related to the resistance of the construction. They then describe the tools needed and in particular the preparation of the wooden formwork, necessary for the realization of the earth casts and their subsequent flattening. A number of details are examined, such as for example, joints, the creation of corners and the openings for doors and windows. The aspect that is most highlighted by the authors is the exceptional solidity of the earth constructions, despite their apparent plainness.

1 TYPES OF EARTH

The three works analyze the features of the various types of earth.

They must not be too dry, that is, poor, nor too rich or fertile; all the types of vegetable earth can be considered good, while the rich earths usually used for bricks (clay) can be employed but not on their own, as they would crack too much; the granular earths, which would not be suited for firing as the grains would be subjected to calcinations in the fire, are valuable for use because they have better grip (Villanueva 1827, p. 8; Accademia dei Georgofili 1793, p. 17).

The member of the Georgofili Academy describes at length the natural signs that make it possible to recognize suitable types of earth:

- if the hoes and plough lift whole clods of earth it is a good sign;
- if the farmers are forced to break the clods to till the soil;
- if once tilled they crack;
- if mice build their tunnels in them;
- when deep furrows made by carts can be seen on the roads;
- when with respect to the land of an estate the roads crossing it are at a lower level for the subsequent water drainage and form a natural bank which is almost plumb (Accademia dei Georgofili 1793, p. 18).

Rondelet states that in order to be able to realize such buildings, earth is needed that is neither too rich nor too poor: the best is the very sandy 'loam', but every type of earth that is dug with pickaxes, hoes and ploughs in pieces that have to be shaken to separate them is good for the formed walls, as are those forming elevations that are supported almost plumb or with little slant. (Rondelet 1803, p. 230).

The color of the earth gives no information about its quality; nonetheless it is necessary to mix different types of earth and, in particular, all the clays (rich, strong, viscous, vegetable and marly soils) must be mixed with the poor soils (light, porous, crumbly, saponaceous, spongy, tuffaceous and peaty) with the possible addition of gravel, masonry debris and small pieces of mineral origin, never vegetable or animal (Accademia dei Georgofili 1793, p. 19).

Attempts must nevertheless be made at mixing the earth: taking rich and poor earth in equal quantities, this is mixed compressing it and is marked with a number. Then one quarter of rich earth is taken and three quarters of poor and this is indicated with another number and so on until many small amounts are obtained of the same size and shape. It is only in this way that the best mixture can be decided and consequently the quantity of the different types of earth needed for building (Accademia dei Georgofili 1793, p. 19–21).

The Spanish author does not deal with the mixing of the earth in such detail, but adds a more practical recommendation: as one digs into the soil, if the earth is dry it can be moistened a little, and removing the clods, turning them over and breaking them into bits the earth is piled up so as to keep the 'substance'.

One must also be careful that it is not too damp, since if it were the blocks would shrink considerably and would result in fissures and cracks between one and the other being formed (Villanueva 1827, p. 26).

Rondelet states that the procedure for the construction of earth houses is very simple: the soil is ground up and is then sieved, being careful to remove the stones that are any bigger than a walnut, and it is then moistened and, once the earth mixture is ready, it is cast into a formwork where it is rammed down with a rammer, to be used turning it at every strike so as to compress and mix the wet earth (Rondelet 1803, p. 230).

2 TOOLS

Another important subject dealt with in detail by the authors is that of the tools needed for the construction of earth walls. Most of them are those commonly used: spades, hoes, shovels etc. And then there are the specific ones: the wooden formwork and the rammer.

In order to make this easy to understand, the publications include illustrations to which the authors refer now and again.

The description of the preparation of the formwork is the most important phase: planks of light wood are used, the driest and straightest, with the least number of knots in them.

Villanueva calls them *cajones* and gives their dimensions: seven or nine feet long and two and a half high. The planks must be about one and a half or two inches thick, held in place by their bars nailed from the outside (Villanueva 1827, p. 26).

Instead, according to the Italian author, the length must be of about six arms and the height of about one and half or one and three quarters; he also stresses that the planks must be planed on the inside because they have to form the smooth surface of the wall.

They then have to be united with bars, four at an equal distance, and lastly two leather or ox nerve handles attached (Accademia dei Georgofili 1793, p. 22).

For Rondelet the elements making up the formwork are the planking used for the temporary frame, the bottom blocked by two wooden elements, the small columns, the *lassonières* or keys, the quoins, the ropes to be tightened with a cudgel after having tied the columns; this is decided also according to the slant (Rondelet 1803, p. 231).

In the illustrations of the three books (Fig. 1) we find the formwork already assembled, which needs the support of eight perpendicular wooden props or columns, tied at the top with a rope and a wooden spiral which secures them together.

In the meantime in the lower part they must be inserted into four big battens which rest on the wall and are held down with chocks that make it possible to regulate the thickness of the walls by moving them.

The most important instrument on which the solidity of the work depends is the one used to compress and ram the earth. It is extremely important because this kind of work leads to extreme results: either it is perfectly good or extremely bad.

The French name of this tool is *pisoir* (Rondelet 1803, p. 229), the Spanish equivalent is *pisón* (Vi-llanueva 1827, p. 27), which in Italian is called *pestone* or *pillo*, as is shown (Figs. 10–12, Table 1) of the manual of the Georgofili Academy (Accademia dei Georgofili 1793, p. 24).

Its realization is more difficult than could ever be imagined, and for this reason is described in all its various stages (Fig. 2).

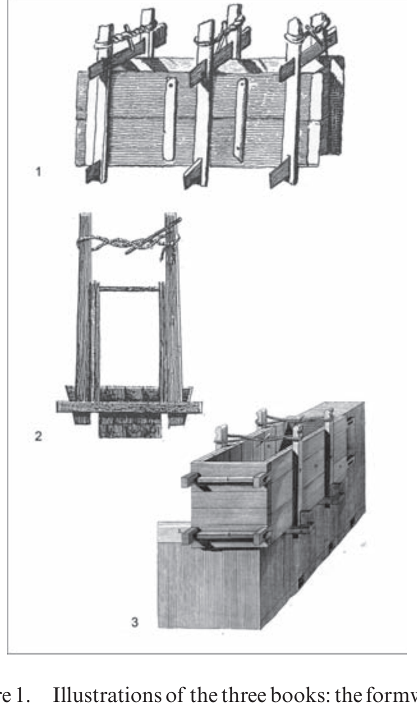

Figure 1. Illustrations of the three books: the formwork. 1) Villanueva; 2) Georgofili Academy; 3) Rondelet.

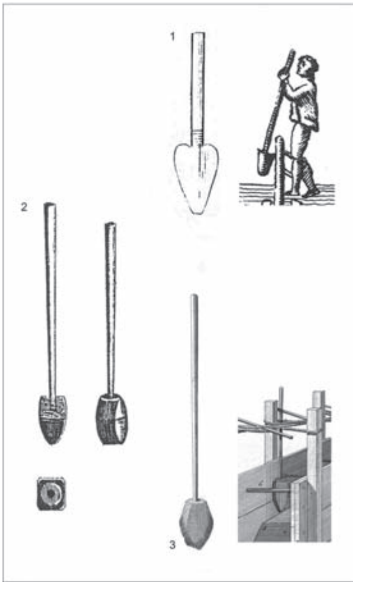

Figure 2. Illustrations of the three books: the rammer. 1) Villanueva; 2) Georgofili Academy; 3) Rondelet.

3 BUILDING PHASES

The description of the construction phases begins after that of the tools: it starts with the foundations, which will be laid as for an ordinary construction. They will jut out by about one arm and a half about the ground, the necessary height to protect the walls from the damp.

At this height the holes will be arranged that are needed to rest the keys of the formwork on, at a distance of one arm and two thirds, and the wall segments included will rise to the height of the keys themselves. If the foundations are not raised and the walls are placed at ground level, like when the simple walls or fences of a piece of land are made, the place where the wall is to be positioned must be flattened (Accademia dei Georgofili 1793, p. 25). Villanueva also considers the possibility of building earth walls included between the wall bays placed at an identical distance to that of the length of the planks. In this case the wooden elements at the head are not necessary, but the formwork is made with just the planks and the already existing wall

Once the wall has been prepared, in the simple case of wall on foundation, the shape can be established and, having tightened the cones and columns by means of the tying of the ropes, construction can begin (Villanueva 1827, p. 27).

The Italian author recommends that before beginning to pour in the earth, the men, inside the formwork, put a layer of thin stones or slivers of

Table 1. The three Treaties: differences and analogies.

TYPE OF EARTH	Rondelet—R. Toutes les terres qui ne sont ni trop grasses, ni trop maigres, sont propres à faire le pisé. La meilleure est la terre franche, qui est un peu graveleuse (p. 230). Georgofili—G. Tutte le Terre in generale sono buone per l'uso indicato delle costruzioni, quando non hanno l'aridità delle terre magre, e l'untuosità delle terre grasse. Tutte le Terre vegetabili sono in generale proprie per tali lavori (p. 17). Villanueva—V. La tierra que debe emplearse para construir tapias ó paredes debe ser arcillosa, pegajosa, compacta, limpia de guijo, y con poca mezcla de arena y cascajo (p. 8).
DAMP	R. La terre […] il suffit qu'elle soit un peu humide, de manière qu'en […] elle puisse […] conserver la forme qu'on lui a donnée (p. 230). G. Della buona terra […] abbondano le rive de' Fiumi, e le falde delle Colline che hanno sopra di loro delle terre coltivate (p. 18). V. Se ha de cuidar de que [*the earth*] no esté muy húmeda […] Conforme se va cavando, si está seca, se rocía un poco; y deshaciendo los terrones, recorriéndola y desmenuzándola, se amontona para que conserve el jugo (p. 26).
SITE	R. Toutes les fois qu'avec une pioche, une bèche, ou une charrue, on enlève des mottes de terre qu'il faut briser pour les désunir […]. Les terres cultivées, les terres de jardin, les terres natureiles […] qui se soutiennent presqu'aplomb, ou avec peu, de talus (p. 230). G. Ogni volta che una zappa, o una vanga, o l'aratro sollevano dal fondo de' bei solchi, o delle intere fette di terra, […]. Quando […] i lavoratori sono obbligati di spezzare le zolle […] Le terre coltivate che si aprono e crepano (pp. 17–18). V. [*The author does not specify*]
BUILDING	R. On fait usage du pisoir en le tournant à chaque coup, de manière à croiser les traces qu'il imprime sur la couche de terre, et à la massiver également dans toute son étendue (p. 235). G. Gli operanti destinati […] a portarla nella forma [*the earth*] dopo averla distesa un poco coi piedi cominciano a comprimerla coi loro pestoni […] I primi colpi ch'essi daranno sieno sempre rasenti le pareti della forma, ed in seguito nel mezzo (p. 26). V. Se va echando dentro de los tapiales á tongadas ó capas de poco mas de medio pie de alto; [...] el oficial ó peon [...] que debe estar dentro del cajon, pisa, aprieta y maciza esta tierra con un pison algo pesado (pp. 26–27).
DOORS AND WINDOWS	R. On fait aussi les jambages en briques […] on peut même les faire en moilons ou en plâtre. Quant aux linteaux, ils se font ordinairement en bois […] Ils peuvent aussi être faits en pierre de taille, en briques ou en moilons (p. 236). G. Le aperture delle porte, e finestre si lasciano nell'esecuzione del muro conforme nella pratica ordinaria […] Queste porte, e finestre si riquadrano, e si rivestono nelle solite forme o con delle soglie di pietra, o con de' mattoni, e dai più indigenti con delle piane di legno (pp. 30–31). V. Si en las tapias ha de haber puertas ó ventanas, es preciso que lleven machos o guarniciones de los mismos materiales, pues con tierra sola son dificiles de hacer y de poca duracion (p. 29).
PLASTER	R. Lorsque les murs de pisé sont achevés, il faut, avant de les recouvrir d'un enduit, soit de plâtre ou de mortier, les laisser sécher pendant quelque tems, en raison de la température du pays et de la saison où ils out été faits […] Il ne faut pas craindre de laisser le pisé quelque tems à l'air (pp. 236–237). G. Se una casa di terra è stata cominciata nel Febbraio, e terminata nell'Aprile, ella può essere intonacata nell'Autunno […] dal che risulta che quando ella sarà terminata nell'Ottobre, o nel Novembre potrà ricevere l'intonaco nella primavera seguente (p. 36). V. Arregladas las superficies interiores y exteriores en las paredes y cielos perfectamente planos con los jarrados, se hacen los blanqueos y revocos, bien sea con cal, ó bien con yeso (p. 78).
WOODEN FORMWORK	R. Cet encaissement est formé de deux tables en bois de sapin […] que les piseurs des environs de Lyon appellent *banches*, composées de planches assemblées à rainures et languettes, et fortifiées par d'autres planches marquées 2, posées en travers, et arrêtées par de forts clous rivés. Pour faciliter la pose en place de ces banches (p. 231). G. Si prendano delle tavole […]le più secche, le più diritte, e le più sane […] Per legare solidamente queste tavole converrà per la parte esterna applicarvi 4 sbarre a giuste distanze, e finalmente dalle due parti applicherete due maniglie di cuoio, o di nervo di Bove. […] Per sostegno […] conviene costruire otto […] colonne perpendicolari di Legno legati superiormente […] con una corda ed un tortiglione di legno […]; mentre per la parte di sotto devono essere infilati in quattro sbarre di grossi correnti bene spianati, posati sul muro (p. 22).

(*Continued*)

Table 1. (*Continued*)

	V. Para construir tapias de tierra es preciso hacer los cajones con dos tableros que se llaman tapiales, de siete ó nueve pies de largo, y dos y medio ó tres de alto. Las tablas han de tener dedo y medio á dos de grueso, aseguradas con sus barrotes, clavados al exterior. Ármanse y colócanse á los gruesos que se quiere por medio de dos cárceles, ó digamos aros, compuestos cada uno de cuatro piezas, que las dos se llaman *agujas*, y las otras dos *costales* (p. 25).
RAMMER	R. Le pisoir est composé d'une masse de bois […] va en diminuant d'épaisseur […] terminée par un petit arrondissement qui réduit son épaisseur (p. 234).
	G. Del Pillo, o Pestone, Strumento col quale si batte la Terra. […] dovrà farsi anche per la parte di sotto riducendolo alla figura di un Cono, ossia di una punta molto rotondata (p. 25).
	V. Un pison [*has*] su plano inferior puntiagudo (p. 26).

roof tiles on the surface of the keys, so as to avoid the subsequent cast of earth blocking them, making it difficult to take them out when the work is finished.

The ramming of the earth then begins, being careful that there is the right quantity each time to obtain an adequate layer and that the first strikes are towards the edges and then towards the centre. Before pouring in new earth, the 'rammers' must be sure that they have rammed the previous layer as much as possible and this can be understood from the fact that the tamper will leave hardly visible marks on the earth (Accademia dei Georgofili 1793, p. 26).

According to Rondelet, once the formworks have been arranged they are moistened inside and, on the bottom, a layer of lime mortar or even earth to stop the sliding of the earth cast inside. When the bottom of the formworks has been slightly moistened, the helpers bring the workers the pre-prepared earth in wicker baskets: they spread out this earth so as to make a uniform layer and then everyone takes a tamper with which they work this layer of earth reducing it by about half of its thickness.

Once this first layer has been compressed the helpers bring new earth to form a second one of equal size, which the workers spread out and ram in the same way. The author also gives suggestions on how to connect the different casts (Rondelet 1803, p. 233–234).

Vandelvira says that once a formwork has been filled, it can be freed of supports immediately since there is no danger that the just completed block of earth loses its plumb or can be damaged by the fact that work continues nearby.

Then the supports are released, the nails taken out, the planks dismantled and they are placed further ahead to form another block of earth like the one just completed.

This one must be prepared just like the previous one, paying attention that the head of the finished wall is properly united with the new wall in thickness (Villanueva 1827, p. 27).

The stratagem suggested in the volume of the Georgofili Academy is on the other hand to make sure that, in setting up the mould for the next formwork, the planks partly cover the finished block, so as to guarantee continuity Accademia dei Georgofili 1793, p. 27).

In all the blocks in succession the head of the form that is used only to realize the corners is not necessary. In fact Villanueva states that, should the need arise to make corners, the formworks will be placed against the extremity of the already formed wall, with the direction of the corner to be obtained, leaving one of the heads and holding down the planks with tie rods passed lengthwise along the thickness of the wall, which are taken away little by little as the block becomes compact (Villanueva 1827, p. 27).

When the first round of blocks is finished, the one above must then be realized. It is therefore necessary to create the holes on the already prepared level ground to rest the form keys on again. These are made by cutting the ground with hatchets normally used for cutting tuff or soft stones (Fig. 3).

The succession of layers must follow the simple rule of beginning from the end at which one finished. This means that if we began the first layer from the right the second begins from the left, the third from the right and so on.

For the overlapping of the blocks one must pay attention that the keys of one block do not fall in line over those immediately preceding them, but with those of two layers before and anyway always half way through the block below (Villanueva 1827, p. 28).

Considering the need for the intersections in the succession of layers, it can be understood how it is indispensable to proceed at the same time with the realization of the perimetric walls and the internal dividing ones, as the latter cannot be connected up to a wall that has been built to its finished height (Accademia dei Georgofili 1793, p. 28).

The houses built in this way are solid, healthy, economical and last for a long time when well

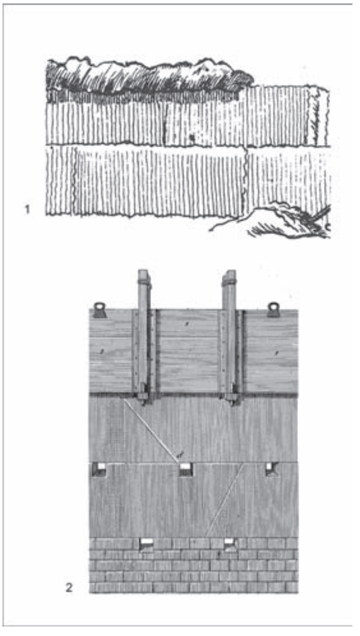

Figure 3. The succession of the blocks. Comparison of the illustrations of: 1) Villanueva; 2) Rondelet.

done. They can be 'superbly decorated' with plaster or paintings, which does not increase their cost too much.

Once finished off with the paintings one would not even suspect that are built of earth (Accademia dei Georgofili 1793, p. 30).

Rondelet specifies that the thickness of the wall must not be more than 54 centimeters and must decrease as the height of the construction increases (Rondelet 1803, p. 234).

The door jambs can be made of stones and chalk while the architraves are usually made of wood; the window and door openings can also be made with canvases and squares of wood.

When the formed walls have been finished it is best to let them dry out for some time, and to make sure that they are nice and dry in the middle before plastering them with chalk and lime: this will be done in proportion to the temperatures of the country and the season in which they are made.

Insisting on the inexpensiveness of Earth Houses, the author stresses once again the 'minimum' expense that such construction entails (Rondelet 1803, p. 236).

Villanueva considers the use of earth walls as the enclosure of a piece of land separately (Villanueva 1827, p. 28), as they are not used to support a covering. In this case, to protect them from rain and snow on the upper part they must be covered inbranches, straw and Spanish broom fronds, or with tiles and bricks.

4 CONCLUSIONS

The three treatises put the reader, even if not expert in the construction field, in a condition to wholly realize a work in earth, making use of the 'instructions' in them. The texts analyzed are easy to understand, explained in detail and exhaustively.

A number of differences can be noticed (Table 1): the anonymous Italian author goes on at length with respect to the other two about the quality of the earth to be used; Villanueva, in particular, also takes into consideration some particular cases, like the construction of boundary walls, pieces of earth walls alternated with sections of walls of fired bricks, the covering of the top of the walls.

These differences are easy to understand if one thinks that the Italian booklet only speaks about earth constructions while instead the treatises of Villanueva and Rondelet are more complex works concerning everything that is pertinent to wall art. The Spanish text appears more concise and technical, whereas the Italian one is more promotional in repeatedly underlining the advantages of the earth building technique. Rondelet's text has a technical-structural and scientific character; it gives great importance to practical experience, complete with illustrations of the construction types and examples, with the aim of bringing new theoretical developments to the subject of earth.

The information given by the three authors on the techniques to build earth walls are extremely important above all when some of the details dealt with by them are different.

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Embodied energy assessment of rammed earth construction in Pozuelo de Alarcón (Madrid, Spain)

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ABSTRACT: This paper aims to illustrate the procedures used to incorporate rammed earth as a forgotten construction material in a contemporary building, and asses its contribution to reduce the environmental impact of the construction, which, has already proved its versatility and effectiveness through our vast built heritage. For the assessment of the environmental impact, the embodied energy has been surveyed using the data reported from the construction process and the values obtained from the literature and the database BEDEC from ITEC. The results offer a good framework to accurately compare the repercussion of the different components of the wall to the embodied energy amount.

1 INTRODUCTION

Construction of arises from the need to provide adequate space for professionals working in an environmental education center (employed in the knowledge and dissemination of environmental values), with a constant increase in its activities.

The initial proposals intended that the building would answer the most representative words of its title, namely: "Classroom", "Education" and "Environment". For the first and second, the configuration of the building itself should teach. For the third, must bring together all aspects that are part of the basic concepts of sustainable construction, employing passive environmental conditioning strategies based on their design, using low impact materials, and making effective management of resources such as water and energy.

The underground of part of the building by the north side, as bioclimatic and environmental integration strategies, was considered a good option for the design. As a result there is a considerable amount of excavation and therefore the need to move large volumes of soil. The use of excavation material itself, reduces very significantly the environmental costs resulting from the act of building. On the one hand, the earth moves, so does not pollute or consume energy in transport, and also helps clog landfills. Furthermore, we are using a material that does not require manufacturing or transportation.

Earth walls are implemented as contention walls, providing also a good thermal mass flyer for heating and cooling the building (Fig. 3).

Figure 1. Front view of the classroom. South façade.

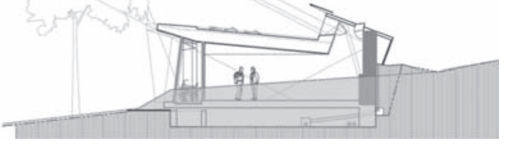

Figure 2. Section through the events hall. Representative section of the building, showing soil interaction.

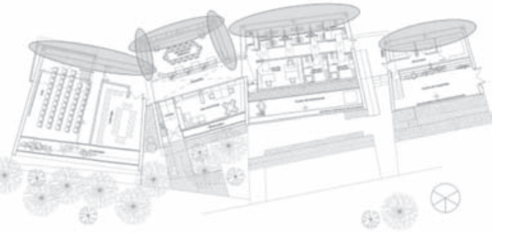

Figure 3. Location of earth walls.

For the implementation of rammed earth walls, usual industrial concrete formwork and mechanical tampers were used requiring less effort by the operator than the traditional manual compaction. This has a greater economical efficiency but is the hot point to discuss, together with the stabilization, in order to achieve sustainable results.

Some information has been already published in order to explain rigurousely the use of earth in the construction of the massive walls in this building (Baño et al 2011a). Some data were also reported during the construction to quantify the inputs and outputs associated to these construction methods (see task 4). Here is a description of the principal characteristics of the construction.

2 DESCRIPTION OF MATERIALS

2.1 *The excavation*

As expected, the volume of soil to excavate was very considerable, so we had to enable and adjacent area to store the vast amounts of soil. Moreover, the discovery of a layer of sand during the excavation led to a separate storage for use in mortars and coatings. It was not necessary the use of trucks to carry any soil for disposal.

2.2 *Moisture*

A Standard Proctor test UNE 103500:1994, was made, like the rest of tests corresponding to this phase of work, in the laboratories of the European University of Madrid. The test we determined that the optimal values of humidity are at 11.4% for a dry density of 1.7 g/cm3, these amounts will set the standard on which the following activities will revolve. Indications were transferred to the staff at work by field tests (Baño et al 2011), who reproduced the test to achieve similar results, thus establishing and from now on, an invariant in the handling of land and thereby setting a parameter for both the testing and the execution of work units.

2.3 *Determination of additives*

Both, grain size characterization of the soil as the tests made for compressed earth block production, suggested the need of additives compensating for the absence of clays in the soil. The experience gained by many authors express the desirability of using cement or lime binders at rates between 6 and 10% by weight, although they all end up recommending testing to substantiate the benefits of the land. (Font & Hidalgo 2011). After the completion of several samples, the final mix proportions include 4% lime (calcium hydroxide CL S-90) and 4% cement (CEMII/B-LL 32.5N) by weight. All mechanical strengths obtained were considered sufficient for the minimum work required (values of compression strength are about 1.85 Mpa for samples with the lime-cement mix) additive. This mix maintains also a tight relationship between its bearing capacity, its environmental cost, and more than possible retractions while drying.

2.4 *Surface finish*

The wall to be constructed is subject to the requirements of use and maintenance of the building, so it must respond to diseases resulting from the wear surface of walls. The constant friction, impacts, or the mere presence of microorganisms in the medium term can result in surface erosion, not troubling from the standpoint of their mechanical behavior, but visually and aesthetically very unfortunate.

Our wall is not exposed to weather external agents that represent a gradual surface wear. But there are some areas with an increased risk of erosion or moisture, so that specific protection should be provided. The first few inches of the lower interior walls are very exposed to use and maintenance, so a skirting board has its reason for being here. The external surface of the wall, when in contact with the ground (it is waterproofed by a polyethylene sheet and protected by a drainage membrane of high density polyethylene), or when rising above the new ground level (waterproof and insulated with natural cork board) may be subject to any aggression result of the hydrostatic pressure of the land or infiltration through microcracking of the protective plaster. Insulation boards need a firm support on which to settle properly.

So it is advisable, in both cases (internal and external surfaces), a reinforcement of the surface conditions of the wall. One purpose of the use of soil as building material in the “classroom”, was to establish a link, firm and deep, between the ancient ways of doing and the real possibilities of their current application. Technical forgotten works can be resuscitated and treated, to be used with renewed meaning. It was therefore proposed a traditional “*calicostrado*” could contribute effectively to achieve the performance required. This technique is used on the first 60 cm of the wall (which leave a protective skirting board inside) and their entire exterior surfaces. It is made in a traditional manner, depositing tiers, a dry mortar 1/3 part lime and 2/3 parts sand on the formwork, before pouring and ramming each earth layer.

Finally, it was proposed impregnation of a consolidant that would provide the rest of the interior surface an additional abrasion resistance, with

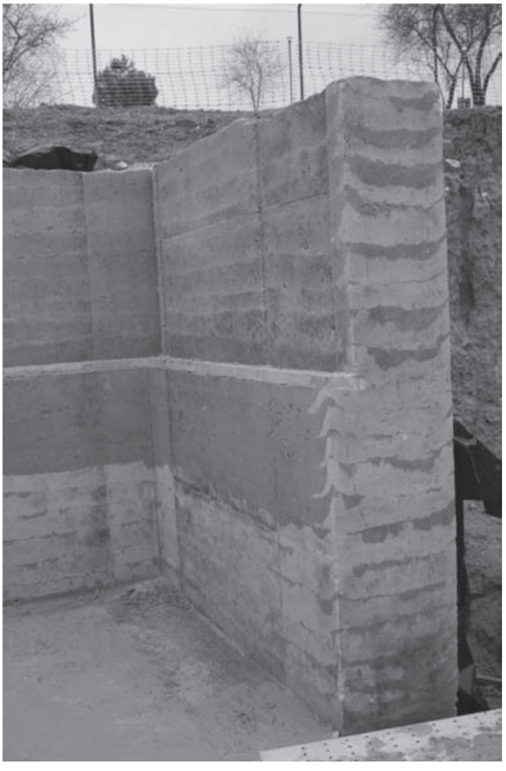

Figure 4. Wall calicostrado. Lime mortar surface finish.

Figure 5. Usual formwork in the construction of concrete walls.

the hope of increasing its useful life. The product chosen was a consolidant A of Quimivisa, monocomponent synthetic resin which is absorbed by capillary action until saturation. As tested in situ, there were not relevant changes in the support, except for a slight dark tone, while maintaining the original properties of the wall.

3 CONSTRUCCION PROCESS

3.1 *Formwork*

The formwork system with metal panels, stretched and top and bottom stud fastening that allow free soil compaction, secured with braces and anchored to the ground with wedges, becomes, within the current market proposals, as the best option. Surely not represent the most appropriate (for example, difficulting the elimination of excess water during drying), but aids to lower costs and to use common tools bringing earth construction to a conventional choice.

The seat of the wall and the placement of the formwork panels shall be made on a brick base, which on one hand cut off from the natural soil moisture, and other grants the necessary firmness and play in the most reliable as possible future site conditions.

The Wall will be implemented in accordance with the possibilities that give us the available formwork boards, so the wall will grow by large horizontal panels limiting the height of the panel, 135 cm. Traditional techniques resorted to lower heights ranging 75–80 cm, in order primarily to the handling of the molds. In our case, the panel will move only in the final work of dismounting, once the entire wall is rammed. So the only steps we take are based on the ease with which operators can carry out the work of compaction, amply covered by the width of 75 cm in lower zones and 60 cm in the upper, which have their purpose in the structural calculations made for the proper performance as gravity retention wall.

The four structures to be run in different lengths, will always have two phases of implementation, height 135 cm each. In a few will be offered a 15 cm step to address the canvas top and not in others. In a few will come to complete this canvas upper with complete filling of the box and others will stop at the level of design required.

3.2 *Mixing and pouring*

The mixing of soil, with the proportions of additives already referred to, and subsequent mixing, is made by mini dumper machine (bobcat), that allow both the displacement of the earth from its place of storage to the point of preparation, and perform works of incorporating additives, even leaving a finest mixing to workers. Soil with additives was used immediately to preparation, being discarted that which was not poured during the job. At night, the soil to be used during the following

Figure 6. Lifting and pouring earth mix.

Figure 7. The compactor Sullair F18.

day, which already had the right humidity, was protected with canvases from rain or accidental weathering. The ready mix was lifted to the formwork by a shaker driven by a transportable crane.

3.3 *Compacting*

Manual compaction does not require special attention (for accumulation of experience) in terms

Figure 8. Finished rammed earth wall in library room.

of technique is concerned. Mechanical compaction, despite entering some uncertainties, gets much higher values in the cohesion of the wall and therefore their mechanical performance, reducing execution time and therefore use of aids. Finally, we chose the compactor Sullair F18, weight of 17.5 kg and a height of 126 cm, very manageable, able to work with a frequency of 500 beats per minute and with a 14.5 cm diameter ram, very suitable for the small scale on which we work.

4 ENVIRONMENTAL ASSESMENT OF EMBODIED ENERGY

Former studies show that the embodied energy of earth buildings is between 30% (Trealor, 2001) and 50% (Pacheco & Jalali, 2012) less than conventional brick cavity wall and/or reinforced concrete structures. But there is not much information about the type of components and process involved in ramed-earth.

An approximated value for energy embodied in BTC (mechanically pressed and 14% cement stabilization) achived by Vazquez (2001), with a clear explanation of the energetic data from the different components, leading to a value –0.4 kWh/kg, which considering a density of 1.8 t/m3 means 2592 MJ/m^3. Considering a much more little stabilization (5%), the energy embodied falls to 852 MJ/m^3.

Further research has been done by Reddy and Kumar (2010), showing and amount of embodied energy in cement stabilized earth walls of 500 MJ/m^3 (for cement content in a range of 8%, and manual ramming and walls 0.2 m–0.4 m thick), considering four components: energy in transportation f soil, mixing, compaction, use of cement.

Lax (2009) also analyses these results and refers to the "inventory of carbon and energy" (Hammond et al 2010) obtaining values of 1200 MJ/m^3, for the same mix assuming mechanical ramming.

To study the environmental profile of our wall we will follow the process diagram proposed by Lax (2009), for a generic rammed earth wall LCA, attending to those particular conditions of our building.

Due to the difficulties to obtain real energy consumption data from the jobsite, an estimation has been made from the environmental values extracted out the BEDEC database (ref). Figure 10, shows the data collection of time and resources used for the construction of one complete wall. An approach to the total energy consumed has been made using both parameters and showed in Figure 11 Embodied Energy per unit values (second column, Fig. 11) are obtained from those individual tasks in the same database.

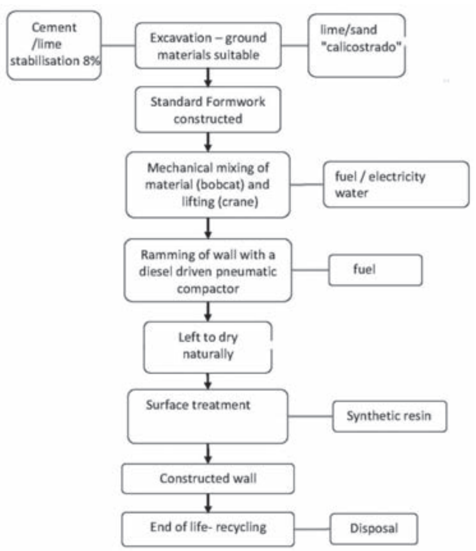

Figure 9. Process diagram for rammed earth wall LCA (adapted from Lax, 2010).

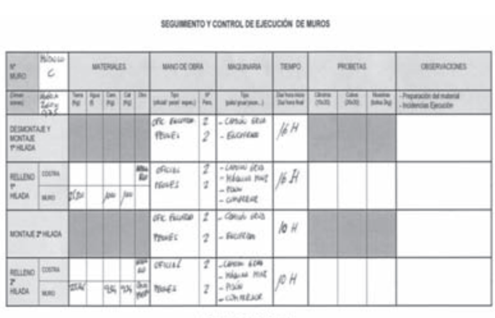

Figure 10. Data report from wall construction.

Consumption	units	Energy Cost		
	Kg/m2/h		MJ	kwh
material components	Kg	Cost per unit	1.640,85	455,79
water	50	0,006	0,3	0,08
sand	284,15	0,15	42,6225	11,84
cement	75,1	3,77	283,127	78,65
lime	162,34	4,82	782,4788	217,36
earth	1665,7	0,18	299,826	83,29
watproof	2,5	93	232,5	64,58
Additional components	m2		1.018,97	283,05
formwork	2,66	383,07	1018,9662	283,05
machinery	h-		95,2672	26,46
Gas.compresor	0,5	60,86	30,43	8,45
Mixing (bobcat)	0,12	304,31	36,5172	10,14
crane	0,24	118	28,32	7,87
Total			2.755,09	765,30

Figure 11. Embodied energy in stabilized earth wall (4% cement + 4% lime, by weight) mechanically compacted with an average density of 1900Kg/m3, formwork with phenolic modular panels, mechanical mixing and pouring with concrete bucket from crane truck (3 m heigth), lime-crusted one side, compacted by mechanical means. With thickness between 75–60 cm.

The data obtained from the jobsite have been transformed in values per m3 of wall, to compare the results with those obtained from the literature.

The final embodied energy obtained (2755 MJ/m^3) approaches the one from a brick masonry wall (29 cm thick) with 2970 MJ/m^3 and it is over 1134 MJ/m^3 for a stone masonry wall and far from 7354 MJ/m^3 of a reinforced concrete wall (BEDEC Database).

5 CONCLUSIONS

As it has been demonstrated an exhaustive definition of the materials and techniques used during a rammed earth construction is necessary to asses rightly the embodied energy of the whole process. Energy consumption varies greatly depending on the tools and materials used, so it results much more important to establish the components of the generic construction process to permit changes depending on each specific project requirements and characteristics. In our case, a very unfavorable conditions have been taken for the steel formwork, considering its reuse and life span it would be possible to reduce de impact, which is over 30%. Values should be reviewed.

As it has been proved by authors mentioned, the greatest factor contributing to the embodied energy of a rammed earth wall, however, is likely to be the cement content. Also in our building, the "calicostrado" takes almost 50% of the energy embodied in material components. It is to notice, that in the database, lime has greater embodied energy than cement, which should be under review.

Finally, the thickness of the wall (75–60 cm) involves a great amount of surface to ram, so as far as this parameter increases in the project the more efforts should be done to collect real data from the tools used.

The values obtained and the method followed supposes an advance that will allow using this data as a reference in environmental assessment tools for buildings like VERDE-Sbtool. Further research must be done to characterize other indicators as CO_2 emissions, and waste disposal.

NOTE

All images are from the authors, but Figure 9 adapted from Lax 2010.

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Earthen architecture in Southern Morocco

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ABSTRACT: Traditional Moroccan architecture is in danger of extinction. There are a large number of architectural sites, abandoned, in ruins, of which most of them are built with earth. With regard to its current state of degradation, there is an urgent need to study, attempt to understand and explain the presence and conservation in the pre-Saharan valleys, before this earthen architecture, "rough but fragile" completely disappears. It is essential to avoid the oblivion of this rare architecture, which constitutes an incredible heritage. Its disappearance would impoverish the world cultural heritage. New social, psychological and economic conditions severely modify the regional and popular architectural forms. The urgent safeguard measures should be oriented to preserve this priceless heritage.

1 INTRODUCCIÓN

La arquitectura de tierra en Marruecos forma parte de las grandes riquezas culturales de este país debido a su diversidad.

Diferentes razones hacen que la arquitectura tradicional del Sur de Marruecos merezca que se realicen esfuerzos para garantizar su conservación y su puesta en valor:

- La renovación del hábitat nos permitirá con un menor coste utilizar o reutilizar un número importante de viviendas que nos permitirán luchar contra el éxodo rural.
- Su remarcable belleza hace que tenga un gran potencial turístico
- Está perfectamente adaptada a las necesidades de la población bien sea sobre el plano estético como el de confort, mereciendo a su vez que se examine las posibilidades de integración en el contexto urbano moderno.
- Constituye un patrimonio cultural excepcional y su desaparición constituirá un empobrecimiento irreversible del patrimonio cultural de la humanidad; teniendo nosotros la obligación de salvaguardar esta parte del patrimonio y asegurar la transmisión de este a las generaciones futuras.

Figura 1. Rutas caravaneras utilizadas durante los Siglos XII–XIX.

2 SITUACIÓN GEOGRÁFICA

El Gran Atlas es una cordillera montañosa de unos ochocientos kilómetros con alturas que superan los cuatro mil metros y que se extiende sobre una gran parte de Marruecos, desde la costa Atlántica hasta la frontera con Argelia. Esta divide al país en dos zonas climáticas: al norte la zona fértil y al sur la zona árida y seca.

Entre la vertiente sur del Atlas y el desierto del Sahara se extiende una zona de unos ciento cincuenta kilómetros llamada "Los Valles Pre saharianos". Como ejemplo de estos tenemos el valle del Dra, del Mgoun, del Tafilalet, etc.

Las viviendas en estos valles están estrechamente ligadas a la existencia de los ríos, ya que donde no hay agua la tierra es extremadamente árida y por consiguiente inhabitable.

En este medio hostil, la intervención del hombre sobre la naturaleza se concretiza en una acción vital. La población autóctona Bereberes ha construido una arquitectura que humaniza el paisaje. Son construcciones que diferencian de una manera muy clara el espacio abierto del espacio cerrado así como el espacio común del privado.

Esta arquitectura que tiene el color del paisaje, impone su presencia a través de una composición espontanea cubista de luces y sombras. La simplicidad de sus formas le da una posición solida y serena. Se trata de una actitud contemplativa del paisaje sin pretender imitarlo.

Estas construcciones en tierra deben su belleza al uso exclusivo de materiales naturales. Se trata de una arquitectura clara y directa que no necesita ser interpretada. Ella da calidad al espacio de una forma explícita, sin la necesidad de recurrir a lenguajes o a códigos de interpretación complejos.

Las necesidades de defensa, el rigor del clima, la escasez de agua, los limitados campos de cultivos crearon un fuerte sentido de la colectividad en estas poblaciones. Por otro lado, la antigua tradición Bereber, la vida cotidiana regida por el Islam y los contactos con la cultura subsahariana han hecho la creación de esta rica arquitectura.

3 TIPOLOGÍA DE HÁBITAT

El KSAR es el asentamiento humano colectivo que encontramos en los oasis, desde el pie del Atlas hasta el inicio del desierto. Se caracteriza por ser un poblado con recinto amurallado y que por razones de mejor aprovechamiento de recursos y respuesta al rigor del clima adquiere una gran densidad edificatoria. Este se emplaza en el borde del terreno cultivable, sin ocuparlo.

Las murallas de tapial que rodea el Ksar se alzan sobre el palmeral controlando los cultivos. En algunas ocasiones, se encuentra una acequia en el interior para asegurarse el agua.

El acceso al Ksar se produce normalmente por una puerta en “chicane”, desde donde se accede a la plaza pública. Alrededor de la plaza se establecen los equipamientos colectivos como: la mezquita, los baños públicos, el pozo, los establos colectivos y la casa colectiva en la que se hospedan los visitantes extranjeros al Ksar. A partir de la plaza nos encontramos con una calle ancha de 2 a 2.5 metros de la que se ramifican otras más estrechas de 1 a 1.5 metros, estas calles están cubiertas por edificaciones encontrándonos con una sucesión de pozos de luz cada ciertos metros.

Muchos de los Ksares se adaptan a las irregularidades del terreno donde se sitúan, pero cuando se encuentran en terrenos llanos, tienen la planta cuadrada o rectangular y sus calles forman una retícula ortogonal perfecta.

La vivienda del Ksar es un ejemplo perfecto de modelo de adaptación bioclimática en la arquitectura. Utilizan la tierra como material de construcción, normalmente solo tienen una fachada que da a la calle y las otras son medianeras con las casas vecinas. Suelen tener de dos a cuatro plantas, a las que se acceden por una escalera estrecha.

Figura 2. Ksar Mansouria. Valle del Draa.

La planta baja es utilizada para guardar a los animales. Las otras plantas se utilizan dependiendo de la estación; es donde se encuentran los dormitorios, el salón y la cocina. La terraza es un elemento importante de la casa ya que se le da diferentes usos como el secado de las cosechas, o donde se duerme durante las noches de calor del verano.

La KASBAH es un tipo de hábitat familiar de planta cuadrada, que desde el exterior se presenta como un gran edificio fortificado con cuatro torres en los ángulos, sus muros incluso los de las torres tienen una ligera inclinación.

La puerta de acceso se encuentra en el centro de una de las fachadas. Los niveles se encuentran alrededor de un patio central, el acceso a estos se realizan mediante unas escaleras estrechas. La planta baja se utiliza como depósito de alimentos y como corral, mientras que los pisos superiores se destinan a la vida cotidiana de las personas con, dormitorios, cocina, salón, etc.

La planta baja y el primer piso están desprovistos de ventanas mientras que los pisos superiores si las tienen.

A excepción del piso superior, los demás están construidos con la técnica del tapial mientras que el último piso y la parte alta de las torres están construidos con adobes, y gracias al aparejo de estos se obtiene una decoración rica y fastuosa.

Normalmente, las Kasbahs se construyen en lo alto de colinas o en lugares elevados dándoles así una gran monumentalidad.

El Tapial es la técnica más utilizada para la construcción de los muros exteriores. La tierra utilizada proviene del mismo lugar de la obra, después de decapar el suelo orgánico de la superficie se extrae manualmente, se humidifica regularmente hasta obtener una consistencia seca.

Se coloca el encofrado de madera que suele comportar unos 20 minutos, en el interior de este se introduce el "maalem" maestro y con la ayuda de un obrero y una canasta de mimbre le va suministrando y vertiendo la tierra dentro del encofrado. El maestro en el interior va esparciendo la tierra con sus pies que seguidamente va compactando regularmente con un pisón de madera. Estas tongadas son de 15 a 20 centímetros de espesor. El encofrado está sujeto por 2 o 3 agujas de madera que para recuperarlas se colocan encima de ellas unos guijarros que reducen el rozamiento al tirar de ellas. Después se desmonta el encofrado para recolocarlo prolongando el muro lateralmente hasta formar la hilada horizontal completa.

Las esquinas se refuerzan con maderas de palmera de 65 a 160 cm. De longitud, estas se reparten cubriendo todo el espesor del aparejo y van intercalándose la dirección de los refuerzos en cada hilada.

Para la fabricación de los adobes, la tierra utilizada proviene también del mismo lugar de la construcción. Esta se mezcla con agua y paja hilada hasta obtener una mezcla homogénea que se deja macerar durante una noche. Esta mezcla se introduce manualmente en un molde de madera con dos alveolos, luego se retira dejando los adobes secar al sol 4 a 5 días antes de utilizarlos. Las juntas de los adobes en la realización de una fábrica se intercalan y se superponen. El mortero utilizado para unirlos está formado por la misma tierra y paja.

Las fábricas de adobe se utilizan siempre para la realización de la última planta, con espesores de 25 a 37 cm. Este sistema permite que según el aparejo de los elementos nos dé lugar a unas ricas decoraciones geometrizadas en bajo relieve, muy características de esta arquitectura.

Otra utilización de los adobes es en la realización de los peldañeados de la escalera, los pilares, los arcos de las galerías de los patios, etc.

Para evitar la erosión de los muros producida por la lluvia, el muro se corona frecuentemente con una malla de cañizo, que se extiende por todo el perímetro y sobresale unos 20 a 30 cm. del muro. Encima de esta malla se coloca un montículo de tierra para sujetarla y evitar que el viento la levante, en algunos casos se utilizan unos adobes creando figuras distanciadas unas de otras.

Los techos se realizan de madera, esta es la que absorbe las flexiones en todos los elementos constructivos. La madera que se utiliza es casi

Figura 3. Kasbah Ait Ougourram en el Ksar de Ait Ben Hadou.

Figura 4. Kasbah en Skoura.

Figura 5. Técnica del Tapial.

Figura 6. Técnica del adobe.

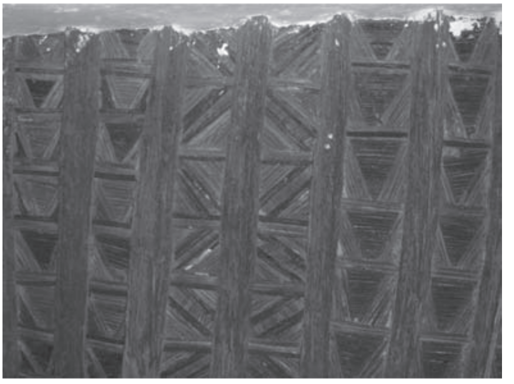

Figura 7. Techo de palmera y adelfa.

exclusivamente la madera de palmera. Los techos se construyen con vigas separadas entre 20 y 60 cm, se cubren con varias capas vegetales como la caña, hojas de palma o la adelfa sobre la que se coloca una capa de tierra prensada de unos 15 cm. La luz máxima que alcanzan las vigas de palmera es de unos 2,5 metros, dicha crujía nos determina el ancho de las estancias interiores y de todo el sistema de traba.

En los techos en los que utilizamos adelfa, estas se tintan con pigmentos naturales y se suelen utilizar en las estancias nobles y en la sala de oración de las mezquitas.

Las cubiertas planas de tierras que son las más utilizadas en esta arquitectura se realizan como los techos descritos anteriormente, a diferencia que el espacio entre vigas en algunas ocasiones se cubren con losas de piedra o ramajes de arbustos al igual que de cañas. Y encima de la capa de tierra prensada se la añade una capa más fina de unos 3 a 5 cm de espesor con un árido más fino y mezclado con paja para asegurar una mejor impermeabilización. Actualmente a veces se introduce entre las dos capas una lámina de plástico tratando de mejorar aun más la impermeabilización.

La pendiente de estas cubiertas so del orden de un 2% y la evacuación del agua de lluvia se hace dirigiéndola hacia unas gárgolas de talladas de madera que sobresalen de la fachada unos 60 cm.

El mantenimiento tradicional de estas terrazas ha de ser constante, una vez al año se renueva parte de la tierra que las forman.

Los muros de tierra, construidos con la técnica del tapial o bien con adobes llevan un revestimiento de protección y de terminación. El revoco y el enlucido que se aplica está formado por la mezcla de tierra y paja. La tierra ha de ser arcillosa y arenosa, empleando de preferencia el limo que encontramos en los bordes de las acequias por su finura. La paja juega el papel de armadura en estos revestimientos haciendo que no aparezcan fisuras por la retracción en el secado de este. En los interiores los revestimientos se realizan a base de tierra mezclado con yeso.

4 CONCLUSIÓN

La arquitectura de tierra en Marruecos forma parte de las grandes riquezas culturales de este país debido a su diversidad.

La arquitectura tradicional de Marruecos está en peligro de extinción. Existe un gran número de conjuntos arquitectónicos, abandonados, en ruinas, de los cuales una gran parte están construidos en tierra. Visto el estado de degradación actual, y antes de que desaparezca por completo esta arquitectura de tierra, "ruda pero frágil", debemos estudiar y fijar los aspectos, intentar comprender y explicar la presencia y la conservación en los valles pre saháricos, con el fin de salvar del olvido esta extraña arquitectura, que constituye un patrimonio excepcional, el que su desaparición, empobrecería el patrimonio cultural de la humanidad. Condiciones sociales, psicológicas, económicas, nuevas modifican gravemente las formas populares y regionales de la arquitectura. El interés de preservar un patrimonio inestimable debería de orientar las medidas de salvaguardia que resultan urgentes.

Pero no podemos plantear el problema de la salvaguardia de la arquitectura de los oasis del sur de Marruecos sin intentar comprender las verdaderas razones de su estado de degradación actual. Con el cambio importante del orden social antiguo se ha condenado a la desaparición la sociedad tradicional y su forma de hábitat. Podemos decir que el estado de degradación de la arquitectura de los valles de los oasis, es el resultado de la conjunción existente de la persistencia de la sociedad tradicional sobre la cual viene a superponerse una sociedad de economía moderna.

La tradición marca las etapas de la evolución cultural de un grupo. A su favor se acumulan los únicos valores perennes de una cultura que engendra su perfeccionamiento en relación con las condiciones históricas. Para un pueblo, es menos su pasado que su futuro el que cuenta y la tradición que no sea optimista y evolutiva macara el fin de una cultura.

La tradición, para que este viva, debe garantizar una continuidad del pasado al presente y un dinamismo en la evolución. Para que no mueran, las civilizaciones se adaptan y evolucionan. El conformismo conservador tiende a fijar la tradición a inmovilizar la historia y la vida. Teniendo a menudo tendencia, en arquitectura especialmente, a considerar como tradicional solamente los vestigios del pasado, cuando a veces no son más que los pastiches de estos vestigios.

Las formas de concentración y de establecimiento humano, bien adaptado a su medio físico y humano, pero inadaptado a algunas de las funciones urbanas modernas como la circulación mecánica, se altera rápidamente y degenera si no le planteamos nuevas reformas y ordenaciones con vistas a rejuvenecerlas y actualizarlas.

Pero desgraciadamente la arquitectura que está en gestación en los oasis es una arquitectura que utiliza nuevos materiales sin ningún tipo de reflexión solamente porque es un símbolo de prosperidad y por una falta de voluntad política consciente y sensible a la idea del interés de la preservación del patrimonio como recurso económico y social para un desarrollo sostenible local. A pesar del esfuerzo realizado por el gobierno de Marruecos con la creación del CERKAS (centro de rehabilitación del patrimonio arquitectónico del sur de Marruecos) situado en la ciudad de Ouarzazate y que se propuso como objetivos: el censo, la protección, la conservación, la restauración y la rehabilitación de la arquitectura del sur.

Después de una decena de años de vida importantes proyectos se han llevado a cabo, por citar algunos tenemos la restauración y la rehabilitación de la kasba de Taourirt, sede del centro, la restauración del Ksar de Ait Ben Haddou, los trabajos realizados en el Ksar de Tamnougalt en cooperación con instituciones españolas, la restauración de numerosos graneros colectivos, etc...

Pro el objetivo más importante que se ha planteado el CERKAS para esta nueva decena de años que vienen es el desarrollo sistemático de la realización del inventario de esta arquitectura para poder continuar con la preparación de una planificación estratégica de actuación y no llegar demasiado tarde. Por esta causa pensamos que todos los trabajos de inventariado que se han realizado en los talleres con la escuela de arquitectura de Valencia en Skoura y el colegio de aparejadores de Barcelona en Tamnougalt y Tinerhir entre otros, han sido trabajos de una relevancia e importancia capital para la labor que espera continuar realizar la institución ya que gracias a estos talleres se ha podido testar la metodología de inventario y adoptarla definitivamente. Ayudándonos a continuar la tarea nada fácil de intentar preservar nuestra identidad cultural y asegurarnos de su transmisión a las futuras generaciones.

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Cataloging and typological study of Mgoun Valley's traditional fortified architecture, Morocco

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ABSTRACT: In the first workshop held in 2011 by the School of Architecture of Malaga in the Pre-Saharan Mgoun Valley (Morocco), a documentation project of historical earthen buildings with heritage value was implemented. The Mgoun Valley, to date, has been inadequately studied, so the project has a double aim: an inventory of the currently existing elements and the ones at risk of disappearing; to identify and document the evolution and transformations of these typologies. The methodology applied in the field is reviewed, as well as the results of the different kinds of typologies recognized.

1 INTRODUCTION

"Des qu'on a passé le cols de l'Atlas, on se sent a l'entrée d'un pays nouveau. Lá expire le monde mediterránéan et lá commençe le monde saharien. Lá se place la frontière entre l'Europe et la veritable Afrique" (Terrasse 1938).

In September 2011, within the volunteer program of the University of Malaga, financed by the Andalusian Agency for International Cooperation, the University of Architecture of Malaga cooperation group, eAM' Coopera, carried out the "First Workshop of Landscape and Heritage in the south of Morocco: proposal for the development of a responsible tourism model in MGoun Valley (High Atlas)". This workshop was formed by professors, researchers and fifteen students with the purpose of allowing students to experience a close but very different reality in a rural environment far away from all comforts, to understand another way of living and relating to the environment. It is a step towards sensitizing in the field of international cooperation, and allows us to do some field work and elaborate projects focused on responsible tourism models connected to the *in situ* discovered heritage: buildings, urban evolution and landscape. Transversely, we have considered the socio-anthropological aspects as necessary for the comprehension of the way of life and the relationships between inhabitants and the environment. Combining heritage aspects with sustainable tourism should be realized on the short run, while tourism is scarcely exploited due to its embryonic state, in order to avoid significant transformations with no possibility of turning back. These models could offer solutions which would improve the level of living in an indirect way, beyond protecting the environment, an essential part of their productive activity.

The interest for the High Atlas zone is not recent. After Roger Mimo's publication, "Fortalezas de Barro" (Mimó 1996) and Vicente Soriano's splendid work (Soriano Alfaro 2006), there have been several workshops promoted by the University of Architecture of Valencia and Barcelona, and supported by el Colegio de Arquitectos, which have focused their attention on this singular architecture in order to bring the richness of rammed-earth constructions in Morroco into our western context. Other experiences were developed in Todra Valley (Cerkas, UPC/Colegio de Aparejadores y Arquitectos técnicos de Barcelona, 1998–2001), Skoura heart (Cerkas/ETSAV-UPV) as well as in Draa Valley (Cerkas/EPFL), with interesting results, that have been part of our preliminary studies.

2 RESEARCH AREA

The ambitious research area is formed by the totality of MGoun Valley, a pre-Sahara area featured by a massif called Mgoun, on the north side of the Central High Atlas, and the Assif Mgoun River. Lately it has been known as Rose Valley due to the activity related to rose cultivation, which helps us to understand the growing interest in tourism in this area as well. Limits are defined by the city called Kelaat Mgouna in the south, which is the first access to the Valley and close to other renowned locations in Dades Valley, and El Mrabtin located 60 kilometres to the north, which lies on the High Atlas. Many urban settlements, of different sizes, are located generally on the two banks of the river or on the dry riverbed, becoming a well-organized system in the territory. The highest zone of urban settlements in the north has different typologies, organizing themselves along the transversal migrant passage that characterizes the sector. In general, it is an arid landscape in which cultivations, an essential part for the development of occupied settlements, stand out along the river.

Supported just by the cartography existing in Google and the bibliographic references we could obtain, which were, in many cases, outdated and ambiguous with regards to the location of the described buildings, and the help of forms prepared before the journey, in just four days of hard work, we registered and catalogued eighty-eight elements (Fig.1) with heritage interest constructed with rammed-earth and, at times, complemented by adobe. We focused our attention, above all, on kasbah, tighremt and agadir (barns) and the elements which stand out in these settlements not only because of their height but because of their meaning and relevance as well. A first observation must be noted in the use of terms that identify the different functional typologies, as our attempt of classification based on western knowledge has demonstrated how complex and easy it is to make mistakes. Our experience in situ has shown us that the local population does not differentiate several terms within the different typologies, minimizing the importance that we, *a priori,* intended to assign to them. This aspect leads us to consider the necessity for combining the result of our work generated in this first workshop with a glossary which is obligatory for a better comprehension of the results, as the experience of similar work recommends (Cancino 2008) (Sykes 1984). Despite some advances realized, the unavoidable linguistic barrier, Arabic or Berber, obliges us to carefully check our conclusions and this work can only be carried out by natives specialized in preservation and heritage due to their capacity to scrutinise our conclusions.

From the elements considered in our field work, the Kasbahs stand out on the landscape because of their height and the towers that flank their perimeter, which also has a defensive function. These kasbahs were used to control the entire territory during periods of conflict between nearby settlements. They are residential buildings occupied by one or more families. The barn, usually known as agadir, was another interesting element due to its strategic location and the relationship between families which is reflected in the French term—grenier collectif. We must emphasize the constructive solutions which probably come from experience and optimization of constructive techniques such as rammed-earth (tabut in Berber) used in other typologies of buildings. In addition,

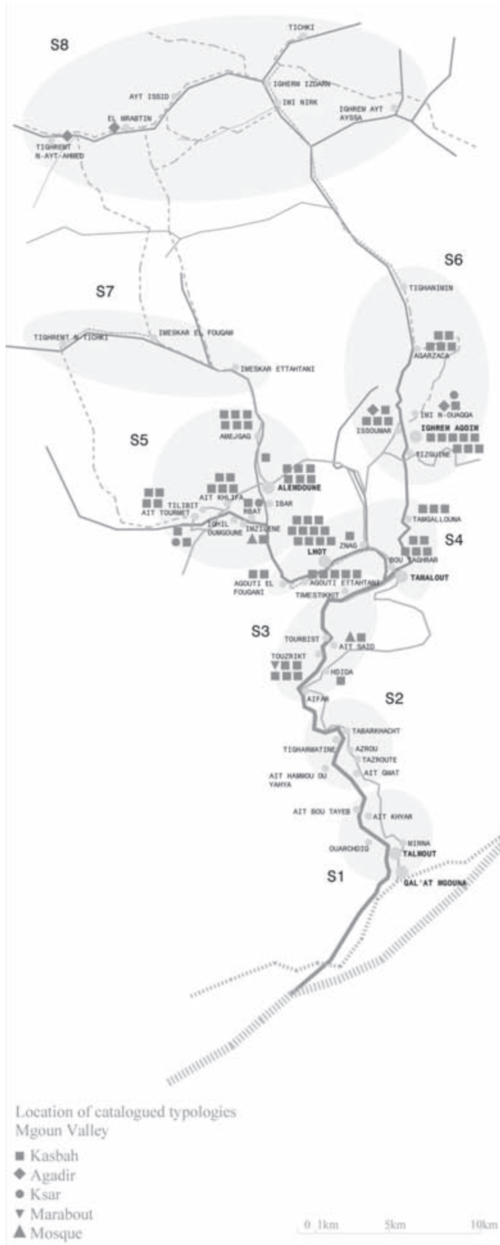

Figure 1. Localization of heritage buildings identified during the first workshop. Own production eAM' Coopera.

we have identified two other common typologies, one marabout and two fortified villages (ksar in Arabic), which were found in a state of neglect. Finally, we have found a mosque whose identified ruins are not significant for a typological classification.

Being responsible for the relevance that a catalogue involves in order to understand a certain culture (Kölbl et al. 2003), we have decided to include the information related to buildings in ruins as well, firstly because we believe it is the best way to keep a registration of some buildings which otherwise might disappear leaving no evidence and, secondly, because they could ease the research on the evolution of these elements in this context. It is known how the buildings made with rammed earth suffer a great deterioration above all due to the effects of heavy rain, which is not so common in the area we are studying. Because of that, ruined buildings are more sensitive to a faster and greater deterioration in comparison with those still in use.

The field work has been focused on the central zone of the valley, identified as sectors S3 to S6 (Fig. 1), leaving the southern zone for the second workshop which will take place in 2012. This scheme cannot be understood as a definite collection of patrimonial architecture in the valley due to the existence of other settlements included in the sectors but not visited (Aifar, Tourbist, Tamalout, Tighanimin, Znag), but as a first approach to their richness and variety that must be completed in future workshops.

3 FIELD WORK

The work realized has consisted of a wide compilation of information which has led to a great diversification of studies once the workshop was finished, not only from a patrimonial field but from the aims already announced. There cannot be the slightest doubt that this type of field work offers the information necessary not only for a patrimonial evaluation, but also to determine the priorities for a conservation project or the origin of pathologies, having great relevance in any level of intervention on the constructions.

As mentioned before, the methodology we have used has consisted of analyzing each settlement in groups thoroughly to allow us to identify the buildings that will be studied afterwards. The groups involved in this project were composed by a professor and two or four students, depending on the circumstances. The time invested in each settlement has depended on the previously unknown amount of patrimonial elements we could find and the possibility to have access inside. We estimate that we have spent one hour on each building, with heterogeneous results due to different determining factors that the group has found in situ: difficulty to gain access to the inside of the buildings, extreme complexity of settlements or buildings to catalog, scarce means used for construction surveys (realized by hand or with a laser range meter in the best of cases), and even lack of time due to having to travel long distances to places where access was only possible on foot, as happens in sector 3. It is also significant how the fact of showing the inside of buildings has become usual for the population, who finds this is a way to have some extra income as well as it allows us to do our work. Using identification

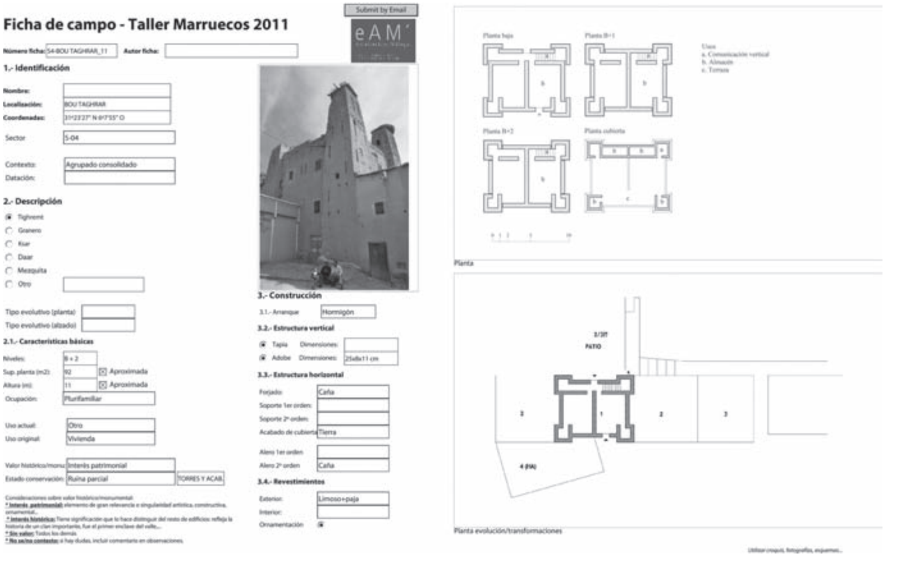

Figure 2. Identification form after elaboration of hand draft. Form: Own production eAM' Coopera.

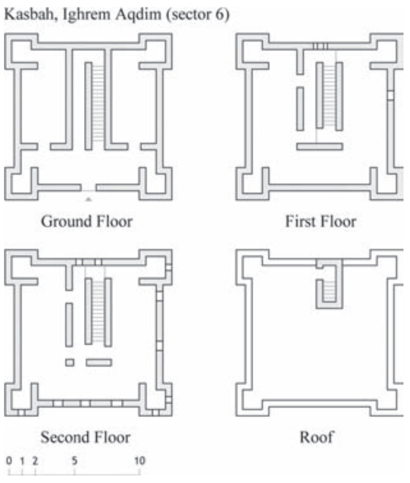

Figure 3. Central staircase and corridor typology.

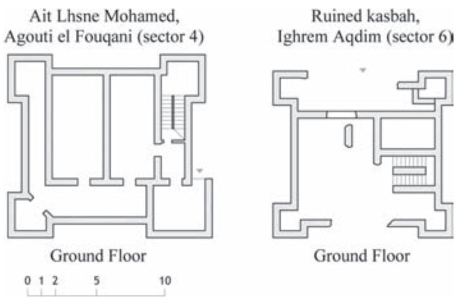

Figure 4. Kasbahs with staircases located next to a tower.

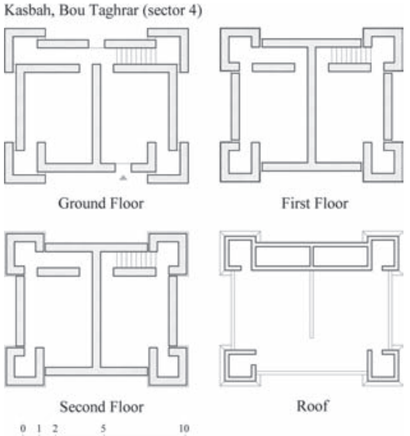

Figure 5. Detailed graphic representation of the old kasbah in Bou Taghrar. Own production eAM' Coopera.

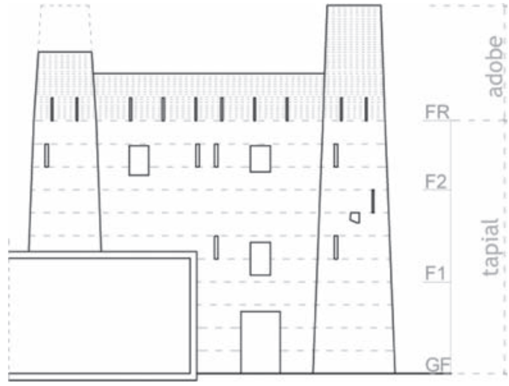

Figure 6. Detailed representation of the kasbah in Bou Taghrar. Back façade (main street). Own production eAM' Coopera.

Figure 7. Detail of one adobe decorated tower of Bou Taghrar's Kasbah. Picture: Alberto Montiel Lozano.

Figure 8. General ornamental patterns in El Fouqani's kasbah. Picture: Alberto Montiel Lozano.

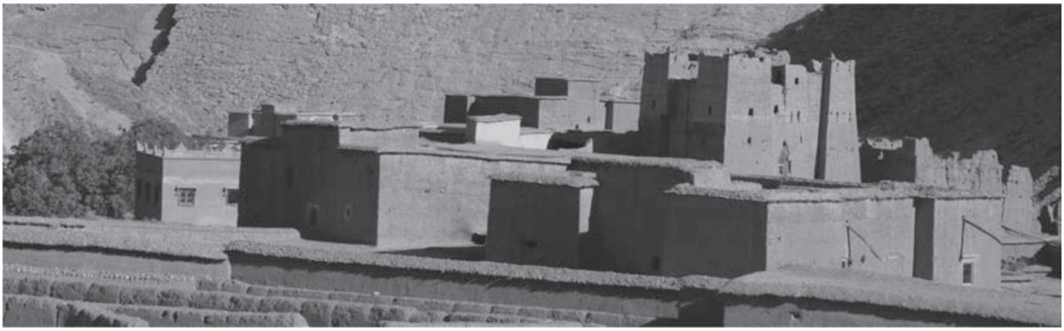

Figure 9. Detail of Znag (Sector 4). Picture: Alberto Montiel.

forms prepared before the field work and based on previous catalog experiences has been barely necessary to organize the information; pdf forms (Fig. 2) will permit, once the compilation generated in Morocco is organized, treatment through any suitable database or representation system which facilitates the search among the immense material compiled.

Tighermatin (sing. tighremt) have been identified and classified according to their typology: one of the most common is the one with a central corridor and stairs creating an axis with the main entrance, with rooms (generally six per floor) on each side of the corridor and towards the façade (Fig. 3). Several examples have been found in Agarzaka and in Ighrem Aqdim. This type is repeated in some barns in Issoumar but on a smaller scale. Another frequent type is formed by stairs next to one of the towers, which often changes its size with regard to the rest (Fig. 4). In these cases we found a different interior organization, with a transversal corridor with respect to the façade which communicates common space with private rooms. Examples can mostly be observed in Agout el Fougani. In both cases and therefore in most of the identified buildings, there is no central courtyard, considered to be the usual typology in several studies in nearby valleys mentioned at the beginning of this work. According to Terrasse (1938), the absence of courtyards is more common in the mountains than in zones with better climatology. The only tighremt identified that follows this typology is located in Imzilene.

The schemes described are generally referred to as single-family tighermatin although there are many tighermatin for more than one family. The most significant example is a tighremt in Bou Taghrar,(Figs. 5–7) due to the antiquity of its construction, its constructive details and because the settlement grew around this building located in a central and strategic point in the valley.

Its interest is remarked in the rich exterior decoration made of adobe, in the tower (borj in Berber) and in the parapet which means the end of the three lower levels realized with rammed-earth as well as it is used as an example to reflect the evolution that these buildings are suffering. There is clear evidence of the building's deterioration (loss of a part of two of the towers, loss of the top of the parapet, besides the general deterioration of the wall section and some sun-dried bricks), provoked by neglect. In fact, the tighremt has suffered a process of evolution and transformation by adding, on one hand, a construction against the main façade, keeping the old part as a warehouse, and, on the other hand, another construction made of concrete blocks that have distorted the building's appearance. (Fig. 6)

These transformations are supplied by elements which do not suit traditional architecture, such as basements made of concrete or drain pipes made of PVC. Despite intending to resolve, somehow, the pathologies that have appeared along time, they do generate often irreversible transformations.

4 CONCLUSIONS

As mentioned, the result of this first workshop must be considered as an approach towards a bigger project whose previous actions are defined and whose conclusions will be able to establish future lines of intervention. This first phase cannot be concluded, in especially in connection with this group dedicated to heritage that we have introduced, because not having completed the catalogue on the high part of the valley, necessary in order to get final conclusions about patrimonial buildings as a whole, their state of conservation, the most common typologies and in short, conclusions that broaden speech and knowledge about a certain geographic area.

However, the great quantity of identified buildings brings some first reflections, basically about the most used typologies, which cannot be considered definitive until completing the work. Compact buildings have been identified, which in most of the cases, stresses the inexistence of a central courtyard and repetition of schemes introduced before, above all the second one in which the location of the staircase permitted smaller variations. A large number of one-hundred-year-old buildings have been registered during our field work, Ighrem Aqdim being especially remarkable due to the great number of forms filled in and also the existence of many recent constructions using the same traditional technics: rammed earth and adobe.

In this context, adobe (tub in Berber) is often used to finish the top of the buildings; however, the possibilities this material offers to realize decorative elements are not exploited in the valley, except for small remarkable parapets, which can be found in the tighremt in Bou Taghrar's or in El Fouqani's (Fig. 7 and 8). It should be noted that the relation between the use of adobe and wealth is direct, as the buildings with decorative figures b e long to the most influential and powerful families, the only ones who can afford it.

The state of deterioration in ancient buildings is generally linked to its scarce use or neglect, aspects in which the cost of periodical maintenance is indispensable. When receiving public funds in order to rehabilitate or conserve buildings is unthinkable and where means are poor, this project we are undertaking, which combines heritage, landscape and tourism, may have, as a result, not only one more step in our individual learning process, but a new look for the local population at their own heritage, which leads to the acknowledgement of the values of earth architecture.

The changes in way of life and organization of families is translated, generally, in transformations in the tighermatin by adding new volumes, leaving the original ones and settling down in the newer, more comfortable ones (Fig. 9). A lack of maintenance is the origin of the deterioration of the tighremt. However, it also means that it is possible to recuperate the original units, which have not been transformed yet.

We consider it, therefore, a great opportunity to preserve and value a heritage with priceless cultural and architectural wealth, which is immersed in a crucial moment with respect to the neglect of the buildings for new typologies and materials that risks its future preservation and the increase of tourism with no constructive criticism, based on trivialization, that might lead to an end of such wealth, as has occurred in many other places in the world (Pié in press). Our aim is not just to catalogue and extend information related to this heritage, but to create viable proposals for sustainable touristic development through the analysis of landscape, urban development, and society. It is a long way we have just commenced, which needs the collaboration of many institutions to succeed.

NOTE

This paper is a part of the scientific research project: *Paisaje y patrimonio en el sur de Marruecos: Propuesta para el desarrollo de modelos de turismo responsable* (AP/050921/11), granted by the Spanish Agency for International Cooperation and Development.

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Contemporary earth houses and evolution models in the Mgoun Valley, Morocco

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ABSTRACT: The Mgoun Valley displays today a complex built landscape that includes a number of vernacular building types as well as contemporary buildings. Vernacular building typologies that fulfilled the representation and fortification needs of a past society has evolved into a contemporary model, in a remarkable process of abstraction that has done away with most monumental referents. This process has produced both material and functional mutations and changes in meaning, as a result of the accommodation to new housing needs and standards. The present paper is a part of the scientific research project: P*aisaje y Patrimonio en el Sur de Marruecos*: *Propuesta para el desarrollo de modelos de turismo responsable* (AP/050921/11), granted by the Spanish Agency for International Cooperation and Development. The text tries to describe, from an approach that focuses on the study of specific building types, the formal changes brought by the evolving process that the architecture of this Pre-saharan valley has gone through in the recent past.

1 INTRODUCTION

The Mgoun Valley, located on the Southern slope of the Moroccan High Atlas, displays an important heritage of earth architecture that has managed to adapt to the environment and establish a material link to it. It seems a remarkable example of the human activity coping with environmental challenges and succeeding at developing an evolving a local building culture that satisfies contemporary housing needs.

Today´s built landscape of the Mgoun Valley contains a complex architecture where evolving vernacular earth buildings co-exist with new reinforced concrete buildings. In this context a particular building type exists that reflects an evolving process from the traditional fortified farm: many formal references have been discarded and retaken over time in a singular abstraction process. The end result is an architecture that has managed to keep its original symbolical meaning while accommodating to new uses and cultural standards.

When we look at the landscape of the valley today we do not see a place anchored in the past. Rather, the built landscape shows a variety of building types past and present, evolved over time, that share the same "genetic code." The first thing that strikes the eye is the presence of the *tighremt* (plur. *tighrematin*), the traditional fortified farm, built in rammed earth, provided with four lean corner towers, expressing its defensive nature and its social and political significance (Montagne 1930, Laoust 1934, Terrasse 1938, Jacques–Meunié 1962).

This original type evolved first by diminishing the height of the towers and enlarging its size, and then by eliminating them altogether, creating two parallel bays that would eventually become three; primary volumes were thus created. A preliminary hypothesis of the process described is shown in Figure 2.

Figure 1. Panoramic view of Äit Tourmet.

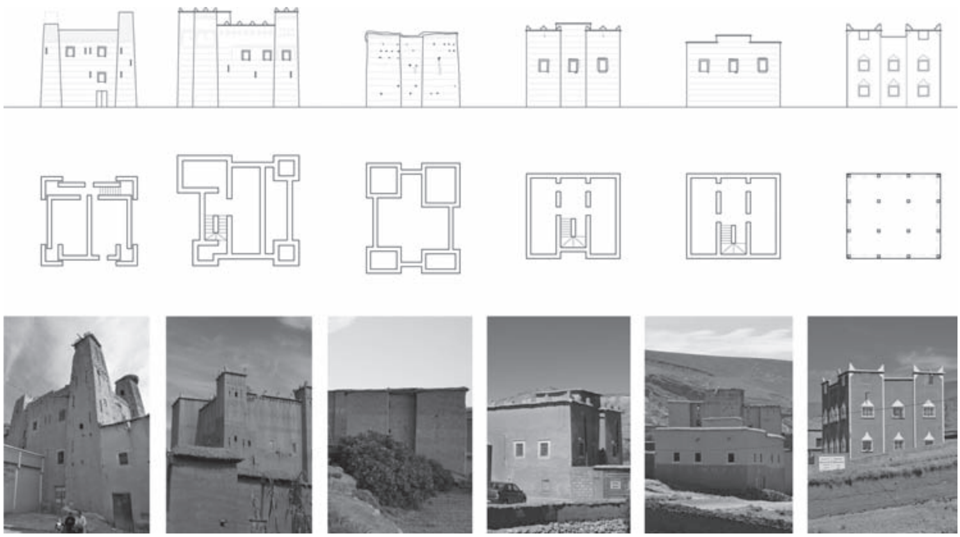


Figure 2. Hypothesis of evolution, from left to right: a. *Tighremt* in Bou Taghrar; b. *Tighremt* in Fouqani; c. *Tighremt* in Bou Taghrar; d. House in Agouti; e-f. Houses in Alemdoune.

Figure 3. Location of the fortified farms (*tighrematin*) under study.

2 METHODOLOGY

Research focused on the formal analysis of the traditional, oldest building type identified in the area (the *tighremt*), and on its plausible evolution as shown by local architecture. A number of buildings were selected (see Fig. 3 for their location) that represented local types belonging to different stages in a line of formal evolution. Pictures and measurements of each building were taken on site in order to compare data as objectively as possible. Since the vernacular construction technique is rammed-earth, dimensions were recorded using constructive parameters: the number of wall sections was used as measurement unit (section meaning that portion of a rammed-earth wall formed in any one completely filled form which has been rammed to capacity, and the form removed).

3 TYPOLOGY

3.1 *Type I*

Type I is the traditional fortified farm characteristic of the XVIII and XIX Centuries. The building documented was a *tighremt* located in the valley near Bou Taghrar (Fig. 4), close to the encounter of the Imeskar and Mgoun rivers. A similar building is shown in Figure 5.

3.1.1 *Formal analysis*

The type is characterized by:

- The presence of towers with a talus (high T/t relationship).
- Towers are tall and lean (high T/t relationship).
- Towers protrude over the walls.
- The top of the walls and towers is built in adobe (between 1/3 and 1/4 of the total height).
- Towers are narrow compared to the walls.

Figure 4. Type I: Tighremt in Bou Taghrar.

Figure 5. Elevation of the *tighremt* shown in Figure 4. Height is given in meters and in number of wall sections.

3.1.2 *Functional analysis*

Vertical communication is done at a side of one of the towers. The building is three storeys high plus a transitable flat-roof. Nowadays all floors are used for storage. Originally the ground floor was used as stable, upper floors were used for lodging. Paradoxically, towers had no remarkable domestic function but storing grain, in spite of their imposing outer look. The narrowness of the space does not seem to allow other uses.

3.2 *Type II*

Type II is a first stage in the evolution of the traditional model that may be dated in the first half of the XX Century, roughly the years of the French Protectorate (1912–1956). Formal and functional changes evolved from Type I can be seen. The building documented is located in Aït Khalifah (Fig. 8), a village located on the banks of the river Aït Toummert. Figure 11 shows a building of similar characteristics.

3.2.1 *Formal analysis*

The type is characterized by:

- A notable reduction in the talus of the towers (relationship $T/t \approx 1$).
- The flattening of towers (lower T/h relationship).

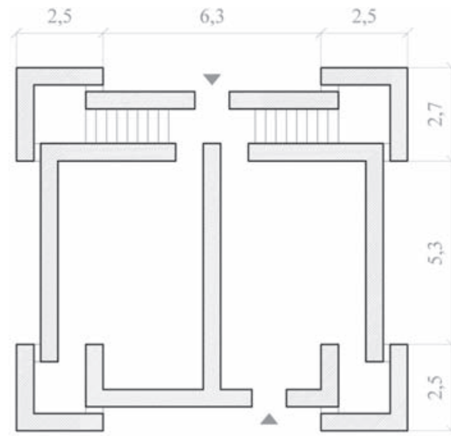
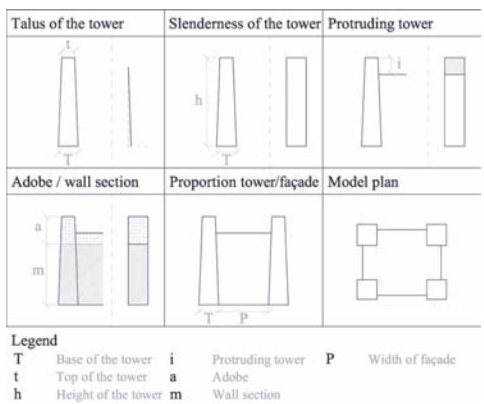


Figure 6. Plan of the *tighremt* shown in Figure 4. Measurements are given in meters.

Table 1. Dimensional relationship of Type I.



- Towers barely protrude over the wall.
- Minimal presence of adobe at the top of walls and towers (about 1/15 to 1/20 of the total height.)
- Towers and walls are the same width ($T \approx P$).

3.2.2 *Functional analysis*

The building is three storeys high plus a transitable flat-roof. Nowadays all floors are used as storage. Originally the ground floor was used as stable, upper floors were used for lodging. No doubt the most remarkable feature of the type is an enlarging of the towers that allows, when compared to Type I, the use as lodging of the space previously used as storage.

3.3 *Type III*

Type three is the second stage in type evolution. An additional formal simplification has taken place as shown by the disappearance of the

Figure 7. Type I: *Tighremt* in Bou Taghrar, not far from the building shown in Figure 4.

Figure 8. Type II: Tighremt in Aït Khalifa.

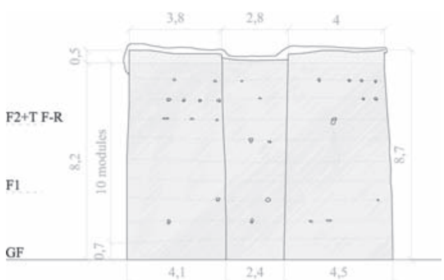


Figure 9. Elevation of the *tighremt* shown in Figure 8. Height is given in meters and in number of wall sections.

towers, substituted by parallel bays, although their symbolism remains in the design of the main façade. The building documented is located in Hdida (see Fig. 12) and was built in the 1960s. Figure 11 shows a building of similar characteristics located in Aït Youb.

3.3.1 *Formal analysis*

The type is characterized by:

- The disappearance of the talus of the towers (relationship T/t = 1).
- Towers do not protrude over walls.

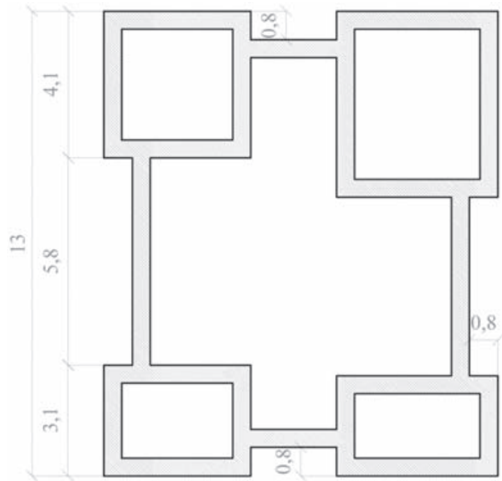


Figure 10. Plan of the *tighremt* shown in Figure 8. Measurements are given in meters.

Table 2. Dimensional relationship of Type I.

Talus of the tower	Slenderness of the tower	Protruding tower
t, T	h, T	i
Adobe / wall section	**Proportion tower/façade**	**Model plan**
a, m		

Legend

T	Base of the tower	i	Protruding tower	P	Width of façade
t	Top of the tower	a	Adobe		
h	Height of the tower	m	Wall section		

Figure 11. Type II: *Tighremt* in Aït Khalifa, not far from the building shown in Figure 8.

Figure 12. Type III: House in Hdida.

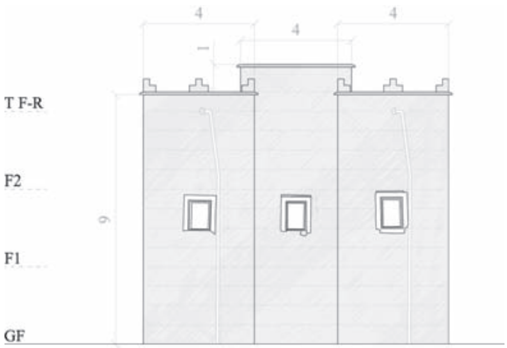


Figure 13. Elevation of the *tighremt* shown in Figure 12. Height is given in meters and in number of wall sections.

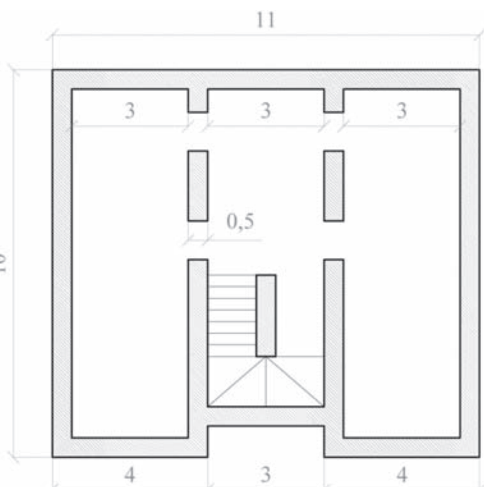
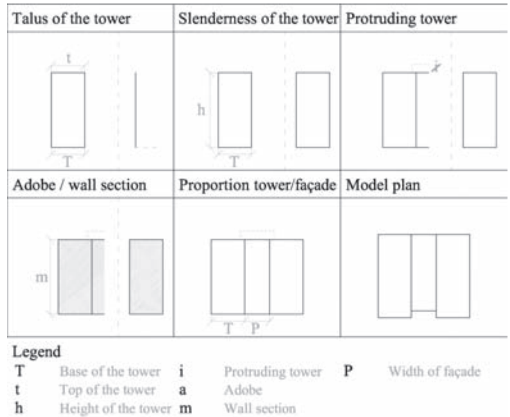


Figure 14. Plan of the *tighremt* shown in Figure 12. Measurements are given in meters.

Table 3. Dimensional relationship of Type III.



- Towers and walls are of equal height and the outer structure of the staircase becomes apparent.
- No use is made of adobe in towers or walls.
- Towers and walls are the same width (T ≈ P).

3.3.2 *Functional analysis*

The building is three storeys high plus a transitable flat-roof. The type is the final step in constructive simplification: towers are eliminated as such and grouped forming three bays clearly marked, the central one serving as communication axis, both horizontally and vertically, the side ones serving for a variety of purposes (storage, lodging, reception).

4 DISCUSSION

Formal and functional comparison of a number of selected buildings in the Mgoun Valley has allowed the identification of three building types evolved from a traditional model, identified as type I. Type II and III buildings share, so to speak, the same genetic code as Type I but would belong to different moments in an evolutionary sequence. The following changes have taken place over time:

- The talus of towers, present in Type I, is gradually lost. Type III does not exhibit it anymore.
- Towers, originally lean, become larger as a result of changes in its function (being used for lodging instead of for stables.)
- Type I towers, taller than the walls and protruding over the façade, have a symbolic defensive character. Towers are gradually lost in the process of simplification.
- On the constructive side an evolution takes place as well. Type I exhibits adobe on the top third of the towers and walls, forming ornaments and

Figure 15. Type III: House in Aït Youb.

Table 4. Relationships between types.

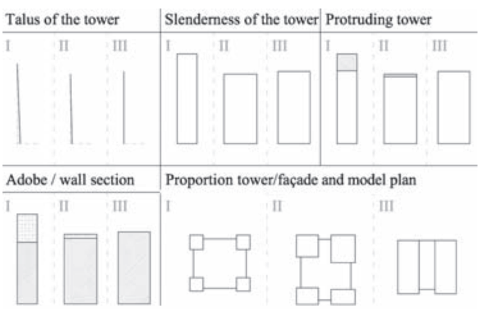


Figure 16. Reinforced concrete house in Alemdoune.

drawings. This constructive feature disappears and ornament becomes totally absent or is limited to the fence of the terrace.

– The most important evolution is a change in plan that involves a change in the relative size of walls and towers. The lean towers of Type I evolve into the larger Type II towers to finally become, by pairs, two lateral bays protruding over the main façade as a reminder of the original towers. These formal mutations come hand by hand with chan-ges in the use of space. Type I towers, important for their symbolic value, were too narrow for any use but storage. Their widening and their eventual simplification as bays allow new uses of the space.

Data show then that there seems to exist a continuous evolutionary process in the typology of earth architecture that has managed to preserve part of the formal and constructive heritage of the traditional *tighremt* (López 2004, p. 38.). But an additional element should be added to the equation. Reinforced concrete building became popular in the last quarter of the XX Century and is now part of the evolutionary chain. The introduction of this technology has broken the long existing link between constructive process and earth construction traditions of the area. It has produced also an illusory return to the formal origins by emulating elements of historic symbolism.

5 CONCLUSIONS

The new reinforced concrete houses, built in most cases with the money earned by owners working six months of the year in other parts of the country, display its corner towers, now barely a reminder of the old, imposing ones. Why do reinforced concrete buildings in the Mgoun Valley area display corner towers? There is no war anymore, and the modular system used in rammed-earth construction might be changed, if desired. Something other than technology seems to be at play. If looked as the last product of an evolutionary process, reinforced concrete houses remind us that "nothing, of any matter, comes out of nothing" (Quatremère de Quince, 1792). This Darwinian look shows us the decoration and formal reminiscences of new buildings as a complex process of hyper-real nature that transcends the simple decorative effect. A symbolic procedure that makes resource to an array of imaginary of traditional signs rooted in the collective memory to mimic its significant, leading to the confusion between the represented and its representation. The result is an architectural landscape simulated and authentic at a time, copied, remembered.

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Lunch in the domes of Tierra de Campos (Palencia, Spain)

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ABSTRACT: Las Cúpulas is a restaurant located in Tierra de Campos, in the village of San Cebrián de Campos in the Province of Palencia (Spain). It's a new building built with superadobe (earthbags). This technique allows the owner to participate in the building construction without previous experience, how to build it on your own using nearby materials: the earth from your own ground.

1 INTRODUCTION

"Buenos días. Llamo para pedir un presupuesto porque quiero hacer un edificio de restaurante, también lo quiero hacer con superadobe, ¿sabes lo qué es eso?"

"... Si..."

Con esta llamada telefónica comienza la gestación de este proyecto en tierra.

2 OBJETIVOS DEL PROYECTO

Las premisas del proyecto fueron: diseño de un edificio para restaurante de unos cincuenta comensales, aseos, cocina y zona de servicio con almacén, cuarto de instalaciones y baño. La técnica constructiva: superadobe.

Los aspectos que se quisieron resolver con este sistema fueron sobre todo económicos, realizar un edificio de bajo coste, una construcción sencilla den-tro de una filosofía cercana al "do it yourself", de hecho los promotores lo entendían como un proceso de autoconstrucción, no podrían hacerlo todo ellos pero si gestionarlo y ejecutar ellos mismos lo máximo posible. Una construcción económica y a la vez de altas prestaciones, arquitectura sostenible "low tech".

3 ANÁLISIS Y ANTECEDENTES

El superadobe, "earthbag", es una técnica constructiva a partir de sacos o largos tubos de lona, tela o rafia rellenos de "adobe", de ahí su nombre. Pero esta definición en alusión a su nombre no es realmente exacta, el saco o tela hace las veces de encofrado perdido para realizar en su interior un relleno de tierra prensada o apisonada, en realidad tapial no adobe.

Los sacos se van disponiendo en hiladas verticales creando los muros de carga o simplemente el cerramiento según los casos.

La técnica se remonta a las construcciones de emergencia realizadas en tiempos de guerra, refugios, barreras y trincheras de protección, se realizaban con sacos de tierra apilados y atados entre sí con alambre de espino, desde ya antes de la Primera Guerra Mundial.

En Alemania, desde 1977 en el Instituto de Investigación de Construcciones Experimentales (FEB: Forschungslabor für Experimentelles Bauen) de la Universidad de Kassel, se han estado investigando prototipos de viviendas antisísmicas basadas en la construcción con largos sacos continuos rellenos de tierra arcillosa, pómez o arena. Algunos muros se fijaban verticalmente con cañas de bambú, en otros casos los independizaban de los empujes de las cubiertas realizando una estructura exenta de madera, y finalmente los revestían e impermeabilizaban mediante varias capas de pintura a la cal.

Pero la técnica de la que los promotores habían tenido conocimiento es la que el Arquitecto iraní-

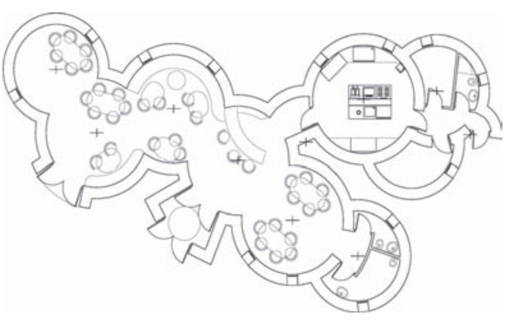

Figura 1. Planta del restaurante.

Figura 2. Vista trasera del edificio. (Autor: M. Macho).

americano Nader Khalili (1936–2008), inspirado en las construcciones tradicionales del desierto, había desarrollado en California. Basado en los sistemas estructurales del arco y la bóveda desarrolló la construcción con superadobe, en principio como solución para dar cobijo y vivienda en las situaciones de emergencia y desplazamiento de personas, pero proponiéndolo también como un sistema de vivienda permanente capaz de cumplir las normativas más exigentes. Viviendas de bajo costo, de autoconstrucción, respetuosas con el medioambiente, resistentes a los terremotos y cuya forma más básica es el domo o cúpula realizada a partir de hiladas de superadobe que se unen entre sí mediante alambre de espino.

Figura 3. Vista de la fachada principal desde el pueblo. (Autor: M. Macho).

4 EL DISEÑO

El diseño volumétrico del edificio estuvo completamente condicionado por el sistema constructivo: cúpulas, una o varias, y a partir de ahí de su geometría, la pregunta fue ¿cuál es el máximo diámetro que nos atrevemos a construir?

Por otro lado la forma de la parcela ayudó en esta decisión, es estrecha y alargada. Así, la planta el edificio se configura como un crecimiento orgánico a base de círculos que podrían continuar y ampliarse indefinidamente, pero utilizando únicamente dos tamaños, dos medidas de diámetro interior: 4.80 m y 4.00 m (Figs. 1 and 2).

Una macla de cinco cúpulas configuran el comedor, estas giran sobre sus centros abriendo un juego de visuales transversales en el espacio interior que evita la repetición espacial y la existencia de un solo eje visual. El acceso principal se sitúa en la segunda cúpula y se gira respecto al eje de la calle principal desde el pueblo (Fig. 3). También desde

Figura 4. Vista sobre los centros de los arcos. (Autor: P. Diez Rodríguez).

la segunda cúpula del comedor se tiene acceso a la cocina, que se diseña en una cúpula más, y a ésta se le adosan otras dos semicúpulas para alojar la zona de servicio y un acceso secundario. En el otro extremo de las cúpulas del comedor se sitúa otra en la que se instalan los aseos. En total son nueve cúpulas.

Las cúpulas del comedor se cierran con óculos de iluminación y ventilación, y en las fachadas se distribuyen una serie de ojos de buey a la altura de los comensales. Se diseña también un acceso directo desde el comedor a la futura terraza (Fig. 4).

5 LA TÉCNICA Y EL PROCESO

Las cúpulas se levantan con una proporción gótica, utilizamos un doble radio que marca la posición de cada una de las hiladas de superadobe, un arco tiene origen en el centro y otro en el extremo. Así cada hilada vuela unos centímetros sobre la inferior, en realidad vamos formando una falsa bóveda por aproximación. (Fig. 4).

La intersección entre cada pareja de cúpulas del comedor produce un arco gótico teórico, que también se construye por aproximación de hiladas.

Todos los muros del edificio crecen simultáneamente, fila a fila, y los empujes se contrarrestan entre sí. (Figs. 5 and 6).

El momento más peligroso de la construcción es precisamente cuando llegamos a la altura de los hombros de la bóveda, el voladizo es muy grande y los empujes no están completamente equilibrados, las hiladas superiores podrían volcar hacia el interior y es necesario apuntalar por seguridad.

Para la realización del superadobe utilizamos una mezcla de tierra y cemento (10:1) y para los acabados morteros de cal. Realizamos varias pruebas, ensayando en el laboratorio la mezcla final. (Fig. 7).

Figura 5. Proceso de construcción. (Autor: P. Diez Rodríguez).

Figura 6. Proceso de construcción. (Autor: P. Diez Rodríguez).

Figura 7. Pruebas de dosificación. (Autor: P. Diez Rodríguez).

El proceso: posicionamos el centro de la fila que vamos a ejecutar utilizando los compases, allí mismo rellenamos el saco con la mezcla según se va posicionando y a continuación se compacta manualmente.

Posteriormente se sitúa el alambre de espino e introducimos varilla roscada para "coser" las filas entre sí al tresbolillo. Así una fila tras otra.

Los cargaderos de ventanas y puertas de paso se resuelven mediante arcos de descarga, una vez más sigue siendo la forma la que trabaja. (Fig. 8).

Una vez cerradas las cúpulas se realizan los revocos exterior y al interior utilizando fibra para evitar las fisuras. Se aplica una primera capa o trullado para regularizar los bordes y canales entre sacos y se realiza una segunda capa de acabado final, en la que se introduce la fibra. (Figs. 9 and 10).

Figura 8. Colocación de cimbras para huecos de paso. (Autor: P. Diez Rodríguez).

Figura 9. Proceso de revoco exterior. (Autor: P. Diez Rodríguez).

Figura 10. Detalle del muro. (Autor: P. Diez rodríguez).

Todos los encuentros se impermeabilizan mediante una pintura asfáltica como refuerzo.

6 OTROS PARÁMETROS DE SOSTENIBILIDAD

Otro de los parámetros que se ha buscado con el proyecto es reducir lo máximo posible el consumo de energía. Para ello en primer lugar contribuimos de una forma estática, con la orientación del edificio, que cierra los paramentos al norte y los abre al sur.

Al ahorro energético contribuye también la inercia térmica de los muros.

Por último, el sistema de calefacción-refrigeración que se proyecta para el restaurante es un sistema de suelo radiante-refrigerante mediante un sistema de Aerotermia.

Este sistema, a través de una bomba de calor aerotérmica captura la energía del exterior en forma de calor y reduce el consumo.

7 COMER EN TIERRA DE CAMPOS

El restaurante se ubica en San Cebrián de Campos, en la Provincia de Palencia, en Castilla-León, en el centro norte de España, en la meseta, en Tierra de Campos, una zona que se reconoce por su arquitectura tradicional de tierra, palomares, casas, casetas, casonas y palacios están construidos por adobes y tapiales, puedes encontrar multitud de tipologías.

La construcción con tierra es una seña de identidad de esta zona.

¿Por qué esta vez construimos con superadobe? ¿Qué es lo que atrajo tanto de este sistema a los propietarios del restaurante para que fuera una premisa del proyecto? Supongo que la facilidad de la técnica que la hace accesible sin tener experiencia previa. Los propietarios lo tuvieron claro: añadir una variedad más en la carta del menú.

Figura 11. Detalle exterior. (Autor: M. Macho).

Figura 12. Detalle del interior. (Autor, M. Macho).

8 CONCLUSIONES

No es habitual participar de una forma efectiva en un proceso de autoconstrucción, esta implicación que ha tenido el cliente, sin tener experiencia previa, ha sido educadora en cuanto que él mismo ha sido consciente de cada una de las implicaciones de las decisiones tomadas, buscando en todo momento como hacer más sostenible el edificio.

Por otro lado, dado el resultado obtenido la apuesta por esta técnica, propia de situaciones de emergencia, pone de manifiesto la enorme capacidad de desarrollo que tiene aún por explorar.

Esto no solo desde un punto de vista técnico sino también plástico. (Figs. 11 and 12).

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Constructive systems in the Spanish North-western area

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ABSTRACT: This paper aims to review some constructive techniques nowadays forgotten but which were some decades ago very important, both in the life of those using them for centuries as in documents and Art´s works of every kind. The economic situation, always quite meagre, fostered the use of the available resources, so avoiding long journeys. The use of local materials means these buildings seem to spring from the soil sustaining them, a sensation that grows when beholding the walls, done out of cereal´s stem or hay´s talk bundles braided on wooden strips, or with corncobs filling a double partition. Also seem to grow from the land these which heaped earth into an elemental wooden´s structure, as well as those closing their gables with fragments of grass or turf, or those freely mixing adobe and rammed earth, or unfired pieces tied to the fired ones functioning as buttresses of mixed walls.

1 ELECCIÓN DEL ASUNTO

Aunque la construcción con tierra está presente en todas las regiones de España, mucho más allá de lo que recogen los textos dedicados a este asunto, que se limitan a citar La Alhambra, Tierra de Campos, cuencas de ciertos ríos y alguna zona más, poco lluviosa, nos ocuparemos sólo de la que se encuentra en el cuadrante noroeste español donde existe una enorme cantidad de técnicas, deteniéndonos, sobre todo, en las tramas de ramas tejidas o en las realizadas con listones, trenzas de cereal y varillas.

Que su empleo ha sido habitual lo constatan los datos recogidos secularmente en los documentos y las obras de arte de todo tipo, donde se representan frecuentemente.

2 ESPACIO FÍSICO Y POSESIÓN DE LA TIERRA

El espacio nor-occidental ha sufrido, durante siglos, una intensa emigración en las distintas áreas que lo componen, motivada por diversos factores. En Galicia, Asturias, norte de León, Palencia, Burgos o Cantabria, la orografía, la escasa comunicación con otras regiones y el pequeño tamaño de las parcelas impulsaron la salida de muchos habitantes, obligados a buscar la subsistencia fuera de los minifundios que constituían gran parte de esta zona mientras que en la cerealista de las grandes estepas también la pobreza empujaba al exilio. En una y otra quedaron levantados unos edificios a los que se pretendía volver, hecho que nos permite examinar cómo fueron realizados.

3 TIERRA Y VEGETALES

3.1 *Encestados*

La tradición de construir con tierra sobre mallas de ramas tejidas tiene un gran arraigo en todo el norte español, aunque su rastro en menos evidente en las provincias vascas o las catalanas, donde los edificios fueron adquiridos por la cercana burguesía, que los alteró mucho, sobre todo por el macizado de piñones.

Estas modificaciones voluntarias apenas se producen en las construcciones dejadas por los emigrantes, a las que desean regresar, pero sí las que fruto del abandono hacen que hoy estén a la vista los diferentes paneles de encestado existentes desde Galicia al extremo occidental de Vizcaya, es decir, la zona que analizamos, donde se colocan formando balconadas y galerías, los extremos de éstas, los cerramientos de hastiales o piñones y las paredes laterales, tabiques y divisiones internas de todas clases.

Aunque casi fuera del marco de nuestro análisis, que se circunscribe al área existente entre el paralelo 40 y la costa y los meridianos 3º a 9´5º, ambos al oeste, los encontramos en la comarca vizcaína de Las Encartaciones bajo el nombre castellano de *verganazo* y el vasco de *otaezia* y también en Soria y en Burgos en los *encestados* que constituyen medineras, interiores y grandes chimeneas cónicas de varas tejidas.

La insólita relación entre el fuego y el uso de las ramas trenzadas y cubiertas de barro se da también más al norte para construir las campanas suspendidas sobre el hogar central, como la que vemos en Tudes, municipio situado en el valle de Liébana.

Figura 1. Encestado revocado en Cantabria.

Figura 2. Encestado sin revocar en Potes.

Fruto de la escasa economía, que forzaba a utilizar los materiales más próximos, encontramos varas tejidas separando propiedades, formando puertecillas, cimentando pequeños refugios de pescadores alzados sobre las *pesqueiras*, impermeabilizando conducciones para el riego de las huertas y realizando los canastros, cabaceiros, hórreros y palleiras, en los que se almacenará el producto de las cosechas.

Sobre la construcción de estos pequeños almacenes agrícolas se ocupan muchos autores, sean clásicos, medievales o ilustrados, así como documentos catastrales del siglo XVIII y XIX, siendo los más interesantes los emitidos por los *Agrónomos Latinos*, los de Alfonso X en sus *Cantigas*, que incluye una miniatura con tres hórreos de tablas, los recogidos por Luis Alfonso de Carballo en 1613,los Diarios de Jovellanos, los Catastros de Ensenada o el texto de Caro Baroja *Granaria Sublimia, Horreum Pensile*, también sobre este asunto.

La escasez de espacio disponible no nos permite incluir ni la abrumadora cantidad de datos escritos ni la enorme cantidad de imágenes obtenidas en la zona, sólo parcialmente revisada, en las que se ve, claramente, las ramas revocadas siempre que formen parte de las viviendas, pero dejadas al descubierto si cierran las partes del edificio que han de estar bien ventiladas, como heniles o pajares.

El uso de las varas tejidas penetra hacia el sur hasta unos 130 kilómetros de la costa. Hay todavía paredes de encestado en Carvajal de La Legua, a escasos metros de la ciudad de León y en varias zonas de Rioja casi con la misma latitud, unos 42´5º pero al oriente ya de nuestro análisis, además de en comarcas asturianas, cántabras o palentinas donde el empleo del *sietu, xardu, zarzo, costanilla* o *encestado* era habitual.

3.2 *Listones y tierra*

Utilizar listones en vez de ramas tejidas es otra posibilidad para la construcción tradicional noroccidental en cuanto la incipiente especialización de las zonas madereras lo permite, facilitando el uso de paneles ligeros para cerrar balconadas y galerías o realizar particiones interiores, sobre todo en Asturias y en Galicia.

El manejo más rápido de los listones consigue muchas aplicaciones. Lo encontramos en los fondos de los balcones y en sus laterales, así como en tabiques sencillos o dobles, colmatando entonces el vacío entre las hojas con variados materiales como desechos de construcción y agrícolas o mazorcas desgranadas, siendo éstas las más características de varias zonas asturianas donde el *taruco* es un distintivo peculiar, mientas que el relleno de paja y barro, conocido como *palla-barro,* es más utilizado en Galicia y en El Bierzo, tanto para llenar el espacio hueco del tabique doble como para cerrar las ranuras que quedan entre los listones una vez clavados en sus bastidores.

Figura 3. Pared de listón y mazorcas.

Figura 4. Pared exterior gallega de palla-barro.

Caamaño, en su obra sobre la arquitectura gallega nos recuerda que la *palla- terra es* un modo habitual de realizar el *banzado* con el que forman las campanas de las chimeneas.

La constante presencia de listones y cañas con revoco en la construcción española pasó a tierras andinas donde también se usaban, aunque desconocían allí el empleo de bóvedas y cúpulas. Pronto se obtuvo la *quincha culta* diseñada

Figura 5. Pared exterior de varillas y trenzas de centeno revocadas en El Bierzo.

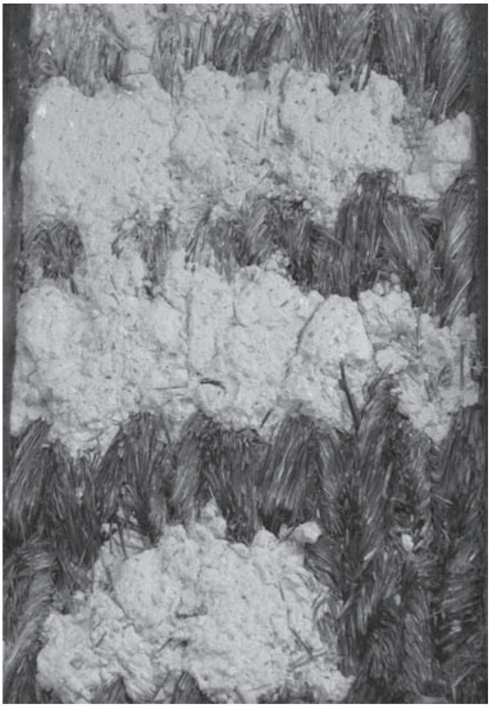

Figura 6. Detalle de la misma técnica en Galicia.

posteriormente no por los nativos sino por los arquitectos, fueran criollos, portugueses o españoles.

3.3 *Varillas, tallos y tierra*

También es habitual en varias zonas del noroeste emplear entramados cuyos vacíos se cierran con varillas rígidas sobre las que se tienden trenzas realizadas con caña de centeno, casi el único cereal que podía conseguirse en las tierras altas, muy utilizado para la construcción de paredes y cubiertas.

El mejor se obtenía en las parcelas de monte, las más elevadas, donde sus tallos se cortaban con la hoz, se almacenaban varios días en montones verticales para obtener un ligero secado y se llevaban a las *eiras* en las que separarían el grano del tallo utilizando para ello el *mallo* o *mayal*, formado por dos piezas de madera unidas con tiras de piel, que desgranaban las espigas sin romper la caña.

Ésta se trenzaba, humedeciéndola para trabajar sin peligro de rotura y se colocaba entre los barrotes del edificio. Luego se cubría con barro blanqueado a la cal.

4 TIERRA APILADA

La tierra apilada como técnica constructiva, aunque muy escasa hoy, también se utilizó en España, tal como podemos comprobar en la obra de Feduchi cuando se refiere a la realización de barracas en la costa levantina.

En el área que analizamos la encontramos en el Bierzo y en los Valles de Vidriales y de Liébana, presentando en éste varios modos de colocación. Simplemente amontonada sobre muros cuya parte baja fue realizada con mampostería o con adobe, va incluso colocada en robustos entramados de roble o castaño cerca de Potes.

5 PIEZAS

5.1 *Recortadas con vegetación*

Mucho más abundantes de lo que un observador distraído percibe, las hallamos en diferentes usos. Elevando paredes y cerrando piñones o rematando muros, están en El Bierzo, el valle del Bernesga, grandes zonas de Tierra de Campos, áreas de Soria, comarca de La Valdavia y otros muchos lugares.

Se encuentra también rematando refugios temporales de todo género, muchas veces desmontados al final de la temporada de pastoreo, lo mismo que se hacía con algunos cubiertos de teja ya que ésta implicaba la posesión del lugar, lo que no era el caso de pastores y zagales.

Figura 7. Tepes de turba sobre muro de tierra en el Valle de Vidriales.

5.2 *Recortadas sin vegetación*

También se usaban las piezas obtenidas de los suelos húmedos, utilizándolas para llenar los vacíos alojados entre elementos sólidos, como machones de adobe, en cercas y cerramientos, generalmente rematados por *tepes* o *tapines,* de turba, musgo, brezo o césped, o sarmientos, ramas, paja o lascas de piedra.

Se conservan en zonas aisladas del oeste como Santa Marta de Tera.

5.3 *Modeladas*

Aunque debió ser usual realizar piezas a mano, llamadas *glebas*, para utilizarlas en la técnica del *chamizo*, que las insertaban en un elemental entramado de ramas, cañas y palos, hoy no queda de ellas más que los recuerdos fotográficos de las precarias viviendas asentadas en los suburbios de la postguerra.

6 ADOBES Y TAPIAS

No tenemos espacio para consignar las amplísimas áreas donde se encuentran, solos o combinados entre sí. El adobe, cuyo origen etimológico es

Figura 8. Antiguo Hospital en Treviño, Burgos.

Figura 9. Palacio en Grajal de Campos, León.

egipcio, de donde pasa al copto y de éste al árabe que recoge este término y lo usa en España, se restringe en las zonas donde se utiliza la piedra, pero forma en ellas tabiques, hastiales o la capa más blanda en la que asentar cubiertas y tejados.

La expansión de este término, que abarca América de norte a sur y el mundo musulmán, desde el oeste de África al este de Filipinas, aconsejaría adoptarlo universalmente en aras de una mejor comprensión, basada ésta en la mayor precisión lingüística.

En nuestro análisis, el adobe está en los interiores de la media montaña, como sucede en Potes o en Cervera de Pisuerga. Abunda, algo más al sur, menos en Salamanca pero protagonizando la construcción en muchos lugares de León, Zamora, Palencia, Burgos, Soria, Ávila, Valladolid y Segovia, así como en zonas de Rioja y Navarra, casi fuera de nuestro estudio. Incluso, denominado *pezo* o *zoi*, en algunos caseríos vascos como el Caserío Urkitza, levantado en el siglo XVI que no ha sufrido muchas reformas. También en la comarca nor-extremeña de La Vera donde cierran los vacíos de los entramados que forman las viviendas más habituales.

Convive con la tapia en muchos lugares de Castilla y León, bien formando el piso superior sobre ella, bien encintando los paños de tierra apisonada.

El dominio de la tierra compactada dentro del encofrado que se denomina *tapial* es evidente también en grandes áreas castellano-leonesas, como el Páramo de León, las Tierras del Pan y del Vino zamoranas, la enorme Tierra de Campos

Figura 10. Monasterio de Las Huelgas, Valladolid.

extendida por León, Zamora, Valladolid y Palencia, la zona zamorana en torno de Ayoó y tantas otras de resonantes nombres como las leonesas en torno a Murias de Rechivaldo, las avileñas junto a Madrigal de las Altas Torres o las segovianas vecinas de Arévalo.

Muy variada, va desde la tapia monolítica, generalmente *calicostrada*, presente en distintos Palacios como el de Grajal de Campos, los de Pedro I o el de Toral de Los Guzmanes y en innumerables fortalezas de Castilla y León como el castillo de Palenzuela.

Abunda hoy todavía la tapia mixta encadenada, la más reciente de las elaboradas en el curso de los siglos, que coloca los cajones de tierra en la malla formada por machones y verdugadas, de piedra o de ladrillo, también presente en *Las Cantigas* del Alfonso X.

La abundancia de edificios realizados en la etapa musulmana, muy larga, no implica que ésta fuera la introductora de la tierra en Hispania. Lo prueba, sin duda, la arqueología de lugares como Hoya Quemada, Cancho Roano, Pintia o Guardamar de Segura. Lo corroboran los textos, con las *Etimologías* de S. Isidoro, las referencias al primitivo templo en Santiago de Compostela que da Pedro de Medina o los escritos de los primeros cronistas musulmanes. Lo certifica el sentido común, que muestra cuánto más fácil es encontrar edificios del siglo XV que hallar los levantados en etapas muy anteriores, sea en el norte, cristiano desde casi el inicio del milenio o en zonas del sur, musulmanas hasta fines del medievo.

Suponer que los introdujo la invasión musulmana es una frivolidad histórica, mayor para el caso de Francia, donde el Islam apenas estuvo tres décadas en alguna zona ocupado en batallar, por lo que sólo levantaría construcciones provisionales.

Es más sensato considerar la importancia que tienen los propios materiales a la hora de utilizarlos, motivando con sus propiedades las técnicas utilizadas en cada zona.

Figura 11. Tierra apilada y adobes cerca de Cubo de Benavente.

7 HETERODOXIAS

Hijas de la escasa economía y de la sabiduría constructiva surgen, como prolongaciones del terreno, muchas construcciones en las que se mezcla cualquier material que permita un ahorro de tiempo o de recursos.

Edificios de tierra que parten de las rocas, construcciones que combinan la tierra apilada y los adobes o tapias encadenadas cuyos machones se realizan con ladrillo al exterior y adobes en la parte interna, atrajeron siempre la atención de los artistas europeos.

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Earth's role on Moroccan High Atlas villages' urban evolution

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ABSTRACT: This paper presents the investigation carried out by the School of Architecture of Málaga (Spain) in a group of rural settlements in Mgoun Valley, located on the southern slope of the High Atlas Mountains in Morocco. The analysis presents the urban evolution of the habitat to be built and the dynamic transformation that has taken place in the last few years. The results indicate: a deterioration of the traditional earthen architectural models, the neglect of the integrated models for urban settlements and a change in the habits of the population of the territory. This study could be extrapolated, taking into account the local peculiarities, to other settlements in the High Atlas and the pre-Saharan valleys in the South of Morocco. In these areas, the negative aspects of globalization and process of cultural uprooting are producing the irreparable loss of local identity, and material and abstract values of the traditional habitat.

1 INTRODUCTION

The paper presents the first conclusions of a larger scale study which is being developed by the International Cooperating Group (eAM' Coopera) of the School of Architecture of Málaga in the pre-Saharan valleys in the southern slope of the Moroccan High Atlas. The paper is integrated within a global project that tackles several questions related to the preservation of traditional architecture, the habitat and landscape, with the aim of foster protection dynamics and models of responsible tourism which give a boost to local development.

The use of the earth as a building material and the models for establishing urban settlements are being altered in the last few years, giving way to constructive and urban types, away from tradition, which threaten to destroy a habitat with unquestionable cultural and landscape qualities.

2 GENESIS AND EVOLUTION OF THE SETTLEMENTS IN MGOUN VALLEY

On Figure 2 it is developed a theoretical model of the genesis and evolution of the settlements in Mgoun Valley. The first phase shows the initial conditions: the river bank (*oued*) which sets the reference framework of the following settlement, and the means for the penetration and traditional communication in the High Atlas valleys. The second transformation is linked to the process of the Berber population being sedentary and the birth of the habitat, that fulfills with the construction of the traditional fortified home

Figure 1. Mgoun Valley. High Atlas (Marocco). Author: J. M. López Osorio.

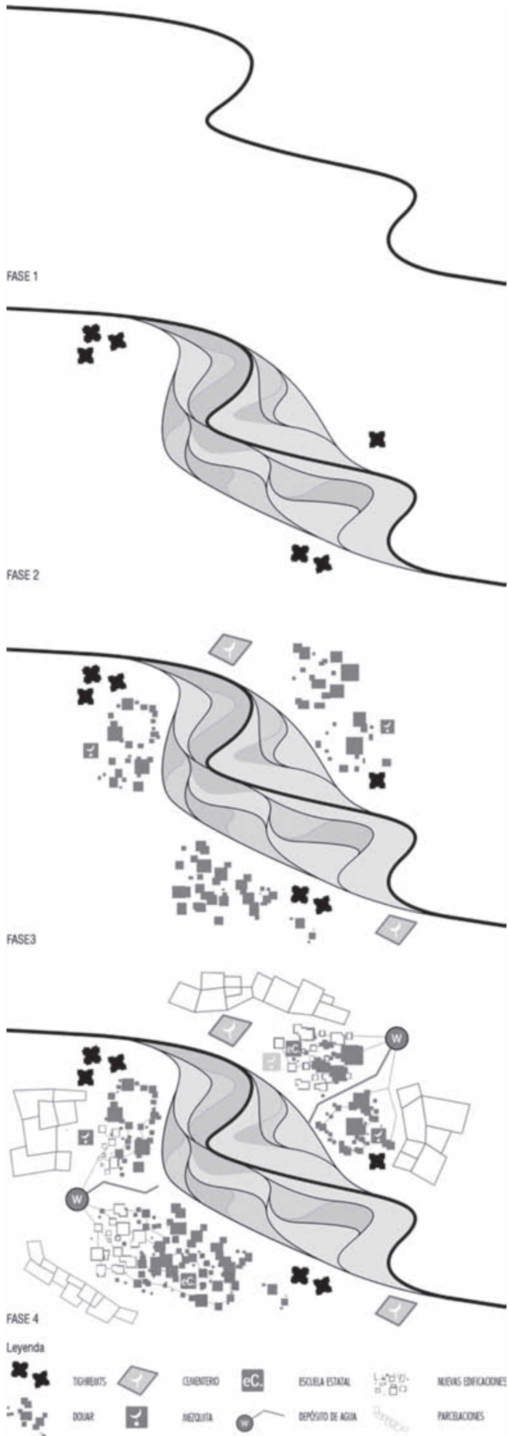

Figure 2. Theoretical model of evolution of the settlements in Mgoun Valley (Morocco). Author: A. García Ramos.

(*tighremt, p. tighrematín*). The human occupation entails the colonization of the river bank and its hydrological control for the creation of the oasis. The process begins with the collecting and canalization of the water in the high course by means of two irrigation ditches placed in both brooks. When the water gets to the area prepared for the cultivation, it branches into a set of secondary irrigation ditches that enable water supply to the different farming plot.

The third evolution phase happens once the defense needs disappear, when the scattered habitat is built up by means of new earthen buildings with a plain typology, where the four towers placed in the corners of the original *tighremt* disappear. The brand new settlement is also provided with equipment as the mosque and the cemetery, giving rise to the appearance of a traditional village (*douar, p. douars*).

The fourth evolution phase presents the current state of the settlement. Water collections from the river bank take place, by means of motor bomb that takes water to a peculiar reinforce concrete deposits, placed in the highest part of the slope, distributing the water into the houses by a canalization network. Likewise, new equipments as state schools and some official building are incorporated, replacing the old traditional mosques for new buildings made of reinforce concrete which depict the urban profile of the new settlements with slender minarets that did not use to exist in the original mosque. The process continues with the construction of new houses, also made up with reinforce concrete, which are disposed near the new gateways and are possible thanks to economic resources coming from emigration.

At last, it is worth highlighting a recent phenomenon which shows the new way of occupying the territory.

The lands placed in the medium slope, out of the cultivation plots, which belonged originally to the community, are undergoing a division and privatization process, showing new shapes or urban development. The initial occupation of the medium slope is carried out by building up a perimeter wall adapted to the terrain irregularities, built with soil walls (tabut), and showing a peculiar fragmented landscape and colonizing the original village surroundings.

3 THE STUDY CASE

It has been carried out a detailed study of one of the most characteristic sectors of Mgoun Valley, placed in the central area of the own *Oued* Mgoun and which constitutes a compact landscape unit of great patrimonial value.

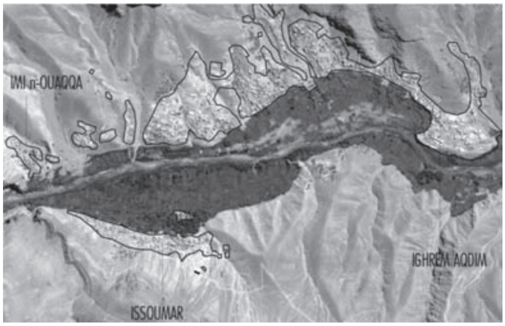

Figure 3. Aerial view of the study field. Own production based on Google Earth, eAM' Coopera.

The study field covers a group of three *douars*: Immi n-Ouaqqa, Issoumar and Ighrem Aqdime, which only share one oasis (Fig. 3) and which are, nowadays, in different transformation phases, despite having many common elements in their genesis and spatial organization.

The election of these settlements was influenced by their peculiar nature, their limited scale and current conditions in their evolution processes. That is possible because they are placed halfway through the high-altitude mountain nucleus, where transformations have not taken place yet, and the settlements in the lower areas of the valley, connected by asphalted roads with the major cities of southern Morocco, where the architectural and urban transformation dynamics began happening in the second half of the XX century.

Nowadays, the approaches to this sector are made by a 7 km-long land road that begins in the asphalted road which runs along the main arterial axis of the valley, starting in the town of Qal'at Mgouna, placed 24 km away.

The main productive activity, in subsistence regime, is agriculture and less important stockbreeding. In the last few years the development of mountain tourism, which has meant an important development in other areas of the valley, also affects this particular area, existing a *gîte d'etape* in the *douar* Issoumar which make possible the accommodation of visitors and hikers.

Next, there is a detailed analysis of each one of the settlements.

3.1 *Issoumar*

The *douar* Issoumar is placed in the left slope of the oued. Nowadays it is possible to get there by the land road that communicates with the rest of the valley, which has meant a strong urban growth.

The oldest nucleus is made up of a group of *tighrematin* built in the beginning of the XIX century,

Figure 4. Evolution of the settlements in Issoumar. Author: B. Marín Zofío.

which can be visited although they are not well preserved. The most dilapidated one accommodated five families that, since 2003, live in new construction buildings placed in the slope. They currently use their old houses as warehouse and stable for animals. The most southern *tighremt* is better preserved and is still inhabited, with water and electricity supplies since 2010.

The group of settlements herein described is currently placed inside the crop field, next to the first and oldest irrigation ditch that provides water to this area. This nucleus was originally placed over the water line, not occupying the cultivation crops. Later, trying to extend the oasis area, a new branch in the river bank made possible an extension of the cultivable area, fitting it in the original nucleus of the actual *douar*.

The cemetery is facing the south of this settlement and connected by a path running through the olive trees. It is demarcated by a soil wall which also has an entry from the main land road. It is also preserved a traditional mosque build of earth, only with a prayer room with a terraced cover. The state school for children under 6 years old is placed next to the mosque, and has two classrooms made up of concrete prefabricated elements. There also exists another school for children up to 13 years old placed in the north side of the village, occupying a building made of reinforced concrete. All this equipments set up next to an existing path between the cultivating area and the remaining group of houses of the *douar*, mostly made of earth, some of them traditional and others with a recent architectural typology.

It is worth highlighting the existence, in the central area, of a *gîte d'etape* which accommodates the visitors the months when the population is not cutted off by snow. It is placed next to the new land road where also the majority of the reinforced concrete buildings are placed, as well as the new divisions of plots with soil walls in their perimeters. In Figure 5 a sketch of genesis and evolution is shown.

3.2 *Immi n-Ouaqqa*

The *douar* Immi n-Ouaqqa is placed in the right slope of the oued and is the closest one to a narrow pass existing in the highest part of the bank. It is probably the most ancient settlement and is placed next to one of the dry bank or gully that goes down by the slope and only collects water on the rainy season. It has a strategic position as a whole, as it is placed by a ford or river cross, where the water depth is not excessive and the distance between both banks is shorter. The nucleus is made up of several *tighrematín* and some houses built of earth

Figure 5. Buildings in Immi n-Ouaqqa. Author: J.M. López Osorio.

around the original ones. There exist several aspects which indicate that the settlement is on its starting point according to the evolution sketch:

– There is no house built with reinforced concrete, preserving the constructive technique of the soil wall (*tabut*) in the new houses, which integrate into the original settlement with the *tighremt* (Fig. 6).

This settlement is lacking of own public equipments, due to its small size and the proximity to the neighboring nucleus. Its inhabitants use to go to the mosque of Ighrem Aqdim, and chil dren go to the school of Issoumar.

There is no house built with reinforced concrete, preserving the constructive technique of the soil wall (*tabut*) in the new houses, which integrate into the original settlement with the *tighremt* (Fig. 6).

– This settlement is lacking of own public equipments, due to its small size and the proximity to the neighboring nucleus. Its inhabitants use to go to the mosque of Ighrem Aqdim, and children go to the school of Issoumar.
– The parceling up of the slope with a perimetral wall has not taken place yet.

3.3 *Ighrem Aqdim*

The *douar* Ighrem Aqdim is the biggest settlement and most developed of the set of three. It is placed, as well, in the right side of the river, with a strong lineal development, with group of houses around the gullies that go down from the slope. It is connected to Issoumar from the existing path next to the river, by Immi n-Ouaqqa. Nowadays, it is connected with the High Dadés Valley by an east-directed land road.

It owns two older nucleuses where several *tighrematín* are placed, in different preservation state, some of them in ruins, and some others inhabited (Fig. 7a). These associations are placed, also, next to the main gullies that go down from the slope and are near the irrigation ditch demarcating the farming plots. A third urban area is placed in the south, containing the vast number of houses, made up of reinforced concrete, and also the main equipments: state official buildings, the biggest mosque and the school where children from the three settlements use to go; all of them made up as well of reinforced concrete.

The *douar* structure shows outskirts full of houses scattered in the slope, and numerous plots demarcated with soil walls, indicating the expansion areas. (Fig. 7b).

An important number of soil houses have been developed around the settlement. They present different levels of evolution, and have finally merged together building up one only *douar.*

Figure 6. New and old houses in Immi n-Ouaqqa. Author: J. M. López Osorio.

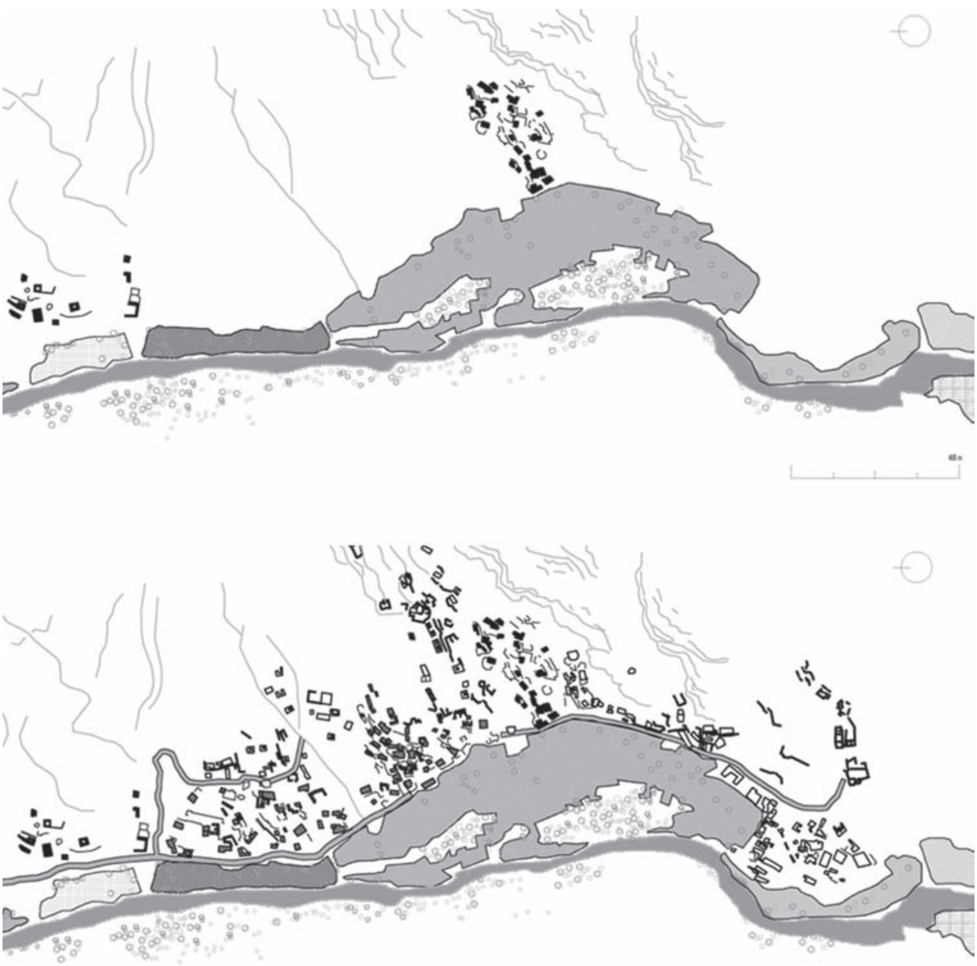

Figure 7. (a–b). Urban evolution of Ighrem Aqdim. Author: B. Marín Zofío.

Figure 8. New construction houses made of earth in Immi n-Ouaqqa. Author: J. M. López Osorio.

4 CONCLUSIONS

The urban analysis of the three different douars investigated clearly shows the evolution dynamics and its growth, not only of the architectural elements, but also of the processes of urban transformation and territory occupation.

According to architecture, it is worth highlighting the abandon of the fortified traditional houses (*tighremt*) that, with some exception, are bad preserved and are used as warehouse or stable. The use of earth for building the new habitat is preserved in many cases, showing interesting examples of evolution which come from traditional typology and adjust to the contemporary new necessities (Fig. 8). Nevertheless, and although the soil wall (*tabut*) technique is still preserved, most of the constructions built in the last few years use structural systems of reinforced concrete and closings made of solid cement, being this collection covered with cement mortars usually painted in bright or earthy colors. This constructive trend has higher economic costs and means the loss of environmental qualities of the earthen house, but represent a symbol for development and social progress, because the most important parts of these buildings are built by the emigrants who come back in summer time. This replacement process of the traditional techniques gets improved with the appearance of state equipments, made of concrete. These buildings are necessary for the development of the state function, but also mean a loss of local constructive traditions and represent a role model by means of the private sector.

The urban aspects as well as the territory occupation aspects show, in the case of the *douars* under study, and with different intensity depending on the case, a breaking dynamic with the traditional model of houses grouping, enhancing the parceling and spatial segregation, and producing a worrying occupation of the slope in outlying locations, increasingly far away from the cultivation plots. The formation of little gardens or orchards is also interesting to bear in mind, as they appear inside the demarcated plots and located out of the oasis. The necessary water is collected from the phreatic levels or the river bank by means of motor bombs which affect the aquifers of the cultivation areas, and may have negative consequences for its control and water regulation.

In short, the lack of a relative strategy in the promotion of traditional construction and urban planning threats with destroying an ecosystem based on the preservation of the oasis and its harmonious rela-tion with the current habitat. An irreversible process in many rural settlements in the South of Morocco, which has to be avoided in some specific enclaves of great architectural and landscape value, as the example that has been analyzed. We must bear in mind that it does not exist effective regulations for planning and preserving the architectural and urban heritage, and its extinction would not only mean the material values loss, but also the loss of the local population identity. Nowadays, in the analyzed sector of Mgoun Valley, with a subsistence agriculture and farming, the sources of income of the family are merely coming from emigration and an increasing mountain tourism, which would be undoubtedly damaged if the important architectural, urban and landscape qualities finally disappear.

NOTE

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Learning approach from the invariants of earthen construction in Andalusia, Spain

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ABSTRACT: The current approach to the conservation of heritage resources in earthen construction, promotes its social valuation and contributes to the recuperation of traditional architectural practices. European Higher Education Area (EHEA) provides the convenient structure to apply locally the architectural conditionings influenced by popular traditions. These particular components offer invariants on construction, materials and design composition off Andalusian vernacular architecture. It is in this context where the opportunity to introduce new subjects of study related to these architectural building techniques and its materials lies. The same thing happens in response to the need of a better relationship between the environment and the important opening to a great diversion of professional specialties. This paper describes the processes to follow during the subject study, in order to start the analysis of the building, including all agents related to the implementation of this architectural technique.

1 INTRODUCTION

1.1 *Background*

Andalusian popular construction is the reflection of a multicultural heritage on the region which is valuable, important and dispersed. The study on earthen construction and the researches about the local patrimony are setting new standards in its social evaluation.

Nowadays there the recuperation of those traditional techniques in the actual syllabus has been encouraged, wherever the relevancy of earth as a construction material is clear, and it also provides a complete analysis on its application systems through different historical periods.

A great number of cases are representative of the heritage value, creating and introducing the discussion of its conservation criteria. Regarding to intervention on heritage construction, discriminate between those applying a successful criteria from those which just build by means of materials from proximate constructions is seen as fundamental.

This last stance, has generated an unequal as much as uncontrolled combination of elements and construction techniques quite different from the originals and, sometimes, incompatible.

This situation shows up that technicians and operators are unaware of the popular techniques on earthen construction and its characteristics itself.

Exposed this reflection, it is appropriate to redirect and expand the knowledge of these materials and systems that nowadays has been claimed by contemporary architecture through sustainable social solutions.

The existing documentary archaeological and historical sources, and makes the approach easier; however they are insufficient in the context of contemporary architecture.

It can be made the same consideration, from a normative point of view, which offers an unsuitable prescriptive content for the use of this material and the associated building systems.

So, the situation suites to reflect and to propose actions from learning and teaching area and from all agents on the sector. In this paper, we expose the strategy fallowed by the authors, in order to revalue the earth from the constructive systems to its dissemination as a current material.

1.2 *Architecture context of Andalusia*

Andalusian architectural conditionings, where it can be clearly distinguish two predominant uses of raw earth construction techniques, the domestic residential and the monumental.

On residential buildings, housing solutions directly excavated on rock mass with adobe walls in the façade stands out, is been currently resolved with BTC. These buildings can be found mainly in medium and high areas of Alpujarra, between Jaen, Almeria and Granada.

In contrast, throughout Andalusia the solutions are made on rammed earth or adobe which is dispersed and almost undiscovered. This kind of systems is seen on towns with buildings over 100 years old. (Fig. 1). The rammed earth is always used in structural load bearing walls or dividing walls and adobe in the inner divisions.

However, in monumental architecture its dominated by the use of the rammed earth in all forms of buildings that have bearing walls thick multi-storey heights.

These buildings reflect the traditional raw earth use material available in abundance and close to the construction place, especially the characteristics of clay soils in the Guadalquivir valley.

Distinctions are embodied as iconographic traces according to the technique employed in a particular historical period. Combinations with basements, chained stone or ceramic brick underline the Roman and Arabic heritage (Fig. 2).

Figure 1. View of a street in Antequera, Málaga (Rodríguez García, 2010).

Figure 2. East sector view of City Walls of Niebla, Huelva. (González Serrano, 2009).

These features can be defined as constructions invariants, meaning that they remain despite time as a hallmark of the region.

In turn, they are complemented by compositional invariant where the treatment of the façades with the distribution of small gaps (closed with locks of cast iron, stone plinths or re-marked walls in different colors,) on walls and ceramic tiles pitched roofs, follow a line of tradition marking differences between small geographic areas or villages throughout the region.

Similar treatments are detected wherever the walls are coated with lime plaster, and window sills are protected with fired ceramic glazed or enameled.

The materials used define one of the invariables on earth architecture construction, allowing the identification of its main elements such as color, textures and limed details in surfaces are protected with coatings.

Those signs mark an easily detectable identity against the particularities of such a wide varied of solutions on andalusian popular architecture. The wood appears on pitched roofs that made with board and covered with mud and straw or clay tile (Fig. 3).

1.3 *Learning and professional context*

Technical training in the construction sector has been organized and channeled to follow trends

Figure 3. Limed wash façade on andalusian popular architecture. Aracena, Huelva (Rodríguez García, 2011).

of the market, facing conventional construction, which incorporates Portland cement, steel and ceramics as major products in widespread use for nearly a century.

The capacitation has focused mainly on the training of professionals who have chosen these building systems for their designs.

This way of acting has led to knowledge gaps on other traditional techniques and materials that should be used in the intervention of buildings whose diversity requires different responses for preservation, particularly in popular architecture.

Moreover, design criteria should be applied on new proposals for sustainable architecture a, that shows the breakdown between the transmission of traditional knowledge and the actual building ways.

Trained technicians in several skills and specializations are required in the addition of the new requirements in the process of making all building work.

Due to the ignorance of technical difficulties the current training face its crisis when making decisions, especially when it is about intervening the local heritage or eco-construction criteria, so this becomes very clear in the process linked to built with raw earth.

Given this situation it is essential to re-channel the objectives and activities, involving all actors in the construction sector.

It is required to have sufficient and appropriate technical skills and labor that enables the construction and / or maintenance of an durable equipped environment, ecological and economic rationalizing resources and energy.

2 PROPOSALS

2.1 *Changes in technical training from study programs*

European Higher Education Area (EHEA) has introduced new curricula programs that modifying the rigid study system in Spanish universities.

The process of change in the Degree of Architecture allows the incorporation of earth in new curricula, as a construction material in the agenda of subjects in the first couple of years.

In the academic programs are described and characterized along with the current product catalog: the rammed earth, adobe, the BTC and linings of earth and lime, providing constructive relationship with the systems for its application.

On the other hand, the development of practical exercises in the subjects of Architecture Workshop is completed with the analysis of architectural models and examples of the last century avant-garde.

These references act as a guideline for appropriate design solutions in response to the various constraints that may arise from an architectural project.

In the second training cycle, particularly for the proposals of the project, techniques mainly used in walls, blocks and earth-engineered, are currently being used. They are oriented mainly to buildings that must meet guidelines for sustainable development, energy saving and use of natural materials.

The subject moves to the third cycle in the Masters. It focus is directed towards professional specialization or research based on two lines: a guide towards training in the study of the causes and effects of injuries on the building and the importance of knowledge for the expert's report and rehabilitation buildings, both in monumental and popular architecture; and new proposals focused on innovative application of earthen construction in contemporary architecture, as an environmental sustainable solution, which defines relevant building typologies. This view of learning, within the architecture with earth, makes a difference of content in the curricula that is very important to bear in mind because, just a decade ago, none of this item were taken into account considerate.

2.2 *Implication of the differents agents*

There should be multidisciplinary and cross-agreements between various areas related to construction in order to make them effective and lead the proposals mentioned above into action.

The basic objective of the professional specialization in human resources and the realization of quality works should be given mainly from three areas of society.

From teaching area: it should promote activities aimed at teachers' training and technical advice from professionals and future work coordinators, for example, organizing collaborations between research groups, (dedicated on the development of new products and systems or quality control processes and performance in work), and/or get in contact with Vocational Training Centers and Employment Workshops to manage the dissemination and training through courses and workshops for specialization.

These activities must address different topics in modules (by degree of specialization), considering training and application of natural products and construction techniques. It should also reassess the work of local artisans, the importance of their knowledge and manage it as a training tool for young people in order to obtain a certificate of professionalism.

From institutional area: ensure that small city councils promote productive areas and bet on training agreements and participation in improving their own architectural heritage.

These bets allow projects to start business ventures and social improvement against unemployment of the youth population. It points to promote and facilitate the generation of jobs. To manage the support of occupational organizations, including schools of Architects, arrange training courses for specialists and counselors also outreach the publication of updated information that transcends the issue.

From business area: it is necessary to establish contacts and cooperation between enterprises in different sectors willing to build a supported commercial network, which through researches help innovation with natural products and their implementation in the market. Favoring small builders who have support from schools workshop to hire labor specifically qualified in these trades.

The availability of facilities and infrastructure it is fundamental to execute the works: machinery, equipment, aids, etc. by coordinating rental management, leasing, and other components.

3 STRATEGIES

3.1 *Action strategies*

Nowadays there are enough resources for knowledge, development and innovation in order to generate a network of communication and interaction channels that can be allocated to rethink the improvement and utilization of our immediate environment.

The strategy is to recreate a construction process that links the production, placing on the market, training of skilled labor and construction work start from hypothetical analysis. All with the purpose of revaluate a product that can, and should, be applied with innovative environmental benefit on the overall sustainability of construction, like in traditional architecture.

On the other hand, the process for obtaining raw material in local environments, allows the reduction of transport cost and production of the material close to the area. It facilitates the development of networks of small local companies. That would create a small-scale industrial structure of, less centralized and more self-sufficient, in opposition to global growth (sometimes uncontrollable), which now cancels sustainable development.

The environmental commitment by these natural and/or low industrialization will require the upgrading of traditional crafts associated with building and the development of studies in the use of local natural materials (earth, lime, gypsum, wood and natural fibers), as well as the respect for the environment and energy saving.

The overall restructuring requires all actors-producers agents, distributors, managers, builders, researchers and trainers to interact across, to generate a multidisciplinary network, first locally and later inserted in a feedback process.

3.2 *Training strategies*

Our University must make proposals focused on boosting projects, generating actions to motivate all the above mentioned actors. As ideas generators researchers, can coordinate training development programs. The link between management of social and productive fabric is based on adequate human resources and information media. Furthermore, its allows a to justify investment in new goals with small companies, stimulating the need to innovate in their products.

The scheduling of tasks oriented towards vocational training is a major activity that can join the three agents. The connection is established by linking the interests of each one of them (Fig. 4):

- The company seeks skilled labor in certain tasks or specialties,
- The University provides monitors or trainers with extensive experience and discretion to manage the tasks of research and experimentation,

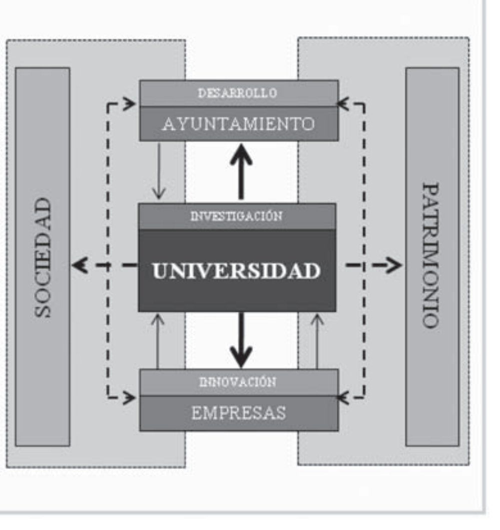

Figure 4. Multidiscipline interconnections and different agents of the proposed structure. (Gonzalez Serrano, 2012).

Figure 5. Course of bio-construction: earth plaster workshop (Canivell, 2006).

– The Council provides spaces for teaching development of teaching tasks and dissemination through social outreach to those most in need.

For the subsequent placing on the market and commercialization of products and improved systems, training cycles will be organized, both for technicians and professionals. To this end, various training (work-shops of employment, schools workshop) will be coordinated, targeted towards European accredited training for professionals and their certificates. This can also promote the implementation of scientific publications showing the results obtained.

3.3 *Management model*

Morón de la Frontera is a sample of self-sourcing management and its influence on local, economic and social development. This community is located in the province of Seville, it is pioneer in local development programs (Environmental 21 City Program of the Government of Andalusia) and has integrated projects promoting its core products.

In 2011, Moron´s handmade lime is declared an UNESCO World Intangible Cultural Heritage in the category of Inmaterial-Good Practice entitled "Revitalization of Traditional Knowledge of the Development of Artisanal Lime Morón de la Frontera, Seville, Andalusia".

In this region, where there is an important source of natural products (lime, gypsum, olive wood) is working alongside with researchers at the University of Seville in the study and development of new products.

In recent years, Moron concentrated the location of various buildings that combine raw earth, especially the BTC with adobe and lime plaster. These examples define a study spectrum on earthen construction to be disseminated because of the quality of the results obtained.

The City Council, -with help of some local companies dedicated specifically at the exploration, production and marketing of natural products—training workshops are managed they are intend to be used for teaching used of these products and their application in various construction techniques.

These advantages of the current model of Moron de la Frontera are driven by needs of resolving social problems such as a high rate of unemployment that's affecting young people and the economic stagnation of various services and firms in the industrial region. The loss-making incentives make the young seek new horizons outside their place of origin.

4 CONCLUSIONS

The issue here exposed is a highly topical issue due to the urgent need to rethink development strategies, efficient use and management of environmental re-sources, land use, land occupation and social cohesion. In this context, general and comprehensive, technicians training capacitation has a key role, to plan, to manage and to intervene in the conservation of the local architectural heritage.

Education and motivation must be done in order to achieve readiness to act and participation from all areas of society: education, institutions and socio-economic companies that generate productive movement for a region.

The demonstrable guarantee of natural materials application in construction and knowledge to their application techniques allows the good acceptance from the customer and technicians, reaching to appropiated resoult on architecture.

The proposed strategies help guaranteeing labor training in a profession that allows people to be out of the labor instability and it is oriented to employment need of their local community.

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Earthen architecture in Guatemala

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ABSTRACT: Adobe, rammed earth, and wattle and daub are important construction materials in Guatemalan architecture. In rural areas, it is common to observe houses built with earth. In the central region of the country, the thick walls of colonial monuments were filled with soil. This shows that earthen architecture techniques have been transmitted from one generation to another as part of the local culture and history since the pre-Hispanic Mayan city of Kaminaljuyú. Today, Kaminaljuyú appears to be just mounds of soil and vegetation, but numerous studies confirm that buildings of earthen architecture still remain in the mounds. This research is the principal reference for this document.

1 BACKGROUND

Earthen architecture is built containing constituent and sustaining materials such as adobe or rammed earth. In Guatemala, soil as a building material is part of the most important architectural and historical periods of the country. The earthen construction systems known as wattle and daub, adobe and rammed earth, have been the techniques used in buildings related to religious ceremonies and civil, cultural, and housing activities. Estimates are that more than half of Guatemala's architectural heritage is built using one or more of these methods (Ceballos 1999).

Small houses with walls of adobe and with corrugated zinc sheets or thatched or tile roofs are part of the landscape in rural areas of the country (Fig. 1). The indigenous pre-Hispanic house, as well as the contemporary one, is built with the same materials; also the design for activities inside is very similar. Generally, the house has a stone foundation, one room, and plastering of mud or lime.

Figure 1. Adobe houses in the Highlands, Totonicapán, Guatemala. Girón, R. 2006.

In some regions the *temazcal* (a type of sweat lodge) is still part of the house and of daily life. It is a semicircular structure, like an igloo which is located in the patio, and is constructed of adobe and stone. The main use is as an individual or group steam bath with therapeutic and purifying purposes. The *temazcal* is a custom which was established in the Mesoamerican region; it has a religious and social function associated with sacred rites.

During the colonial period in the 16th century, soil was the predominant material for construction.

Rammed earth walls were introduced during the colonial period; this technique gives more stability and makes the structure more monolithic because the soil is compacted layer by layer with a rammer. Houses were made of wattle and daub (bamboo walls covered with mud), adobe with thatched roofs or mud bricks. The thick walls and buttresses of monumental constructions were raised and filled using adobe mixed with brick and stones (Ceballos 1990), as can be observed in religious and civil buildings that still remain in the baroque city of La Antigua Guatemala, which was declared a Cultural Heritage of Humanity by UNESCO. In 1773, an earthquake destroyed the city of La Antigua and the ruins that remain still show its effects.

But earthen architecture´s background in Guatemala dates to before Spanish colonization. During the Middle Pre-Classic period (600 BC), the Maya built the Mound of the Snake, whose remains are located southeast of Guatemala City. The mound is a raised area of rammed earth that reached a height of more than 12 m and was more than 5 km long (Ohi 1992). The structure is principally composed of a mixture of charred mud compacted along with sand. Several functions have

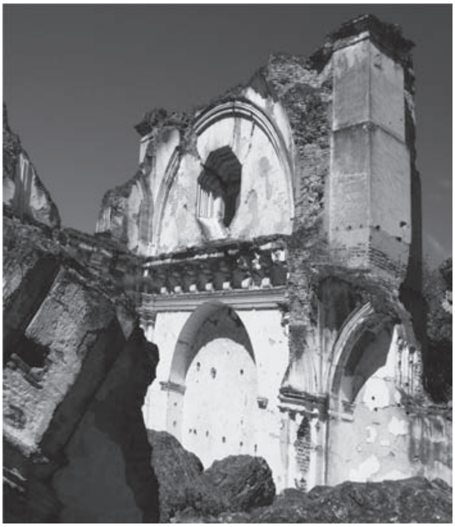

Figure 2. The rammed-earth technique was used in the walls of The Recolección church in La Antigua Guatemala. Gordon, G. 2008.

been attributed to the construction, most importantly as a hydraulic canal to Kaminaljuyú and as a defensive wall. The outstanding attribute of the remains of the Mound of the Snake is that it shares space with, and is integradted into, a colonial-era aqueduct wich was built with bricks and uses the pre-Hispanic Mound for its foundation.

At the Kaminaljuyú Pre-Classic complex (1000 BC), the Maya built a metropolis with temples, residences, and public spaces made from rammed earth, clay, pumice and talpetate (sand and clay compacted layers). Due to the urban expansion of modern Guatemala City, only a few vestiges of this pre-Hispanic space still remain, covered by several layers of soil and vegetation.

2 KAMINALJUYÚ

Kaminaljuyú (Fig 3), Early Pre-Classic (1000 BC–200 AD) to Post-Classic (1200 AD), was the first city that existed in the highlands of Guatemala's central valley, the area where Guatemala City currently stands. The name given, in 1935, to this archaeological site comes from the Mayan language K'iche' and it means "hill of the dead", because multiple tombs were discovered buried at this site.

In pre-Hispanic times, this Mayan settlement was an important socio-political center, not only because of its size, but also for its strategic location. It was the main economic center, and its influence

Figure 3. Aerial view of Kaminaljuyú in Guatemala City. Google Earth 2012.

extended over the vast territory of Mesoamerica, a region that included part of Mexico, as well as Guatemala, Belize, Honduras, El Salvador, Nicaragua and Costa Rica.

Artistic and architectural breakthroughs were also developed, with urban space planned along north-south axes, large public plazas and ball game platforms, and the construction of temples. Sometime after 900 or 1000 AD, the city suffered a political, economic and cultural degradation which led to its subsequent abandonment, the same process observed in other towns in the highlands and the greatest Mayan centers of Petén (Museo Miraflores 2012). Most of the abandoned earth-based structures tend to erode, collapse and turn into mounds, and over the time this was exactly what happened with the ruins of Kaminaljuyú, however there are vestiges that have survived, such as the Acropolis and the Palangana, two of the few structures that have been released from the layers of vegetation that were covering them. During the late 19th century, the English explorer Alfred Percival Maudslay drew the first diagram of Kaminaljuyú's layout. Because of this contribution it was possible to locate the most important mounds. In 1942, the Carnegie Institution of Washington developed a plan based on quadrants with numbers and letters that established the nomenclature that today identifies the mounds. Approximately 200 mounds and 13 ball game courts were found, with almost all of the structures composed primarily of mud (soil mixed with water), talpetate and pumice.

A large number of studies, evaluations, and research projects have been undertaken to obtain data on this unique archaeological complex.

It has been discovered that beneath the vegetation-covered mounds are ancient pyramids, stone sculptures, jewelry, and several tombs with skulls and ceramic offerings. Most of the mounds have two or more construction stages. Usually the final construction stage has been lost due to erosion and weather damage, and the only remnant is the soil layer of the mounds. This last stage of

Figure 4. Kaminaljuyú´s mound. Gordon, T. 2012.

construction generally dates from the Late Classic period.

3 ARCHITECTURE

3.1 *Techniques and materials*

The inhabitants of Kaminaljuyú used the soil mixed with water as the main construction material because it was easily found in the area. Major constructions were filled with mud, talpetate and pumice on the inside, while the outside was covered with clay and talpetate that was sometimes colored red, yellow, green, black, or blue (Museo Miraflores 2012). Lightweight, but perishable, materials were used as roofing.

A portion of Kaminaljuyú is preserved today as a park, and it is in this part where the Mound C-II-4 is located. This mound is also known as the Acropolis (Fig. 5) and corresponds to the early Classic period and was the building of the governmental leaders. Mounds C-II-12 and C-II-14 are also found in this area and are known as the Palangana (Fig. 6), named after the shape of the ball game courts.

In the Acropolis and the Palangana it is possible to observe the slope-panel architecture (talud-tablero), similar to the style of contemporary buildings in the city of Teotihuacan in Mexico, with the difference that the ratio of the slope in Kaminaljuyú is usually greater (Figs. 7 and 8) (Schávelzon 1984).

The slope-panel is the architectural system formed from an inclined basal wall (the slope) on which stands a rectangular element (the panel) (Villalobos 2006). This system is repeated on each platform. To summarize, the slope is the inclined sustaining element and the panel is the rectangular element supported.

In 1993, the Tobacco and Salt Museum from Tokyo conducted a conservation and archaeological exploration project in Mound D-III-1, which they called the Building of the Incrusted Obsidian. Since its discovery in the early 1960s, it showed an incomplete stairway with six steps of 1.20 m width and with a riser height of 0.70 m. Four structures were also located on the north side of the stairs, each one 0.70 m high, and 1.50 m wide with a noteworthy 0.15 m frame incrusted with round obsidian pieces (Ito 1994). The Japanese stratigraphic excavations identified five different stages in this structure that established that this mount was made with soil mixed with clay and rammed earth.

Figure 5. View of the stairs of the Acropolis. Gordon, T. 2012.

Figure 6. Remains of earthen architecture in the Palangana. Gordon, T. 2012.

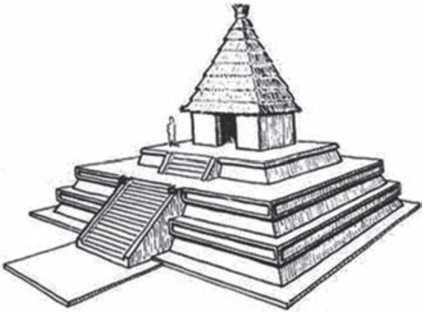

Figure 7. Detail of Teotihuacan panel in Kaminaljuyú´s architecture (Redrawn according Kidder and Marquina). Rivera, V. & Schávelzon, D.1987.

Figure 8. Detail of a slope-panel, talud-tablero, in the Acropolis building. Gordon T. 2012.

4 CURRENT SITUATION

In Guatemala the biggest flaw of the soil used as a building material is that there is not a technical building code that regulates the quality of the constructions that helps it to be resistant to the frequently seismic activity. It is not fully taken advantage of the benefits of the soil. In most of the territory the soil is used simply because it is affordable. Architecture and urban expansion play an important role in the way that societies develop, but the intensive and uncontrolled growth of Guatemala City was one of the main causes of the destruction and disappearance of the pre-Hispanic Mound of the Snake and the city of Kaminaljuyú. Because the integration of the archaeological site into the new urban landscape was not planned, much of what was left has been destroyed to make space for new construction. In addition, climatological and biological factors, and the frequent seismic activity in this region have also contributed to the damage of the archaeological site.

Despite the fact that, in 1964, the Guatemalan Institute of Anthropology and History declared the Kaminaljuyú Park a protected area and the mounds untouchable, the majority of structures have unfortunately disappeared. In 2010, there were only 35 mounds left (Arroyo 2010), a truly disappointing situation. That same year, Kaminaljuyú was added to the World Monuments Watch List of Endangered Sites.

5 CONCLUSIONS

Due to the fact that Guatemala is located in a highly seismic zone, and with the overwhelming use of concrete and steel structures, earthen architecture has fallen out of favor. Another reason for its unpopularity is that it has become associated with lower-social-class constructions. While it can be said that only mounds can still be seen at Kaminaljuyú, that does not mean that there is nothing underneath. Compared with other Mayan cities, the remains of Kaminaljuyú are not as impressive as those elsewhere that were constructed in stone; nevertheless the vestiges of this urban complex are testimony of the Mayan civilization. It is an example of the earthen architecture which was developed in the pre-Hispanic period, as well as of the technological and artistic skills achieved, which makes it of great importance to the heritage and history of Guatemala.

This archeological site and the Mound of the Snake are disappearing before our very eyes, because of human damage, its forms are deteriorating and its extension is increasingly diminished. Perhaps those layers of soil and vegetation were all that somehow protected it until now, and it would have been best to have kept it that way. In any case, research must continue, but the most important thing is that the site must be protected.

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Earth and gunpowder: The earth in the modern fortresses

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ABSTRACT: The earth has played a role key in modern fortification. It has a long constructive tradition. It is easy to obtain locally. It has deformation possibilities in opposition to the gunpowder artillery. Then, it is the most suitable material in fortresses. The military engineers used exposed banks in the open air, but they also used covered ramparts of turf, grass or banks between walls of masonry or brick. The use of each one depends on the geographical location, physical properties, availability and permanent or provisional character of the construction. This paper synthesizes the military theories of earth constructions at the end of the 18th century in the Spanish territory. The fortification theory was homogenized by the French influence. The campaign fortification was imposed and new defensive challenges appeared. The investigation has compared academic sources and technical reports issued by engineers of some Spanish fortifications in Cartagena, Monzón or Menorca.

Earth as a building material was necessary to build modern fortresses. When experts in fortifications looked for a material to face the gunpowder artillery, they found earth as a powerful ally. They planned the fortresses to follow the defensive tactics. But, at the same time, they found that earth had the best properties to annul the impact of the bullets. The deformation of the earth banks absorbed the kinetic energy of the bullets. The tracing plans and the material defined the new fortification that replaced the medieval fortresses. The new fortresses offered more resistance and made the constructive process easier.

The first earthen ramparts can be found in primitive castles, such as Maiden Castle. This castle was built only with ditches and banks. Therefore, it is possible to say that earthen fortifications have a long history. But the main contributions took place in the period of bastioned fortresses. The military experts, working in the engineer corps of the European Royal Courts developed their ideas in the battlefields. At the same time, between 16th and 18th centuries, several theoreticians wrote the most famous treatises about assault and defense of fortified towns.

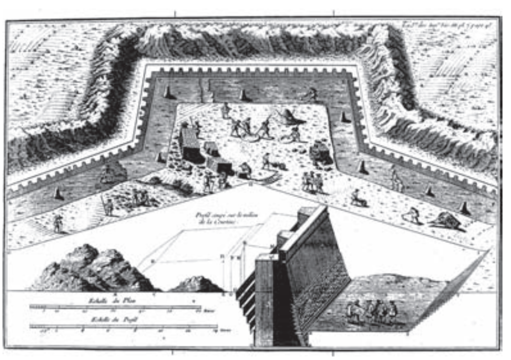

Figure 1. Working with earth in modern fortresses (Belidor, 1729: 03).

When engineers had to build with earth, they had to resolve some difficulties with talent. How to extract the earth? How to calculate the extracted volumes in order that the generated emptiness, equivalent to the pits, compensates the volume of the ramparts? How to transport the earth to minimize the economic cost of the work? How to organize the workers? How to guarantee the stability of the different banks? How to resolve the problems of dampness? How to prevent the earth from being washed away by the rain? How to design the walls containing the earth? How to construct if soft soils do not exist? The Spanish treatises contain several of the responses, but these answers were combined by the 18th century. At the same time, the technical reports from the engineers from the Royal Court, explained the construction history. The surviving fortresses offer different examples to be compared with the writings.

This paper illustrates the main observations related to the military construction in earth from the 18th century treatises: Du Fay (1692), Larrando de Mauleón (1699), Fernández de Medrano (1700), Cassani (1704), Tosca (1727), Belidor (1729), Calabro (1733), Muller & Sánchez Taramas (1769), Le Blond (1766, 1777, 1778), Lucuze (1772). Their words offer the theories of the

18th century and, especially, the keys to approach this heritage. It cannot be forgotten, the influence that these treatises had on the engineer's education. They sometimes worked following directly the academic sources.

This study of some Spanish fortifications (Cartagena, Valencia, Monzón, Menorca…) allowed comparing the theoretical words and the technical reports. It can be concluded that engineers answered these questions when they decided to use the earth:

1. How to build stable banks giving uprightness in order to avoid that enemy could climb the rampart?
2. How to build a strong rampart resistant to the atmospheric agents?
3. How to make the work of the *sappers* more difficult?

They answered the first questions studying the natural slope of banks and the earth properties. They used different revetments, such as turf, grass, masonry walls or brick walls. The durability was guaranteed with these revetments. The work of *sappers* was impeded using different materials inside the earth, such as "fascines" -long bundles of sticks, baskets or branches. All these materials stabilized the earthworks and gave cohesion to the ramparts.

The earthen ramparts without stone or brick revetments usually were constructed with vegetal revetments. Vegetable revetments were usually fixed lumps of turf (*tepes*). Sometimes, on the glacis the engineers recommended to plant trees. When the war was starting, the soldiers were felling the trees and were constructing stockades. The glacis was a broad, gently sloped earthwork or natural slope in front of a fort, separated from the fort proper by a ditch and outworks and so arranged as to be swept with musket or cannon fire.

The masonry walls (lime and stone) containing the earth were the most commonly used in the Spanish fortifications. The engineers used brick walls when it was difficult to obtain the stone (Monzón Castle). The earth was confined between two sloped walls with foundations. These walls were called scarps and counterscarps depending on their position in relation to the ditch. The walls also had internal buttresses. A lot of vaulted spaces called casemates appeared inside the ramparts during 18th century. These were mortar-bomb or shellproof chambers located within the walls of defensive works. Generally, they had openings for weapons, loopholes for muskets or embrasures for cannon. At that time, the rampart comprehended a mass of earth faced with masonry and placed in the most exposed area.

When the explosive bullet damaged the revetment, the brick or stone fell down opening a gap and giving a natural step to the enemy. So, engineers built inside the earth, wood frames with resin that was dried with fire, to prevent for the wood to rot. Sometimes, vaulted structures were built, preparing the space behind the wall to construct interior counter walls (Viollet-le-Duc, 1868). The ancient architects used this practice, and the modern engineer copied them. The most common solution to build stable ramparts was to use the fascines. Fascines can be found since the last period of bastioned fortresses in the 19th century. Those long bundles of sticks were built on a support and were compressed by esparto grass or wire. In siege warfare the fascine were 2 m long and 30 cm in diameter. The theoreticians used the term 'sausage' to represent the fascine that had more length. If the fascine had stones inside the bundles of sticks, it was called ballasted fascine (Lucuze, 1772).

The constructive technologies used by the military engineers in relation with the earth were consolidated from 16th century. Between the 18th and 19th centuries, there was a rationalization of the constructive process in earth. The main materials that engineers were using with earth were ashlar, rubble, lime, sand, water, wood and brick. In a later period, engineers started to use the hydraulic mortar in the strongest vaults and in the rubble joints of the ramparts.

The works began with a survey of the site. Once all the trees and scrub had been cleared out of the way, the engineer in charge of construction determined the central point of his intended work. Here he set up his planning table, which held a large-scale and very carefully drawn plan, and had a horizontal sighting arm, which pivoted about a pin, set in the centre of the plan. The engineer orientated the table by compass, and swung the sighting arm around until it coincided with the capital line (centre) of one of the bastions on his plan. He directed his assistants to the required line, and they walked along it with their measuring chains and rods until they reached the point that was assigned for the salient, and then they a picket. The process was repeated for each bastion. Sometimes the drawing plans take into account the pre-existences.

The workers began to work on the most exposed front. The treatises recommended the construction of the foundations simultaneously up to six feet (1.67 m). The workers had to wait while the foundations were acquiring consistency. Next, they were continued the work raising the bastions ramparts and, after, the curtains between the bastions (Muller & Sánchez Taramas, 1769: 277–278).

Normally, the workers started the earth movements after the drawing. They excavated the pit and were piling the earth to construct the banks of the scarps and the glacis.

When they had to excavate in rock, usually in mountainous region, the work was very hard. When they did not find earth, they were alternating earth with crushed stone. They were using the soft earth to crown the ramparts, such as in Saint Julian Fort in Cartagena (Guimaraens, 2008).

The skilful engineer had to calculate perfectly where to start the excavation to balance the earth movements. An economy of movements was obtained in this way. It was fundamental to define the horizontal plane of the terreplein. The engineer had to calculate suitably the minimal slopes to facilitate the water evacuation, the rampart stability but, at the same time, avoiding the escalation of the enemy.

The foundations in rock of the scarp and the counterscarp needed an excavation in steps. The workers had to build fabric bands of lime and stone up to six feet (1.67 m) in different phases. They were extending the rows following the magistral line. When they came to the end of the row, they initiated a new one for the origin. Some theoreticians, such as Muller & Sánchez Taramas (1769), recommended an open hollow in the soil of six inches depth (13 cm) to received the wall and prevent it to slip on the rock. When the hollow was opened, it was cleaned of rubble and dirt, and then wet, down to guarantee that the lime would penetrate into the rock orifices, and so obtain a good bonding between the wall and the rock.

The rock is ideal as a foundation because of its strength, but, at the same time, the irregularity of the rock forces the rampart profile to adapt. The treatises recommended excavating into the rock horizontal hollows with the same length as the wall. In these holes well-dressed ashlars were laid in a very thin lime mortar. The ashlars provided a uniform seat that absorbed the irregularities and provided a horizontal building plane. On this plane the scarps were built.

Before initiating the construction of the scarps, time had to be given for the work to set and cure. When the slope was considerable, the engineers had to design the ashlar course with steps. Every step had tread depth of six feet (1.67 m).

In some Spanish fortresses, such as the Monzon Castle, the rock rises up to the terreplein level. In these cases, it was essential to execute foundations with steps. If the exterior surface of the rock was smooth, the workers had to drill and open cavities in order that the mixture of lime would interact with it. The construction of the revetment, as opposed to the rock, had to be done slowly. The seat of the revetment could separate from the rock. In these cases there was no specific role for the earth.

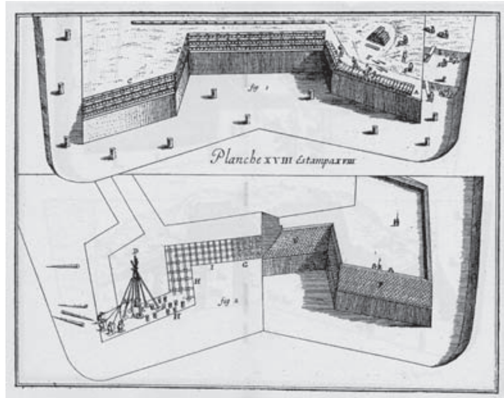

Figure 2. Work with fascines. (Fernández de Medrano, 1700. Estampe XVIII).

If the soil had a heterogeneous composition, the foundation was refilled by ordinary rubble. The foundation trench was dug down into the ground until reaching bedrock. If the soil had good consistency, ditches were excavated four to six feet depth (1.11–1.67 m). The width of the ditch was based on the height of the revetment. A frequent mistake was to calculate the width of the foundation using the height of the foundation, not of the wall (Muller & Sánchez Taramas, 1769: 263).

It was very interesting to notice in the constructive process, how the stacking of soil was done. The advice of many theoreticians of the 18th century is explanatory. They recommended stepped earth on the sides of the terreplein. There was a space between the revetment and the bank. To reduce this empty space, the treatises were reducing the tread size of the steps. They wanted that the batter was self-supporting to reduce the pressure on the revetment. The revetment only had to resist the pressure of the earth between the batter and the revetment. This solution was only possible when the earth was sufficiently cohesive. The ideal solution for the treatises was to work the revetment supported on the natural batter. Thus, the revetment only had to resist the pressure of the rainwater. The workers were opening holes in the revetment to prevent this water pressure. The rainwater flowed in this manner until the ditch.

It was recommended that the earth fill should not be disturbed during one year after constructing the revetment. The wall had to acquire consistency. The authors did not want the dampness of the soil to impede the drying of the lime. They recommended executing the interior joints with a mixture of lime and ash of one and a half feet thick (41 cm). This hydraulic mortar facilitated the water to spread and dry rapidly and to prevent the dampness from penetrating and spoiling the masonry.

The most usual resource to reduce the pressure of the earth was to stabilize and to compact the soils. For this, fascines and branches were arranged in horizontal caps. The trunks were nailed into the soil defining the perimeter. The layers of fascines or earth could not exceed one and a half feet (41 cm). The idea was that the earth layers could be compacted well with the rammer. The final aim was that the revetment was consolidated before the soils were compacted (Muller & Sánchez Taramas, 1769: 259–262).

The revetment was built on the support surface of the foundation. However, one to three feet (0.27–0.82 m) of the revetment was removed from the base of the wall and a buried banquette was built that some treatises called the foot of the scarp (Fernández de Medrano, 1700: 202). From this point, the scarp was constructed following the slope defined in the project.

The construction of the scarps and counterscarps followed the usual method. Big ashlars were placed in the base. Ashlars were placed also in the angles up to the height of the cordon. The cordon was the coping or top course of a scarp or a rampart. Sometimes it was a different colored tost and out from the rest of the wall. It was the point where a rampart stops and a parapet begins. The treatises recommended that the working of stones and bricks in military architecture should follow the batter.

The surface of support of every ashlar was horizontal. Nevertheless, the lateral surface was perpendicular to the pressure of the earth (Muller & Sánchez Taramas, 1769: 285–286). The faces between ashlars were constructed with rubble. The interior of the walls was refilled with lime, stone and sand. This was very important to the work of the main stonecutters, belonging to the civil branch, in all the works where there was stone. When the stone was not of quality (Monzon Castle) other materials were used, such as brick or a combination between rubble and brick (rubble with chains of brick).

Rubble and brick stuck fast with mortar in the course of the 18th and 19th century. Muller & Sánchez Taramas (1769: 282) proposed to refill the hollows with rubbles and mortar, in order that the joints were as narrow as possible. The waterproof cement in contact with water was usually composed of a mixture of two parts unslaked lime, one part sand, and one part pulverized tarass (a stone of volcanic origin). When tarass was to be added, a passable substitute was provided by burning and pulverizing tiles. Joints of ordinary mortar were used in the parts of the wall removed from the water. When the engineers used brick, they recommended a quality mortar, with are duced thickness to avoid its detachment. Joints had to be repaired from time to time. In some cases, the workers decorated the joint, as is observed in Saint Julian Castle and Galleras Castle, both in Cartagena.

It is necessary to mention the works of masonry related to the military architecture. Bricks were in use in the coils of the interior vaults and in loopholes and embrasures.

In the middle of the 19th century, the earth that was protecting many of the vaults constructed with brick was replaced with concrete. Its composition is unknown, in the studied cases of Cartagena and Menorca. The concrete to which many engineers refer in their works might be from the modalities written by Herrera García (1863: 7). Herrera distinguished three types of concrete: concrete done with stone and brick, asphalt concrete and lead concrete.

Though time, the provisional fortification acquired more relevancy than the permanent fortification. The treatises called them campaign fortresses. The earth was the main protagonist in these fortifications. One of the authors who better describes the role of these constructions was Sebastian Fernández de Medrano (1700).

Fernandez de Medrano distinguishes between ramparts of earth covered with turf, ramparts with fascines and traditional rammed earth walls. He explained the different reasons to choose these campaign fortresses.

The first one was the lack of stone or brick. The second one was the speed or provisional nature of the construction. There were cases where the construction of earthen ramparts could be later re-dressed to turn it into a permanent fortification (Fernández de Medrano, 1700: 205)

The rampart covered with turf was constructed taking the line of separation, as a reference between rampart and ditch. From this line, the workers amassed earth with a batter of forty-five degrees (the batter depended on the consistency of the soil). The layers of turf were arranged with the grass towards the rampart. The turf was nailed with little stakes and was lined up planning an enclosure. In the interior, the earth was compacted to reach the height of the turf. On the first layer of turf and soil, there was sowed grass, oats or another grass with roots to consolidate the soil. Thin willow branches were placed in the turf, with the buds of the branches orientated towards the exterior. Then, a new layer was constructed on the top and so on, up to the final height. Fernández de Medrano wrote that the buds of willow could grow but they had to be cut in times of war. The trees endanger the defense of the fort. The branches obtained from the felling could be used in the stockades (Fernández de Medrano, 1700: 207).

If the soil was sandy, the treatises recommended replacing the turf with the fascines. The fascines were distributed with the faces towards the exterior and the tops towards the terreplein. The sides joined by nails positioned in two or three points where the branches were tied. The earth between the fascines was compacted, as in the turf ramparts. When the workers were constructing a layer of earth and fascines, grass or oats were sowed on the top. On the head of the bundles, tying them transversely, was a 'sausage' (long fascine) that was against each of the low fascines. The hollows of land were refilled. Oats or grass stand firmly again and a new layer of transverse fascines was started (Fernández de Medrano, 1700: 208).

Fernández de Medrano, employed in Flanders, did not forget about the construction of rammed earth walls that was very common in Spain. He recommended this system to the engineers, who only had suitable soil for walls and no other materials. Nonetheless, Fernández de Medrano recommended building the scarps with stone up to the level of the campaign. He also recommended constructing the sides of the ditch with stones, if it contained water (Fernández de Medrano, p. 211.).

The study of the authors, on some Spanish fortifications of the 18th and 19th century has allowed confirming the following points:

There exists in the constructive practice of the military engineers a strong influence of the treatises handled in the Academies, specially the Mathematics Academy of Barcelona.

This academy, founded with the influence of Sebastián Fernández de Medrano and directed by Pedro de Lucuze, defined a tradition and a method of construction that was followed by the main Spanish military engineers. The technical reports corroborate the mentioned practices.

In this way, the Moroshorn work, Galeras Fort, Saint Julian Fort (Cartagena), and the forts in the Isabel II Fortresses (Mahon), offer a significant example of building in earth with lime and stone. On the other hand, the Mateo Calabro's technical testimony, which is employed at the Castle of Monzón, is clear about the construction with earth and brick. The Christmas Fort in Cartagena, a fortification of the 19th century corresponding to the plan O'Donnell (1860), is an example of the substitution of the vaults with earth by the vaults of concrete and brick. It represents a brief period of transition towards the steel fortification, but this is another history.

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Mixed building techniques in Abruzzi (Italy): Cob, adobe, stone and brick

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ABSTRACT: In the Italian region of Abruzzi, traditional earthen buildings are currently widely studied, however, the mixed building technique using clay, stones and bricks has not been widely analyzed. This study identifies several examples, located in various areas of the region, pointing out common features and possible differences due to the type of terrain or to the building site. Singular cases can be the small vaults covering narrow rooms, such as the passageways, or a portion of a stairway. The mixed building technique was used during the first half of the 20th Century in some small villages in the inland of the Abruzzi Region and they are still complete today. We can find it above all in buildings with stone and brick, recently abandoned, where it is possible to identify the minimal use of the mixed building technique due to deterioration. This technique is still alive in vernacular culture.

In the Italian region of Abruzzi, the traditional earthen buildings coexist near the new houses. Some of them are abandoned, or used as an accessorize and scarcely inhabited (Conti 1999).

The earth houses are concentrated in two areas of the region: one in the North in the province of Teramo, along the Tordino, Vibrata and Salinello valleys; the other one in the South, between the Pescara and the Alento valleys in the provinces of Chieti and Pescara. This last area preserves about the 60% of the earth buildings in Abruzzi. In other territories, such as the Sangro Valley and the Peligna Valley, the few manufactures have shown that in the past the clay has been used to build houses in this region where the most used is the cob technique, locally called *massone*. Interesting studies on traditional earthen buildings of Abruzzi have been made (Ortolani 1961, Morandi 1984, Forlani 1990), and in the last few years this theme has been widely examined (Conti 2006); in 1997 it has been conducted a first general census of this kind of structures (Vv. Aa. 1999).

Instead, the use of earth with other more materials has been less examined, such as stone and brick, according to the different variations of the building technique and to the methods of reinforcement and structural strengthening.

In general, in Abruzzi there are earthen buildings in which some sections were built with more resisting tools: bricks and stones.

If it was a two floors house, with a structures at 2.20 meters of height arranged by fixing wooden parallel beams on the wall; finally a layer of marshy canes, so-called *incannucciata,* was put as a supporting basis for the upper trampling floor built with baked bricks. The same proceeding was used for the saddle roof with roof tiles. The two-storey houses needed a stairway that could be internal or external, in this second case it was built with baked bricks and a loggia (Fig. 1) placed on pillars made with a more resistant material (Conti 1999).

The introduction in Abruzzi of the first furnaces Hoffman, at the beginning of the 20th Century, allowed a wider use of the baked brick.

As a consequence, the production costs decreased and the bricks started to be used for some important portions of the earth houses, such as the basement and the edge beam, or the reveals of the doors and the windows. This shows that the ancient builders were acknowledged about the issues of this tool.

Their empirical experience is now recovered in modern technical manuals concerning earth (Minke 1994).

Figure 1. Casalincontrada, a loggia built with baked bricks.

When the new furnaces were introduced into the Abruzzi region, in the 20th Century, the canes had been substituted for the flat brick tiles at the floors and roofs. There could be also other portions built with more resisting materials such as the chimney and the edge beam, frequently built with bricks, and the inner stairway, especially in the most recent buildings. There are also 'mixed' structures, constructed from the cob technique, combined with different materials such as river stones and baked bricks, or buildings where the earth is used to thicken bricks or stones. In other cases it is possible to identify masonries where the external curtains are totally built with baked bricks, while in the air space the real supporting structure is made using earth. It has recently set up a new strengthening method consisting in covering the earth masonry with a new water-proof brick wall sticking the original one. This modification is used to protect the most exposed walls, generally looking north (Conti 2004).

In some cases, the contemporary presence of clay and other materials in the same structure, can cause some hassles. In a earthen construction, the external walls can be more spoilt right at the chimney corner, as in the case of a rural building in Moscufo [Contrada Colle di Giogo n. 23; Strada Comunale Senarica], a place nearby Pescara.

Nevertheless, the use of different materials don't always cause any problems (Fig. 2), so in other cases these materials help improving the stability and the duration of the structure (Fig. 3). In the same manufacture of Moscufo we can find horizontal rows of baked bricks put at a certain height over the wooden element (Fig. 4): the bricks that are more water-resistant than the earth, allow a better conservation of the wooden structure.

In the Province of Teramo, almost all the earthen buildings are rural structures and adjoining the main house of the farms. The building technique

Figure 3. Moscufo, rural building in Contrada Colle di Giogo: the chimney corner.

Figure 4. Moscufo, rural building in Contrada Colle di Giogo: horizontal rows of baked bricks.

Figure 2. Moscufo, rural building in Contrada Colle di Giogo theure chimney corner.

used in this area is above all the cob, with a mixture of earth and straw and sometimes river gravel.

In some places, such as Sant'Omero, there are earthen buildings also in the urban plain. The most widespread kind of rural houses in this area is the called "italic house" with an external stairway and a southward loggia. Such a style is more widespread in an urban context.

Although the main building technique is the cob, there are many structures in adobe.

There is also a building of the end of the 19th Century employing a mix of earth and baked bricks mixed to river stones. This is a large building

[S. Omero, Via S. Pietro], on a hilltop, with two external stairways; it is built using stone, brick masonry and adobe. At present it is unused, even if it survives in a quite good condition.

Indeed in Nereto in the province of Teramo, there is an unusual kind of earthen constructions created employing different techniques: adobe, cob, bricks and river stones. In the other area of the Abruzzi region, between the Pescara and Alento rivers, the most part of these buildings are placed in the rural territory of Casalincontrada and Manoppello, near Chieti. In this area, the main used technique is the cob, with a mixture of straw and clay and in some cases also gravel.

Many buildings have wattle floors and roofs; in the rural area of Manoppello, this manner was used before 1922 when had been made a furnace and so allowing the substitution of flat tiles with bricks.

Indeed, in other structural elements there is an interesting utilization of baked brick; in a small earthen building [Manoppello, Locality La Fornace, strada statale n. 530] actually used as a rural storehouse, the door is consolidate by baked bricks (Fig. 5) opportunely clamped in the earthen masonry, like as in the essay of the 1800s (Conti 2004).

Many examples near the town of Chieti have a brick or stone basement or a mixed basement with both the materials, to support and reinforce the whole structure and also to avoid the possible damages due to the snow.

The great deal of these structures in this area show that the presence of the basement allows a better conservation of such a structure along the time (Graham Mchenry 1984). In some buildings the basement is very high and reaches the shutter of the first floor: they belong to the mixed technique group because of the use of the cob doesn't point up all the structure (Figs. 6 and 7).

In the rural area of Chieti there are many interesting examples; an isolated house on a hill

Figure 6. Casalincontrada, rural building; basement created using more resistant materials.

Figure 7. Casalincontrada, rural building; basement created using more resistant materials.

Figure 5. Manoppello, rural building in Locality La Fornace: door reinforced with baked bricks.

[Chieti, via dei Peligni 42–44, Locality Fonte Vecchia] has been built with bricks on the basement and with the *cob* for the height walls, otherwise, the external stairway and the small adjoining rooms are built with bricks. It is in a excellent state of maintenance.

In the neighborhood [Chieti, via Colle Marcone, Locality Colle Marcone] there is a few number of rural buildings, isolated on a hilltop; the basement of the northern wall shows a first 1 meter high portion of bricks and a subsequent coat of baked bricks, *adobe*, until the first floor; the other remaining walls are built with the cob or *massone*, some of them are covered with bricks.

Not too far away from Chieti, in Bucchianico and in Vacri there are other small earthen examples, with a reasonably high basement, built by other materials.

The first one [Bucchianico, Contrada Colle dei Gesuiti] is an inhabited house, with an internal stairway and baked brick basement; the second one too [Vacri, Locality San Vincenzo, Val di Foro] shows a mixed building technique with a high stone and brick basement supporting the floor and with clay bearing walls at the upstairs.

Not too far away from Chieti, in the rural area of Turrivalignani [Locality Castellana, Casa Cipriani] there is a large manufacture, with three units, two of which are two-storey earthen buildings linked with external stairways; also this building is abandoned.

In the countryside of Manoppelo, instead there are a lot of buildings presenting a basement with more resistant materials; among many examples, there is a small rectangular one-storey building, isolated on a hill [Manoppello, strada comunale Pesole]; the building technique used is mixed, with *massone* and stone for the basement (Fig. 8). At present it is a storehouse.

Nearby there is another building [Manoppello, Locality Colle Sant'Andrea, strada comunale Campagnoccia], with an external stairway and a small one-storey stable; the building has a stone basement and an external stairway with solid bricks. It is very bad preserved and abandoned.

Indeed in the same area [Manoppello, Locality Defenza, Masseria De Cecco] there is a manufacture, abandoned, belonging to a farm. This small building has been made using the *massone* technique and has a very high stone basement. In this building there is another unusual element: under the roof there is a brick edge beam. This is a particularly interesting element as in general

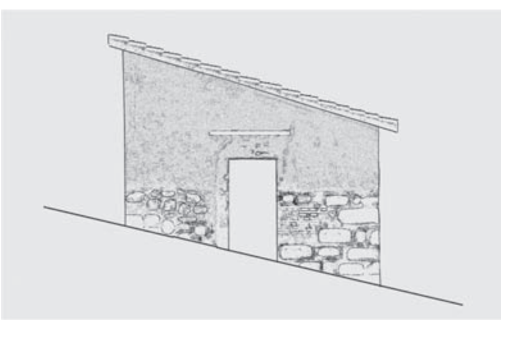

Figure 8. Manoppello, rural building, Strada Comunale Pesole: basement created using more resistant materials.

in Abruzzi, the contact points between the covering and the wall in the earthen houses, show non solved problems; in most cases there are no mediation elements between the two structural systems such as horizontal elements, perimetrical timbers or masonry eaves. The use of brick or stone structural elements to avoid the timbers to push on the bearing walls and the covering to turn downwards is less frequent (Conti 1999). Only in a few cases there are brick ledges, like as in Casalincontrada [Locality Fellonici] built up using the *massone* technique.

Not too far away from Chieti, in Torrevecchia Teatina [Strada Comunale Alento] there is a rural house near the Alento river, with a masonry internal stairway; the building has been put up with the cob, which is nevertheless evident only in one surface because of the second side has been covered with a brick wall, whereas the other sides have included subsequent buildings. A brick frame surrounds the whole eave. In spite of the strengthening of the basement and the brick facing, this building is however in ruin.

The strengthening method for the earthen masonry using new brick walls has been widely used in the region (Fig. 9). There is an example near Teramo [Corropoli, strada comunale San Salvatore]: despite the modification, this large isolated manufacture survives in a very bad condition and abandoned. In Spoltore, near Pescara, there are many examples of this strengthening method. They have been erected in second half of the 20th Century and primarily concerning the north facing walls [Colle Maiano; via S. Martino n.14; via S. Martino n. 14]. Indeed in Spoltore there is a large isolated building [Contrada Tavolaro], near the Tavo river on a plain; here the new masonry lays on the west wall. In Chieti there was this kind of intervention too [Chieti, via Fosso Canino, Locality Madonna della Vittoria; strada per Casalincontrada 68, Locality colle S. Antonio]; the building located in colle S. Antonio, dated back to the beginning of the 20th Century, has got an external baked brick stairway and it is moderately covered with new brick walls protecting the original earth masonry.

The great number of strengthened buildings is in Casalincontrada, and most part of them are into the urban area [two in via IV Novembre; via Delle Croci 7; via Iconicella]. The structure located in via delle Croci is isolated in a plain; its actual good conditions due to a new brick wall with a sub-foundation and drainage works. The building in via Iconicella, completely covered with bricks, is still conserved, even if the protection masonry is damaged at the apertures.

In the site of Fellonice, a Casalincontrada hamlet, there are a lot of earthen buildings; one

Figure 9. Casalincontrada, rural building; surface covered with a brick wall.

Figure 10. San Omero, building in Locality Case Alte: the original earthen building is increased by a brick raising.

of theme shows different strengthening interventions, such as a brick and cement protection fillet, at the basis of the building, as well as a new brick wall at the most exposed side. Another building, [Fellonice, n. 84], has a brick external stairway and a loggia, the north and eastwards walls have a strong brick covering and it has been strengthened with cement element. It is inhabited and partly used as a storehouse.

In the countryside near Casalincontrada there are other strengthening examples [Locality Contrada San Marco; via delle More n. 71, Casale Massa]. The Casale Massa, is a farm on a hill ridge, constituted by more buildings, one of them is a earth building: the two head-pieces have been built up using the *massone* technique, while the central part is a blocking masonry of rubble and bricks, in which the clay is used to meld the stones.

Almost all the manufacture has a wrapper on bricks to protect the earthen structures. Notwithstanding this, the building is in a ruin, some walls felt down and it is abandoned. When such a kind of intervention has been employed for all the external walls of the manufacture, it is difficult to recognize the earth building technique, with the subsequent loss of type identity.

Covering the earthen wall with a new brick masonry, especially when there isn't an adequate foundation, doesn't guarantee the preserve of the structure, that so becomes impossible to be inspected.

Sometimes new brick walls might be built, this was done when roofs lifted to incorporate upper floors in what once was an earth building; some examples are in many areas of Abruzzi.

Near Teramo [San Omero, Case Alte] there is a two-storey building, with four rooms and an internal stairway; the original building increased by a brick raising (Figs. 10 and 11).

The variety of "mixed" techniques using earthen masonries, baked bricks and stones regards also other examples, like an edifice in Chieti [via Madonna della Vittoria], one of the spine walls is built using earth while the other carrying elements are made with bricks. The building is now a ruin with the side-wall, the covering and the floors collapsed. There are other examples of mixed technique: the earth can be used as a melting element in carrying masonries made with backed bricks and rubble. In Villamagna, a village near Chieti, [Contrada S. Severino n. 5] there is a building in which the clay ensures to aggregate rubble and baked bricks, it is rural isolated building with an external stairways that now has felt down; moreover a mixture of clay can be placed into the

Figure 11. San Omero, building in Locality Case Alte: the original earthen building is increased by a brick raising.

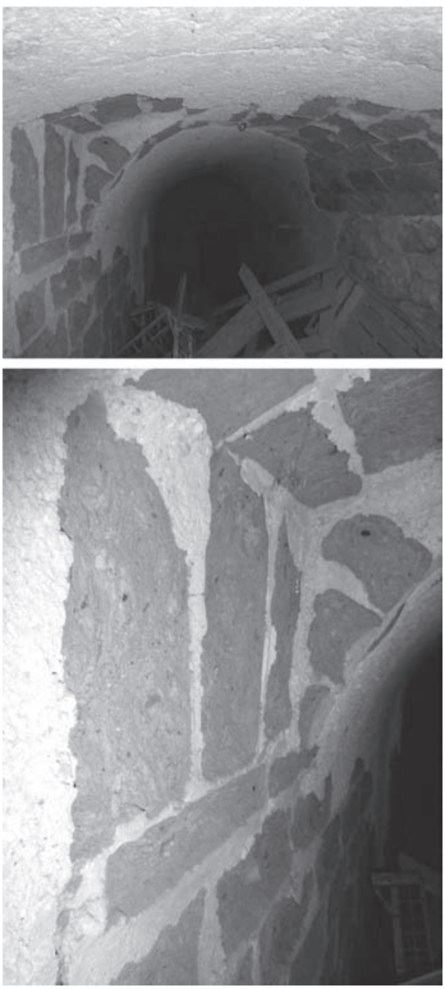

Figure 12. Caporciano, building in Quartiere Capolaterra: use of adobe.

walls in the air space between two brick and stone walls. In Tortoreto, near Teramo, there is a small building actually derelict.

In some interesting cases earthen bricks are used for small vaults, like as for narrow spaces such as passageways, entrance-halls, stairways; these particular manufactures are especially present in some little villages in the inland, around the city of L'Aquila. They are dated back to the first half of the 20th Century and they survive in some recently abandoned and damaged buildings [Caporciano, Quartiere Capolaterra] where it is possible to identify the use of adobe inside some works with masonries totally made with stones and bricks (Fig. 11). We have to remind that the earth is cheap and has thermal-hygrometric qualities particularly needed in cold mountainous areas. This aspect, little examined, should be studied again.

CONCLUSIONS

The aim of this study was to show that in the Italian region of Abruzzi there are many different kinds of building made with 'mixed' techniques that we can recognize only after damages that allow analyzing the carrying structures of the buildings.

This testifies that it is necessary to find out the theme of the 'mixed' building techniques, that is to say building with earth and other materials: this could mark a high percentage of the building legacy that is still barely known and so more vulnerable.

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Earthen architecture landscapes as identity items in southern Morocco—Studies in Mgoun Valley, High Atlas

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ABSTRACT: The pre Saharan valleys in southern Morocco, located between the High Atlas Mountains and the Sahara desert, make up a territorial unit with a strong identity. The acknowledgment of its landscape, environmental, social and patrimonial merits is necessarily linked to the land recognition as a key item in the spatial, architectonic and social construction of these valleys, as well as in the shaping of the collective imaginary made of inhabitants and tourists. The work gathered in this study was realized by the cooperating group of Malaga's School of Architecture in Mgoun Valley. The objective is an approach to earthen architecture understood as a live cultural landscape, in order to foster its enhancement and guarantee its survival and development.

1 STUDY FOR THE ENHANCEMENT AND DEVELOPMENT OF EARTHEN ARCHITECTURE LANDSCAPES

This investigation is the result of the works carried out around the I *Landscape Workshop and Heritage in Southern Morocco: Proposal for the development of a responsible tourism model*, held between the 20th and 30th September, 2011. The workshop focuses it's subject to study on earth works, their habitat and their landscape as the engine for development. The objective is, on the one hand, to obtain a general knowledge about earthen architecture landscapes in southern Morocco within its physical and cultural dimension and, on the other hand, to initiate a line of specific work in Mgoun Valley. The methodology applied in this workshop, which is based on a documentation work and fieldwork, lets us know five main aspects to focus at:

1. The linking of the main historical factors.
2. The identification of the main landscape and environment units.
3. An approach to social and cultural backgrounds.
4. The acknowledgment of landscape identifies items, paying special attention to earthen architecture.
5. The detection of the actual transformation processes which are putting earthen architecture landscape survival and territory sustainability at risk.

It is worth explaining that numerous studies about earth works in southern Morocco have been carried out, but those studies about landscape are still scarce and becoming increasingly more necessary. As Jose Manuel López Osorio, the workshop coordinator, states *the only possibility for regional development means having to preserve landscape and heritage values* (López 2003, p. 8).

2 MGOUN VALLEY, TERRITORY AND IDENTITY

Faissal Cherradi asserts, *earthen architecture constitutes one of the great cultural wealths of Morocco* (Soriano 2006). We can find this architecture along the valleys placed in the south of the Atlas mountain range under cover of the fertile lands of the oasis.

Man intervention in the modeling and working of earth in order to create habitable spaces, along with the management of water in the oasis growing and a certain stockbreeding, have enabled the development of a characteristic habitat and culture.

The results of the processes of anthropization in the course of time are earthen architecture landscapes real identity items.

Mgoun Valley, better known as "Valley of the Roses", is placed in the southern slope of High Atlas, in the region of Souss-Massa-Draâ, about 100 km in the northeast of the city of Ouarzazate. It is confined on the one hand, in the north by the massif of Irhil Mgoun, where the third highest peak of Morocco is placed, 4068 metres high and, on the other hand, in the south by the basin od Dadés river and the Jbel Saghro desert.

The valley has its head in the city of Qal'At Mgouna, in the vicinities of the N-10 highway which connects Ouarzazate and Er-Rachidía. In the opposite part of the valley, about 2200 metres high the dar (*duar*) of El Mrabtin is placed along with other small settlements.

There exists, between both settings, fifty populous clusters, plus numerous nomad settlements, placed in the highest altitude of the valley.

We can differentiate within the unit in order to study, two great areas: the Southern and Northern slopes.

The Southern slope stretches along Oued Mgoun, between the cities of Qal'At Mgouna and Bou Taghrar (1427 m and 1576 m respectively), that is to say, between the meeting of the Dades River, in the south, with the affluent Assif Oati, in the north. It is the best communicated area of the valley, due to its smooth orography, with an asphalted road which flows in parallel to the river in its eastern bank, except in its higher section, to the north of Hdida, where the road branches off due to the rugged topography and the non-existence of productive lands. In this section we find twenty population centers, with some ksar and numerous duar which live on the vast cultivable extensions. Fortified perimeters rising over rocky stratums in the centre of the oasis are quite characteristic, as for example Kasbah Itran and Tighremt Mirna (Fig. 1). These fortifications, nowadays in a state of abandonment, were the origin of the modern duar.

Finally, it is worth highlighting that high demography and accessibility favoured an uncontrolled growth of building, which extends beyond the centre of population and occupy plots of land along the road. This is producing important and quick transformations in the landscape, not only due to a model of extensive growth, but also because they introduce new constructive typologies using reinforced concrete which produce considerable and severe changes in the housing units and appreciably alter the landscape.

It is placed, in the confluence of both rivers next to the nucleus of Bou Taghrar, one of the most fertile zones of the valley, taking shape of a neuralgic center where the flows coming from the south and the north are connected. It is also here where we can appreciate the transition between two landscapes. The most urban and extensive landscapes are located to the south of the valley, and the most rural landscapes to the north, with well defined landscape units, between craggy valleys and open ones.

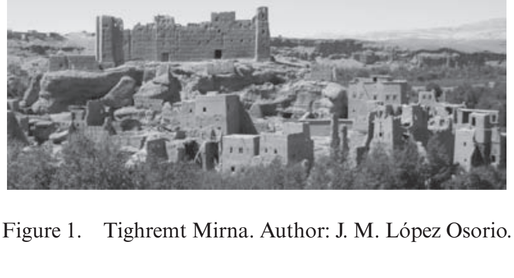

Figure 1. Tighremt Mirna. Author: J. M. López Osorio.

Secondly, the northern slope of the valley, in the north of Bou Taghrar, embraces territories of the most precipitous orography, over 1550 m. This one bifurcates into two river basins where five landscape units can be distinguished:

1. In the south, Assif el Oati Valley, between Znag and Agouti el Fouqami, perfectly demarcated by the sheer mountain walls.
2. In the western slope, an open and extensive valley along the Assif Tourmet and el Oati affluents. A very anthropizied area, with numerous settlements, amongst them the dar of Alemdoune stands out.
3. In the north of Alemdoune, the valley narrows and another landscape unit comes out, in the town of Amejgag and breaking through the narrow passes of Assif Imeskar.
4. In the Eastern side, in the bank of Qued Mgon river, we can find the Issoumar Valley, a perfectly defined unit where earth works landscape presents one of the most beautiful views.
5. Finally, placed in the most northern part beyond the massif peaks, we find seven villages. Really fertile green landscapes are placed next to the river source and its difficult accessibility has helped preserving its land architecture.

Beyond any difference, the whole valley is characterized by the red colour of the earth, the rocky walls and its buildings. The earth and the stone are indispensable elements in the characterization of the physical landscape in all scales herein; from relief to buildings. The land is also a narrator of cultural meaning, because according to García Leon (2009) we can recognize the culture living in a region "*through the artful devices each civilization introduces, affecting the culture of construction, urban space, the territory and landscape*".

The other identity element is the oasis, which makes this earthen architecture landscapes being potentially attractive and unique scenarios.

Although the present work highlights the architecture and earth modeling, we have to bear in mind that it is the oasis element which makes this architecture possible and enhances it as a landscape. However, there is absolutely no doubt that land architecture has a patrimonial and aesthetic interest by itself, it is the oasis that gives these landscapes a special power, beauty and identity, making them especially attractive for tourism. From this point of view, the understanding of this interdependence is a key aspect for the development of policies and actions design to enhance, protect and develop the area.

This is why the approach from the landscape helps us get an overview of earthen architecture within a comprehensive context where architecture, nature, historical buildings, culture and the group imaginary fuse together setting up a meaningful unit.

3 GENESIS OF THE EARTHEN ARCHITECTURE LANDSCAPES

The natural ecosystem that characterizes the region of the south of the Moroccan Atlas is the stony desert (*hammada*). According to the data contributed by Jordi Badía Pascual, "*99% of the region is arid, barren, with no water or a fertile stratum of earth*". The productive areas placed in the oasis make up the 1% of the fertile territory, which justifies its condition of "*ecosystems in extreme sustainability situation*" (Badía 1998). The population settlements are concentrated in them, in a constant fight for survival this began in the Early Middle Ages, when the gradual soil impoverishment forced the nomadic tribes to become sedentary. According to archaeological finds discovered and recent analyses of pollen (Soriano 2007), the Maghreb was a savannah biome, rich in flora and fauna species, with a land full of zones with perennial gramineae, bushes and arboreal types.

This historical aspect is essential in order to understand the construction and existence of these landscapes, since the gradual effect of desertification had forced the reorganization of territories of the nomadic tribes. With the fertile land shortage so close, it takes place a fight for survival which begins in the Middle Ages and that would be the purpose for wars and continuous tribal conflicts. The fight for survival would be the fight for the right to occupy the productive soil. It will also be the beginning of land architecture and the habitat transformation.

The rivers basins are the only collectors of water coming from thaw floods (proceeding from the high summits of the Atlas) in spring time, and from heavy rain in the beginning of summer time.

This happens because the soil lacks vegetal and arboreal species to retain the little water that may occur. The rivers basins are therefore the final collectors where water becomes stagnant and with it the alluvium and slime sediment, very rich in organic matter necessary for the agricultural development.

Against the uncontrolled excess of seasonal water, two main climate issues appear: a strong solar radiation, and *chergui*, a dry warm sandy wind, coming from the Sahara. In this context the basins constitute themselves as fertile and independent environmental units that enjoy a certain microclimate as far as they keep safe from the winds of the Sahara. They have a guaranteed water supply and a restricted solar radiation due to the high walls that form the river basin of the valleys. That is why these valleys are constituted as landscaping and environmental units, where agriculture is possible and, with it, the settlement of the population centers (Fig. 2). These circumstances together with the sociopolitical factors determine the appearance of the earthen architecture landscapes and the oasis.

4 HISTORICAL SEQUENCE IN THE PHYSICAL AND CULTURAL CONSTRUCTION OF PRE SAHARIAN VALLEYS

- A progressive and slow desertification of the territory takes place, which causes the transition from the savannah biome to the *hammada* (stony desert). This process sets throughout the Middle Ages, the unique fertile ecosystems which are reduced to the fluvial river basins.
- It supposes the gradual settlement of the best adapted nomadic tribes around valleys. It is the beginning of the fight for the control of water and the necessary fortification of the architecture.
- The arrival of Islam with the Arab conquest in the VII century introduces the scientific knowledge of an evolved agrarian culture which may allow a sustainable and self-sufficient management of water, by the development of irrigation systems and a complex infrastructure of *khetaras, saguias* (irrigation ditches), channels, wells and laundries.

Figure 2. Cultivation plots next to the Dar of Ait Youb. Author: J. M. López Osorio.

This hydrological network and a better knowledge on agriculture, will allow the growing with irrigated crops of new species. The introduction of the date palm (*Phoenix datylifera*) will help take root and stabilize the land of orchards at the same time as it offers a shelter to the solar radiation improving the soil's humidity conditions. This makes the creation of a cultivation system by layers optimize the production. This system is made up of a superior strata consisting of palms, an intermediate strata of medium size trees with a large number of fruit trees (fig trees, walnut trees, almond trees, apple trees, pomegranate trees…) and a last level, where seasonal crops are produced (maize, wheat, forage, and vegetables like carrots, potatoes, turnips, marrows, tomatos…).

– The agriculture improvements allow the stabilization of new lands in the torrent beds, vacant until then, extending the productive area of valleys and allowing the towns to grow and to relax their fortification needs.
– From the XVII century onwards, the decay of the Trans-Saharan commercial route that connects Tombuctú and Marrakesh begins. At the end of the XIX century, with the French occupation of Tombuctú, the caravan commerce found its end, causing an economic decline in the region, which increasingly depends on the subsistence economy of the oasis.
– With the French Protectorate in 1912, a slow process of emigration begins, which gets intensified from the decade of the 50's and the 60's onwards. The growth of the population and the restlessness to improve their life conditions motivate the continuous rural exodus to the cities. This emigration produces, therefore, a gradual process of abandonment by the populations, being the cause of new imbalances.
– A phenomenon of reconditioning new homes and "second residence" construction in the outside of the ksar or fortified enclosure takes place. This process gives rise to the development of the duar: tight groups of houses which, in this evolution step, looks like an urban spread of growth just like an oil smudge, where European imported constructive systems are commonly adopted, with reinforced concrete framed structures and cement block walls.
– Finally, a slow but increasing arrival of visitors takes place, related to a cultural and adventure tourism attracted by the beauty of landscapes and the culture and hospitality of their inhabitants.

5 THE EARTH: CONSTRUCTION, IDENTITY AND LANDSCAPE

According to the landscaper Rosa Barba, "*the earth belongs to what we recognize as a previous condition, in the sense that it precedes us. The earth gives support and confidence; it talks about a human condition which sets the landscape as something permanent in our memory. On the other hand, water offers the possibility of an artificial world of Nature, and the vegetation is the most evident mark that there exists a landscape*" (Barba 2000).

Beyond "the natural" image that these territories may offer, we have to bear in mind that we are talking about spaces that have been highly affected by human intervention which, in the struggle for survival in a territory with such extreme conditions, has used earth, water and vegetation to build his own habitat. Earth is the main constructive material in the architecture, shaping an urban and landscape image provided with a strong entity. The mud walls are used for the building of the historical construction (*kasba* and *tighremt*), in the fortified town (ksar) or in the group of houses (dar).

Also, the mud wall is used in the construction of peripheral fences which delimit property patches, many of which have not been built yet. These constructions have been spreading very quickly in the last few years, transforming noticeably the surroundings. The mud walls conform to a sign of identity of the contemporary landscape of the valley, and have their rationale in the emigration and the change in the structure of land ownership. We found them in peripheral zones to the main bodies (Azrou and Znag are two good examples of it) (Fig. 3) and throughout the communication channels. Their horizontality and low height favor integration to landscape, but they anticipate strong transformations of the habitat, as they delimit lots that will be built in the near future.

On the other hand, the adobe has been traditionally used in the superior levels of kasbahs,

Figure 3. Earthen architecture landscape in the dar of Znag. Author: T. García Ruiz de Mier.

lightening the walls and allowing the development of peculiar geometric decorations.

Another main issue in the definition of landscape image is the flat earth cover, building up a rich image in tonalities, textures and forms, and which provides us a homogeneous and integrated map-reading of the surroundings.

Finally it is possible to emphasize, the importance of the mosques whose minarets are a landmark in the landscape. They are constructions made of reinforced concrete that, despite introducing an urban status shift, identify and characterize the nowadays habitat.

Besides the architecture, the land is also the base on which the ways, streets, public spaces, channels, slopes, terraces, etc, are given a shape, making possible, therefore, the construction of the social usage space as well as the productive space of the oasis.

Stones and boulders are one of the natural resources used in the definition of anthropic environment. These materials are found in the construction of the walls that contain and delimit the territory all throughout the communication channels, in the terracing of the fertile soil and in the demarcation of the threshing floors. Its use in the nomadic settlements is also characteristic, either in the construction of small volumes; or for the fencing of the threshing floors around the caves, or to gather the cattle; or piled up in landmarks as if they were indicating the temporary occupation of a cave. The stones are also used in the construction of dividers which divide the water throughout the fluvial courses, making possible the beginning of an irrigation network.

6 TRANSFORMATION AND IMBALANCE AGENTS

We have seen how the transformation during time seem to have been adapted to the territory in a process of logical construction and "negotiated" with natural dynamics. It has favoured the development of a sustainable model from the environmental point of view with very low rates of resources consumption and waste production.

The earth and the stone, along with other raw materials proceeding mainly from agriculture and animal breeding, allowed the basic needs of shelter to cover, food and spaces for social usage. It is, as we have seen, a subsistence economy which depends on the annotated productive spaces of the oasis. This means that we are dealing with very fragile units, where the struggle for the environmental, social and economic sustainability is an increasingly difficult challenge to confront. A model of development has not been able to keep up with the new times nor to absorb the population increase, making the region sink into a certain level of poverty. This has motivated the appearance of two phenomena of demographic flows which are deeply transforming the space configuration and, with it, the landscape: the emigration and the tourism.

Nowadays Mgoun Valley is subject to multiple pressures related to the globalization and the climatic change. While desertification advances, the global processes are importing models which harm the traditional laws of physical and social construction. It is putting at risk the survival of the preexisting models.

The emigration, although it is a source of wealth, is also an agent of destabilization and uprooting. According to the studies developed by J. Lacomba and M.J. Berlanga in the Moroccan High Atlas, the *emigration consolidates social inequalities* (2006, p. 5) and weakens the traditional communitarian structures.

In the case of Mgoun Valley, more than a fourth part of the inhabitants has been affected by the emigration, which is accompanied by the disintegration of the traditional social institutions, the penetration of the market economy and the diffusion of innovations and urban habits (Laouina 2002, cit. Lacomba 2006).

The result of this process is perceived in the fast and uncontrolled growth of the dar (Fig. 4), and in the introduction of new architectonic typologies imported from Europe that alter the earth landscape substantially, and putting at risk the sustainability of the model. This in fact is fed by the changes in the legislation on the ownership of the land, pushed by the communities and the Central Government.

On the other hand tourism is attracted by the enjoyment of the landscape. This turns the landscape into a source of resources, and an alternative for the economic development of the region, as well

Figure 4. Walls demarcating future urban growth. Author: J. M. López Osorio.

as an opportunity for its enhancement. But the tourism can also be a threat and cause of strong imbalances, if it is not regulated to guarantee the environmental and social sustainability.

7 TOWARDS THE ACKNOWLEDGMENT OF THE CULTURAL LANDSCAPE

The preservation and the enhancement of earthen architecture as a heritage, needs an ample vision to be able to recognize, not only its constructive and architectonic qualities, but it also its value as cultural landscape units.

An approach from the point of view of "cultural landscape" is proposed for this. It is a concept that was recognized at the World Heritage Convention in 1992 (Fowler 2003). This conception guarantees the preservation of earthen architecture as a patrimonial resource, putting it in service for an economic reactivation of the region, causing the reinforcement of the community self-esteem.

A work of identification and stock-taking of the resources do not seem to be enough for this recognition to be effective. It becomes necessary on the one hand to know all the nuances composing the imaginary collective of inhabitants and tourists and, on the other hand, *to narrate a history able to attract visitors and investments*, as Joaquím Sabaté states (2004) as far as the patrimonial parks.

In this sense, the organization of the cultural landscape in relation to determined itineraries could be useful, introducing a temporary spacial sequence, articulated along a didactic and narrative route. At this point the contributions from J.M. García León (2009) are interesting. He explains how "*from the recuperation of means of communication not only do we grant values to the natural and cultural resources, but also we integrate the elements to be protected and preserved, profiting the landscape in benefit of the communities in decay*."

In the case of Mgoun Valley, a specific study for each of the landscaping units composing it is proposed, where an integral analysis for the recognition of the land architecture as cultural landscape is approached. In order to do that, it would be necessary to go beyond the stock-taking of the architectonic pieces, and to deepen the development of the landscaping studies, the knowledge of the economic and social structures and the construction of a historical and cultural narrative that gives sense to the differentiated physical and social construction of each unit.

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The *barraca* of the Valencian agriculture field: A construction built with earthen techniques

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ABSTRACT: The Valencian *barraca* (thatched cottage) is a building made with earthen techniques, representative of the vernacular architecture of the agriculture field, nowadays an almost extinct type. The evolution of the building includes various constructive techniques for enclosures: the technique of the *canyisso* (reed mat), the technique of the *fang renugat* (cob) and the technique of the *gassons* (adobes). A priority is to recover the knowledge on the implicit values of this type, an example of sustainable housing.

1 INTRODUCTION

The Valencian *barraca* is a construction made with earthen techniques, belonging to the Mediterranean popular architecture and it represents the characteristic residence of the smallholdings of the agriculture field. It is an example of symbiosis between the house and the place (Fig. 1).

The origin of this building is uncertain, could be traced back to Roman times, but also related to the primitive constructions of the Neolithic period (Almerich 2002, 159).

Given the small size of the *barraca* and its vulnerability to fire, *barracas* are grouped with different functions and connected by a coverage passage. This connection can occur in perpendicular or parallel.

The *barraca* is built by the farmer, with help of the *barraquer* (builder of *barracas*) for more specialized tasks, using local techniques and materials of their environment that require little or no manipulation. Earth is a key component in the evolution of different construction solutions of the enclosure.

Figure 1. Set of *barracas* in the Valencian agriculture field (Pastor, private file).

Nowadays there are very few *barracas*, the study proposes the enhancement of this building, representative of the vernacular architecture of the Valencian agriculture field, emphasizing its testimonial character as sustainable habitat.

2 DESCRIPTION AND DISTRIBUTION

The *barraca* is the characteristic home of the Valencian farmer. It is a simple building which program includes domestic and labour functions developed in two floors over the entire rectangular plot of variable proportions between the sides between 1/2 and 1/3.

This type was abandoned between the sixteenth and seventeenth centuries due to the incursions of the Moors in the Valencian coast, forcing the inhabitants of *barracas* and *alquerías* (farmhouses) at the beach and in the agriculture field to take refuge within the walls of the city. It was reborn in the eighteenth century and reached its peak in the nineteenth century (Michavila 1918, 27–29).

Outside Spain, similar buildings can be found in Sweden, Norway; Italy, the Crimea and in the vicinity of the Great Lakes of Limans (Odesa) (Gosálvez 1998, 8). In Spain we find design variations of this building, depending on whether they are *barracas* in irrigated lands (from Murcia and la Vega Baja) or *barracas* in unirrigated lands

(Castellón, Tarragona, Mallorca and Menorca) (Ferré & García 1998,159–164).

The *barraca* was widespread in the Valencian agriculture field and introduced a variation as the fishermen home in the maritime areas of El Cabanyal, El Canyamelar, El Cap de França, El Grau and Natzaret.

The *barraca* is normally built by the owner helped by the *barraquer* for the more specialized tasks like the roof.

In terms of interior distribution, originally there was no differentiation of spaces. There was a main room with a fireplace in the middle around which the other functions were organized. Max Thede ([1933]2009, 105–118) refers to three ways to organize the internal space of the *barracas*: the first one has a whole single space, another one with two spaces, one general and one for bedrooms and a third type with different spaces and a side-corridor.

The interior distribution in its more advanced stage has a single family program. A side-corridor occupies half of the rectangle, in it lies a kitchen bench and it is the place where the family usually stays. It is both corridor and hall to which two rooms converge: a main bedroom and the *estudi* (living room or bedroom for single sons). Sometimes there is one more bedroom. In the back, a staircase leads to the *andana* (space under the roof) aimed at storing the crop and for the silkworm rearing. In order to avoid possible fires the kitchen with the stove is usually outside in a smaller *barraca* separated from the main one, including also a space for the animals. This distribution is the most common in the *barracas* of the agriculture field (Thede 2009, 112) similar to the ones of the fishermen of El Cabanyal (Gosálvez 1998, 14–16).

The front and rear façades correspond to the short sides of the rectangle. In the front one facing East (Fig. 2) there is a door and a small window. The rear one has a door to the corral. On the upper part, these façades have small openings that provide ventilation for the upper floor or *andana* (Gosálvez 1998, 14–16).

Figure 2. Current view of a *barraca* from the agriculture field (Pastor, 2012).

3 THE CONSTRUCTIVE EVOLUTION

The *barraca* is built with traditional techniques based on experience and transmitted by direct learning. The building materials belong to its environment and require little or no manipulation: clay earth, water of irrigation canals, wood from trees, reeds, lime and esparto.

There are several successive stages in the structural evolution of the *barraca* that are analyzed subsequently.

3.1 *First stage: the reeds and the mud*

In the first phase, only the reeds and mud are used. The reeds are grouped in bundles of various thicknesses and stuck into the ground. These intertwine on the gable summit and form the roof as a single space. This structure of reeds, is covered inside and outside by a layer of mud or clay: inside to condition the space and outside to isolate it from humidity.

Daily living is largely in the open so the interior space of the *barraca* is for rest, a single space with the fireplace in the middle. The back side has a slight curvature and is used to store farming implements (L'Escrivà 1976, 41–48).

3.2 *Second stage: the reeds, the mud and the wood*

In a second phase of evolution a new material is introduced: the wood directly felled from the elms, poplars or from any other three from the margins of the irrigation canals.

The roof remains gabled but stronger. It is built by sticking into the ground the hard branches from the trees that have been previously sun-dried. For their covering mud is no longer used, but different types of reeds from the marshes (L'Escrivà 1976, 41–48). The curvature in the back of the *barraca*, acquires the apse form.

Daily living is still in the open and the *barraca* is a single space almost exclusively aimed at the family rest at night.

3.3 *Third stage: Technique of the canyisso (reed mat)*

The first outlines of side walls make their appearance. The walls are made with reed mats covered with mud and whitewashed (L'Escrivà 1976, 181). This primitive method described by Sanchis Guarner (1953, 17), consists of: "a series of wooden props, usually from mulberry, called *vents,* which hold the frame of the roof as studs. The space between the props gets covered with reeds tied with esparto and a last layer of clay". The gable roof is made with remains from different kinds of reeds: *borró, mansega* and *senill* (L'Escrivà 1976, 48).

3.4 *Fourth stage: Technique of the fang renugat (cob)*

In a next step the farmers build stronger external walls, with the *fang renugat* technique, consisting of a mixture of mud and straw with some water dried in situ (Fig. 3).

The enclosure of about 50 cm thick grows to a height between 50 and 120 cm. It is formed by gradation of superimposed layers in an irregular way of about 10 to 20 cm high, using the hands as instruments, and sometimes also a wooden formwork (L'Escrivà 1976, 181–182). Another solution incorporates some small diameter logs stuck into the ground as a stiffener for the wall (L'Escrivà 1976, 181). The roof is gabled and covered with weeds from reeds and rice.

3.5 *Fifth stage: the technique of the gassons (adobes)*

Over time the *barraquer* learnt to build walls with clay pieces produced in situ and called *gassons* whose size is usually 40 × 35 × 6 cm (Gosálvez 1998, 11). The composition of adobe is the same as cob but with more water, its polyhedral shape is acquired in wooden molds where the pieces achieve consistency drying in the sun.

Once the foundation layer is tamped, the wall is constructed by placing the adobes up to approximately 2.5 m above ground level. One of the most common bond is called *punter i boser,* two adobes in the long run and one across (Ruiz 1999, 30). In order to place the adobes and to seal the joints a mortar is used, composed of earth with or without additives such as lime or plant extracts.

Figure 3. Sample of cob (Pastor, 2012).

The resistant walls built with adobes are reinforced sometimes with mulberry tree logs stuck into the ground and embedded in the wall (Fig. 4), they support the roof trusses (Guarner 1957, 18).

The enclosures are protected on the surface from erosion and leakages by covering them with a lime grout, or with a whitewash on a previous rendering made of earth and straw.

Daily living begins to take place inside the *barraca* so the interior is covered with plaster to make the room nicer and cleaner. The fireplace that had always been in the middle gets closer to the wall and modifies the distribution of floor with a side-corridor. The roof becomes increasingly important and reeds of better quality are used. At this stage the *culatas* begin to disappear.

Interior partitions are made of a variety of reeds from the Albufera called *senill* that is covered with mud to provide better isolation and stability.

The necessity of space demands the creation of a second level, that at first covers only part of the floor and is used for storage. Later it is expanded to the whole and forms the *andana*, which is aimed at drying and storing the crop and also at silkworm rearing (García Mercadal 1930, 59).

Figure 4. View of a wall reinforced with logs (Pastor, 2012).

The upper part of the front and rear façades operates as an enclosure. It is built with reed mat covered on the outside with clay and fastened to three studs which end in the roof structure. In order to provide light and ventilation to the interior space some narrow holes are made in this enclosure (Fig. 5).

The building takes on greater significance and the roof is more complex, requiring a more solid foundation. This consists of a trench 50 cm wide and 40 cm deep filled with stone masonry. The foundation also isolates the wall from the humidity of the earth and protects it from groundwater (Gosálvez 1998, 17).

The meeting of the adobe wall with the floor is solved by placing a wooden profile of 7 × 11 cm. Trusses of about 2 m are nailed to this profile along with the floor joists working as braces (Gosálvez 1998,18).

The trusses converge in a wooden profile of 5 × 7 cm, forming the vertex of the gable roof (Fig. 6). The slope of the roof is stiffened by some more wooden profiles.

The wooden joists or roof braces rest on a beam supported by two logs working as pillar, placed in the transverse partition on the ground floor.

On the wooden joists, a thick reed mat is placed. This is the floor on which crops are stored (Fig. 7) and it is reinforced partly with wooden boards creating a way to walk in the space under the roof.

The roof is covered in a first layer with reed mat arranged horizontally and leaned on the trusses. In a second layer some other thicker reeds are superimposed as guides. Hereafter some other are placed in a perpendicular and separated 40 cm. The last layer consists of straw weeds of about 1.5 m long.

3.6 *The enlargement*

Perhaps coinciding in time with the economic boom derived from silkworm rearing and more

Figure 5. Upper part of the façade made of reed mat (Pastor, 2011).

Figure 6. Interior of the *andana* (Pastor, 2011).

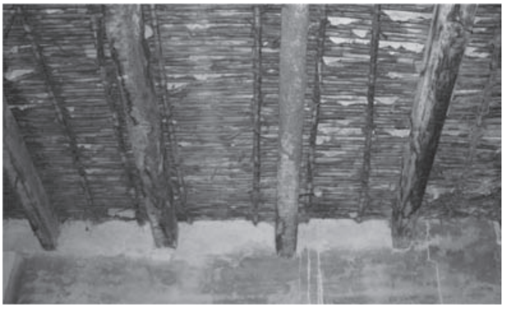

Figure 7. Floor of the *andana* made of reed mat (Pastor, 2011).

chances to increase the family, the necessity of space, results in no enlargement but in the duplication of the building. The experience of its constructors allows them to repeat the known type more easily than to experiment with new ones of bigger dimensions and unknown structural behavior.

The *barracas* are usually grouped in pairs and given their vulnerability against the fires, they accommodate different functions, one for daily living and the other as kitchen and space for animals (Casas Torres 1944, 87). They are arranged one after the other or connected by a covered passage built in perpendicular or parallel.

4 CONCLUSIONS

Changes in the agricultural economy have been the cause of the progressive disappearance of the *barracas* as a result of depopulation of rural communities.

In recent times, the application of traditional construction techniques has been hampered by the lack of some of the materials used, by the loss of knowledge on the technique and by the changing lifestyles. All of this has led to other types of rural buildings and to changes in the existing ones, away from the tradition and from their habitat

A priority is to recover the knowledge on the implicit values in the popular architecture, emphasizing the importance of earth as one of the most widely used building materials since ancient times because of its easy obtaining, its ability to adapt to the environment and its high thermal inertia. These characteristics qualify it as material to incorporate to the contemporary architecture and validate it as suitable material for sustainable architecture.

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Excavated housing in Crevillente (Spain): Constructive and typological study

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ABSTRACT: Underground architecture has sheltered man for many centuries, but the current need to emphasize the bioclimatic approach makes the study of excavated housing essential. This traditional construction is a part of the collective human living experience but also a reference in using the natural conditions of each region through simple proposals based on ground thermal inertia. The aim of this paper is to show the typological evolution of the excavated dwelling in Crevillente, in southeast Spain, compared to other worldwide architectural proposals or urban solutions. To show their adaptation to the regional geography and to comprehend both formal and material characteristics of these simple typologies, which do not need extra energy contribution for interior conditioning. This work is part of the doctoral thesis of the author.

1 INTRODUCTION TO TROGLODYTE ARCHITECTURE

It is often considered that troglodyte buildings do not deserve to be classified as proper architectural solutions and they have often been neglected because its implementation is not based on complex concepts or advanced techniques. However, after a thorough analysis, underground proposals can become great architectural solutions nowadays and the aim of the present work is to show it.

As an introduction to troglodyte architecture, we want to show the main features of the four major types excavated according to the direction of excavation.

1.1.1 *Horizontal excavated architectures*

In these architectures there is a minimal human intervention in the configuration of the living space. They are based on basic conditioning of natural caverns through simple architectural interventions subtly adapted to the natural environment.

1.1.2 *Vertical excavated architectures*

These primitive architectures have a vertical direction of excavation and perforate the subsoil from the surface. They were open at the top but, after the evolution of construction tools overtime, they begin to be covered to gain verticality and to increase their dimensions, leading to more complex and spacious constructions.

1.1.3 *Shallow excavation architectures*

This type of shallow architectures are obtained on rocky elements, by creating new forms and spaces above the ground line. They are constructions involving a greater excavation in soils with definite values of hardness or resistance but also soft enough to be carved and shaped with rudimentary tools.

1.1.4 *Mixed architectures*

This typology is a new pattern of excavation based on the synthesis of two types: vertical excavation and horizontal excavation. This system starts by opening an inner courtyard vertically excavated and, once a new plane is generated, an horizontal digging continues around this empty space. This solution has generated a considerable diversity of forms and groups, by creating original troglodyte structures throughout the Mediterranean region.

2 UNDERGROUND ARCHITECTURE IN SPAIN

Caves in our country have been spread out to all areas where there are certain initial conditions such as extreme temperatures, low precipitations or excavable grounds of sedimentary materials.

Although these caves initially appeared as a basic survival shelter, in many cases they have acquired the status of a real popular housing. Today, many settlements are been recovered thanks to the addition of new infrastructures, to improve habitability conditions or the momentum of its integration in consolidated urban structures.

Such is the case of some regions of southern Spain (Guadix, Purullena, Caniles, Baza or Gor in Granada; Valencia, Paterna or Bocairente in

Valencia and Crevillente in Alicante) where entire neighbourhoods are preserved still today and where caves are highly prized for being cool in summer and warm in winter, provided that they are well preserved.

In other areas further north (Aguilar de Campos in Valladolid, Calatayud, Epila, La Muela, Cariñena or Juslibol in Zaragoza) many of these excavations are used to preserve agricultural tools, to keep the wine at a low and stable temperature or as a meeting place in original rural tourism establishments.

3 ORIGIN OF CREVILLENTE CAVES

In the late sixteenth century, the first town centre of Crevillente was developed with a complex and disorderly development. After long periods of poverty, the capacity of the existing town overflows with the demographic revival in the eighteenth century, so it begins an excavated development to the north area, on the slopes of the mountain (Fig. 1).

Some people dug caves with housing use in the northern ravines of the town and this is how it appears a different building type that will have a wide use and acceptance even nowadays: the caves.

4 TYPOLOGICAL ANALYSIS OF CAVE-HOUSES IN CREVILLENTE

4.1 *Main typologies*

Cave-houses of Crevillente form original settlements on the hills of the entire town. They are excavated houses where the characteristics of the land condition the result and where there is no much typological planning previous to construction, unlike in conventional building.

The following are the main types of excavated housing in Crevillente related to a typological identification.

4.1.1 *Cave*

This underground typology corresponds to totally excavated spaces in the ground, where there is no element or exterior added construction in the front (Figs. 2 and 3).

4.1.2 *Cave + Attached constructions*

This underground typology presents added constructions in its exterior besides possessing excavated rooms (Figs. 4 and 5). These adjacent areas can be accessed from the outside (it is the easiest solution as it only adds a construction outside the cave, without affecting the excavated rooms) or can be accessed from the inside (they are new constructions which are included within the excavated typology).

4.1.3 *House + cave*

In this typology, the cave-house is showed as a conventional home and its excavated character goes unnoticed because exterior constructions occupy the entire façade (Figs. 6 and 7).

In this case, the excavated rooms are used only in certain seasons of the year as homeowners take advantage of conventional constructions in winter (where the humidity is lower) and live in the cave during the summer (due to its greater thermal comfort).

4.2 *Basic rooms*

In the distribution of underground spaces, the dining room is the point of access to the housing.

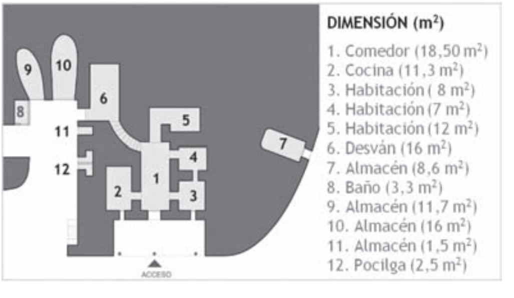

Figure 2. Main floor of an excavated house in the CAVE typology. Image of the author.

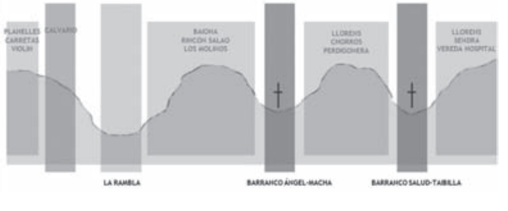

Figure 1. Schematic cross section of the cave neighbourhoods in Crevillente. Image of the author.

Figure 3. Outside and inside view of an excavated house in the CAVE typology. Images of the author.

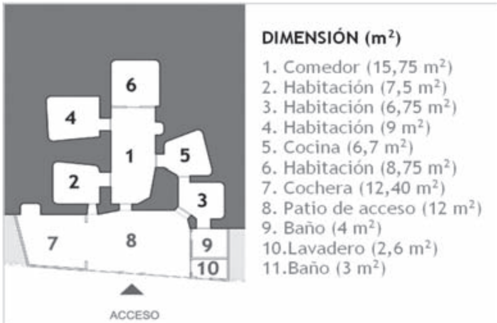

Figure 4. Main floor of an excavated house in the CAVE + ATTACHED CONSTRUCTIONS typology. Image of the author.

Figure 5. Outside and inside view of an excavated house in the CAVE + ATTACHED CONSTRUCTIONS typology. Images of the author.

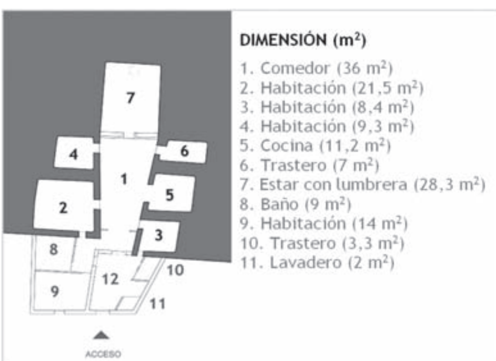

Figure 6. Main floor of an excavated house in the HOUSE + CAVE typology. Image of the author.

Figure 7. Outside and inside view of an excavated house in the HOUSE + CAVE typology. Images of the author.

From this space with elongated shape, a room with direct exterior ventilation is dug symmetrically on each side and also different rooms are dug in depth according to the specific family needs. Thus, there are homes that can reach even 5 levels towards inwards as a result of the typical evolution of the family; however, an excavation so deep implies that spaces only may be ventilated at second or third order from previous ones, making it difficult for air renewal.

The following describes the basic rooms and some unique elements of excavated houses in Crevillente.

4.2.1 *Dining room*

This is the room that organizes and distributes the rest of the interior spaces. It has between 8-10m length, 2-2.5m wide and 2.5m height and it is the room where daily life is based in the cave.

4.2.2 *Bedroom*

Bedrooms are usually rectangular or square shape and they have a slightly lower height than the dining room, but never less than 2m.

In most cases, in a cave-house there are three rooms with the function of bedroom with an average size between 7-12m^2 (although rooms of even 30m^2 can be also found).

4.2.3 *Kitchen and bathroom*

Whenever possible, these areas are placed outside in small buildings attached to the façade of the cave to facilitate the installation of new water pipes and sanitation to improve the quality of daily life. Nowadays, most of the caves have front attached constructions with these functions.

4.3 *Singular elements*

4.3.1 *Spinner room*

It is a fairly long room that appears around the second half of the nineteenth century. At that time, work was generally done at home and the house was used as a space for manufacturing and spinning hemp (Fig. 12). This task required a major workplace due to the length of the yarns used and often required the use of the entire house (from the door to the bottom).

Today, it is very difficult to find cave-houses that keep this peculiar room because since 1960 the carpet industry emerged significantly in Crevillente and it joined the more experienced spinners in their factories. Thus, gradually the small spinner workshops closed in the municipality and, therefore, the use of this room stopped in the excavated housing.

4.3.2 *Attached constructions*
These constructions are recent buildings attached to the front of the cave-houses without being a structural part of them (Fig. 8). They are usually small and simple constructions with current materials (often formed by three or four brick walls covered with fibrocement roof) that were mostly made during and after the war (1940–1950) or in the acceleration process in 1980.

They are located outside the excavation and provide a usual place for wet rooms to avoid smells and smoke fumes inside thanks to direct ventilation to the street.

4.3.3 *Chimney*
Crevillente traditional chimneys are made of stone or clay (though brick is the more modern material), they have a height between 1.5 to 1.8 m and different shapes such as conical (characteristic of Guadix and Baza regions), truncated (typical of Crevillente (Fig. 13)) or even parallelepiped shape.

Nowadays, chimneys have lost their original function as in many cases kitchen is located in a building attached outside. Even so, they still play an important role in providing some aeration and ventilation to the room where they are placed.

4.3.4 *"Lumbrera" (Skylight)*
A "lumbrera" is a parallelepiped skylight located in the deepest room farthest from the access, in order to generate a cross ventilation through natural draught and provide light to deep spaces (Fig. 9).

Figure 8. Left image. Main floor of an excavated house with spinner room. Carreres, M. *Coves vivenda i coves filadores a Crevillent: 125*. Right image. Attached construction with kitchen use.

Figure 9. Left image. General view of a traditional chimney. Right image. General view of a traditional "lumbrera". Images of the author.

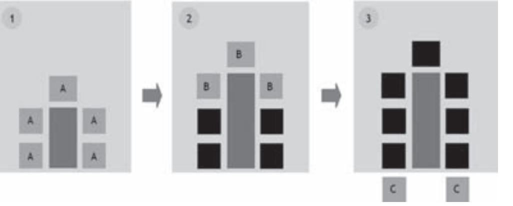

Figure 10. Evolution scheme of the main floor in a cave-house in Crevillente. Image of the author.

It is approximately 1.5 m high and it is usually covered with flat tiles; it has commonly small windows protected by wire mesh on both sides that allow the air exchange and the regulation of temperature and humidity within the cave.

5 CONCLUSION

After long periods where architecture has taken advantage of the economic wealth and the growth of a limitless technology, what was once common has become unacceptable nowadays.

Excavated houses are faithful to a commitment of sensibility to traditional intelligence (adapted to the particular needs, place and environment) by reinterpreting traditional solutions that have never failed: those that ignore waste of money and present simple technological proposals with equal effectiveness in global terms.

A total or partial buried construction regulates the internal thermal stability and improves thermal insulation, by making a "bunker" effect of protection. However, it also generates some disadvantages to resolve, for example, the existence of moisture through direct contact with the ground, the difficulties of air exchange or the problem of natural lighting in deep rooms. Therefore, all these disadvantages require a change of perspective when it is necessary to consider an underground architectural project.

In general, site plays an important role in the final number of underground spaces because the ease or difficulty of excavation influences the kind of final rooms. Thus, despite the needs of each family, natural relief and terrain type are factors that determine the size of the dwelling.

The excavation of cave-houses is available in areas with slopes and a favourable configuration where two main factors are combined: on the one hand, the area is composed of sedimentary materials and on the other hand, the weather must be mostly dry, with low rainfall and significant annual fluctuations of temperatures which make ideal the use of an underground protection as a refuge.

However, in many cases geographical, environmental or social agents are not the only conditioning facts, but the influence of personal roots to these buildings is essential to explain their continuity to the present day.

Since its emergence in the eighteenth century, the number of cave-houses in Crevillente has fluctuated depending on the social demand of low cost housing. These excavated houses have been adapted to current needs by using the interior space in summer and using the exterior constructions in winter.

Rooms have been transformed over time by very specific adaptations of the interior space or deep changes in their floor development, as shown in Figure 14. It shows how the evolution of the initial structure goes through a first excavation of indispensable rooms (A), a second phase of expansion when the number of inhabitants increases (B) and a third phase in which different elements are built attached to the cave in the outside (C). That is how the dwelling adapts its development to the needs of its users.

This new typology is originated as a natural construction with intrinsic dependence on the landscape and is increasingly becoming more artificial since, despite coming from a necessity adapted to the land, its development involves the addition of external elements outside the initial construction.

They are simple, low cost architectures, where people have been an active part in their excavation, making much more tangible the sense of ownership and belonging to their homes. Architectures where its peculiar beauty and originality deserve further attention and social value because, although today they are being destroyed by current buildings, they will always be in the memory of those who have enjoyed of them.

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Peruvian earthen architecture: Reflections on traditional constructive techniques

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ABSTRACT: This study, carried out by the authors from a research developed in 2011, presents a series of reflections on Peruvian earthen constructive systems. Undoubtedly, these solutions are the result of a perfect combination of adaptation to local climate, seismic resistance and low cost of production. There is certain continuity between the Pre-Inca constructive skills and those of the following civilizations (Inca or Viceroyalty). The "Constructive Grammar" does not change drastically through the centuries. Earthen architecture is always the protagonist, according to the availability of autochthonous raw materials, such as reeds, cactus gel and carob timber.

1 INTRODUCTION

1.1 *The area of study*

Peruvian earthen architecture is present in two wide areas of the country: traces of earthen architecture in various archaeological sites can be found along the Pacific coast (in particular from Lambayeque up to Arequipa), and an omnipresence of adobe architecture in the area known as La Sierra, a region that occupies the central third of the country, characterized by its Andean climate.

The study focuses on these two areas, with the aim of collating information on various constructive earthen techniques, combining features of archaeological sites with sample of/examples of vernacular architecture (Fig. 1).

Figure 1. Map of areas/provinces with earthen architecture, visited during the research. (Authors: Cristini & Ruiz Checa).

1.2 *The research method and the addressed visits*

Visiting the different archaeological sites has enabled us to understand a range of constructive techniques, including those relating to the people that began occupying the Peruvian coastal area (Alvariño Guzmán 2001), and at the same time, other constructive traditions that were developed in the less accessible pre-Andean territory (Velarte 1978). In total, 7 provinces of the Country have been selected, and more of 10,000 kms have been covered in two months (including the Province of Lambayeque, Ica, La Libertad, Ancash, Lima, Arequipa, and Cusco). More than 15 archaeological sites have been visited after speaking with different earthen architecture specialists and key-contacts.

More specifically, in the north of the country, the authors visited the archaeological sites of Huaca del Sol and Huaca de la Luna (Moche Civilization, 100–700 a. C.), and Chan Chan, (Chimú Civilization, 900–1470 a. C.), both close to the northern city of Trujillo (Rodríguez Suy Suy 1971, Campana Delgado 2001). Archaeological sites visits were completed by talks and discussions with experts and technicians, in particular in the ancient sites of Chotuna (Moche Civilization).

In Lima and its surroundings, it was possible to get to know in detail the Lima Civilization (550 a. C.) especially in the areas of Huaca Puccllana, Huaca Huallamarca and Pachacamac (Cardenas Martín 1998). In the outskirts of the city, it was possible to study the site of Caral (Shady Solís et al. 2008), which together with Ventarron and Collud form the "golden triangle" of primordial Pre-Columbian Cultures (5000–1800 b.C.).

On the other hand, the visits to the southern provinces centered on the surrounding of Nazca

(Cahuachi and Paredones, examples of Nazca Civilization 100–700 a. C.) and on Arequipa city (Tejada Schmidt, 1937). In the interior mountain area, visits were mainly made to the various Inca archaeological sites, including Pisaac, Ollantaytambo, Macchu Pichu, Qenco Quzco, Sacsayhuaman (Inca Civilization 1470–1533 a. C-Esquivel Fernández 2010).

1.3 *The success of a raw material: adobe*

During the various visits it was possible to classify the construction materials, typologies and geometries, the latter of which are frequently related to their earthquake resistance properties. Regarding this last point, the employment of different shapes is noteworthy: cross, circular or zig-zag floor layout. Also is frequent the use of sloping structures for earthquake resistance, whit a constructive process similar to a foundation walls with trenches. In terms of the materials used, the employment of a multitude of rich types of adobes (Fig. 2) or lump combinations is significant, among which we should mention: lumps (cut/just-lined), flat convex adobes, "loaf" shape adobes, "molar" shaped adobes, conical adobes and prismatic adobes (with/without pattern).

With regards to the lumps, these, along with the adobes with a prismatic shape, are typical of the Ventarrón-Collud Civilization (Aprox. 5000–1800 b.C.). Their dimensions change substantially from one region to another, but in all cases they are characterized by dimensions which are greater than the standards found in European archaeological sites.

Figure 2. Examples of "molar" shaped adobes, "loaf" shaped adobes, prismatic or conical adobes. Museo Antonini, Nazca. (Authors: Cristini & Ruiz Checa).

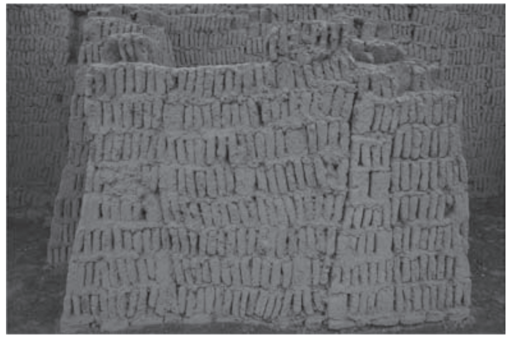

Figure 3. Detail of *librillo* bonds, with sloping walls profiles in *Huaca Puccllana,* archaeological site, Lima (Authors: Cristini & Ruiz Checa).

Thus it is possible to observe the presence of modules more than 50 cm long, and almost 20 cm high. These pieces are manufactured in response to the use of archaic patterns and the easy molded manual process. It's interesting to highlight that on some models the producers' marks are visible, like trading stamps. These pieces most likely correspond to different production workshops, as has been proven in adobe studied in Northern provinces (such as La Libertad/Trujillo). Adobe is also the main raw material found in the archeological sites surrounding Lima. In this case the bonding is characterized by header/stretcher bonds or *librillo* bonds (a soldier brickwork with a few centimeters of looseness between the pieces-Fig. 3), forming sloping walls, built using a process similar to a basic trench system (Cardenas Martín 1998).

Other, perhaps less elaborate pieces are made in loaf, molar and conical shapes. These can be found in the more recent Chimú, Moche or Nazca civilizations. In this case, the trapezoidal section of the building constructive elements responds even more specifically to earthquake movements.

2 THE LOGIC OF THE GEOMETRY: THE TRAPEZE

2.1 *A "trapeze shaped constructive culture"*

Throughout the visits to the different archaeological sites and the rural contexts it has been possible to identify different bond systems and constructive solutions, which in the majority of the cases, answer to the aforementioned rules. In fact, the constructive "fingerprints" left by the different civilizations reveal frequent trends. The load bearing walls are always made of earth, and are trapezoidal in shape. This can be observed both on a large and a small scale; from the very configuration of the adobe modules, to the design of the openings and wall sections.

Undoubtedly, the trapezoidal geometry is omnipresent all over the country and throughout the different Civilizations, both on a symbolic and constructive level (Hartkop 1985). The trapezoidal shaping has been used both by the Pre Inca conquerors (between the 6th and 14th centuries), and by the Inca civilization itself (after 15th Century).

In this way, the trapezoidal section walls are built using elements that follow the same geometric tracing. Even the openings, such as the doors or windows, or the niches repeat this geometrical "obsession" (Fig. 6).

This "trapeze-shaped culture", which is clearly visible in façades and in the inner parts of the structures or foundations, always responds to a sloping geometry (Tejada Schmidt 1937).

Whether the basis of these foundations are large ashlar masonries bonded with by mortar (Andes Mountain System/ Sacred valley-Samanez Argumedo 1983) or adobe in its simplest form (desert or coastal regions), they always follow the same design. Frequently the bases of the walls which were built in the Colonial era come from older sloped Pre-Columbian foundations, always displaying a certain inclination in terms of the vertical line (Figs. 5–7). The trenches corresponding

Figure 4. Examples of trapezoidal units (adobe) in Chotuna archaeological site, Chiclayo Province (Authors: Cristini & Ruiz Checa).

Figure 5. Example of sloping wall, in *Huaca Arcoiris* archaeological site, *Trujillo* Province. (Authors: Cristini & Ruiz Checa).

Figure 6. Examples of trapezoidal opening in rammed earth stores; Huchuy Qosco archaeological site, Cusco Province (Cristini Ruiz Checa).

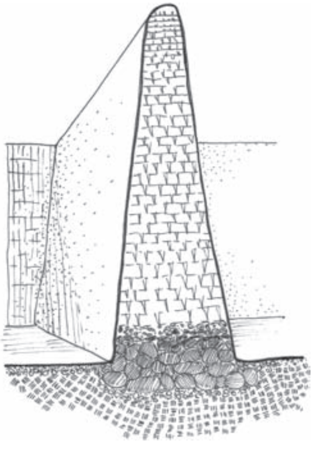

Figure 7. Examples of trapezoidal sloping walls, frequent in *Trujillo* and *Chiclayo* Provinces (Authors: Cristini & Ruiz Checa).

to these bases are often filled with compacted earth and homogeneously sized ashlars. Furthermore the depth of these trenches is not greater than the thickness of the walls they receive, thus always making good use of rocky outcrops.

3 THE HYBRIDIZATION IN DOMESTIC ARCHITECTURE: MIXED EARTH TECHNIQUES

3.1 *Earth with autochthonous raw materials*

There is certain continuity between the Pre-Inca constructive skills and those of the following civilizations (Inca or Viceroyalty). The "Constructive Grammar" does not change drastically through the centuries (Fig. 8).

Earth is the most widespread raw material, whether it is used on its own or with other materials, the combination of which can include: earth

Figure 8. Example of constructive continuity: contemporary earthen architecture in Colca Valley, Arequipa Province. (Authors: Cristini & Ruiz Checa).

and sand, earth and straw, earth and reeds (*quincha*), earth and cactus gel, earth and *guarango* (a type of carob tree).

From this framework it is interesting to highlight the latter three alternatives, as they are the least known and least studied combinations in Europe: *quincha*, the mixture of earth and cactus gel, and the combination of earth with *guarango* timber.

3.2 *Quincha wall system*

A *quincha* structure, also known as a light half-timber structure with wicker screens (Fig. 9), is an autochthonous constructive technique which has proven to be an effective solution in case of earthquakes.

This is fundamentally owing to the great elasticity granted by a half timber structure (Fig. 10), which absorbs the vibrations and allows them to be dissipated.

On the other hand, other interesting factors worth considering include its lightness (Fig. 11), the ease of assembly and the reduction of load in the hypothetical case of collapse. Moreover it's important to highlight the good thermal performance of this wall.

It is used in all the regions of the country, both in rural and urban settings, and is particularly useful when employed in dividing walls or partition systems.

3.3 *Extract of San Pedro Cactus*

The second combination, as previously mentioned, is a constructive mixture made from an extract of the San Pedro cactus (*Echinopsis Pachanoi*, syn. *Trichocereus Pachanoi*) and earth. This combination provides the earth mortar with impermeable properties (ideal for using in covers due to its great waterproofing ability).

The gel is extracted after a careful process of cactus maceration (taking 15 days-Fig. 12), after

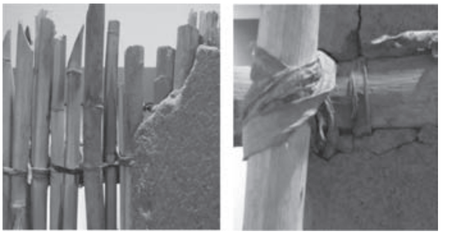

Figure 9. Detail of a *quincha* dividing wall, M. Antonini, Nazca (Authors: Cristini & Ruiz Checa).

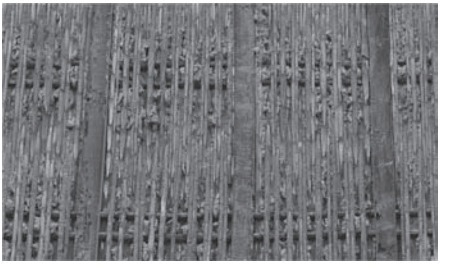

Figure 10. Examples of quincha dividing wall, Lima city centre. (Authors: Cristini & Ruiz Checa).

Figure 11. Details of the wicker screens, filled with earth, in a *quincha* wall, Lima (Authors: Cristini & Ruiz Checa).

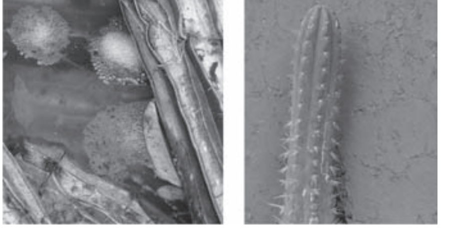

Figure 12. Detail of San Pedro cactus maceration, *Echinopsis Pachanoi*, syn. *Trichocereus Pachanoi*, (Cristini & Ruiz Checa).

which the water is leaked slowly and the extracted substance is hardened.

It is subsequently added to the sand and earth mixture, creating a water-repellent mortar, which is still used nowadays in protective layers for horizontal housings covers (Fig. 13).

3.4 *Guarango timber structure*

Finally, in the Northern area of the Country another autochthonous binomial constructive technique, based on earth and *guarango* timber, can be found (Fig. 14).

This timber comes from a robust species of carob tree, with a broad and dense crown that can reach up to 12 m high and which is better known for its fruit, a species of locust-bean.

It boasts a really resistant wood that rarely suffers attacks from wood bugs, and thus there is a long tradition of its use in Peruvian vernacular architecture.

These timber trunks combined with earth can be found in vertical structures (posts or pillars, Fig. 15) or in horizontal systems (ceilings or covers), based on daubed earth and straw layers, extended over the wood surface and subsequently whitewashed.

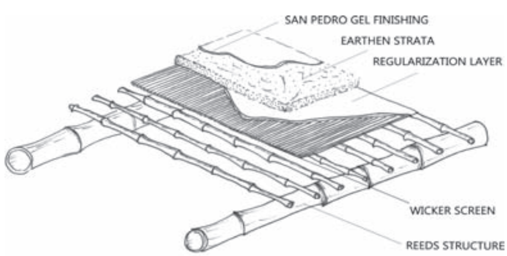

Figure 13. Constructive layers in horizontal housings covers.

Figure 14. *Guarango* tree and a covering structure, made with this timber. (Authors: Cristini & Ruiz Checa).

Figure 15. Example of contemporary house in Tucume, Chiclayo Province. A *Guarango* structure, with daubed earth and straw layers, lately whitewashed. (Cristini & Ruiz Checa).

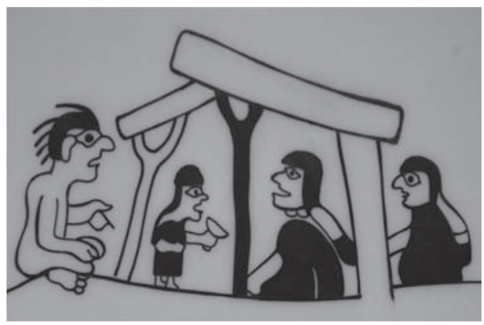

Figure 16. Example of Pre-Inca graffiti in Tucume archaeological site, Chiclayo Province, in which is visible a *guarango* timber structure. (Authors: Cristini & Ruiz Checa).

4 CONCLUSIONS

The direct contact with seven different Peruvian provinces and the visits to more than 15 archaeological and rural sites, have permitted a direct understanding of the evolution of earthen constructive techniques in the country.

All this is thanks to the discovery of a wide range of technical combinations, evident throughout a vast geographical area and an extensive time period: from 5000 BC to the Colonial era, and covering more than 10,000 km of land.

Objectively, the presented study is just an initial approximation, open to possible future research.

But aside from the introductory nature of this analysis, it's possible to note how Peruvian earthen architecture displays incredible coherence in its evolution, overlapping in time and above all reflecting strong technical/formal continuity (Fig. 16).

Different lines of investigation (Blondet, & Torrealva & Vargas Neumann) are being carried out in different departments of the *Pontificia Universidad Católica de Peru* (PUCP) that make the preservation and the maintenance of these constructive solutions possible, through contemporary experimentation and improvements in traditional methods (Sánchez Puerta 2010, Cabreras Arias 2010, Gallegos Gallegos 2010, etc…) with adobe experimentation, cactus gel or *guarango* timber.

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NOTE

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Earth construction techniques in the Northern High Atlas, Morocco

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ABSTRACT: When we use the term "earth construction", meaning all the buildings by different cultures and countries, we are grouping together a plurality of subjects. Thus, we cannot ignore the relevance of studying the specific technical features adopted in each region. The common characteristics of all the primitive construction are the complying with the geographical environment, the functionality and the traditional legacy of specific typology. These features should be kept in consideration also when studying earthen architecture which is a complex product of a specific culture that through it expresses a remarkable sign of its cultural identity. In this paper we anticipate some first results of the "I+D Arquitectura habitacional de tierra en el Alto Atlas septentrional. Midelt (Marruecos) (Cód-20110499-ADSIDEO-2011,1926-PAID-06-11-2011, *Universitat Politècnica de València*), showing the technology developed by the inhabitants of the northern part of the High Atlas, which has been used for hundreds of years and as we shall see, is still used today.

1 ORIGIN AND GEOGRAPHICAL FRAMEWORK

For many centuries the Eastern High Atlas has been frequented by many traders coming from the south, looking to establish communication with the north of Morocco and so spread their products around the Mediterranean.

Due to the geographical conditions of this range, in the eighth century the pass Tizi N'Talghoumt (1900 m.) was already a strategic positioned pass, joining through this corridor, two of the most important inland cities at that time to trade: Sijilmassa and Fez.

The first reference to a city in this area dates from the XI century and is given by the Andalusian geographer Abu Obeid El Bekri (1067), although there wasn't a reference to any settlement in the area of Outat until the XIX century (Aouchar 1988–1989). The three major tribes now settled in the valley of Outat are the Ait Ouafella, the Ait Izdeg and the Ait Merghad.

The Ait Ouafella, Berbers Sanhaja belonging to the old confederation Ait Idrassen, were the first in terested in the pastures of the place and exerted control until the arrival of the Ait Izdeg. Charles Foucauld (1888) refers to the Ait Ouafella saying, *"concernant les Ait Ouafella. Il comptaient environ 460 fusils. Les Ait Ouafella ne comptent pas actuellement avec les Ait Izdeg. Ils en son séparés politiquement"*.

The Ait Izdeg, natives of the High Todra, after the transhumance to the Ziz Valley, reached the north face of Ayachi (3747 m.) in the early XIX century, driven by two main reasons: the continuous conflict with the southern tribes, and the great drought that devastated the south-eastern Morocco between 1776 and 1782 that forced them to seek new settlements.

The Ait Merghad, natives of the Ghris, Ferkla and L'Imedghass valleys, belonging like the Ait Izdeg to the old confederation Ait Yaflmane (2) forged to fight the Ait Atta. In the Outat, this tribe was divided between the three major tribes of the region: the Ait Izdeg, the Ait Ouafella and Ait Ayach (Peyron 1976). The first reference we have with respect to the existence of ksour in the Outat valley is given by the priest Charles de Foucauld, who in his work (Foucauld 1888) quotes 16 fortified earthen cities along the two banks of the Outat River. Despite being a few more today, most of them referred to in this document still exist, and among them are Tatiouinne, Sammoura and Tabenaâtout, cities that have been studied in detail for the purposes of this paper.

Today the inhabitants of these cities of earth are migrating to the big city of the valley, Midelt, a new town founded in 1920 under the French protectorate as a result of the large amount of mineral resources present in the area.

This neglect is happening in an uncontrolled manner as we have seen throughout various expeditions carried out in the area in recent years and the process of destruction is constantly accelerating. This emergence justifies the need of rigorous studies aimed at documenting architecture and contributing to the knowledge and, hopefully, to the maintenance of this heritage at risk.

Figure 1. Ksar Sammoura (1).

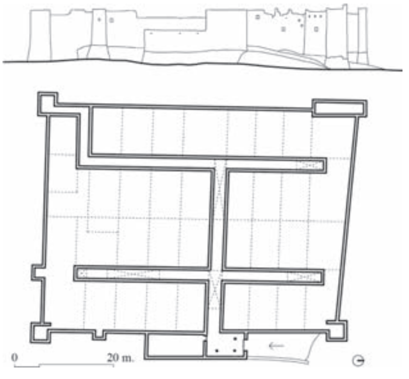

Figure 2. Ksar Tabenaâtout.

According to Abdelaziz Touri (Casanovas 1998), "the changes in recent decades have had multiple effects on this rough but fragile architecture. Neglect, lack of maintenance and ruin are just some of the aspects of this widespread degenerative phenomenon, which leads to the "explosion" of the ancient architectural complexes. Before they disappear, it is important to preserve, safeguard and rehabilitate them in order that they can offer proper living conditions in accordance with the demands of modern life. But beforehand it is necessary to study them, know them and recognize them."

2 HABITAT

The quintessential urban settlement in the Outat Valley is the ksar. This is typically characteristic architecture of southern Morocco and more specifically the pre-Saharan valleys. Here the particular relevance can be seen, not just in terms of size and architectural richness (it is much poorer) but also because of the geographic location: it is the only place in the northern part of the High Atlas where ksour can be found.

In these cities the buildings par excellence are made from raw earth materials. The architectural style of the ksar had to be adapted, as much as possible, in order to combat the severe weather conditions of the mountain, but the adopted cover system, with terrace contrasts with the seasonal rainfall and snow in this area.

The ksar housing system is like an individual cell, which works more or less in accordance to a common framework; this 'basic familiar unit' can be recognized in each ksar of the valley. The result of a progressive grouping of families with common interests gives rise to self ksar.

In our study we analyzed the constructive system of three houses located in three ksour:

– Ksar Tatiouine (1680 m.), situated on the east bank of the river Outat, very close to its source, is probably the oldest ksar in the valley and nowadays also the most deteriorated. In the course of time it has been occupied by various tribes, including Ait Izdeg and the Ait Merghad.
– Ksar Sammoura (1550 m.) is located on the top of a hill in the place where the Outat River divides in two. Its high geographical position places it in a strategic point for the control and command of the valley. Since its construction it belonged to a single family, the Ait Issoumour, of the Ait Izdeg tribe. During the second decade of the XIX century the family became the leaders of this place.
– Ksar Tabenaâtout (1525 m.) is in the middle course of the river; located on the east side, near Sammoura, but at the bottom end of the valley, next to the river-bed. Nowadays it is used only for grain storage and as an animal shelter, though it is mostly in good conservational state.

3 THE HOUSING

The house has a rectangular floor shape, consisting of a maximum of two or three levels and

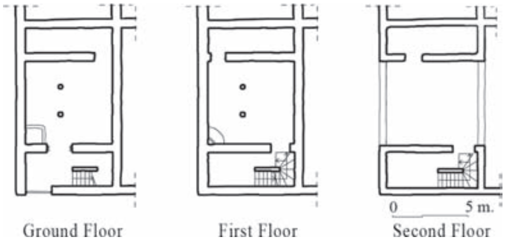

Figure 3. House in ksar Tabenaâtout.

occupies a floor surface between 60 m^2 and 100 m^2. The access point always appears on the shorter side, and the longest side can be the dividing wall sheared with the other dwellings, the outer wall, or the wall de-fining an interior street.

The structure consists of load-bearing walls made with rammed earth for the ground and first floor, and adobe wall on the third floor. Perpendicular to its longest wall there are two walls of rammed earth which split the interior space in three parts; this scheme is almost constantly used and repeated in the ground and first floor.

The use of each one of these spaces is precisely defined. On the ground floor, at one side is the access to the housing. Upon entering you first encounter the hall which is no more than 2.30 m. in length in which the stairs to upper floor are located. Following that is the biggest room which is between 30 m^2 and 40 m^2 approximately and is used for sheltering animals. Here there is usually a manger where the alfalfa (animal feed) is put. At the back another room of similar dimensions to the first serves as a store room for the animal feed.

The same pattern is repeated on the first floor but in this case the bigger room is usually where the family lives. Here they cook with a small oven, eat and also sleep. The back room is used as a central cupboard and place to store grain.

The second floor is usually not completely built. Following the diagram below, the central area is a terrace habitually used as place in which to dry grain. The final room, at the end, is intended to accommodate family and guests.

4 USED MATERIALS

4.1 *Stone*

In general it can be found around the ksar. In the Outat Valley the stones used for construction come directly from the river. They are used in the foundations and the starts of the walls, up some wooden lintels like an arch.

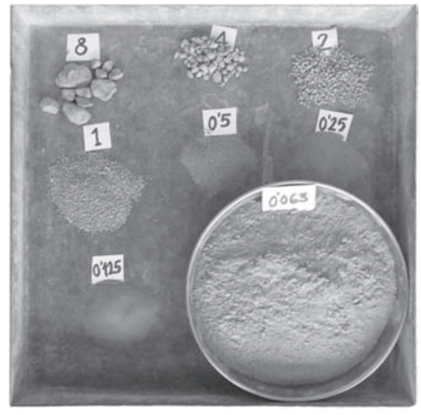

Figure 4. Granulometry; samples.

4.2 *Earth*

The base material for these constructions is the earth. Normally it comes directly from the same place, eliminating the first 80 cm. to prevent topsoil. It is also very common to use earth obtained from the collapsed buildings that have been abandoned, giving a true example of sustainable architecture.

The only preparation which the earth is sometimes subjected to is the screening, whereby foreign matter and coarse gravel is removed. For the direct usage inside construction there are places that are known for the better quality of their earth. Below is a granulometry analysis done on this earths "qualities sanctioned by doing", obtained on site.

The sample is reddish, very thin and without apparent organic matter. When this is hydrated it can be very unctuous and odorous.

The analysis of the graphics show an inflection point in sizes less than 125 µm representing 80% of the sample. This part is a very thin continuous curve up to very small sizes. The remaining 20% of the sample is uniformly distributed up to 8 mm.

The land is mostly $CaCO_3$ which has a small clay content not greater than 5%. The fact that the clay content is low means that drying contractions are relatively low and on the contrary this favors the water permeability of the walls and roofs, which require auxiliary waterproofing.

4.3 *Wood*

Although nowadays the landscape beyond the alluvium valley earth is practically deserted, 100 years ago it consisted of a forest of more than 4500 ha of oak and cedar (Mouhib 1999). Thus the most widely used wood is cedar. This timber has a high durability and at the same time is easily manageable. Its mechanical properties make it an ideal material

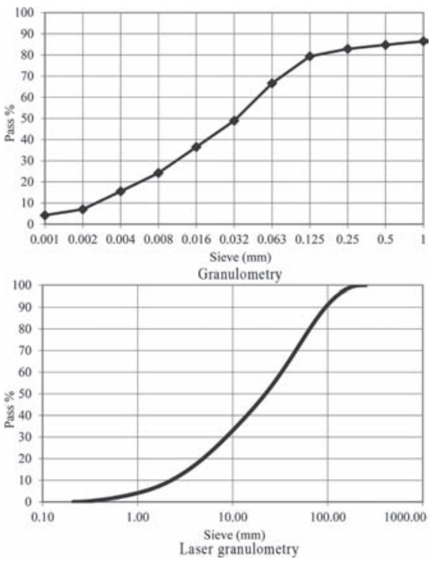

Figure 5. Granulometry; results.

for beams and girders thanks to its flexural strength, but it is also suitable for supports and pillars because of its good compression resistance. Its characteristic smell also serves as a good insect repellent. It is also used to cover the beam spacing in the ceiling (though it's presented in the form of a slab or woodchip shape), in lintels, doors and windows. Others less used timbers are thuja and savin juniper.

4.4 *Straw*

It is used as an ingredient in the construction of bricks because it improves their consistency and prevents shrinkage while improving in particular the thermal insulation. This same dough is used to coat and protect both the walls of rammed earth and the roofs.

4.5 *Esparto*

In the Outat Valley the esparto is woven to create a mesh that is placed over the wood-based floor structure, acting as permanent formwork to prevent the depletion of the compressed soil layer. In the case of the roof it also provides thermal insulation. This can also be found in other constructions, for example acting as a rope in the tying of the wooden bases.

4.6 *Reeds*

Reed is not an original material of the valley, being more typical of southern Morocco, although nowadays its use is being implemented mainly in new constructions and reparations.

It replaces the old wooden slabs covering the infilling and to create decorations on the underside of the floor.

4.7 *Plastic*

This material is being introduced in place of esparto, especially in the decks; it is believed to improve waterproofing.

5 CONSTRUCTIVE ANALYSES

5.1 *Foundation*

Usually consists of stones of different sizes placed over a ditch from 0.50 to 1.00 m. wide, in tiers from 0.50 to 0.80 m. height, joined by a layer of mud, thus ensuring the stability of the wall. The depth of the ditch depends on the soil bearing capacity becoming built without foundations on the occasions of direct support on firm rock. On a slope the foundation is made through a stratification of layers until a horizontal support surface is achieved.

Sometimes this base of stone is prolonged above the ground level in order to protect the structure from runoff and capillary moisture that gives rise to erosion reducing its bearing capacity. Generally this "socle" does not exceed 80 cm in height above the ground, while in hilly terrain it consequently rises.

5.2 *Walls and columns*

To construct walls, rammed earth and adobe techniques are used; these have been passed on from generation to generation by the *Maâlem* (master builders). Often the used earth comes from near the ksar, this helps to guarantee its transport and availability and at the same time speeds up the process.

The rammed earth walls of the Outat Valley have variable dimensions, ranging from 0.45 to 0.90 m.

Figure 6. Left: foundations, rammed earth wall and adobe. Right: executing the rammed earth wall.

in thickness, to 0.825 m in height, with a variable length of 1.50 to 2.05 m.

At least 3 people are needed to help construct the rammed earth walls; one worker prepares the earth by wetting it until it converts into dough. Once this has dried naturally another worker carries the dough from the pit with the help of baskets and a third person lays and compacts it by means of a hammer into layers of 15 cm in thickness. The times and yields for the process are as follows:

– The positioning of the formwork lasts about 20 minutes, while the filling process is performed in 40 minutes, according to yields obtained by the authors.
– Regarding production, during summer a normal team can usually produce between 8 to 10 formworks a day in the case of the ground floor, while in-winter the normal production is between 4 and 6. During summer on the first floor the production ranges from 6 to 7 formworks a day; during winter from 4 to 5 (Nijst 1973). The lower production in winter is due to the increased time needed for drying. On the other hand the lower production on the upper levels is due to the larger time that is needed for transporting earth to the construction site. Drying out of the wall requires at least 48 hours; this is necessary to obtain the required strength to enable us to make another rammed earth wall at the next level (Kölbl 2010).

Once the wall is completed it is covered with stubble to protect it from rain until the roof subsequently covers it. Nowadays it's becoming increasingly more common to use plastic sheeting for this purpose.

According to *Maâlems* own experience they tend to bear in mind a number of recommended precautions when constructing a rammed earth wall. These recommendations are stated in the report of July 2010 by CERKAS (*Centre de Conservation et Réhabilitation du Patrimoine Architectural des zones atlasiques et sub-atlasiques*) on the Dra Valley, from which we extracted the following:

– In carrying out the rammed earth, the vertical joints are sandwiched between two consecutive rows.
– The rammed earth always starts at one corner of the wall, crossing the joints alternately at the corners to avoid the opening of the wall.
– Wooden beams must be placed in the corners, crossed and bound together.
– In anticipation of putting in the floor slabs, upper walls of the rammed earth will be protected from rain with branches, esparto or plastic.

Regarding the distance between walls, in the Outat Valley it doesn't exceed the 6.50 m; vertical supports are placed at an approximate distance 2.50 m to cover the space. Unlike the south, in these houses the pillars are always made from wood.

From the second floor the construction technique changes with the walls then utilizing adobe. The adobe walls follow different patterns from which it's possible to obtain different decorative motifs. In Outat, specifically within the housing its use is limited only to the formation of walls, partitions and stairs, not being used, unlike the south, for pillars.

Once the walls are finished they are covered with a roof, but the perimeter walls are raised from 30 to 50 cm above the floor slab; this extension is made with adobe or a rammed earth wall. This is formed using an orthogonal layout that retains the earth and facilitates the removal of water.

The water is released to the outside through the wooden gargoyles of Sabina at least 1.40 m. in length, built the wall around its thickness. Currently some walls have vertical cut-outs between 10 and 15 cm. wide made in the rammed earth wall and covered with limestone or concrete mortar, which avoid splashing the gargoyles with heavy rainfall.

As already mentioned the pillars are made of cedar. Besides splitting the spans they are placed close to the rammed earth wall to release it from the point loads produced by the support beam. That beam rests on a capital that binds to the column with a joint.

5.3 *Floors and roof*

In general the structure of the floor slabs comprises, beams, joists, slabs of wood, esparto and earth.

Beams 30 cm in diameter are arranged to 1/2 or 1/3 the width between walls, and are embedded for over half its thickness. If the lengths of the beams are longer than 2.5 m they tend to be propped up with wooden pillars.

Joists, approximately 10 cm in diameter, appear with a maximum spacing of 40 cm. The space between them is covered with slabs or wood branches of varying lengths. Above them a layer of esparto is placed, locked or not, which makes an insulating layer and prevents the loss of lands of the upper layer. This last layer is put in place while still damp, having an average thickness of 20 cm after its compaction.

The roof floor slab is completed with a new layer of earth mixed with straw, between 5 cm and 10 cm, which provides extra insulation. During this process it is important to consider a proper system for the collection and drainage of water. The first is obtained by generating slopes and by

Figure 7. Column, capital and beam.

Figure 8. Bottom view of the floor.

subdividing the whole roof increasing the height of the walls up the last floor slabs; the second is achieved by installing gargoyles or by cutting chases into the walls to create a drainpipe line system, as previously mentioned. Today this process is being altered by the addition of reeds to replace the slabs of wood and plastic misbelieving it capable of improving the waterproofing.

5.4 *Openings*

As the wall is constructed horizontal pieces of wood are laid out in accordance to where the hole is to be created. Once the wall is stable, the earth below this threshold is removed.

5.5 *Stairs*

Their construction is based on two walls, one is usually the building envelope and the other executed for those purposes, within them a network of beams and slabs of wood are laid and the steps are made using adobe. The steps are completed with the placement of round wooden nosings that enhance its durability.

5.6 *Ornament*

This Outat architecture shows virtually no embelishment. The only decorations are found in the shape of a frieze on the main entrance door of the house of the ksar or on the corners of the tops of the towers. In any case they are simple geometric patterns that are the subject of another study.

6 CONCLUSIONS

The knowledge of construction techniques is the first step in learning, appreciating and giving value to an architecture that has merit to be the greatest cultural legacy of the Alawite country. At the same time we must understand the needs and problems of the resident population; they should be helped in improving their living conditions which is the only way to prevent neglect and the consequent loss of this important estate.

On the other hand, knowledge of maintenance and restoration interventions that have not been contaminated by foreign material (cement, plastic etc.) to their habitat are a source of techniques sanctioned by use for centuries.

NOTES

1. All photos were taken by the authors of this communication.
2. The old Sanhaja confederation of Berber tribes, among which are the Ait Izdeg, Ait Merghad, Ait Yahya and Ait Hdidou. All coming from the southern High Oriental Atlas, the Valleys of Todgha Ghriss, Dades, Imedghrass and high Ziz.

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Earth constructive systems in northeastern Segovian domestic architecture

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ABSTRACT: Study of domestic space in traditional architecture from north-east Segovia (Spain) and analysis of bearing walls and framed structures building systems, where *adobe* plays the principal role. Current use of mud in housing, analyzing the possibilities of "BTC" as an alternative to recover an adequate architecture, respectful with the surrounding environment, which not only interacts with the landscape but enriches it in a process where different solutions have provided effective and aesthetically interesting responses in the past. Responses that stand out for their beauty, as opposed to the current options, very conditioned by the emergence of industrialized materials and rigid rules.

Derivado de nuestro ejercicio profesional venimos trabajando repetidamente en un área muy determinada del nordeste segoviano, donde en el ámbito de la arquitectura domestica nos hemos encontrado con multitud de inmuebles sobre los que hemos intervenido en los mejores casos o hemos sido testigos de su demolición en otros. De todos ellos hemos procurado dejar constancia grafica e ir recopilando información, que a día de hoy, nos ha servido para extrapolar una serie de características invariantes y relacionables con la región donde radica.

Recientemente se nos ha planteado la posibilidad de intervenir sobre un caserío prácticamente en abandono. En el marco de un proyecto de investigación universitario, realizado con la colaboración de alumnos, hemos tratado de establecer una serie de premisas a la hora de intervenir, basadas en la protección y conservación del Patrimonio vernáculo existente, adecuación y recuperación de la estructura urbana y sus servicios y el desarrollo de criterios y parámetros para la edificación en nueva planta.

Es en el desarrollo de estos parámetros para las edificaciones de nueva planta, donde en consonancia con la propiedad se establece desde el inicio la necesidad de plantear y desarrollar una propuesta evolutiva de la arquitectura domestica tradicional y la actualización de sus sistemas de construcción.

1 LA ARQUITECTURA TRADICIONAL; CONTEXTO HISTÓRICO Y CULTURAL

La región mesetaria, situada entre la cuenca media del río Duero y la cadena montañosa conocida como "Sistema Central", ha vivido una evolución en las tipologías edificatorias tradicionales de la comarca propia de la incorporación de modelos importados desde ámbitos en los que históricamente se habría dado un mayor desarrollo de la agricultura extensiva de cereal, con lo que los tipos desarrollados hasta el siglo XX procederían de formas introducidas entre los siglos XI y XII, razón por la cual se generalizan formas y rasgos morfológicos semejantes a los de otras regiones castellanas como Tierra de Campos.

Víctima de una constante despoblación a lo largo del siglo XIX y para ello no hay más que comparar los datos que proporcionan fuentes como Sebastián de Miñano (1826) o Pascual Madoz (1845), este región sufrirá una mayor incidencia desde los años 60 del siglo XX, en que se producirá una casi total dejación de las formas de vida tradicionales e incluso el abandono habitacional de los pequeños municipios.

La arquitectura de la comarca Noreste de la provincia de Segovia configurada por pequeñas Villas y caseríos se adapta perfectamente a los entornos en los que surge, aprovechando los materiales próximos, adecuándose a su clima y a los recursos que la región permite, con lo que sus formas y las soluciones constructivas adoptadas son idóneas para la adaptación al medio y quienes generan los principales rasgos vernáculos de sus edificaciones.

La arquitectura tradicional de la comarca Noreste de Segovia tiene aquí un buen ejemplo de las trazas que la caracterizan, siendo paradigma de un perfecto equilibrio con el paisaje y la economía tradicional, lo que implica la escasa necesidad de cambio desde tiempos antiguos, al menos medievales.

La reciente y radical industrialización y el consecuente cambio social, afectado esencialmente por una forma de producción muy distinta de la autóctona y por el consumismo característico, ha producido la invalidez y la inoperancia de las construcciones y de las formas arquitectónicas aportadas por la tradición secular, desestabilizando el equilibrio existente desde antiguo entre estos modos de vida preindustrial y el ámbito natural en el que se desarrollaban.

2 MORFOLOGÍA Y ELEMENTOS PRINCIPALES

Modelos vernáculos propios de una arquitectura de barro, con sus muros de mampostería en la planta baja y de entramados de madera formando plementerías rellenas de adobe y luego revocadas con mortero de barro. Las cubiertas de teja seguirán la tradicional disposición de torta y lomo, “a la segoviana”. Los patios y los corrales se ubicaban frecuentemente ante la casa.

Algunas viviendas dispondrán de los tradicionales hornos semicirculares que aparecen en los volúmenes interiores de las casas, con chimeneas con forma de pirámide truncada ejecutadas con fábrica de ladrillo de tejar en la parte saliente de la cubierta exterior. Las casas presentan huecos y vanos irregulares buscando una óptima orientación que protegiese el espacio interior tanto de la lluvia y el frío viento como del exceso de sol. El recercado se hacía en principio con piezas de madera, con cargaderos funcionando como dinteles.

Predominaron las casas de una sola planta, con un uniforme color parduzco y algo rojizo característico del tono terroso del mortero de barro y de los adobes, hechos con la arcilla de la zona, combinado con las cubiertas rematadas con tejas cerámicas curvas.

Los escasos habitantes actuales han alterado un tanto los usos tradicionales, aunque las formas constructivas propias de la zona han sufrido una mayor agresión por parte de quienes se han construido en el pueblo sus segundas residencias: los habituales “veraneantes”, descendientes de quienes emigraron desde los años 60 del siglo XX, en especial a Madrid.

Desde principios del siglo XX fueron apareciendo casas de carácter más urbano, de dos plantas, con ventanas ordenadamente dispuestas en las fachadas principales, con balcones centrados en la planta superior y recercados de piedra en los vanos, incluso con muros de mampostería revocados con mortero de arena y cal y sillerías en los aristones, definiendo así mejor las esquinas de los edificios y enfatizando la fachada principal.

Figura 1. Cedillo de la Torre (Segovia), horno de adobe semiesférico.

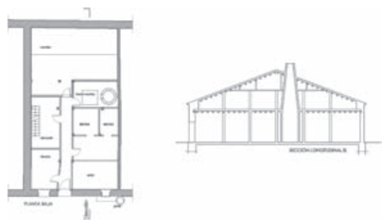

Figura 2. Vivienda de una planta más sobrado. Cedillo de la Torre (Segovia).

En los pueblos llamados “de barro” este material se encuentra utilizado de forma destacada, y a veces exclusiva, en las construcciones. Teniendo en cuenta las características físicas y mecánicas que le dan al material sus condiciones de aislamiento, elasticidad y resistencia a cambios térmicos no es difícil explicar los motivos adaptativos de su empleo. En nuestro caso, además del barro, en forma de prisma moldeado y secado al sol (adobe), encontramos también madera y piedra entre los materiales de construcción, si bien el empleo de la fábrica de adobe es su principal referencia característica. La madera y la piedra se utilizan como elementos estructurales: muros de mampostería en la zona baja y entramados de madera rellenos con adobes en las partes altas del muro, coincida o no con un forjado.

En la planta baja aparecen, generalmente, muros de mampostería de piedra, de entre 2 y 3 pies castellanos de espesor, en la fachada principal, en tanto que en el resto del perímetro los muros se ejecutan con fábricas de adobe de 2 pies de espesor, en ocasiones armadas con pies derechos de madera. Las plantas superiores, cuando las hay, se ejecutan con estructura de madera entramada, empleándose el adobe como plementería. Sólo la fábrica de mampuesto de la fachada principal alcanza dos niveles.

Es muy habitual que los edificios que presentan dos alturas en la fachada principal tengan sólo una en la fachada posterior.

3 EL ESPACIO DOMÉSTICO EN LA ARQUITECTURA TRADICIONAL DEL NORDESTE DE SEGOVIA

La concepción del espacio doméstico parte de la necesidad de cohabitación de hombres y bestias en ámbitos contiguos. La edificación se adapta a la parcela en la que se inscribe, partiendo de un esquema habitacional humano, que se repite casi como una invariante formal, y la adición en torno suyo de los espacios destinados a usos agropecuarios: corral, cuarto de aperos, gallinero…

La invariante o planta-tipo se compone de dos piezas en la fachada principal, generalmente orientada al mediodía, colocadas a los lados de un zaguán de acceso, de mayor o menor tamaño dependiendo de cada vivienda. Una de estas piezas se emplea usualmente como comedor y la otra como cuarto de estar o labores femeninas, y ambas piezas dan acceso a las alcobas interiores empleadas como dormitorio, de reducidas dimensiones, que carecen de luz y de ventilación a excepción del dormitorio marital que habitualmente dispone de ventana.

La edificación se distribuye a través de un pasillo central que da acceso a distintas dependencias de servicio situadas a derecha e izquierda del mismo (cocina, despensa, secadera, escalera que conduce al sobrado…) y que comunica el acceso del edificio con el fondo de la edificación, donde suelen ubicarse las cuadras.

Es en las dependencias propias para las bestias donde las viviendas presentan una mayor variedad, casi siempre adaptándose a la geometría de la parcela, de manera que en muchas ocasiones veremos cómo en función de la misma el espacio destinado a los animales se encuentra situado en un lateral de la vivienda, dotándosele de acceso independiente siempre y cuando el tamaño y la disposición de la parcela lo permitan. En muchas ocasiones este ámbito no sólo se destina al cobijo de las bestias sino que también se adapta, aumentando su amaño, para poder albergar aperos de labranza, como arados, cedazos, palas..., así como carros. No obstante, se sitúe donde se sitúe, siempre se mantiene su acceso desde el pasillo que articula la planta de la edificación, aun contando con el acceso directo al exterior referido.

Figura 3. Planta de vivienda, Sequera de Fresno (Segovia).

De las estancias distribuidas a lo largo del pasillo cabe destacarse los secaderos y los hogares, que en muchas ocasiones cuentan con hermosos hornos de cúpula semiesférica construidos en adobe y que desde el sobrado son perfectamente identificables, significándose en la cubierta de la edificación a través de tiros de chimenea ejecutados con fábricas de cerámica cocida de gran belleza.

El último elemento que queda por definir es el sobrado o cámara superior, un espacio residual que tiene una función termorreguladora. Forma parte del sistema de cubierta ventilada tradicional de este tipo de edificaciones. Se trata de un espacio ventilado bajo cubierta que permite regular la temperatura de los ámbitos vivideros, reduciendo el impacto de las bajas temperaturas invernales y también del fuerte soleamiento estival. Teniendo en cuenta las características propias del clima mesetario, estas propiedades térmicas y de oxigenación lo convierten en un perfecto almacén para los excedentes agrarios, al ser un lugar fresco y seco que facilita la conservación de determinados alimentos, con lo que resulta ser un magnífico granero. Para posibilitar la ventilación en este espacio en la fachada de las casas se abren huecos de dimensiones reducidas sobre el forjado del techo de planta baja y bajo el tejaroz de arranque de la cubierta.

3.1 *Características estructurales*

Ejecutadas con materiales autóctonos (piedra, madera, tierra y cerámica), se trata generalmente de construcciones de una o dos plantas elaboradas con muros perimetrales portantes que en la fachada principal son de mampostería de piedra caliza asentada con morteros de arena y cal y en el resto de la edificación de adobe armado con pies derechos de madera.

Las crujías interiores, los hastiales y las plantas superiores, en caso de haberlas, se ejecutan con sistemas entramados con plementería de adobe, generalmente de menor dimensión que la utilizada en los muros perimetrales.

Los forjados se construyen con machones de madera normalmente sin escuadrar, a 45 cm. de distancia de interejes y secciones variables que no superan los 15 cm de canto. Sobre éstos se dispone un entablado de pino de 2 cm de espesor y tabla ancha.

3.2 *Cubiertas*

Las cubiertas del tipo "par y picadero" se realizan con jácenas y pares de secciones muy desiguales. Dejan diáfano el espacio inferior, denominado "sobrado", que sólo es interrumpido por los pies derechos que sustentan la cubierta. Entre los pares en vez de tabla encontramos "ripia" o "chilla", obtenida de la corteza, las ramas o de los restos del escuadrado de la madera y que sirve de soporte a la torta de barro y paja sobre la que se asientan las tejas curvas cerámicas dispuestas como es costumbre "a torta y lomo" o "a la segoviana": únicamente con canales sin doblar con cobijas en la mayoría de la superficie.

El remate perimetral de la cubierta se realiza con tejaroz, aunque encontramos algunas edificaciones con cornisas parcialmente de piedra o de ladrillo cerámico e incluso alguna solución muy modesta de canes de madera.

Otro de los elementos singulares propios de la Arquitectura Popular de la zona, observable aquí en algunas de las edificaciones, son las "cobas": planos transversales triangulares colocados en la parte superior de los hastiales y dispuestos entre las dos vertientes principales que se alinean con la fachada inclinándose hacia el interior del tejado y matando el ángulo de dicho hastial. Estas cobas mejoran el equilibrio estático de la cubierta, además de proporcionar una mejor estética a los hastiales.

Cabe destacar las chimeneas, de las que quedan muy pocos ejemplos originales. Al exterior la chimenea se forma por un aparejo regular de ladrillos de tejar recibidos con mortero de cal y dando lugar a un volumen tronco piramidal o troncocónico de tamaño y disposición variable.

3.3 *Acabados*

El acabado exterior de todas las edificaciones es originalmente de mortero de barro con paja o de cal y arena. Recubre la totalidad de la edificación a excepción de los recercados de los huecos realizados con sillares de piedra caliza o ladrillo cerámico, estos últimos ya entrado el siglo XX. Actualmente encontramos algunas mamposterías desprovistas de sus revocos originales, bien por el lavado natural y el desprendimiento resultado del abandono o víctimas de las actuales y torpes modas de supresión de los morteros tradicionales para "sacarle la piedra a las casas", dejando así una mampostería pobre al descubierto. También encontramos sillares en la construcción de las esquinas de algunas de las edificaciones que forman vistosos aristones.

El sistema de acabado del interior de las viviendas es muy básico y aparecen suelos de tierra compactada, en ocasiones encalados, baldosas de barro en las viviendas de mayor categoría y pavimentos hidráulicos con mayor o menor decoración a partir, sobre todo, de la segunda década del siglo XX.

El resto de la vivienda se encuentra encalado, utilizando como soporte la tabiquería entramada de adobe del interior y los forjados de madera que pueden encontrarse con su color original o sutilmente tratados.

3.4 *Configuración formal y rendimiento energético*

Los edificios estudiados presentan fachadas con pocos huecos. Son éstos de reducidas dimensiones y de colocación controlada, situados en su mayoría en la fachada principal, generalmente orientada al sur. La disposición de los huecos se realiza de una forma ordenada en la fachada principal, a ejes con el acceso cuando la distribución lo perite y ampliando sus dimensiones en relación con el resto de vanos. En los otros muros se sitúan de forma aleatoria y casual en respuesta a necesidades puntuales y de organización de los ámbitos interiores. Los espacios destinados al ganado y los aperos carecen de huecos en su mayoría y ocasionalmente cuentan con portones de acceso. Estas características, unidas a la existencia del sobrado bajo la cubierta, hacen de estas edificaciones conjuntos de gran inercia térmica, que tanto en verano como en invierno garantizan unas condiciones de confortabilidad adecuadas y que sólo han de suplementarse en invierno con la lumbre del hogar y los pertinentes braseros dispuestos según el uso discrecional de las distintas estancias.

4 CRITERIOS Y PARÁMETROS PARA LA EDIFICACIÓN EN NUEVA PLANTA

Tal y como expresábamos al inicio del artículo por invitación de la entidad Mercantil FRANIFIN S.L., se nos ha presentado la posibilidad de intervenir en un caserío, donde la intención prioritaria parte de la reactivación de la vida en el caserío conservando los valores y las características primordiales que dan sentido al conjunto, posibilitando su arraigo al territorio histórico y garantizando su perpetuación en el tiempo. Ha de entenderse que en relación con la demanda real y la reocupación del caserío, de producirse, ésta sucederá de una manera progresiva y atenuada y es por ello esencial fijar un criterio común que pueda mantenerse con los años. Por todo ello conservar la génesis de la arquitectura existente como base del futuro desarrollo del conjunto se presenta como una solución no sólo acertada sino claramente viable, ya que, tal y como hemos estudiado, la eficiencia, racionalidad y atractivo de esta arquitectura nos permite responder con plenitud a los criterios de la demanda actual.

4.1 *Análisis de la demanda actual*

Dada nuestra relación con el entorno y el conocimiento de la comarca y su desarrollo histórico y social podemos suponer que la demanda doméstica en este ámbito se puede organizar en tres grupos perfectamente definidos:

1. demanda de segunda vivienda ocasional para períodos estivales y vacacionales en general
2. primera vivienda para profesionales autónomos relacionados con la economía de la comarca o que ejerzan profesiones que les permitan no depender de una situación laboral rígida
3. primera vivienda para personas que retornan al entorno rural desde las grandes urbes y que generalmente ya no forman parte del mercado de trabajo

4.2 *Soluciones y características constructivas*

Sin entrar en el desarrollo de las tipologías o soluciones arquitectónicas propuestas. Constructivamente es donde estas edificaciones más deben de aportar, corrigiendo los errores cometidos en las construcciones de nueva planta y en las rehabilitaciones que se han venido haciendo en las últimas décadas en la comarca. Si bien no han de dejarse de lado los medios que el mercado proporciona en la actualidad deben de tenerse en cuenta infinidad de factores que la construcción actual ha dejado de lado, buscándose soluciones que causen un menor impacto medioambiental y resulten económicamente más sostenibles. En este sentido, recuperar técnicas de construcción con tierra cruda, aplicando soluciones con bloque de tierra compactada (BTC) no sólo permite reducir el coste energético en la producción sino centrar la misma en el área de la edificación, evitando grandes costes de transporte y generando empleo en el lugar o su entorno próximo.

5 PROBLEMÁTICA Y ADECUACIÓN NORMATIVA

Como antesala de la enumeración de las ventajas e inconvenientes que presenta hoy en día la posible aplicación a las construcciones del BTC (Bloque de Tierra Comprimido) es conveniente introducir el marco normativo en el que se encuentra el material. Se trata de un tipo de material que ha quedado fuera de los distintos Documentos Básicos del CTE, existiendo solo a día de hoy, en el territorio español la Norma UNE 41410 Bloque de tierra comprimida para muros y tabiques. Definiciones, especificaciones y métodos de estudio. Editada por la Asociación Española de Normalización y Certificación. AENOR en diciembre de 2008.

Para poder aplicar el BTC desde el proyecto, la posterior ejecución de obra y el mantenimiento del edificio es necesario realizar una ligera aproximación a la posible comprobación del cumplimiento del material de las exigencias básicas que marca el CTE aplicables a vivienda o soluciones alternativas que aporten unas prestaciones equivalentes a las marcadas en el código. Para ello se utilizarán algunas características técnicas que manejan algunos de los diferentes fabricantes de BTC.

5.1 *Seguridad estructural*

Resistencia de cálculo a compresión de la fábrica:

Partimos de una resistencia normalizada a compresión (f_c), según UNE 41410, para un BTC5 de 5 N/mm^2 y consideramos un mortero M 3.5 con lo que según la tabla 4.4 del CTE DB SE F y asimilando el bloque de BTC a un ladrillo macizo, la resistencia característica a compresión de la fábrica será de 2 N/mm^2.

La resistencia de cálculo a compresión se determinaría aplicándole a la resistencia característica a compresión un coeficiente de seguridad en función de la categoría de control de fabricación y categoría de ejecución. Se considera un coeficiente de 2.5 (correspondiente a categoría de control de fabricación I y nivel de control B, según tabla 4.8 del DB SE F.

Resistencia de cálculo a compresión: 2/2.5 = 0.80 N/mm^2.

5.2 *Seguridad de incendio*

Resistencia al fuego de la estructura:

Asimilando el BTC a una fábrica de ladrillo macizo, debido a su parecida composición mineralógica, y según la tabla F1 el Anejo F del CTE DB SI podríamos considerar una REI-120 para espesores comprendidos entre $110 \leq e < 200$ y REI-240 para espesores ≥ 200 (considerando la fábrica sin revestir).

Reacción al fuego de elementos constructivos:

M0 según UNE 23727:1990

A1 según UNE-EN 13501-1:2002

5.3 *Salubridad*

Protección frente a la humedad. Fachadas.

No existe restricción en el CTE en la utilización del material y es incluso posible la aplicación del catálogo de elementos constructivos del CTE (cuadro 3.1.2.) que aporta valores de características técnicas para bloque de tierra comprimido (BTC).

ρ: Densidad (kg/m^3) $1770 \leq \rho \leq 2000$

λ: Conductividad térmica (W/mK) 1.10

5.4 *Protección frente al ruido*

No existe restricción en el CTE para la posible aplicación del material, teniendo sólo que justificar debidamente los valores límite de aislamiento.

5.5 *Ahorro de energía*

Limitación de la demanda energética.

Es posible la justificación de las exigencias básicas del CTE, aplicando los valores de características técnicas del catálogo de elementos constructivos a unos cálculos higrotérmicos. Para completar dichos cálculos se estima un factor de resistencia a la difusión del vapor de agua (μ) de 10, igual al utilizado para arcilla cocida para piezas de albañilería, debido a la similar composición mineralógica.

6 JUSTIFICACIÓN DE EXIGENCIAS BÁSICAS DEL CTE

La justificación de las diferentes exigencias básica que marca CTE para una construcción residencial presenta los siguientes condicionantes:

6.1 *Seguridad estructural*

La falta de normativa que permita manejar unos parámetros de características mecánicas y coeficientes de seguridad imposibilita justificar ante un organismo externo las exigencias básicas marcadas por el código. No obstante, aplicando los criterios descritos anteriormente se podría llegar a resistencias de cálculo a compresión de 0.8 N/mm^2, valores más que suficientes para tensiones admisibles, ya que el criterio más restrictivo para el cálculo de fábricas es la estabilidad, la cual se aporta con esbelteces geométricas muy reducidas debido a criterios higrotérmicos.

6.2 *Seguridad de incendio*

La alta resistencia al fuego y el alto grado de reacción al fuego de los elementos constructivos hacen del BTC un material idóneo para utilización frente al fuego.

6.3 *Salubridad*

La justificación de las exigencias básicas que marca CTE podría ser posible con la aplicación del BTC, con espesores mínimos de 25 cm, en la construcción de fachadas de edificaciones situadas en la zona geográfica a la que se refiere el presenta artículo (Segovia) utilizando siempre un revestimiento continuo exterior, tipo mortero de cal. No obstante, las soluciones constructivas que plantea CTE no citan el uso del BTC y sí el ladrillo cerámico con espesores de 1 pie, por lo que habría que comprobar el grado de absorción de agua.

Condiciones de las soluciones constructivas según punto 2.3.2 del DB HS.

R1 + B1 + C1 ó R1 + C2

R1: revestimiento continuo de 10–15 mm con resistencia media a la filtración.

C2: hoja de espesor alto, tipo 1 pie de ladrillo cerámico o 24 cm de bloque cerámico, bloque de hormigón o piedra natural.

6.4 *Protección frente al ruido*

Se estima una RA(dBA) de 54 DB para una fachada de 30 cm de espesor, por lo que el cumplimiento de las exigencias básicas del DB HR podría ser posible.

6.5 *Ahorro de energía*

La utilización de una fachada compuesta por un revestimiento continuo exterior (mortero de cal), un muro de BTC y un revestimiento continuo interior (guarnecido y enlucido de yeso) dificulta el cumplimiento de los parámetros de transmitancia máxima que marca CTE, teniendo que utilizar espesores mínimos de BTC de 1.35 metros para poder cumplir con dicho parámetro, lo que obliga a la utilización de grandes espesores de cerramiento y a una consecuente disminución de la superficie útil de la vivienda.

Como alternativa a los grandes espesores de cerramiento se podrían plantear dobles hojas con materiales aislantes naturales intermedios, tales como: algodón o lana.

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Earthen structures in the missions of Baja California (Mexico)

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ABSTRACT: The use of soil was common in the building of missions in the Mexican region of Baja California. Adobe was used in churches and additional buildings as a response to the urgent need of constructions and before it was substituted with stone. Not all the missions have been preserved until today. The missions built and occupied by Franciscans and Dominicans allow us to have a better idea of the architectural history of these buildings. On the other hand, just some remains of the Jesuit missions have been preserved. All of them constitute a significant Mexican heritage, representative of a period when consolidation of borderlands was as important as the evangelisation of indigenous population. The mission as an institution was equally useful to the purposes of both the Catholic Church and the Spanish Crown.

1 FOREWORD

In 1699, Padre Piccolo, the founder of the mission of San Francisco Javier de Biaundó, travelled from the Loreto mission to the opposite coast in the peninsula of Baja California with a view to finding a favourable spot for the docking of galleons coming from Manila that needed to obtain provisions after their long voyage across the Pacific. The expedition, described in a letter to Padre Juan María Salvatierra, served as a magnificent synopsis of the expedition and occupation of the territory, where the construction of mission churches was a fundamental item in the consolidation of the settlement and evangelisation of the population.

This construction involved a process that went from the erection of an initial vegetable structure to the final stone building, with an intermediate stage in which an adobe structure filled the most urgent liturgical needs. This text aims to analyse this process in which earth is the main ingredient, as we can see in the series of missions built in the peninsula of Baja California between 1697 and 1832, constituting a Mexican heritage that deserves every effort to conserve and revalue it. All of this forms part of the research carried out in the R&D project funded by the Ministry of Science and Innovation, "The missions of Baja California between the 17th and 19th centuries. Cultural landscape and implementation of value," developed between 2009 and 2012.

2 OCCUPATIOIN OF TERRITORY IN BAJA CALIFORNIA

The peninsula of Baja California constituted a peripheral space in the colonial context, where steady settlement was sought from the very early 16th century although it was not until the end of the 17th that it was consolidated, an aspect magnificently documented by authors like Miguel Léon Portilla (2000). The arrival of the Company of Jesus marked the first important occupation phase during which a series of missions were erected scattered about the south of the territory. The expulsion of the members of the order between 1767 and 1768 was also a key moment: a watershed that led to the arrival of Franciscans and Dominicans and the definitive allotment of the south sector of the peninsula and, by extension, the whole coast of what was known at the time as Alta California, which underwent a similar occupation process from 1769 onwards, as described by Martha Ortega Soto (1999) and Iñigo Abbad y Sierra (1981).

It was precisely the Jesuit order that turned the missions into an indispensable element to attain successfully both spiritual, material and territorial control of the native people and the Pacific coast, acting as an authentic advance party of a political system which had recourse to it at given moments, according to Eugene H. Bolton's account (1990). In this context, it was the members of the Company of Jesus who defined a management model that determined what Ignacio del Río (2003) called the Jesuit Regime, insofar as it represented a way of understanding the spread of faith and in which the characteristics of the territory led to the fusion of religious and political tasks.

These functions required suitable spaces in which to carry them out and which were determined, more than by the links with the peoples to be evangelised, by the political implications of the need to control a specific area like the Baja California coast, exposed to a great deal of external pressure.

That would explain, like in the case of the Dominicans' building programme, that a defensive element was included in their plans, an aspect that in the case of the Jesuit missions had been a component incorporated more as part of the decoration of the buildings than as a real element, as we can see in examples like the missions of San Francisco Javier de Biaundó or Santa Rosalía de Mulegé..

3 FOUNDATION & CONSTRUCTION OF THE MISSIONS

Many sources provide details about the foundation of the missions, and the first moments of the construction of their most essential components were no exception, as we have pointed out in other works (2007 & 2011a). A perfectly established work method is surprising, regarding both the location of the new settlements and the construction phases they employed in their primary architectures. These guidelines suggest a systematic procedure, going from the choice of place, clearly determined by the information provided by the natives, to the initial temporary vegetable structures, which gave way to stable adobe buildings, which allow us to identify the use of processes, materials and building methods at each stage before making the final stone building, as we are told by authors like Barco (1988), Baegert (1989), Clavijero (1970) or Palou (1994).

In any case, these buildings are erected thanks to the experience of both the priests themselves in the case of Miguel del Barco and the building of the mission of San Francisco Javier de Biaundó in the 18th century and the soldiers, who participated in the construction of the preliminary adobe structure that served as a church until the definitive building was made, as described by Padre Piccolo and narrated by Ignacio del Río (2000).

Figure 1. Santo Domingo Mission. 1775.

It was essential to train the native people in order to have plenty of manpower to build some components considered indispensable for the evangelisation and indoctrination process fast enough, using it as a good excuse to inculcate new habits that would contribute to the "civilisation" of the groups of natives, restructuring their familiar surroundings by arranging them hierarchically, where the centre would be the church and, by extension, the mission itself, a practice described to perfection by Nieser (1998) and appraised by Sorroche Cuerva (2011b).

The structures that have lasted until our day provide us with some testimonies of this process, which would explain the reason for constructing with soil, for which they used adobes on top of stone foundations and in which other local materials were also used. So, although the Jesuits only have the remains of the mission of San Francisco de Borja as a clear example of a process that was common practice in the other foundations built until 1767; the mission of San Fernando de Velicatá, built in 1769 and the only one erected by the Franciscans, shows us the remains of what must have been the main building and whose structure barely remains standing, and is currently at the mercy of the inclemency of the weather.

It is definitely the remains of the Dominican missions, despite their state of repair, that best reveal the typology of the missions made of earth in the area of Baja California. They are building units set around open spaces around which all the different areas were located, such as the sleeping quarters for the natives and monks, rooms for military use and defence structures, where, as we said above, soil is the undeniable protagonist from a structural point of view, the most trustworthy descriptions of which are provided by authors like Meigs, who visited them between 1926 and 1930 (1994).

4 SOIL AS A BUILDING MATERIAL

If we visit all the missions, we can see the diversity of materials and building methods used. These are in some cases solutions of extraordinary structural quality, which, as far as earth is concerned, provide less important examples due to the poor condition of the remains that still exist. In this sense, that earth was a material used to erect these buildings is not only evident by examining these remains, but also thanks to the references we find in the sources that speak of structures like churches, sleeping quarters and storerooms made out of adobe.

Added to this we have inventories of tools and instruments to build and maintain them. It is interesting to note that when the Jesuits were expelled and the missions were taken over by the Franciscans, the latter made lists of the items contained in them in 1773, as part of the process involved in handing the management over to the Dominicans, and as a result of the agreement between both congregations, brought about by the readjustment of objectives carried out by the governor, Gaspar de Portolá, and the visitor, José de Gálvez (2003). In these inventories, studied by authors like Coronado (1994), there is a detailed description of each mission, especially of objects listed under the headings "masonry" and "carpentry". In these sections, apart from references to the above mentioned departments and their building characteristics, setting apart those made of adobe, the mention of *adoberas* (adobe moulds), *adoberas de horno* (kiln moulds), *ladrilleras* (brickworks), *escuadras* (carpenter's squares), *cartabones* (set squares), *plomadas* (plumbs), etc., is a token of the knowledge of the basic principles of adobe construction that the people who lived there possessed.

Together with the sources, collections of documents and chronicles, examining the missions that were built in the peninsula of Baja California and visiting them gives us an idea of the dimension of the population and territorial control exerted from the end of the 17th century and allows us to reconstruct the building process and the use of materials and techniques in such an out-of-the-way territory, far from colonial decision-making centres and subject in many cases to a degree of self-supply that clearly required them to erect their own buildings, as is reflected to perfection in works such as that by Vernon (2002).

Not all the religious sites share the same characteristics. We have mentioned in passing the features of the most important cases of each of the orders. In any case, all the remains of their adobe structures are not still standing, although we know they existed. What we do know is that the occupation process after the expulsion of the Jesuits was determined by haste to build the missions, which permitted the consolidation of settlements to stabilise the borderlands, apart from evangelisation. Thus, from 1769 onwards, the mission of San Fernando de Velicatá, at the centre of the peninsula, was the final point in the above mentioned territorial restructuring order dictated by Viceroy Gaspar de Portolá. This led to the arrival of the Dominicans in the eighteen seventies to close the itinerary designed as the Camino Real de las Misiones, which connected this mission with the first Franciscan mission in Alta California, San Diego, also founded on the same date. In this way, it was the responsibility of the Dominicans to close this itinerary, which is currently the most complete set of earth structures that can be found in Baja California.

5 ADOBE MISSIONS IN BAJA CALIFORNIA

Although in the existing descriptions we can see the variety of materials used and the many buildings that formed them, let us examine the most outstanding examples that have lasted till our days to understand the physiognomy and characteristics of their earth structures.

As regards these missions, we have already pointed out that each of the three religious orders that went to Baja California left their adobe structures within an integral occupation process that forms part of a perfectly established general dynamic. In the case of the Jesuits, we have said that only one of them remains today, scantly protected by a metal structure: San Francisco de Borja, the remains of a spacious building in the shape of a Latin cross similar in size to those later built by the Dominicans.

All the knowledge we have of the other Jesuit missions is indirect. In this sense, in the letter we mentioned above from Padre Piccolo to Juan María Salvatierra, he has the following to say about the adobe structure of San Francisco Javier Biaundó (2000): "*Mientras se iba tomando lengua y noticia del camino y distancia que había desde este paraje a la mar de la contracosta quiso el capitán [Antonio García de] Mendoza con los soldados ocuparse en hacer unos adobes para la nueva capilla de San Francisco Javier. Divididos, pues, en dos cuadrillas de a siete soldados [cada una], hicieron en dos días dos mil y quinientos adobes. Y el capitán, que dio principio a la obra, con su compañero hizo quinientos adobes la primera mañana, y la otra cuadrilla, por la tarde, fizo seiscientos adobes*".

The exact measurements of this building are given here (2000): "*En fin, los compañeros en dos días levantaron la capilla de siete varas de largo y cuatro y media de ancho. En otros dos días quisieron levantar para mí, indigno de todo alivio, un aposento y un salita, y en otros dos días se techó la capilla que, aunque de zacate, quedó hermosa*".

As we have said, the Dominicans had the most important group of missions. Rosario Mission is one of the most important, both because of the valley in which it was situated and which it controlled and because it is a mission made in two building stages, which meant that it was moved from the initial site, which was also the case of other foundations such as San Francisco Javier and Nuestra Señora de los Ángeles, the first and the last missions founded by the Jesuits.

In the case of the mission in Rosario, there are hardly any remains left of the two buildings, although it is one of the best examples to allow us understand the mission in its geographic context, permitting us to see the reason why this location was chosen, away

Figure 2. San Fernando de Velicatá Mission. 1769.

Figure 3. Mission of Nuestra Señora del Rosario. 1775.

from the irregular flow of the rivers and streams of Baja California described by Meigs (1994).

This same author (1994) explains that the basic structure of these missions was made around a courtyard in general terms, but it was not applied in all cases. In the first mission at Rosario. "… the main feature of the site was a spacious enclosure or courtyard, around three sides of which buildings were placed, while all the openings not closed by buildings were filled in with sections of wall […]. In the courtyard, activities could be performed without danger of robbery or attacks by wild Indians and at the same time the people would congregate in a place where it would be easy for one of the priests to watch them." The church stood out among these buildings for its size and physiognomy, which usually meant it was the most clearly identifiable structure, as the author himself says: "In the north of the courtyard, standing out from it, was the largest building, the church, running all along the main entrance. This building can be identified by its size [44 × 9 metres]…"

The very structure of the site denotes some of the features of these missions, which are very well described in the chronicles the priests wrote after their expulsion. As regards the sleeping quarters of part of the native population, Meigs says (1994): "The long row of rooms three and a half metres wide in the east of the courtyard was probably the dormitories for the Indians living at the mission …" This reference suggests that part of the floating population of natives that went to the missions stayed there for a given period of time to help with the building works and maintenance.

Similarly, the role the military garrison played in these buildings can be seen from the space dedicated to their quarters, which leads us to believe that the number of soldiers was larger at this mission than at others, where the sources speak of two or three soldiers.

As far as the techniques and materials used there are concerned, as Meigs also points out (1994): "Although the traces of walls make it possible to reconstruct partly the floor plan of the mission, there is no similar proof to give us an idea of its vertical outline. Besides, as far as the author knows, no sketch or other image of this or any other mission built by the Dominicans in Baja California before they were destroyed has been conserved (if it ever even existed). We know that the buildings at Rosario Mission had mud-covered girders in the roofs. This can be deduced from the fact that no fragments of roof tiles were found near the buildings. The walls were probably plastered like in other missions, because near the exterior embankment the remains of a kiln that was probably used to fire lime were found. The lime could be extracted from the large numbers of shells at hand, or poorer quality lime from caliche. They are both used occasionally nowadays." An interesting description, especially since no mention is made of the adobe structures that have lasted until our day, one of the features that best defines both types at the present time.

As regards the second Rosario Mission, it is located in a more advantageous spot than the first and is believed to have been founded between 1799 and 1802. Its floor plan is less pretentious and unified than the former, without its multifunction courtyard Meigs (1994) describes how at the very edge of the terreplein where it was built, *"… there stands a building a bit apart, which measured 4 by 17 metres (probably divided into rooms), which might have been a storeroom. Further up, completely on the terrace, was the main courtyard surrounded by walls, with one end forming a pen and a three-room building on the opposite side. The largest room in this building is believed to have been the church, for it is not only higher than the building mentioned above but seems to have been more painstakingly constructed. The adjacent room, which measures 6 by 10 metres, was probably the sacristy, and the* *little room that measures 2 by 3 metres a cell or a confessional box.*"

As in the first case, the area of the military garrison is different from the mission itself: "*Behind the main courtyard, as usual, was the military courtyard, at a corner of which, according to tradition, stood the soldiers' living quarters*" (1994). But what leaves no room for doubt is the fact that the building system used counted on the use of earth as a basic material, besides others to be found near the mission. (1994): "*As a whole, the ruins of the second mission are less deteriorated than the first, as was to be expected, and allow us to have a clearer idea of the construction details. The foundations of the solid earthen walls are stones from the river bed, gently stuck with adobe mortar. The superstructure is adobe brick (made up of a mixture of earth and chipped organic residues), mostly 30 by 30 by 7 centimetres, laid out in rows and held together by twenty-five or twelve millimetres of mortar of the same material. The timber that could have been used in the mission for roofs, doorframes and similar things has disappeared entirely, either because it has rotted or because it was used as firewood. Timber could not have been an important element in the structure, because the only supply available was weak little willow branches.*"

Another important mission founded by the Dominicans is Santo Domingo. It is again an example of the selection process of the final site thanks to a first building. It is one of the most outstanding missions in Baja California to judge from the remains that still exist. The description given of it by Meigs (1994) provides quite a clear idea of what it was like in the early 20th century and of its conservation process until the present day: *"The courtyard is a quadrangle, smaller than the one in the first Rosario mission, for it only measures. 58 by 53 metres. The church is small too, 15 by 8 metres. Along with other adjacent buildings, it occupies all the side of the quadrangle giving on to the stream. The building details worth noting are: foundations of cornerstones from the nearby hills, roughly connected to form a fairly smooth exterior surface; adobe walls one metre thick, containing large pieces of rock, plastered inside and out; heavy wooden lintels and built-in shelves; at least one of the buildings (next to the church) had an attic; and a buttress made of stones roughly joined together to prop up the attic in the west."*

Furthermore, in this mission there are traces of the use of earth in infrastructures like: "*…the solid adobe and stone terreplein two metres high and up to three metres thick that seems to have served as a dyke to divert waters flooding down from the hillside…*" (1994). And we find the same system also in one of the diversion channels of the irrigation ditches (1994): *"According to local tradition, there was a low adobe dyke across the stream near the current upper ends of the irrigation ditches.*" This use is complemented by the presence of adobe in a kiln believed to have been used to burn lime, where the buttresses and some andirons were made by this technique.

Figure 4. San Vicente Ferrer Mission. 1780.

The San Vicente Mission, the largest of those founded by the Dominicans, is one of the most outstanding adobe buildings in the peninsula, always according to the Dominican model (1994): "The most remarkable feature of the layout of the San Vicente Mission was its size. San Vicente was the largest of the Dominican establishments, despite the fact that its population was not particularly numerous. The layout of the buildings according to the plans suggests a few reasons for this size. Within the surrounding wall, 'three *varas* high (Spanish measure .84 m) with towers' (Sales, report 3:70), which follows the irregularities of the boundaries of the natural platform of the buildings instead of all being gathered around a central courtyard, the buildings are grouped in two unconnected similar-sized quadrangles" (1994).

"One of these quadrangles, which runs along the front edge of the south side of the platform, was undoubtedly the main religious centre, with a church measuring 22 by 6 3/8, the priests' cells, sleeping quarters for the Indians and probably some warehouses. The second quadrangle, at the foot of the promontory, is not well conserved. It was probably the guards' headquarters" (1994).

In the case of San Miguel Mission, we find several aspects of interest (1994). Not only the technique used to build it, but its structure, which is laid out around a courtyard and reuses a Pre-Hispanic space as a referential element for reducing and indoctrinating the native people.

6 CONCLUSIONS

Today the series of adobe buildings in the Baja California missions constitute an important part of what their structures originally comprised. Although one of the factors that have most affected them is weathering, they have also suffered from acts of vandalism.

Immerse in a deterioration process from the very moment they were abandoned in the first half of the 19th century, the fact that they constituted a source of reusable materials, like the roofs, was the reason that their degradation started immediately.

At the present time conservation works are being performed on them. Since the nineteen nineties, there have been attempts to stop the deterioration process by means of stabilising interventions. A preservation method created by the INAH, which consisted in covering the adobe structures with a paste made out of clays from the region with the addition of a natural adhesive of vegetable, animal or mineral origin, such as cochineal nopal sap, manure or lime. The small amount conserved, less than 40% in some cases, makes it impossible to reconstruct them in the literal sense of the word.

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The architecture of earth in the northwest of Argentina: Tradition and modernity

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ABSTRACT: In the region of northwest Argentine, the use of the earth prevailed in the construction of the habitat throughout the different historical periods. The technological knowledge transmitted by generations, allowed its survival until today, in the rural areas. The most used constructive technologies were the adobe masonry and roof of mud "cake" or of straw. The natural landscape with these constructions, with their color and texture characteristics defined the vernacular heritage in rural areas of the valleys, canyons and highlands of the region. The present article exposes, with a critical vision, the traditional architecture and the constructive and architectonic innovations that are manifesting in the towns in the last decades and in consequence, the changes that are taking place in the traditional built profile.

1 SITUACIÓN DE CONTEXTO. REGION DEL NOROESTE

La región del Noroeste Argentino NOA, es una zona de transición entre el altiplano de Bolivia y Chile y la región de las llanuras y los bosques de la Argentina. En una vasta extensión territorial abarca las provincias de Jujuy, Salta, Catamarca, Santiago del Estero y Tucumán, constituyendo con una superficie de aproximadamente 368,000 km^2 un poco más del 12% del total del territorio de la Republica Argentina (Censo 2010-Instituto Nacional de Estadística y Censo).

Por sus características y posición geográfica, constituyó una de las principales vías naturales de acceso y de comunicación al territorio argentino desde el norte. Durante el período prehispánico fue el área más poblada y de desarrollo cultural del país; recibió la influencia de las culturas andinas de Bolivia y Perú. El auge de la inmigración europea, entre 1880–1914, no dejó importante huella en la población de la región como ocurrió con otras regiones del país. La provincia de Jujuy, sobre todo en los poblados de la Puna y la Quebrada de Humahuaca, en donde llega con más fuerza una inmigración proveniente de Bolivia, presenta un alto porcentaje de población de ascendiente mestiza. Hoy, con una población de 4,557,770 habitantes (Censo 2010), casi el 11% del total del país, el NOA se constituye en una de las regiones menos poblada de la Argentina.

Geográficamente, está fuertemente condicionada por el relieve, con cordones montañosos dispuestos en dirección norte-sur, que forman y delimitan salares, amplias mesetas y valles, que se conectan con las quebradas y los valles inferiores. Esta variada geomorfología que asciende de sudeste a noroeste, de 200 msnm hasta los 3500 a 4000 msnm con picos de montaña que alcanzan 6000 m, ha llevado a diferenciar tres paisajes ambientales característicos: valles, quebradas y puna. En concordancia con esta geografía, el clima varía de cálido húmedo en los valles bajos a frio y seco en la puna.

Por la disposición y estructura geológica de fallas y pliegues, la región concentra actividad sísmica tal que la define como zona de riesgo moderado (INPRES Instituto Nacional de Prevención Sísmica).

2 LA TECNOLOGIA DE TIERRA. SISTEMAS CONSTRUCTIVOS

La expresión formal y constructiva de la arquitectura de tierra en la región del NOA, estuvo ligada a los distintos períodos históricos en que vivió la región y solo ha presentado—en las áreas rurales—relativos cambios a lo largo del tiempo.

Vestigios de construcciones de las culturas nativas que poblaron el territorio (desde el Período Temprano 650 d. C.) y de la cultura inca, durante su siglo de permanencia en él (González Rex 1972), revelan el uso de la tierra como material complementario en la construcción de muros y techos. La disponibilidad de este material y de la piedra (en la técnica de muros dobles rellenos con tierra apisonada o ripio y muros simples) en el lugar de emplazamiento, determinó la combinación entre ambos materiales, el uso y modos de aplicación. Estudios arqueológicos llevados a cabo, han llegado a referir que el sistema de mampostería de adobes fue utilizado en tramos de muros de piedra y en sectores de elevación de estos. El tapial, fue una técnica constructiva utilizada en poblados del Período de Desarrollo Regional en los valles áridos (de 1000 d.C. hasta la llegada del Inca) que se combinó con pilares de piedra que reforzaban dichos muros de tierra (Raffino 1988). Con la presencia de los Incas en la región se evidencian cambios y mejoras en la resolución constructiva, sobre todo de los muros de piedra.

Con la llegada de los españoles a mediados del siglo XVI, en 1535 (Lizondo Borda 1942) se inicia el período conocido como hispánico-indígena, tras el cual y hasta el presente, de los distintos sistemas constructivos en tierra utilizados, el de mampostería de adobe fue el más utilizado en la construcción del hábitat tanto en valles, como en la quebrada y puna.

2.1 *Sistema de mampostería de adobes*

Las características y proporciones que presentan los muros de adobes son similares en toda la región del NOA. Según la disposición del aparejo, el ancho del muro, generalmente de 0.40 m, puede superar 0.60 m y llegar 1.20 m, como sucede en las iglesias y casas de hacienda del período colonial, donde es claro que se buscó guardar relación de altura y ancho del muro, afín de lograr muros resistentes a cargas y garantizar el confort térmico en los espacios interiores.

Los adobes son rectangulares y sus dimensiones varían según el sitio y el tamaño de la adobera que se disponga, la cual siempre es simple o doble y sin fondo. En las construcciones tradicionales, las medidas varían generalmente de 20–24 cm × 30–38 cm × 8–12 cm, pudiendo encontrarse adobes de mayor tamaño. En la actualidad, en las construcciones que incorporan estructura de hormigón armado (columnas y vigas) el ancho del muro está dado por estos elementos estructurales, por consiguiente, el adobe es de menor tamaño y su función sólo es de cierre.

La tierra también es utilizada en otros componentes constructivos de la mampostería. El cimiento y el sobrecimiento se materializa con piedra y mortero de barro y, dependiendo de la región y de su emplazamiento, sea en el poblado o en el campo, las construcciones populares pueden o no presentar sobrecimeinto o llevar un zócalo, con tomado de junta con barro o cal y cemento (Fig. 1).

En el muro, las juntas horizontales y verticales y el revoque, sea de una o dos capas, son de barro, aunque puede que la junta vertical no vaya llena.

Figura 1. Vivienda en el poblado de Tumbaya. Jujuy.

En la actualidad, el mortero de barro es reemplazado por mortero de cal, arena y cemento, para los revoques como así también para asentar los adobes, posibilitando así una mayor adherencia entre soporte y revestimiento.

La aplicación de una capa de protección, sea un revoque o una pintura a la cal u otra pintura al agua, depende tanto de las condiciones climáticas -lluvia y viento- como así también en donde esté emplazada la construcción. En los poblados, las construcciones de alrededor y en cercanías a plaza, tienen siempre la fachada revocada y pintada, no así los muros laterales. A medida que nos alejamos del centro y en el campo, el muro de adobe queda expuesto.

2.2 *Sistema monolítico con encofrado*

El tapial, técnica conocida también como tierra apisonada o tierra comprimida, no fue utilizada en la construcción de edificios. Se utilizó tanto en la puna, quebrada y puna como cerco divisorio, para delimitar terrenos o cerrar los conjuntos residenciales del hábitat rural, como es común observar en la puna (Fig. 2).

Figura 2. Cerco en tapial, la puna de Jujuy.

2.3 *Sistema de entramado*

En el hábitat popular de la llanura y del piedemonte, en donde además de la tierra hay disponibilidad de material vegetal se puede encontrar construcciones con el sistema de entramado. En la región, la técnica mixta de tierra y madera, es denominada quincha, a diferencia de la región del litoral argentino, que con ciertas variantes es conocida como *enchorizado, estanteo* o *palo a pique*, como también se la conoce en la provincia de Santiago del Estero. Son pocas las construcciones que persisten con la técnica de la quincha, en la actualidad su uso quedó relegado para depósitos, letrinas y cocina. En la llanura húmeda de Tucumán -al este de la provincia- la disponibilidad de la caña posibilita su uso para la estructura de entramado como de armazón para el cerramiento.

La estructura bastidor está constituida por cañas o ramas, unidas con fibras vegetales o alambre al parante u horcón, dispuestas en horizontal y vertical, con separaciones cada 5 a 20 cm. El relleno se hace con el embarrado de fibras y hojas.

El sistema de tierra con entramado de madera para la resolución de techos planos está muy difundido. En clima seco y con importante amplitud térmica, la terminación de cierre se realiza con barro, es el techo conocido como entortado o torta de barro. En climas cálidos y lluviosos, sobre el entramado-cielorraso de cañizo o jarilla-la cubierta es de paja o de tierra y paja u hoja de palma o suncho, que puede ir sobre una capa de barro.

3 FORMA Y CONFIGURACIÓN DE LA ARQUITECTURA DE TIERRA

Con la colonización y dominio de los españoles, a partir de mediados del siglo XVI, se produce en la región del NOA una total transformación de la configuración de los pueblos y de la vida de la población nativa. Situación que se patentizó en la organización política-social y en las actividades económicas-productivas. La fundación de nuevas ciudades y el desarrollo de centro de población sobre los ya existentes "pueblos de indios" (Nicolini 1993) que se produce principalmente sobre la ruta que vincula la Puna con la región de los Valles Calchaquíes (zona oeste de la región) y de la Quebrada de Humahuaca, respondieron a un claro principio estratégico de dominio del territorio, plan en el que primó el aprovechamiento de las bondades del sitio del emplazamiento y de las rutas de comunicación, que fuera trazadas por los incas.

La Arquitectura del siglo XVII al XIX.

La arquitectura pública y doméstica durante el período colonial fue el resultado de la conjunción de modelos europeos y el conocimiento tecnológico de materiales y técnicas que los españoles traían de su lugar de origen, así como el saber de las culturas nativas que poblaron el territorio (Gutiérrez 1984). La mano de obra para las construcciones como para todas las actividades manuales recaía principalmente en los indígenas. Paul Groussac refiere cuando escribe de la primera etapa de la ciudad de San Miguel de Tucumán: "*Las paredes eran por lo regular de adobe o de tapia francesa, los techos de paja o palma, según la región (…)*" y *"(…) se ensayaba una cornisa de barro, unas rejas de palos torneados, se embaldozaba, se blanqueaban las paredes*". (Paul Groussac 1981). En el siglo XVII si bien en las ciudades se comienza a utilizar el ladrillo cerámico, en las construcciones rurales se mantenía la tecnología de tierra y la mano de obra indígena.

La expresión y los componentes tipo que las construcciones presentaron durante estos siglos, fue denominada y reconocida como Arquitectura Colonial. Se mantuvo hasta fines del siglo XIX cuando un nuevo estilo arquitectónico comienza a ser apropiado en los poblados y ciudades: el italianizante, el cual, en las áreas rurales sólo se manifestó en la composición de la fachada.

3.1 *La iglesia: Monumento Histórico*

Los edificios que se levantaron durante este período, se construyeron en requerimiento a las actividades que se desarrollaron y que formaban parte de la vida tanto de los españoles como de los nativos: la iglesia y la vivienda.

La iglesia o capilla, era el principal edificio público que se levantaba en la generación de un asentamiento, como parroquia en los poblados, como espacio litúrgico en las encomiendas o haciendas o en las misiones. Fue y es en la actualidad el lugar de encuentro de las actividades religiosas y sociales del pueblo. Por su escala y desarrollo, su volumen se destaca sobre el perfil del poblado (Fig. 3).

Figura 3. Vista de la Iglesia de Tilcara, Jujuy.

Erigida sobre las rutas de acceso al NOA, por la puna para continuar por los Valles Calchaquíes y por Quebrada de Humahuaca (Buschiazzo 1967) las iglesias en las áreas rurales se destacan por su valor histórico y arquitectónico.

Esta arquitectura de volúmenes puros, con muros portantes de adobe de ancho espesor–0,80 a 1,20 m-, con aberturas de reducidas dimensiones y techo a dos agua, respondió tanto a exigencias constructivas-estructurales como ambientales. Con espacios-atrios, abiertos, al exterior para cobijar al pueblo, que desarrollaba gran parte de su vida al aire libre, está íntimamente vinculada, por una parte, a la sencillez de la técnica de construcción con tierra y, por otra, al sentir popular de las comunidades locales (Fig. 4).

La composición de la iglesia, de nave única con predominio de largo sobre el ancho, torre-campanario a los pies de la iglesia, molduras en torres, pilastras, arcos cobijos y la estructura de par y nudillo en techo, fueron elementos tipológicos trasplantados de modelos arquitectónicos de Europa, que constructores y religiosos trasladaron de sus lugares de origen a este nuevo sitio. La composición y planteo arquitectónico de las iglesias de la región del NOA responden a la de iglesia mudéjar (Nicolini 1981).

Figura 4. Iglesia del Carmen, Valles Calchaquíes, Salta.

Figura 5. San Carlos, Valles Calchaquíes, Salta.

3.2 *Arquitectura Doméstica*

Así como es reconocida la expresión arquitectónica y tecnológica de las iglesias del período colonial, en las construcciones del hábitat disperso y de los poblados, se reconoce una composición y configuración arquitectónica que responde a modelos y elementos tipológicos de la arquitectura colonial y el italianizante. Los poblados rurales, y sobre todos los más alejados de las vías de comunicación y de los centros de desarrollo, han mantenido -hasta el presente- en sus construcciones la expresión arquitectónica de los modelos antes citados. (Fig. 5).

La vivienda, el conjunto residencial y la casa de casco de hacienda, aislados y disperso en el paisaje natural o insertos en la trama del pueblo, son los tipos arquitectónico funcional, que representan la arquitectura vernácula de la región. Su concepción responde a la composición de casa a patios (Gutiérrez & Viñuales 1972), con o sin galerías y su escala de desarrollo dependerá del sitio de emplazamiento, su capacidad como unidad autosuficiente y del poder adquisitivo del propietario (Fig. 5).

El conjunto residencial es el hábitat disperso característico de poblador rural de la región, sobre todo en la puna; de crecimiento evolutivo a diferencia de las casas de hacienda y de los poblados, está constituido por un grupo de construcciones -unidades habitaciones- de carácter funcional o polifuncional que delimitan el espacio patio, dentro del cual siempre estará el infaltable fogón y horno. Todo el conjunto cerrado por un cerco, generalmente de tapial, se completa con los corrales y la huerta.

Las edificaciones en tierra son construcciones simples de una sola planta, simples de una sola planta, con fachadas sin ornamentación ni cornisa y pendiente de techo con caída libre a la fachada o al patio. Las aberturas son mínimas y de reducidas dimensiones, con predominio de lleno sobre vacíos. Tanto la vivienda dispersa como la de los poblados, dependiendo de las características climáticas, con o sin revoques no están pintadas, de allí su mimetización con el paisaje natural; solo las carpinterías pueden destacarse por su color, en rojo, azul o verde o por su trabajo de tallado de la madera de los dinteles.

El carácter tranquilo y adusto del hombre rural, se manifiesta claramente en su arquitectura de tierra que se mimetiza con las formas y color de sus valles y montañas. La policromía está presente en sus ropas y en las manifestaciones y ritos festivos.

Hacia fines del siglo XIX, un nuevo estilo arquitectónico: el italianizante, entra en los poblados, las construcciones comienzan a presentar cambios en sus fachadas, las que se organizan en módulo que son definidos por el ritmo de pilastras, zócalos y balaustrada, que se acentúan por la disposición de las aberturas, que son de mayores dimensiones y de desarrollo vertical. (Fig. 6).

Los muros resueltos con adobe o ladrillo cerámico, son más altos y en la fachada se incorpora balaustradas y cornisas que ocultan el techo. El agua de lluvia es evacuada a través gárgolas de chapa, algunas con forma de animales. El ritmo y la repetición ordenada de estos componentes caracterizan la expresión y carácter particular de la calle y del poblado. El patio, la galería y las habitaciones que abren a estos, se mantienen en la composición de las viviendas de este período.

3.3 *La Arquitectura del siglo XXI*

En los últimos años, poblados de los Valles Calchaquíes y de la Quebrada de Humahuaca – declarada Paisaje Cultural de la Humanidad por la UNESCO en 2003-, han comenzado a experimentar transformaciones significativas que se evidencian en la vida de sus habitantes y en la fisonomía de su arquitectura. Atraídos por su pasado histórico, bagaje cultural y accesibilidad desde las principales rutas de comunicación, las comunidades están siendo invadidas por nuevos valores y expresiones arquitectónicas, por el avance de la tecnología de las comunicaciones y de la construcción, por otras culturas -la de los residentes estacionales y visitantes- y por las exigencias y requerimiento de un creciente turismo. Los cambios e innovación se están dan con una celeridad tal que ponen en evidencia la falta de control y la ausencia de una reglamentación urbana e inmobiliaria.

La tierra en su uso y expresión formal-funcional también presenta ciertas variantes. En obras nuevas, algunas construcciones incorporan componentes tipológicos de la arquitectura colonial o de la arquitectura popular propia de otros países, que no dejan de ser imitaciones parciales y fuera de contexto, que se contraponen al tradicional perfil construido del poblado.

La reglamentación de estructura sismo resistente (encadenado de columnas y vigas de hormigón armado) exigidas por las municipalidades de toda la región para las edificaciones actuales, ha contribuido a que el adobe sea utilizado y se suponga tiene el mismo comportamiento al de un ladrillo cerámico. (Fig. 7) Viviendas, locales comerciales y hoteles, se construyen con grandes aberturas, con superficies vidriadas que permitan visuales; el muro de adobe cumple sólo la función de cierre y con el predominio de vacios sobre llenos, la capacidad térmica que caracteriza a la tierra pierde todo sentido. Volúmenes de dos y tres niveles con ventanales, planos de techos en voladizos, luces superiores a 5 m entre apoyo, marcan indiscutiblemente la complementariedad de la tierra como material de construcción en las nuevas edificaciones.

En obra privada, la vivienda del poblador, que en la mayoría de los casos es autoconstrucción, la estructura sismo resistente no siempre está presente; en algunas resoluciones sólo se construye una viga solera o collar sobre la que apoyará la estructura del techo. En la vivienda de veraneo, barrio de viviendas del estado y obras de servicios: bares, restaurantes, hoteles, en la cual puede participar un profesional de la construcción, las edificaciones son con estructura de hormigón y adobe o bloques de hormigón para cerramiento. (Fig. 7).

Figura 6. Calle en Maimará, Jujuy.

Figura 7. La nueva construcción con estructura de hormigón armado.

Figura 8. Remodelaciones. Calle en Tilcara, Jujuy.

El uso de colores destacados en la fachada, es otro factor que marca la expresión de la arquitectura de tierra de este siglo, así como lo es la técnica de *bolseado* del revoque, que es cuando queda modelado el aparejo de la mampostería.

Las remodelaciones y ampliaciones de las construcciones para habilitar a nuevas funciones, es otro aspecto importante a considerar, porque casi en la mayoría de las acciones ha significado una alteración de la homogeneidad constructivo-estructural del edificio, por la sustitución o la incorporación de materiales diferentes al original. (Fig. 8).

4 REFLEXIÓN

En el presente trabajo se intentó mostrar, con una mirada objetiva y crítica, a la arquitectura de tierra en su expresión formal y funcional, a través de la historia y de los distintos estilos arquitectónicos, con la impronta de un saber tecnológico, apropiado y transmitido por la comunidad de generación a generación. La expresión constructiva de su hábitat, simbiosis de arquitectura y paisaje, llegó a definir y caracterizar la arquitectura tradicional y la identidad de los poblados rurales de la región del Noroeste de la Argentina.

En la actualidad, en las puertas del siglo XIX, por el incremento de actividades económicas: productivas y turismo, en sectores de los Valles Calchaquíes y de la quebrada de Humahuaca, los poblados están comenzando a evidenciar un crecimiento edilicio por la construcción de restaurantes, hoteles y locales comerciales, que está marcando una transformación a la fisonomía del poblado. Se observa un "nuevo" lenguaje arquitectónico, con variables componentes tipológicos y una mengua de la calidad constructiva en el uso de la tierra, que presentan algunas remodelaciones y obras nuevas; manifiesta en resoluciones no muy acertadas a nivel de proyecto y de ejecución de obras, así como la presencia de una arquitectura que resulta ajena al contexto.

El paisaje cultural de la región del NOA está integrado por distintas dimensiones: el patrimonio construido, los modos de vida, las manifestaciones culturales de la comunidad y el contexto que los contiene. La arquitectura de tierra no se destaca por sí misma como una entidad aislada, sino incorporada en ese contexto, sea éste el paisaje natural o el paisaje construido: pueblo, calles, casas e iglesias que se articulan en el espacio natural, elemento contenedor de la arquitectura.

La identidad y sus valores no es un hecho estático, evoluciona y se recrea y se apropia de nuevos valores; lograr y mantener el equilibrio entre lo existente, lo tradicional y lo nuevo y moderno es el propósito que debería estar presente en los profesionales y técnicos que actuaran en estos poblados. Conocer el saber y el sentir de la cultura local para rescatar y apropiar la nueva arquitectura al espacio y a la arquitectura regional es un principio.

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Earth architecture and construction in the colonial archaeological site of Piura la Vieja, La Matanza (Piura, Peru)

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ABSTRACT: This paper expounds on part of the results dealing with architecture and historical construction which have been obtained from the archeological works developed under the research project *San Miguel de Piura: primera fundación española en el Perú*. This project, which was started in 1998 by a research group from the Universidad Politécnica de Madrid and the Universidad de Piura, is supported by the Agencia Española de Cooperación Internacional para el Desarrollo (AECID) and La Matanza municipality (Piura, Peru), having also the Fundación Diálogos and the Fundación Diego de Sagredo as collaborators. In the archeological campaigns carried out to date it has been possible to unearth, identify and describe colonial earth structures (mainly adobe and rammed earth), having recognized Castilian construction techniques, but also others which may indicate the continuity of local tradition or the reuse of pre-Hispanic preexisting elements.

1 INTRODUCTION

The city of San Miguel de Piura represents the first urban founding that Spaniards established in Peru. Its first location dates from 1532, and it is known as San Miguel de Tangarará. Pizarro named it as San Miguel, and, apparently, it was completed with the toponym of the closest indigenous village. Little is known about the specific location of this site, although many authors suggest it could have been somewhere in the Chira Valley. Barely two years later, the city of San Miguel moved to a second settlement by the so-called Monte de los Padres in the Alto Piura. There, between 1534 and 1578, it became a city of certain relevance where they could test a complete urban planning that could have served as a reference for subsequent foundations settled in the area.

Most of the historians suggest that the severe weather conditions, the persistence of an eye disease -mentioned in almost all the sources as *mal de ojos* or evil eye-, and the torrential rains that literally disintegrated the most exposed parts of their houses, gradually forced Piura inhabitants to abandon the city. However, other strategic and functional reasons might also have been determining in its relocation. In any case, around 1578, a third settlement was provisionally established in a place called San Francisco de Buena Esperanza, in the Paita Bay, by the Pacific. The city was severely damaged by the attacks by Francis Drake in 1579 and Thomas Cavendish in 1587. Consequently, the 7th viceroy of Peru, D. Fernando de Torres y Portugal, ordered the last moving of the city to its current location in the Chilcal de Tacalá in 1588. From then on, the primitive settlement in Alto Piura, where twenty hectares of ruins of the first Spanish city in southern America are still preserved, has been known as Piura la Vieja.

This paper has been developed in the framework of the research project *San Miguel de Piura: primera fundación española en el Perú*. Since 1998, this project counts with the participation of the Universidad Politécnica de Madrid and the Universidad de Piura. It is supported by Fundación Diálogos (Spain), the Escuela Técnica Superior de Arquitectura de Madrid and the municipality of La Matanza (Piura, Peru), and lately also by the Agencia Española de Cooperación Internacional para el Desarrollo (AECID) and the Fundación Diego de Sagredo (Spain). This project covers a great amount of studies, fieldwork and research activities in the fields of geography, history and archaeology on the historic San Miguel, with special attention to the urban, architectural and constructive aspects. A numerous and multidisciplinary team of Spanish and Peruvian specialists (archaeologists, geologists, architects, historians, engineers and surveyors) are part of this project whose main objective is to develop a systematic excavation of the ruins of the old city of San Miguel de Piura. This has been planned with the view of consolidating and restoring its architectural remains as well as creating the infrastructures needed to enable its opening and exhibition to the public so it can contribute to the sustainable development of Piura la Vieja, the municipality of la Matanza, and the region the of Alto Piura. So far, four seasons of excavation -in 1999, 2005–2006, 2008-, and another three of surveying -in 2006, 2007, and 2009- have already taken place.

2 THE CITY OF SAN MIGUEL: URBAN LAYOUT AND ARCHITECTURE

As in Mexico, the Spaniards found in Peru an extraordinarily developed urban culture: the Inca Empire. The evolution of several mountain cities as Cajamarca or Cuzco shows the transformation process of the primitive pre-Hispanic cities during the colonial period. This makes the Inca legacy evident in the urbanization process of Peru. On the other hand, along the coast, the Spaniards barely found urban areas still in use by the indigenous in the beginnings of the XVI century. The great urban experiences of the north coast, from the Mochica and Chimú times, had been abandoned hundreds of years before the conquerors reached them. Hence, Spaniards founded numerous cities, mostly developed *ex-novo,* in the coastal areas of Peru. However, traces of possible pre-Hispanic urban and semi-urban elements can be detected in cities as the *Ciudad de los Reyes* (Lima) and even in the second foundation of San Miguel de Piura by the Monte de los Padres.

The urban layout of the city of San Miguel de Piura recalls the grid design of the first semi-regular models characteristic of the early founded Spanish cities as San Cristóbal de La Laguna in Tenerife (1496), Santo Domingo (1494), and Santiago de Cuba (1511). The city shows the importance of the most remarkable urban element in the Hispano-American city: the Plaza Mayor (main square). In San Miguel, as it is a military settlement, the main square has been substituted by the Plaza de Armas. Its imposing size, approximately 100 meters long and wide, shapes it as an urban element with great character. Regarding the mounds surrounding this space, it is possible to state that some of the noblest buildings of the city were located around it.

We know, from a text by Juan Salinas de Loyola that the urban complex of San Miguel de Piura had a Master Church, a Mercedario Convent and Cabildo Houses. By the middle of the sixteenth century the city had reached a hundred inhabitants, 23 of which were *encomenderos.* This figure represents a considerable amount taking into account that, by that time, Trujillo had the same number, and the *Ciudad de los Reyes* had around 30 of them. The city served as a base for the Castilian expeditions that explored the southern regions of Ecuador during the central decades of the 16th century. Until the construction of the El Callao harbor, every expedition disembarking in the northern ports of Tumbes and Paita going further into the continent had to use this route that passed by San Miguel.

The description of Piura la Vieja made by Juan Salinas de Loyola after 1570 has become a priceless reference to everyone working in this issue due to his references to the physiognomy and composition of the city (Jiménez de la Espada 1965): "*La plaza en medio y della salen ocho calles, y por ellas cuadras de solares de a ciento ochenta pies cada un solar en cuadra, y cada cuadra tiene cuatro solares; las calles de ancho a treinta pies, y por ser el pueblo pequeño, lo son también las calles, y no con los nombres que acá se acostumbran."*

There is little information about the historic construction of the city of San Miguel during the times of its colonial occupation between 1534 and 1580. However, the archaeological campaigns, surveys and systematic prospections carried out in the site evidence the powerful stamp of the Castilian building traditions present in the remains.

The variety of construction materials found in San Miguel de Piura is remarkable. This confirms the presence of a well-developed building typology. In this sense, some of the main building systems and documented bonds can be highlighted: faced quartzite masonry with clay mortar improved with lime used in the foundations, stone and clay fillings for the interior of the buildings, adobe walls with earth and lime mortars, rammed earth floors with ceramic remains in exterior pavements, stone thresholds, fired clay interior pavements, lime mortar pavements, timber structures and curved ceramic tiles for the roofs (Villanueva Domínguez et al. 2002: 284–285).

The main conclusion drawn from these campaigns of work is the confirmation of the descriptions by Juan Salinas de Loyola (Jiménez de la Espada 1965): "*Podrá haber hasta cien casas, pocas más o menos, y los materiales con que están edificadas son, los cimientos de piedra, y lo demás de adobes y tapias, y cal, y ladrillo, y las cobijas de paja, como llueve poco; y que antes van en disminución que no en acrecentamiento, por las causas que tiene dichas, aunque los edificios se mejoran*."

Other writings by Spanish chroniclers from the 16th century abound in this constructive universe, and they sometimes offer complementary data of great interest. That is the case of Zárate, who relates the way in which buildings are erected over compacted earth platforms: "*los quales edifican haziendo las paredes de los quartos de adoues, con cinco pies de ancho, y en medio lo inchen de tierra todo lo necessario para subir el aposento, hasta que las ventanas que salen a la calle queden bien altas del suelo".* Regarding this, the archaeological excavations have discovered in Piura la Vieja pretty similar building procedures.

3 MASTER CHURCH OF THE CITY OF SAN MIGUEL, PARADIGM OF BUILDING TECHNIQUES USED IN THE EARLY COLONIAL PERIOD

Among the colonial constructions that have been better studied thanks to the archaeological excavations, one stands out specially. This building has been interpreted as one of the churches of the old Spanish village. In the texts by the *corregidor* Diego de Pineda (1557–1558) there are already references to the temples of the city of San Miguel: "*Por tanto, que ruega y encarga al muy reuerendo señor Bachiler Juan López Guijarro, vicario de la iglesia desta ciudad, haga decir vna misa solene al Espíritu Santo,…E después de hauer dicho e acabado la misa en presencia de los susodichos, el dicho señor corregidor dijo que juraua y juró por Dios y por Santa María…Y ansi hecho el dicho juramento, el dicho señor vicario y el dicho señor correguidor salieron en procesión con toda la gente que estaba, lleuando la cruz delante con la solenidad que de presente se pudo hacer. Y fueron en procesión a la Casa de Nuestra Señora de la Merced desta ciudad. E allí se dijo misa de Nuestra Señora. E dicha voluieron en procesión a la dicha iglesia. Y allí el dicho señor vicario dijo ciertas oraciones invocando la gracia del Espíritu Santo al dicho efeto*."

During the survey development in the 2003 and 2004 campaigns -completed almost entirely between 2006 and 2007- the potential interest of a mound of elongated morphology next to the southern corner of the Plaza de Armas arose. Both its location, very close to the urban center, and its dimensions undoubtedly suggested that it was a pretty distinguished building that could be the major church of the old colonial city. The archaeological excavation of this *Singular Structure I* has been developed during the 2005–2006, 2008 and 2011 seasons. These works made clear that, indeed, it was a church of a length of 140 Castilian feet and a 50 feet wide plan (approximately 39.00 m × 14.00 m). The accuracy of its dimensions according to the Castilian measuring unit clears up any initial doubt about the design and execution of this structure in the Colonial period.

The use of this building as a church has been confirmed thanks to the discovery of a wide Altar Mayor (High Altar) that appeared at the eastern end. The access was through an elegant stairway of seven rammed earth steps covered with lime mortar (Fig. 2). A differentiated space has been documented next to this structure at the back of the altar. This space could have been used as a sacristy. Another high mound located at the south western end of the old temple could have been the base of a *espadaña* or a belfry. The general typology of this temple recalls the previously studied Túcume Viejo church (Vela Cossío 2007). Similar to that church, it might have been organized in three aisles separated by timber studs supporting a wooden roof, though in the interior of the old temple we have only found traces of this last structure and none of the studs. At the same time, several burials with liturgical orientation were exhumed in the interior of the nave during the excavations.

Regarding the construction date of the church, the archaeological material (mainly ceramic and metal remains) found in the fillings from both the church floor and the compacted earth layers of the mound in the south west corner of the building front, indicate that it was erected when ceramic material waste of European origin already existed. Consequently, it had to be later than 1534 (Astuhuamán González & Vela Cossío 2010). Indeed, the construction might have taken place a

Figure 1. View of the excavations of the old church site. UPM-UDEP.

Figure 2. View of the Altar Mayor (High Altar) of the church. UPM-UDEP.

decade after that, since in 1543 the viceroy Vaca de Castro had already defined the jurisdiction of the Lima and Quito bishoprics. This implied the consequent need to build churches in the cities founded in them. The subsequent period from 1544 to 1548 has been considered too tumultuous to build. After that time, the calmer decade of 1550 marked the consolidation of San Miguel de Piura as one of the main centers of the rising Viceroyalty of Peru. In fact, around 1550, Pedro de Cieza de León, who had been in San Miguel, stated it (Cieza de León [1553] 1996: 157): "*y no embargante que esta ciudad se tenga en este tiempo en poca estimación por ser lo repartimientos cortos y pobres, es justo que se conozca que merece ser honrada y privilegiada por haber sido principio de lo que se ha hecho y asiento que los fuertes españoles tomaron antes que por ellos fuese preso el gran señor Atabalipa*".

The remains of the church studied during the last excavation campaigns revealed the building techniques used in the area during the early times of the colony and also allowed to analyze the probable persistence of local constructive traditions after the Spanish Conquest. At the same time, the possible re-use of pre-existent structures for the colonial buildings in old San Miguel de Piura could be confirmed. The importance of this site mainly lays on the fact that it is one of the few sites that has survived to the present time almost intact due to its early abandonment.

Fortunately, this moment has been documented during the excavation. The stratigraphic records show a level of a great fire which has not been documented in any written sources. However, the fire traces are fully recognizable in the different grid areas studied in the front, interior and back parts of the building. A layer of burnt earth and ashes is distinguishable over the old pavement of the church. This floor was made with rammed earth and whitewashed superficially. It is situated at a higher level from the street, which confirms Zárate's description. The fire could have been produced between 1573 and the definitive abandonment stage (1578–1580), since in 1573 a court process against Joan de Saavedra took place, and he was temporary arrested in the sacristy of the still standing church of San Miguel de Piura. The stratigraphy also suggests that after the fire the church roof has never, or at least not sufficiently, been repaired. Consequently, the typical torrential rains of the area probably contributed to the building collapse soon after the fire. This can be supported by the high level of conservation of the fire traces.

The kind of materials used in the construction of the temple probably favored the fire, especially the exterior thatch that could have covered the wooden roof. This hypothesis is supported by the fact that no remains of ceramic tiles have been found and in addition, well preserved roofs of this kind, with a thick layer of mud and thatch, can still be found in other colonial temples of the region, as it can be seen in the San Lucas church of Colán. The roof of this last example, as well as the already mentioned one of the Túcume Viejo church, apparently had intermediate structural elements supported by studs which divided the main space into three aisles (Villanueva Domínguez & Vela Cossío 2006). The existence and location of this kind of studs has not yet been archaeologically confirmed in the case of Piura. However, the use of local carob tree wood for the roof beams has been proved by the discovery of some partially burnt remains of it in the interior of the temple.

It has also been archaeologically stated that the building collapsed towards its interior. In fact, the ruined walls present a surprisingly good conservation status and this has provided enough data to confirm that the walls are made of adobe with earth mortar enriched with some lime bonds (Fig. 3). The footing of these walls was protected by an irregular masonry base, four Castilian feet high and similar section (approximately 1.10 m). This masonry was made of quartzite stone from the hills nearby. The stones have no cutting traces, but they have been carefully arranged to constitute faced walls. Attending to their irregular dimensions, the bigger ones have been used to create the exterior faces of the walls which were filled up with smaller ones and well-compacted mortar. These footings form the foundations of the walls, but rise considerably above the street level. Similar configurations can be currently found in the traditional building techniques used in the same region.

Regarding the original disposition and bonds of the adobe courses, little can be said, since they have

Figure 3. Excavation detail where the remains of the church ruined adobe walls can be seen. UPM-UDEP.

collapsed. The adobe bricks are parallelepiped prisms of variable dimensions, ranging from 0.46 m × 0.22 m × 0.12 m to 0.36 m × 0.18 m × 0.10 m (Rodríguez Rodríguez & Campos Napán 2010). However, these variations could have been a consequence of their deformation after its ruin. Traces of its primitive exterior coating have been found, consisting on a simple layer of lime mortar. Analogous walls, with the same masonry footings and identical dimensions of three or four Castilian feet wide (approximately 0.90 m or 1.20 m), can be identified on the surface of a wide area of the site. It can be said that it is the most common constructive typology in most documented structures, but especially among those clearly related to the Colonial urban layout.

4 LOCAL PRE-EXISTING RE-USED STRUCTURES AND PRE-COLONIAL BUILDING TECHNIQUES

Nevertheless, this is not the only wall typology identified on the surface of the site. Several other structures executed with different techniques absolutely different from the building traditions of the metropolis have been found as well.

The excavations carried out in 2005–2006, 2008 and 2011 allowed a better study of this problem and have offered considerable data about the possible existence of a former pre-Hispanic settlement in this place. The existence of overlapped structures in various directions have been stated, as well as the use of masonries different to the ones described in the base of some walls and located mainly in the peripheral structures of the complex. As a matter of fact, these elements could be pre-existent structures of pre-Hispanic times substituted by colonial buildings or even re-used in their construction, but they could also be indigenous contributions to the conquerors building procedures. Among the existing elements on the surface singularly more alien to the Castilian building traditions, basically three main groups of structures can be considered: wall footings with particularly big stones placed vertically, stepped-shaped or variable width wall footings, and base platforms or terraced double walls.

The first group corresponds to the structures located in the south east sector of the complex. Apparently, they could be walls belonging to boundary structures, not to buildings. They are formed in a similar way to the previously described ones, but they present at certain intervals a great amount of big stones arranged vertically in both the exterior whytes, always with its flatter sides facing the exterior of the wall. As in the rest of structures that will be described, it is difficult to determine if they derive from the survival of local constructive systems or they are reused or remaining elements that belonged to the times before the Spanish foundation of the city.

Regarding the second type of elements, they are walls whose masonry footings show a change of width or a stepped shape. This variation could be caused either by the building of reinforcements in the base of the walls, increasing its lower width that way, or to its execution over a base wider than the rest of the structure. In any case, these walls have a section of exactly five Castilian feet width (approximately 1.40 m). Even if they could be elements of Spanish construction, we have decided to include them in this section, mainly because the use of reinforcements at the walls base is relatively common in the local building traditions. These walls have been found in different places of the site, but its major concentration has been documented close to the southern edge of one of the main streets of the old city.

The third and last group is formed by big platforms over which some buildings were erected. These elements are formed by a perimeter masonry wall similar to the one firstly described and a filling of rammed earth to the top level of the wall. The singularity of these structures lies in the fact that over them a second perimeter wall appears, recessed approximately two meters from the first one. This confers them a terraced appearance undoubtedly linked to pre-Hispanic traditions. This second alignment of walls presents analogous characteristics to the first one and would probably form the footing of the supporting structures of the buildings themselves. However, these double terraced walls could also have been erected during the Spanish occupation of the site, but using, local workers or building techniques. This type of element is mainly found in the northern part of the site, forming a huge structure of rectangular plan, of approximately 91 × 60 m. Above it, a contemporary cemetery currently exists, but at that time, there could have been the Mercedario Convent mentioned in the historic sources and which has not yet been identified.

On the other hand, apart from these three groups of identifiable on the surface structures, evidences have been found, in one of the grids excavated in the northern end of the old street located north of the church, that suggest that some buildings could have been raised over massive platforms of pre-Hispanic tradition specifically designed to withstand earthquakes (Fig. 4). This kind of great adobe structures have been extensively documented in other sites which belonged to the different cultures dominating the coastal regions of northern Peru before the arrival of the Spanish conquerors, and especially in old monumental buildings from the Moche o Mochica culture, developed between

Figure 4. Particular of the adobe structures identified as traditional pre-Hispanic platforms. UPM-UDEP.

the 1st and 7th centuries (Alva 2004: 183–184; Sondeguer 1998: 242). Its singular shape makes them easily identifiable, as they are made up, not by continuous horizontal courses, but by a series of adobe square-section pillars attached to each other. This type of discontinuous structure, showing constructive joints periodically arranged, has been analyzed by many authors as a defensive mechanism from the important earthquakes which have frequently affected the country. Once more, no evidences have been found to confirm that these structures were built prior to the Spanish foundation of the city, but this fact will be clarified in future archaeological campaigns. These works will also help in estimating the chronology, extension and frequency of use of this kind of pre-Hispanic elements as a base for the buildings forming the urban layout of old San Miguel de Piura.

5 CONCLUSIONS

This research project has already proved that Piura la Vieja is a key archeological site to understand not only the town-planning and architectural procedures developed by the Spaniards in the early times of the Viceroyalty of Peru, but their manner of dealing with pre-existing urban structures and local traditional building techniques and even in general their relationship with a non-Inca indigenous population.

The study of the constructions existing in this old settlement, mainly consisting on rammed earth and adobe walls, is being especially important to clarify these and other questions, as a rich variety of pre- Hispanic and Castilian building techniques has been found in it. Future archeological campaigns may help to shed light to these important features of the Colonial and Peruvian history.

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Earthen architecture, an evergreen type of building method

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ABSTRACT: Modern earthen architecture could also benefit from the earthen architecture of the past. In Slovenia, there are very few examples of new earthen architecture. Most investors reject earth and its composing materials as useful and modern building materials. The origin of this problem lies in the notion that earthen architecture is associated with poverty, farming and dirt. We usually use a theory of the vernacular architecture of a selected region to empower local people. In Slovenia, mud architecture or earthen architecture has a negative image. Clay is the most commonly used material for rendering walls; the use of rammed earth is stigmatized or very poorly understood in practice. The paper explains where the obstacles lie and how to overcome them. The best way to do this is by providing useful practical examples and guidelines for local communities, architects, potential investors and last, but not least, institutions such as schools and the chamber of economy.

1 INTRODUCTION

The field of architecture is closely connected with the invention of new shapes which objectify new interrelations. These relations exist either between materials and building blocks or between the users of shapes. Inventing shapes is directly linked to the totality of actions. The perfection of something stems from a good knowledge of problems and a clear definition of a problem. A form in vernacular architecture evolves from materiality of the needs of users of erecting building, available resources at site or close to the site of a building and knowledge of the builder. This is economics of architecture. The theme of economics from the viewpoint of the invention of spatial forms originates in vernacular architecture, which is often associated with the term cultural heritage (Zupančič. 2011: 15).

Loam, wood, straw and stone are the most common materials used in vernacular architecture of Slovenia. How they are shaped and how they are used in construction it depends on the region. Earth, clay and loam with their wide set of variations of usage are present especially in traditional architecture of Northeast part of Slovenia. There are two major rivers Mura and Drava and mainly flat fields. Both rivers provide great amount of mud, gravel and clay and Selected parts of the fields close to the rivers are regularly flooded, and the mud is deposited.

The result of this natural cycle and inflow of mud reflected in traditional architecture of this area, also. Architecture of this area relies on loam and wood.

However, when observing the buildings from outside it is not easy to distinguish between constructions made of loam and constructions made of bricks. Mimicry of past and new architecture is sometimes quite perfect. The only help to us is the damaged surface of façade where the sincere face of construction is exposed.

Gable end is constructed with bricks, the solution is following the idea of economics in architecture. Bottom part is made of thick walls of rammed earth (approx. 45–50 cm of thickness); upper part consists of bricks (single or double layered bricks of 6/12/24 cm) and wooden roof construction (see Figs. 1 and 2). The upper part (area B, C and D in

Figure 1. A house in the village of Bukovci: walling construction of rammed earth is exposed. A—wall made of rammed earth; B—gable end wall made of bricks.

In the village of Bukovci traditional single storey houses are common along the street and the majority of them are made of rammed earth.

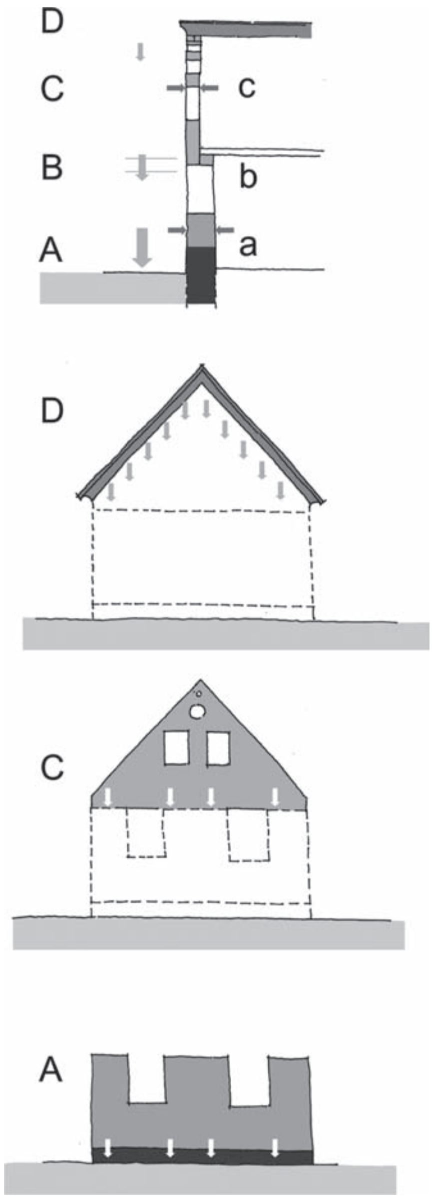

Figure 2. Scheme of the walling construction and the loadbearing forces. A—rammed clay walls; B—a brick "collar"; C—gable made of bricks; D—roof. With the letters a, b and c is marked thickness of wall; the tectonics of widths is clearly presented.

Fig. 2) of the building is not easily reachable (250 cm above ground level).

Here the choice of bricks is logical; brick walling entails less intensive work. Bricks are modular and they are easily assembled in a wall. However the build in energy is higher for bricks as for rammed earth. It is also a reduction of weight for load-bearing walls of ground level.

2 THEORETICAL FRAMEWORK

Any activity in terms of experimental learning outside the rigid lecture spaces may be useful and may encourage participants to go beyond the limits of their current spatial awareness and material possibilities. Experience is often understood exclusively as a product of the senses. We perceive and experience space because we can move in it. Experience can be understood as a particular combination of active and passive elements: on one hand, it means experimenting, on the other hand, it is a consequence of 'something' that a child experiences during the process (Zupančič, Čerkez. 2011: 40–41).

Describing architecture and teaching spatial design include a wide field of activities. Theory and practice are like wattle, each theoretical model originates from previous practice and is extrapolated further to seek spatial and structural advance. Making a scale model is one of the first physical and spatial expressions of learning an architectural language. Scale model is a result of synchronic process of mind and hands using paper, wood or any other material. Pallasmaa goes further and says that the evolution of the human brain may well have been a consequence of the evolution of the hand. The mobility of the hand and arm is coordinated and judged by spatial positions and relations (Pallasmaa. 2009: 33).

When we describe children exercises where the use of hands and fingers is involved, we try to evoke children's sense of touch—tactility. When adults conduct practical work (courses, architectural workshops) where participants interact *in situ* with given material and construct full-scale models

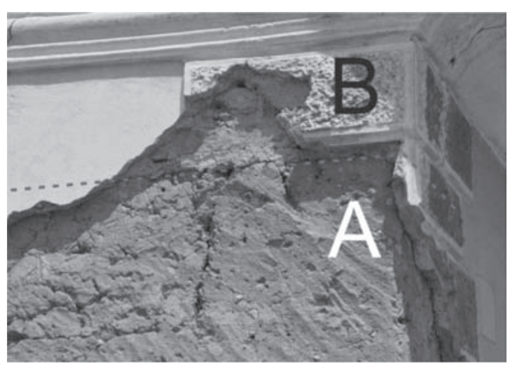

Figure 3. Detail of gable end. Double layered brick wall (B) above rammed earth walls (A). The brick layer is like a "collar" of the house.

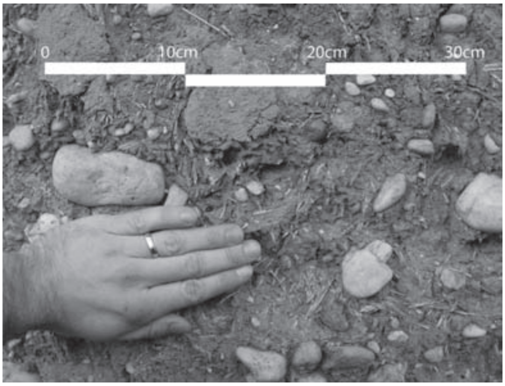

Figure 4. A cellar in the village Strehovci, vineyard Strehovskibreg. This method is called "blatnjača", and is the simplest constructive feature in earthen architecture of Slovenia. "Blatnjača" or "mud house" is a predecessor of rammed earth method (Juvanec. 2010).

Figure 5. The size of stones in the mixture of 'blatnjača'.

we try to teach them special skills through practice (i.e. working with stones and constructing a dry wall corbelled shelter). Usually the skills concerning working with mud (earth or clay) and well developed tactility are inseparable attributes of good participant. Hands are one of the first and most useful human "tools" when handling with the materials.

Several papers published in last few years describe an experimental investigation of rammed earth and compression behavior of small scale models (cylinders) and full scale models (column, walls). Walker and Maniatidis describe the variation or deviation of results while testing performance in small and full scale models. (Maniatidis, Walker. 2008: 238). Deviation is originated by the use of aggregates. Scale models (i.e. 100 mm cylinders in diameter) should be theoretically and practically made of the same selection of materials as full-scale models, however when testing rammed earth this could lead towards measurements that exceed expected values. Considering the physical size of aggregates especially gravels; there is no reliable test of rammed earth model smaller then full-scale element. Figure 5 presents the size of gravel stones as part of average consistency of compacted mixture of the "blatnjača" (Fig. 4).

Presented size of stones is not an exception; here any test of small scale model could present a great share of deviation from the element in full-scale model. Rammed earth composite are specific and may not be tested as other industrialized products as concrete, steel or composites.

3 ARCHITECTURAL PRACTICES IN SLOVENIA

In the context of an average builder rammed earth is a construction technique of the poor people for the poor people. This negative premise has it logical explanation. After both World Wars the time of restoration of houses, settlements and infrastructure was the main priority. The need for new construction materials and other structural equipment was enormous and the factories were constantly over the edge of their production capacities. Essentially the rural area was always the last part of the supply chain for construction materials. A rising number of new houses made of rammed earth is recorded from the end of Second World War to the early 70ies (Zbašnik. 2005). Clay and loam were at hand, the cost-performance ratio was acceptable. Another parameter we should take in this explanation: there was no other construction material available in reasonable delivery time. Using earth for dwelling was an inevitably choice of relatively poor families living in Northeast part of Slovenia (especially in Ptujskopolje, Dravskopolje and Goričko). A rapid reduction of rammed earth building construction occurred during the 70ies. In 1963 there was a great earthquake in Skopje and new regulations (building act, 1967) were introduced. The building act included more accurate seismic values, prescribed more strict limitations for constructions and for any building the building permit was required. The combination of those events and the relatively constant production of cement and steel were an excellent opportunity to promote reinforced concrete. The process of standardization of constructing buildings prescribed usage the reinforced concrete, steel and bricks.

From that perspective the earthen architecture become a synonym of poverty. Upon the influence of contemporary architectural approaches in the 70ies, the earthen architecture was closely linked with underdeveloped countries of Africa and South America.

According to the described objectives (we observe from the matter perspective) the usage of loam, mud, adobe or clay mixed with straw was marginalized and set away from the mainstream of architecture, construction and dwelling. And at this point we may realize why nowadays we could hardly distinguish from so called mud houses and 'normal' houses in the village of Bukovci. From the information gathered on the filed the so called 'normal' house is made of commercially available materials i.e. concrete, bricks, steel beams or wood. To live in a house made of rammed earth set the dwellers in a position of people living in a mud house made of dirt. This is just a misleading general perception. All those burdens are concerned with society and their values. The question is: how to surpass the obstacles set in people minds and in minds of experts in the field of construction? Is it necessary to be like that?

4 DISCUSSION

After the Second World War in Yugoslavia development and renovation of industry was promoted. As any other revolution also here the past and tradition were socially stigmatized and set aside. Schools promoted development of technical knowledge. Prosperity was guaranteed by so-called industrialized society where all the goods are produced and controlled. Nevertheless this was needed to establish firm ground for the development of towns and infrastructure.

The other side of the medal is not so bright, along with the promotion of industry a great portion of manufactured products, skills and skilled people slowly disappeared. This is what happened with rammed earth: in the 70ies there were several masters of rammed earth called *'mojsterbutač'*(Zbašnik. 2005: 42); while nowadays there is not any master of rammed earth in Slovenia. Tactility of hands for rammed earth slowly vanished too. The youngest houses constructed of rammed earth in Slovenia are 50 years old. The age of these structures is not a problem, yet.

If we would like to step further towards positive practice promoting and building using traditional techniques and local materials, we should rearrange our aims in two general directions: the first is towards education of younger generations; the second is directed towards institutions. Education is not meant to organize occasional workshops but to include contents of earthen architecture in programs of primary schools. The education is needed also in local communities implementing programs as joint ventures of architectural bureaus, chamber of economy and heritage offices. In vernacular architecture there was constant adaptation, invention and reconstruction but the knowledge was able to be passed over from one generation to the next. The essence is the relation of man and landscape—cultural landscape.

Another area where rammed earth building method could be used and presented is in primary schools. Education process for primary schools prescribes learning outside, also. Building recommendations for designing primary schools and areas around them predict open air classroom (Plestenjak, M. Urbanc, J. 1999). Physical appearance of those designed places is not prescribed and it is just recommended to use materials that are not dangerous for the environment. Here could be rammed earth used as architectural expression of place and also as a local learning material.

Empowered with positive experiences from the field of preserving dry stone structures and promoting dry walling as possible profession, we should be more proactive in the field of earthen architecture. In 2011 we held an expert workshop of dry walling and we build corbelled dry wall structures in Kras in Slovenia. The public and expert response was astonishingly positive and from the beginning of 2011 till 2012 (February) there are 5 active masters of dry walling. Before the 2011 there was only one master. This program is running under the title Project Kras 2012 and it is led by University of Ljubljana, Faculty of Architecture.

Rammed earth as traditional technique in Prekmurje and Pomurje could be used or introduced for auxiliary buildings as sheds, garages, saunas, garden huts, pavilions, apiaries and for domestic non-public single storey warehouses. Similar idea originates from late 18th century from François Cointeraux and the School of *'Agritecture'* Cointeraux established his first school in Grenoble (1786) and later in Paris (1788). He promoted the idea to construct small shelters using pisé, the technique quite similar to the rammed earth. The term Agritecture consists of combination of agriculture and architecture. Cointeraux established schools for Agritecture, lectured and eagerly promoted pisé, his students obligated to force theory into practice, so they built great variety of buildings for farmers and also an experimental buildings close to the school. His enthusiasm was great but finally he was rejected by other professionals when he announced that the practical technique placed the ability to build a house in the hands of every man, who would build it for himself 'without any help from masons' (Lee. 2007).

The proposed action plan to build secondary buildings using rammed earth it is not a recitation by reconstruction, it is respectable architecture that gives new value to vernacular techniques. In vernacular architecture there is no discontinuity, it is just a constant adaptation depending circumstances. As Hollis mentioned for the medieval buildings that: buildings were not drawn or modeled in their totality before work began on site, and much was therefore left to chance and ingenuity (Hollis. 2010: 132). This could be copy-pasted in the field of vernacular architecture. Our aim is not fabrication; it is rather re-evaluation of method. And last but not least the knowledge of rammed earth building methods in practice it is a growing requirement in heritage management. Long term monitoring (load bearing performance, surface changes, humidity of material, exposure to seasonal weather conditions, usage of buildings, the estimated life span) of full-scale experimental buildings may lead us towards better understanding, planning and constructing new buildings. The proposed experimental project could be applied in Pomurje and Prekmurje, while there is no potentially high seismic activity predicted.

5 CONCLUSIONS

A review of benefits associated with rammed earth expose many positive attributes and few weak points. It is not the aim to list all the benefits and some weak points, while they were described in deep by many authors; here is just a short list: Minke, Walker, Volhard, Juvanec and ZbašnikSengačnik. We could sum up the benefits in a list: the low embodied energy of the material; short transportation lines; fire resistance; wall made of rammed earth regulates healthy internal air humidity and generates improved internal conditions to dwell in. From that angle the contemporary earthen architecture could also benefit from the use of earth by earthen architecture of the past. To dwell in a mud cottage is a privilege (healthy local, empowered people from builder to heritage employee, reasonable land management, and sustainable energy consumption).

The negative attributes of clay are low water resistance and great shrinkage percentage as well as the cracks produced by the uneven drying. These negative connotations may be solved by better planning and well handling with the material during the constructions processes. In Yemen they use qudad method for plastering, where the cracks are gradually filled with new material (Zupančič. 2009). Considering these delicate attributes our proposal is just to build secondary buildings. Usually the perfection of the detail and surface finalization is not the same as when we construct buildings to dwell in. The proposal is meant as a first step towards promoting benefits of the use of earth in architecture.

Experiences from practical workshops have presented us how the knowledge transfer works. The knowledge transfer shift may be achieved by the function of identifying living environmental values by using the methods of architectural analysis of space and the function of spatial structures (Zupančič. 2011: 15). In Northeast Slovenia the coexistence of buildings using rammed earth, adobe and other earthen renderings with buildings using contemporary constructional materials is a result of a variety of conditions. Juvanec point out: 'mud houses', 'rammed clay' houses, those built with adobe, or from bricks, from wood or in stone, are externally the same and difficult to distinguish (Juvanec. 2010: 45).

Singe story constructions when rammed earth is applied have approximately 40 to 50 cm thick walls. This is close to the thickness of a wall designed and constructed using: wall rendering (2 cm), bricks (29 cm), thermal insulation (15 cm) and final enclosure render of façade (1 cm) which is a 47 cm thick wall. Rammed earth is a low energy material to produce, to build in and to manage, so here we may use the term: the material has a reduced environmental impact.

We are developing a set of national building standards of materials used in traditional vernacular architecture in Slovenia. Our approach is divided in sections: *documentation* (field trips, measurement of the buildings, preparing architectural drawings with descriptions, CAD modeling); *analysis* (order, array of used materials, archive data—"heritage meta data"); *pilot projects* (several full scale models using controlled regime—measurement of the structural joints and observing the envelope of the building); *analysis and interpretation of results* (comparing with standards available in other countries). Planned full scale models are actual buildings as sheds, beehives, etc.

Upon those standards we may conduct workshops for students and workers and provide training courses about how to apply this building method in new architecture and to reach a degree as skilled rammed earth builder. Our aim is to establish a Slovenian group of people interested in rammed earth and a network of professionals. We have some positive experiences in the field of dry stone architecture in Slovenia. The methodology remains the same, only the subject is modified.

Organizing network of professional may lead towards better understanding of mentioned building technique. With constant practical and theoretical improvement we could help to upgrade skills of introduced masters for rammed earth. Those standards should be readable and understandable documents covering life cycle assessment, carbon footprint and work flow. From those modestly described goals we may follow next level: promotion of earth as material with unique local identity resulting in new architecture. Local material and labor are part of architectural economics. In Prekmurje there are some isolated actions promoting mud, clay and loam in ethnology. In Melinci there are *'ciglarskidnevi'* (brick days), each year villagers present the process of producing, moulding and baking the clay bricks; the second event is pottery in Filovci, where all the steps are demonstrated and visitors may cooperate in the process.

We are aware of the realm using earth, mud and clay in modern architecture will remain outside the architectural mainstream. At the moment the knowledge flow does not exist or it is weak (it is captured in scholarly circles, only). Our aim is to raise awareness that rammed earth is an evergreen type of building method and it could be more acceptable (or understood) in the field of experts (architects, structural engineers) and institutions (municipalities, agricultural communities, schools). We could introduce and implement guidelines for builders using practical examples starting with site preparation, material procurement and building maintenance. Building full scale models of so-called secondary structures enables us to pass on information about different ways of constructing and to build a knowledge base available to all interested people.

We can finally consider another point of view: rammed earth is an intensive labor and time consuming building method, however those remarks may be used as therapy for special social and health programs (programs for preventing abuse of drugs, social rehabilitation of marginalized groups or even as team building program). Concerning this matter rammed earth building technique could provide social and economic shift in the Northeast part of Slovenia. The clay could be next local material using local knowledge and local labor; the result is local architecture in the context of local environment with no global architectural uniformity but architectural diversity with identity and built in cultural values.

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Conservation of earthen architecture

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Elements for the definition of good practices for the conservation and the restoration of the historical urban fabric of a Moroccan pre-Saharan oasis

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ABSTRACT: The research "Conservation, rehabilitation and valorization of the traditional earth built heritage" coordinated by the Faculty of Architecture of Cagliari has provided the inspiration for the collection of good construction practices in the historical part of the oasis of Figuig, situated in the Moroccan Oriental Region. Built in a dense urban fabric with courtyard houses that lean one on the other, Figuig represents an aggregate in which man's work, profoundly affects the very existence of the settlement. The poor care or even abandonment of the buildings is only partially the cause of the significant deterioration the oasis is facing today. This contribution aims to highlight what are the values of the built fabric of the oasis, its building traditions, materials and construction techniques, focusing on the problems that occur more frequently to the technicians responsible for their conservation and trace the path to the definition of guidelines and best practices.

1 INTRODUCTION

This contribution reports on a research for the individuation of best practices for the conservation and restoration of the earthen built heritage of the ancient city of Figuig in Morocco. The research has been originated by the result of several experiences conducted by the author on behalf of the University of Cagliari with respect to issues related in general to the conservation of earthen buildings.

I refer primarily to the recent experience made with the compilation of the "Manuals for the rehabilitation of the historical centers of Sardinia" coordinated by prof. Antonello Sanna, and the personal contribution to the edition of the manual on earthen architecture. The manuals of Sardinia certainly lie in the rich vein of the Italian manuals for restoration but they nevertheless have a specificity and originality due to the particular region to which they refer. In particular, the manual dedicated to earth building, and the thematical manual attached to it (Sanna, Atzeni, 2009 and Achenza, Sanna 2009), were the first scientific attempt to reorganization and structuring of knowledge and experimentation in the field of earth building in Italy, suggesting a methodology of investigation and technical solutions until then unedited in the country.

After all, the long-established Italian tradition in terms of conservation and restoration has to necessarily be considered a point of reference and a starting point, especially for those neighboring countries that still, sometimes because of a lack of specific culture, have to achieve these issues.

The Italian production of manuals related to the regional architectural heritage (Abruzzo, Sardinia, etc.), or to specific cities (Rome, Citta di Castello, Genoa, Matera, etc..), or to architectures built with specific materials (wood, stone, etc…) propose a well established methodology for the analysis of historical buildings, starting from the virtual dismantling of the fabric in order to allow a total knowledge of the methodology of implementation of each building element, the materials used and their assembly, accompanied by a vast iconographic repertoire (maps, drawings, photographs) that describes and documents the still existing artifacts and examine its details.

We should however point out that, although we have made small steps forward, the world is still suffering a certain shortage on manuals, specifically of those related to the material earth, which, although considered to be less resistant and durable than other building materials, or perhaps rightly because of it, has not been the subject of intense reflections, especially in regards to popular housing, as it happened instead for those architectures constructed with other historical materials such as stone or wood. It is true that in recent years on several occasions the desire to structure some important researches in this direction has been shown, as for example the one conducted by the team CRATerre in Morocco in collaboration with the local CERKAS and the Getty Conservation Institute, and in Mali for the city of Timbuktu, coordinated for the UNESCO by prof. Mauro Bertagnin.

Yet the rich and original earthen world heritage would deserve greater attention with respect to issues related to conservation and maintenance, due in the first place to the specific nature of the material used, but also for the character of authenticity that most historic centers built with earth around the world still preserve, values considered of major importance in the vast theme of heritage conservation.

Morocco boasts eight sites inscribed on the World Heritage List, for which eminent conservation and management plans have been issued (Cerkas 2005). But at the same time the country is very poor on general conservation standards for historical popular architecture in a broader sense, the same architecture that so strongly characterizes and identifies the Morocco's landscapes. It's certainly significant that there are no university structured courses dedicated to the preservation and restoration in the two schools of architecture in the country, in Rabat and Fez, but episodic training courses, seminars and local workshops.

In addition, it is not widespread in the population a basic education that can effectively prevent the growing phenomenon of hybridization of local vernacular cultures with imported building methods, materials and construction systems. Must not forget that the phenomenon is very difficult to fight, taken into account that the primary source of income in Morocco are the remittances from abroad of people that coming back home bring with them the very symbols of wealth and innovation that so little complement the local heritage, taking away to the old centers that dignity and decorum that has always marked them. There's a general indifference, sometimes denial, surely due to a lack of knowledge, of what is history and identity, urban landscape and preservation of vernacular building.

2 THE RESEARCH

In this complex context is located our research which has as its object the city of Figuig, an oasis on the edge Western Sahara, one of the most known and beloved in Morocco.

Figuig is a remote city and connected to the nearest city, Bouarfa (about 90 km away), through a single access road, narrow and poorly suited to the heavy traffic that developed in the past years. The rail network, built up to Bouarfa at use of coal mines, is no longer in operation. The position enclosed in hills and surrounded by three quarters

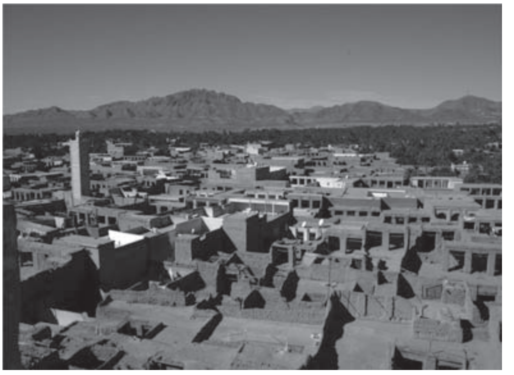

Figure 1. Aerial view of the oasis.

by the Algerian border, closed now for almost 15 years, make it a place rather difficult to reach.

The subsequent abandonment of the settlement and of the agricultural activities now represents a real emergency. And even though the traditional memories are still alive in most of the elderly population, there is significant loss of interest in young people regarding anything that is tradition and craftsmanship. The awareness of the particularity and uniqueness of the oasis, derived from an important history, the nerve-center position for the country maintained for centuries and the trading and exchange vitality for the local economy are now often just a memory. The awareness of the identitarian heritage is to be entirely reconstructed, even if the pride of belonging is not missing.

Like all oasis Figuig also appears like a system in perfect balance between water supply and land use, an urban center where the man's work, construction and agriculture, profoundly affects the very existence of the settlement. The condition of poor care or even abandonment of buildings and lack of maintenance of the palm grove is only partially the cause of the significant degradation the city is facing today.

Despite the many difficulties the administration of Figuig has promoted several initiatives to overcome the isolation and the consequent delay in the development, supporting actions aimed to the:

- Maintenance of the built heritage discouraging the intrusion of external negative influences;
- Strengthening the attention given to the captation and distribution of groundwater, a medieval system example still today of proper use of water resources;
- Activities aimed at sustaining a conscious use and proper development of the territory (enhancement of activity of composting, organic farming, etc.);

– Put in value of precious archaeological sites around the city;
– Guarantee the support for business development of cultural tourism;
– Enhance specific training to support the preservation of traditional processing methods, in different sectors (construction, ceramics, weaving, etc.).

According to the predefined programs, the revitalization of the ancient settlement cannot be separated from the restructuring of the oasis as a whole, on the one side promoting the limitation of the consumption of agricultural land, already very limited, and redeveloping the ksour that, in the state of abandonment in which they are now, can only experience the aggravation of their poor conditions.

To this must be added considerations regarding the use of materials foreign to the oasis, because of the very high monetary costs of the indispensable carriage, certainly, but also for energy issues, as they are often unsuited to the climatic conditions of the place. On the other hand, it is possible to find certain unanimity of thought regarding the superiority of the climate control in the building construction model proposed in historic fabric than new construction.

The research, focused on the need to proceed with the proper conservation and restoration of built heritage, aims in the first place to highlight what are the meanings and characters of the built fabric of the oasis, individuating traditions, local materials and construction techniques, focusing on the problems that occur more frequently to the technicians responsible for their conservation and thus giving guidelines on good practices giving them elements for a proper approach to the renovation of the existent, not to obtain a conservation tout court of the *ksar* as historical monument, nor to promote the traditional model for the new building, but to preserve a high quality building fabric restoring the texture and resolving the technical deficiencies, and equipping it with modern facilities required by the contemporary model of life.

Figure 2. The courtyard, view from the terrace.

The research has revealed several problems. The first is undoubtedly a serious lack of regulations on conservation and building rehabilitation. Deficiency that we noticed is not only at national, but consequently also at regional and local level. And together with the legislation are also absent local regulations and guidelines in a general sense. Indeed, as explained above, only the eight World Heritage Sites are subject to regulation, however reduced, and rightly contextualized for each site.

It also revealed that not only the rules of the discipline are lacking, but a culture that itself can recognize such a discipline. The population therefore tends not to recognize the intrinsic value of its assets and opts rather for their replacement or demolition. Only a thorough work of education carried out hand in hand with adequate professional training at all levels, can provide a valuable opportunity to safeguard the oasis itself. The acceptance of the recent request made to UNESCO for inclusion in the provisional list of the WHL, is a first real attempt on the part of the municipality to obtain a recognition of the important historical significance and authenticity of the oasis.

To this has to be added a further shortage document referred specifically to the city of Figuig, represented by the near absence of basic historical, cadastral and urban maps. It is true that in these last ten years have been carried out analysis of the urban fabric by different of Italian and French universities, which have mapped small areas of some *ksour*, but the work was done each by different graphical methods and often with measures only referred to the ground floors. The first outputs of this research is, therefore, to signal an opportunity/urgency to carry out a mapping of the actual state of the seven historic urban agglomerates. A bird's eye relief in the first place will be sufficient to carry out a photographic survey. In a second stage the metrical mapping of the ground floors, not always easy because of the difficulties caused by an innate sense of unease of owners to show their homes, will complete an overall picture sufficiently.

The analysis of the historical center showed a dramatic lack of maintenance of the housing stock. For most of the causes this lies in the shortage of young and motivated people to take care of the family home. Most of the young families who decide to stay in the city have the dream of building a new Western-style home in the reduced expansion areas of the oasis. The abandonment of maintenance practices is also due to the progressive loss of local construction knowhow, and what is worse,

Figure 3. One of the tables resulted from the research.

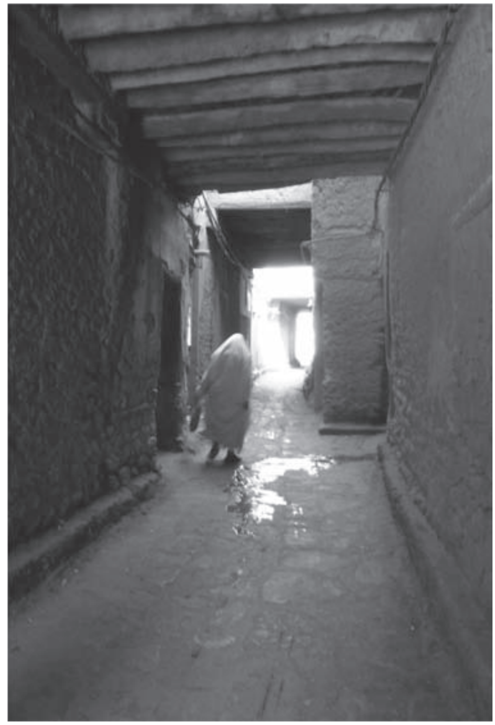

Figure 4. Covered road in the Ksar Zenaga.

the hybridization of a tissue, that despite everything has been kept up to date well recognizable.

It is also considered important to emphasize the weight that a decisive action of sensitization of the population conducted simultaneously with a scientific-technical approach can have to heritage conservation. The transmission to future generations of traditional knowhow, still well preserved, rebuilding an awareness of their local identity and limit the introduction of technologies that hybridize and affect the existing structures are all activities that must be coordinated together with the resumption of local artisan products (preparation of basic materials—adobe brick, lime and palm wood beams-) and the training of workers skilled in conservation.

The analysis of the town revealed the simplicity and ease of the construction methods used. An architecture that uses the few materials available on site with enabling technologies and leveraging the intrinsic characteristics of each material and element. The palm wood, very durable and enormously flexible, lime, derived from a plentiful and pure quality limestone, the soil, not particularly cohesive, but still suitable for the production of bricks, together they have contributed to building a coherent, effective and functional system.

At the same time we have witnessed through the deep analysis of the built heritage the weaknesses of the building system in front of the new threats posed both by the aforementioned process of abandonment, and the hitherto unknown phenomena related to weather events of particular violence generated by the climate change in progress. Floods and torrential rains occurred more and more often in the last decades, and lately almost yearly, that put a strain on the structures, especially in the *ksar* at the foot of the cliff, Zenaga, unexpected and very difficult to manage. For this particular reason it would be appropriate to issue a more thorough research on emergency safety measures for those buildings that are more susceptible to damage.

The solutions suggested as best practices derived from experiences already made in locations that have similar climatic conditions and isolation, and are susceptible to insights that can be replicated in all the contexts of pre-Saharan area starting from the eastern Morocco, extending up to Libya and Egypt that have, often for coincidence of the founding peoples, very similar features in the settlement and its construction, and similar issues related to their conservation and regeneration. Some of these solutions have already been adopted successfully for the preservation and management of the

Ksar Aït-Ben-Haddou, as result of a coordinated research between CRATerre and CERKAS.

The good practices proposed for conservation and restoration are simple and totally non-invasive, made with local materials, natural and consistent with the historic building fabric. The suggested choices are decided primarily after the nature of the existing heritage fabric, archaic, fragile, not always put in work in a cultured manner, and, more, integrated into an even more delicate system, the oasis. Each intervention has been checked to avoid structural stiffening in the system and the introduction of materials and items that may not cooperate fully with the existent.

Particularly importance has been given to the materials available on site, placing an emphasis on the need to avoid when possible monetary and energy costs caused by unnecessary transportation on wheel for retrieval building materials to Figuig.

At the same time we tried to respond to the requests coming from the residents generated because of changing ways of life, concerning the introduction of new technologies and innovative construction solutions. It is the case, for example, of the proposed solution for the expansion of the rooms' dimension, or for the insertion of glazed windows into massive walls.

3 CONCLUSIONS

This research represents an important data base for the definition of a reference theoretical and practical document at use for local administrations. Furthermore it represents a starting point for the compilation of more defined guidelines defined to favor a more correct use of the historical heritage and its proper maintenance, and propose methods of analysis of the urban fabric in order to operate consistently with the existing fabric.

It is also more broadly aimed at "people". It is hoped that these tool will help to preserve the precious architectural legacy of earthen architecture Morocco and other countries nearby which also reflect the same traditions.

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Cave-Houses in Valtierra, Navarra, Spain

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ABSTRACT: Nowadays, more than 300 caves can be found in Valtierra, Region of Navarra, Spain. Most were dug during the 19th century and then, many were abandoned in the 1960s. The caves, excavated by farmers and day-laborers, were built along the facade to take advantage of natural lighting. Some caves even had two-floors to achieve this objective. The rooms were excavated into the earth and were limited in number only by what was feasible with specific characteristics of the earth. After the abandonment of the caves, many of them changed their use and others were forgotten. Thanks to an initiative carried out in the 1990s by the City Council of Valtierra, six of them were restored and rehabilitated into rural accommodations. Through the analysis of these cave-houses and their rehabilitation, a relatively unknown construction method in Navarra is revealed; although this method has been used in La Ribera region.

1 INTRODUCTION

When discussing cave-houses we must place them in the context of traditional popular architecture. They have existed since ancient times and can be found in such different countries as France (Rochemènier), Tunisia (Matmata) and Iran (Kandovan). These constructions are found in many parts of Spain, from the North Plateau, through the region of Valencia, the Madrid area, Castilla-La Mancha and the Ebro Valley, which is the focus of this study, not forgetting the Canary and Balearic Islands, where underground housing also exists.

The concept of this architecture is quite different to what is understood as built architecture nowadays. What makes the difference is the building system, being in this case defined by the subtraction of material rather than its addition.

As Leoncio Urabayen says in his book *La casa en Navarra* (Urabayen 1929), 'the walls are the result of producing a space that did not exist before'. It is a type of vernacular construction that adapts and transforms the natural land as building material.

Throughout history, these constructions have been associated with the idea of poverty and insalubrity, a kind of housing inhabited by those people who could not afford anything better. Julio Caro Baroja (Caro Baroja 1981), respected anthropologist and historian, relates them to a model of primitive housing typical of a non-industrialized society.

This architecture is a faithful reflection of the historical, social and economic changes of its surroundings, which is demonstrated its merging with the landscape and relief.

In the region of Navarra one can find many municipalities with constructions of this type located in La Ribera region; some of these towns are Milagro, Arguedas, Andosilla, Azagra, Mendavia, Caparroso, Peralta and Valtierra among others.

2 VALTIERRA

The town of Valtierra is located south of the region of Navarra, in the area known as La Ribera. It is bordered to the north by the Bardenas Reales, to the east by Arguedas, to the south by Castejón and to the west by Alfaro (La Rioja) and Cadreita, and spreads out southwest and northeast from the Ebro to the Bardenas, sheltered by some hills and rocks which are easy to cut through.

Because of its location in the Ebro´s basin, it has a continental climate, with sudden temperature changes caused by the north wind: the Cierzo; the annual average temperature is about 14ºC. In terms of humidity, the air is dry, with 450 mm of precipitation per year.

The soils where the cave-houses are located are clays, loams and gypsums, whose softness and impermeability, together with the aforementioned climate, make them perfect for underground construction.

3 HISTORICAL DATA

The greatest development of the caves took place between the 18th and 20th centuries, but it was in the 19th century when they reached their heyday.

Figure 1. Valtierra in bird's eye view.

Many neighbors, farmers and day-laborers built their own cave because they could not afford a stone or brick building.

History tells us that in Valtierra, when a neighbor was about to start his own family, he chose a plot of land and started building a cave; nobody had to approve the construction, just as nobody prevented it. It was only after 1845, the date when the "Union of Irrigation" became the owner of the town stockyard, when the villagers started to obtain their caves via permits granted by the City Council. Nevertheless, none of the owners paid any taxes, and they could bequeath the cave.

Félix Zapatero, in his *Monografía de la villa de Valtierra* (Zapatero Pérez 1933), writes about the existence of around 180 caves in 1933, which hosted a quarter of the population; nowadays the City Council talks about more than 300.

In the mid-50s social housing was starting to be built and it was assigned to the inhabitants of the caves, which avoided the perpetuation of this way of living; the inhabitants, attracted by the advantages offered by the new buildings, abandoned the caves, reconverting them into barns, warehouses or places to meet or hold social events.

By the end of the 90s, the City Council decided to rehabilitate some caves and offer them as rural accommodation and touristic attractions; likewise there are some other caves restored by the actions of lone individuals. There are still more than 200 caves in the process of being restored.

4 THE CAVES; HOW THEY WERE

Félix Zapatero (Zapatero Pérez 1933) writes in his book about the sensations he felt when he reached Valtierra and discovered one view of the town at sunset, when, with the outline of the hills still visible, a vast number of illuminated cavities appeared, resembling a huge warren: 'offering in the XX century an enormous contrast with the bold and comfortable rooms that modern architecture demands.'

Both Leoncio Urabayen (Urabayen 1929) and Félix Zapatero (Zapatero Pérez 1933) explain in their books how cave-houses were in the 1930s. They write about caves of many sizes and shapes, from a single hollow as a barn, to more elaborate caves with one or two floors. The bedrooms were big and clean, divided with curtains and whose walls were plastered and whitened with lightly-blue stained lime. The rooms were slightly arched and the floors were mostly made of packed earth, it being possible to find some with fired mud tiles or mosaics. The kitchen was always by the entrance. The cave was ventilated by the chimney, windows, balconies or even corridors.

Both authors are in agreement that the caves were much more comfortable houses than they might have appeared, being better than many houses built in the town. Conditions in the caves were always pleasant and consistent, with temperatures between 18 and 21ºC, the sun always entering the rooms, and without dampness or odors.

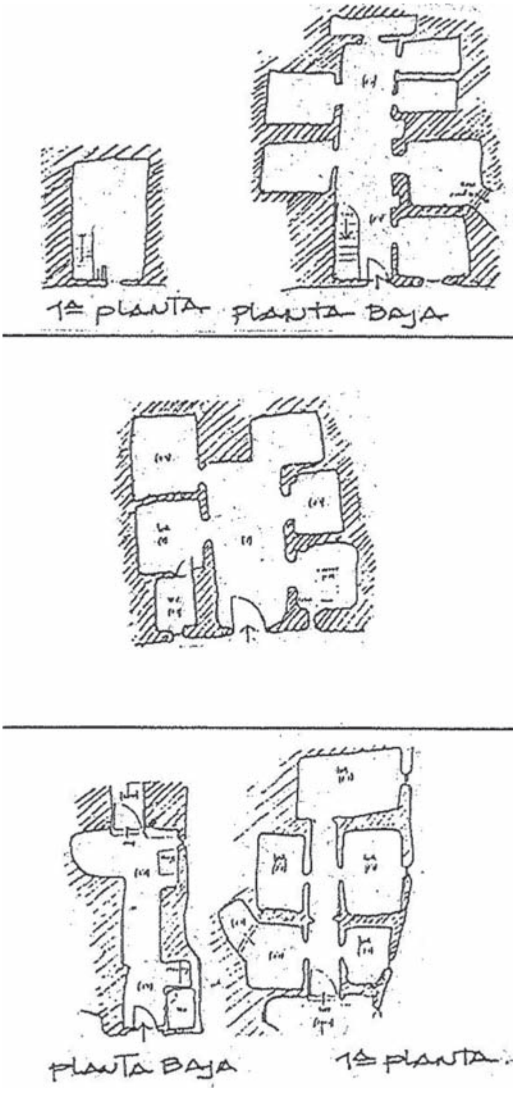

Figure 2. Examples of some caves. (Obtained from the City Council, project done in 1997).

Figure 3. Tools footprints in a cave wall.

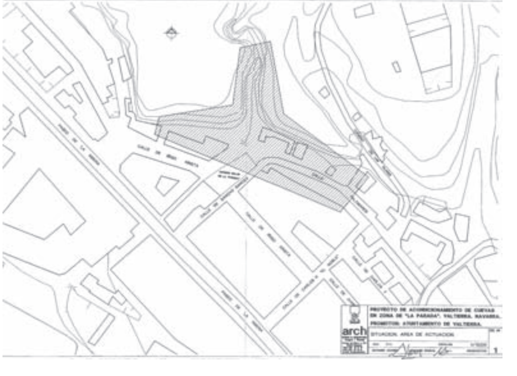

Figure 4. Caves location (Obtained from the City Council, project done in 1999 by Alfonso Azagra and Joaquín Roncal).

5 BUILDING PROCESS

The people of Valtierra chose the site before building, and began to dig through the facade. They usually carried out such projects when they had time off from their agricultural work, corresponding with crop cycles or rainy days. The tools used to dig were the same as those used in the fields: picks, spades, water to soften the ground and baskets to remove the debris and rubble.

The organization of the rooms across the sites was decided by natural factors, trying to get as much light as possible, focusing on the section running parallel to the rock face, adapting itself in each case to what the materials had to offer, and to what was wanted or needed.

A vertical plane was first dug into the rock and then, working horizontally, they dug into the bowels of the earth. The first place worked on was the kitchen, being the warmest room in the house, it acted as a buffer to the other rooms; it was the widest room, and contained a window to the outside as well as a wood stove and fireplace.

The hardness of the earth and its capacity properties would determine the thickness of the walls, the rooms' size, as well as the proportions of the vaults. Several rooms would be opened up depending on these characteristics. The excavation started from the ceiling downwards to check the resistance of the soil to excavation.

In this area we find caves of one or two floors with four kinds of indoor plans:

- Floors organized as a succession of interconnected spaces with no corridor.
- Floors with corridors: galleries or halls that separate the rooms.
- Combinations of the previous two.
- One room floors, the most basic type found.

6 THE CAVES: HOW THEY ARE NOW

A study carried out by the City Council in 1997 speaks of the caves located on the hill "El Castillo", in the north-eastern area of the town of Valtierra. That study shows how, in that year, the landscape near the caves was a mess, dotted with ancient caves in ruins, some unfinished constructions, rubble and garbage. The study focuses on about 21 caves, the conditions, characteristics and uses of which are described.

Cracks, expansion and fissures were observed during the analysis of the caves, most of them due to the lack of maintenance or the poor quality of the plaster materials. We can assume that the state of the caves' conservation was linked to that of the hill; as a result of their lack of maintenance, water freely circulated through existing cracks into the caves, worsening their conservation condition.

The predominant color inside the caves was white, leaving green and brown for doors and windows. The floors were finished in ceramic, cement and plaster, although the originals were made of packed down earth.

The surfaces and ceilings were whitewashed, and some had wooden beams for reinforcement; for the enclosures, brick works were found, as well as woodwork for doors, and curtains as a means of dividing interior rooms.

The hill facade unified the caves and manmade elements existed all over it, such as access stairs leading to different levels, annexes advancing over the street, chimneys, poles and street lighting wires, creating an image of contrast.

Concerning the uses of the caves, we know that four were kept as temporary housing, three were for recreation uses only, eight were used as warehouse, one as a garage, another one as a dog yard and the last four had unknown uses. Just five of those caves enjoyed running water, seven were equipped with electrical installation, only four had good means of ventilation and plumbing, eight regular and four bad. In the short term only eleven of them represented viable opportunities for adaptation.

7 THE RESTORATION AND REHABILITATION PROJECT

Following the "study for the adaptation of the troglodyte habitat for tourism", finished in 1997 and alluded to earlier, possible interventions into the area in question were explored, and it was noted as an "area for future developments in facilities and tourism, as well as for seasonal accommodation, in conjunction with works to improve the environment and its vegetation, local housing, and all other measures necessary for the development of the mentioned tourism project, thus stimulating commercial activity and rejuvenating public spaces, and adapting the broader environment to the site.

All these measures are reflected in the "Detailed Study" and the "Development Project". It was decided that the adaptation of the caves would proceed in the same way, creating and executing a unique rehabilitation project for the whole set of caves that combined remedies for both the interiors and exteriors, as well as construction solutions for ventilation, plumbing, sewage systems, etc. all across the hill.

The fields became property of the City through a transfer executed by the "Union of Irrigation", the former owner, encompassing the management and implementation of the projects.

The project involving the caves' reconditioning and improvement was drafted in 1999, with the restoration and rehabilitation works taking place between 2001 and 2002, converting 6 of the 10 caves covered by the project.

It was in August 2002 that the caves were opened as rural housing, named "Bardeneras Rural Caves", and offering the opportunity to accommodate up to a total of 35–45 people with a capacity of 4–8 people per cave. The caves are equipped with different numbers of rooms, kitchens, bathrooms, electricity and running water.

The resort was very favorably received and therefore the City Council, noticing the scope and range of possibilities this could offer, decided to support the restoration and rehabilitation of two other private caves for tourism and another one for personal use. A new ordinance was drafted, in which the use of the private cave was controlled, whereby owners

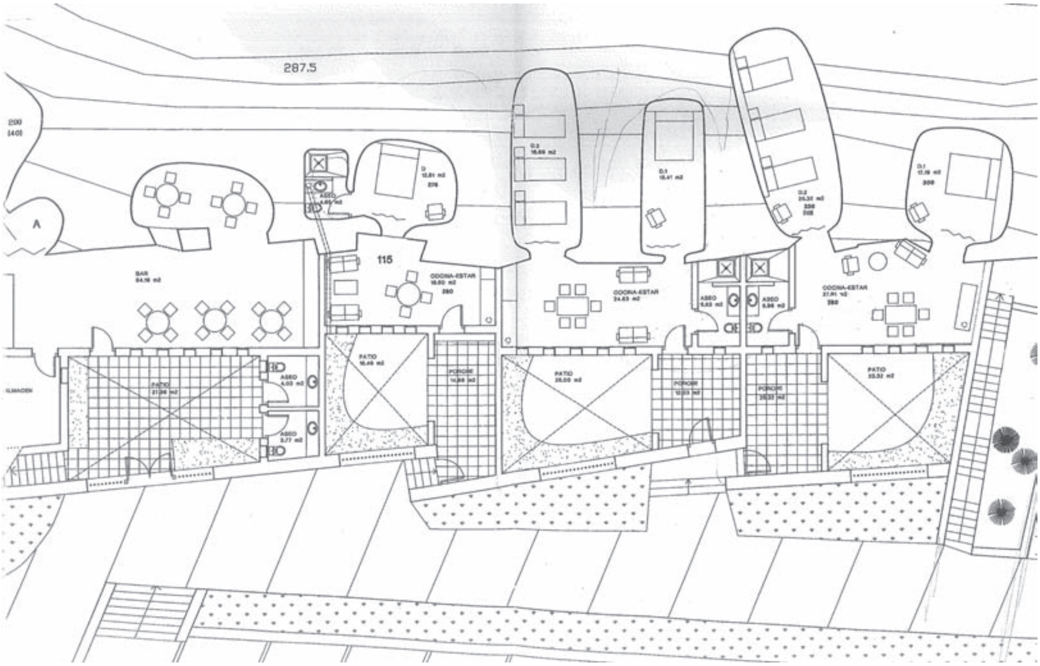

Figure 5. Reformed state of the caves as rural housing (Obtained from the City Council, project done in 1999 by Alfonso Azagra and Joaquín Roncal).

Figure 6. Panoramic view of the “Bardeneras Rural Caves”.

of caves should pay an annual fee which would be reinvested in the caves so that they could be maintained. It also regulates their use and any alterations made to them, with the tenants, in order to carry out any refurbishment or modifications, having to apply for permission to the Council. These regulations control various issues, such as use and typology. For example, they prohibit the painting of the walls except those parts made of brick or wood, and as long as dark colors are used.

Ten years after the opening of the caves, there is still plenty of work to do in and with them to provide the best possible result.

The City Council is always aware of the repairs necessary to ensure their proper preservation, making use of the months of January and February to carry out the reforms and maintenance required, as these months constitute the tourism off-season. Eight caves are currently offered to the public with a capacity of 50 people, besides a bar-restaurant built into the hill.

8 CONCLUSIONS

These caves are truly meaningful in the history of the town and its inhabitants. Valtierra's people have always lived closely linked to this architecture, and it has become a sign of identity that everyone feels and holds close: most of "valterranos" (natives from Valtierra) have at some time lived in caves or owned one of them, whatever the use they currently have. These caves have the dual qualities of being both natural and man-made so they provide the area with a reference point as much cultural as it is scenic within the collective memory of the inhabitants. Human habitat is integrated with the environment, directly related to the earth, water, air, sun and the human being, who, through great endeavor has transformed nature for the construction of his home.

The recovery and rehabilitation of the area has led to a reassessment, not only of the caves and people, but also of an identity. This means the reassessment of a very significant fragment of the history and culture of Valtierra, unique and beyond the scope of Navarran themes. A way of life now extinct is revealed, a way of building unthinkable in modern times appears before us. This recovery and enhancement transport us back in time, to times still latent in the popular memory.

We are offered a traditional environment that cannot be found in the rest of Navarra and its surroundings, with a major tourist attraction bound up both in the landscape and its history.

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Cobquecura, a southern earthen Chilean town: Intervention criteria for the reconstruction after Chilean 2010 earthquake

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ABSTRACT: Chile is a country with one of the highest and most frequent seismic activity in the world. Even though, most of the traditional architecture is built with raw earth techniques. After the Chilean earthquake of February 2010, the level of damage of earthen architecture was severe and diffuse: there were whole earthen towns with complete collapses, and a lot of others with structural damages; also, a great number of houses were demolished. In this context, we analyse the case of Cobquecura, a little town built with earth, located very near to the February 2010 earthquake epicentre. This article aims to describe the earthen architectural typologies and the building technologies, analyse the damage and the intervention criteria for restoration and structural consolidation, inside the Reconstruction Plan in Patrimonial Area, Funded by the Chilean Ministry of Housing (MINVU).

1 INTRODUCTION

1.1 *Chilean seismicity and 2010 earthquake*

Chile is one of the most seismic countries of the world: its 4300 km of coastline border the Nazca Plate, which moves about 9 cm every year under the South American plate, pushing and creating a phenomenon of subduction that constantly hit the Chilean territory with earthquakes of great magnitude. Only in the twentieth century there were about thirty earthquakes that have exceeded magnitude 7ºRichter (less magnitude in Chile is not considered an earthquake). The largest ones were those of Valparaiso in 1906 of 7.9°; Talca in 1928 of 8.3°; Chillán in 1939 of 8.3°; and Valdivia in 1960 of 9.5°, considered the largest earthquake in history.

The earthquake of February 27th 2010, with epicenter in the central south of Chile, is considered the second most destructive of the Chilean history, and the sixth one in the world history (after the last Japan earthquake).

The earthquake started at 3:34 Chilean hour (UTC-3), had a duration of 2 minutes and 45 seconds, and a 8.8° magnitude in the Richter scale. The epicenter was in the Pacific coast, just 17 km from Cobquecura city, and the rupture area was 600 km long, so the earthquake was perceived with great intensity in the 5 Central Chile regions (Metropolitana, Valparaíso, O'Higgins, Maule and Bio-Bio), causing considerable damage to building and infrastructure. As a consequence of the earthquake, 45 minutes after the first shock, a big tsunami from the Pacific coast penetrated 200 meters in the coastal Maule and Bío-Bío, causing the complete destruction of a dozen small towns, and the archipelago of Juan Fernandez in front of the coast of Valparaíso.

1.2 *Cobquecura: The place of the epicenter*

Cobquecura is a little town (570 km²) of 1.500 inhabitants, located in the south of Chile at the beginning of the Bío-bío Region (lat. 36º8′ south, long. 72º49′ west), between the foothills of the *Cordillera de la Costa* and the Pacific Ocean, in a small valley crossed by the river of the same name. The Bío-bío Region is one of the five regions that formes the Chilean "Central Valley", a rich and fertile valley between the *Cordillera de Los Andes* at east and the *Cordillera de la Costa* at west, along the Pacific Ocean, characterized for being a great rural zone, where good climate makes possible the production of wheat, cattle, fruits and the best Chilean wine, and where rural earthen architecture has its maximum expression. This was also the area where the Spanish conquest of the Chilean territory was concentrated, and still nowadays it's possible to see the Colonialism legacy in the architecture of hundreds rural towns with great identity.

The area where the Cobquecura town is now located, first of the Spanish conquest was long inhabited by the *Mapuche* culture, with few dispersed little settlements. The exact date of the spanish foundation is not sure, but there are some documents that say that the first catholic church was built in the half of the XVII century, so that's is considered as the foundation date of the town. Nowadays, Cobquecura keeps in its urban features the characteristics of its double foundation: the main longitudinal streets following the ground levels (pre-Colombian legacy), and the quadrangular pattern urban planning, designed by the Spanish.

In *Mapudungun* language -the language of the native population of the south of Chile and Argentina: the *Mapuches*- the town is called "*stone bread*" (*kofke*: bread and *kura*: stone), because of the very common use of the stone cut into thin sheets Cobquecura has some special features -for being a colonial settlement, due to its localization on the coast -and not in the hinterland as most part of the colonial rural towns-, just where the Central Valley ends and the rainy southern area begins; so the landscape around Cobquecura has the particularity of being a mix between rural cultivations fields, ocean and forest.

The central area of Cobquecura town is one of the few Colonial historical centers well preserved in Chile, and mostly the only one in the Bío-bío region, declared in 2005, a National Monument in the category of "Typical Zone" -a protected area-by the Chilean Law of Monuments. From the architectural point of view, the technological features, as well as the urban conformation, Cobquecura represents a very homogeneous and well preserved ensemble -not destroyed by the Modernity progress as it has happened in many Chilean historical centers-, that constitutes an important example of Colonial vernacular architecture (Fig. 1).

Cobquecura has also a big importance for the world earthen architectural heritage, for being an example "out of the rules" of the earthen constructions: it is in a rainy and cold area, on the coast (with a high humidity), in a very seismic zone, and it has survived all the strongest Chilean earthquakes. In Chile, it is the further south town built with earth.

Figure 1. Cobquecura's main street view (Jorquera N., 2011).

2 THE BUILDING CULTURE

2.1 *Building typologies*

As in all the Chilean Central Valley, the main architectural typology in Cobquecura is the "*Casa Patronal*": a large rectangular building, organized around several courtyards, divided into areas for the rooms and others for the production processes, characteristic of the farm system. Around each courtyard there are spacious roofed galleries, the *"corredores"*, that allowed to work and to stay outside, but protected from inclement weather. The *Casas Patronales* of Cobquecura have many courtyards with different functions and belonged to the richer families.

The rest of the town is composed by more little houses -very common in the entire Chilean Central Valley-, they are rectangular shaped, with the longest side parallel to the main road, and an average depth of 5–6 m; behind the house there is a big yard, for having some animals, trees and little cultivation fields. The house communicates with the outer space through a *corredor,* a filter element open but roofed, punctuated by wooden columns, presents always towards the yard (*corredor interior*), and in many cases in the outer road side (*corredor exterior*). The corridors, both exteriors and interiors, besides serving as circulation spaces, have the important function of protecting people and earthen walls (in adobe masonries) from the sun and principally from the rain. The presence or absence of the exterior corridor, is more an urban than an "private" choice, because a lot of Chilean Central Valley towns, *pueblos*, are characterized -in an elegant and functional way- by continuos facades with exterior corridors; but this isn't the Cobquecura case.

In the traditional house, the entrance door is generally in a central position on the facade, and the access to the house is trough a closed little corridor called *Zaguán* -Arab heritage arrived in Chile from the Spanish of Andalusia-, that connects the street with the interior corridor and with the courtyard, on the opposite side. The sequence of rooms are placed on both sides of the *Zaguán*, each one with a door that opens directly to the interior corridor and the courtyard, and a door or window towards the road side, usually placed in a speculate position. Independently of their use, the rooms have a regular size, and the circulation among them is through a door located in the center of the interior dividing walls, or from outside through the interior corridor.

Over the time, with the growth of families or due to changes of ownership, the houses have changed, often following the same "rules": besides changing the internal division of the rooms, the most common operation is the closure -and sometimes the division- of the interior corridor, to make it part of the internal circulation and to obtain more rooms, especially for building new bathrooms. The second operation is the addition of a second part to the house, perpendicular to the main building -and following the same line of the property dividing wall- giving as a result the L shaped building, or more rarely C shaped. The added construction has usually smaller dimensions, in height and depth, and it has a single slope roof, different from the roof of the mainly building that has two slopes. Usually, a new interior corridor is built on the courtyard, demonstrated that it is considered an essential part of the house.

The corner houses have a slightly different characteristics: they are already born L shaped, to face both sides of the road. However, also in this typology, the part that faces the secondary perpendicular street, is often smaller in size (and sometimes in the rooms depth), and it is connected to the main part of the house with an oblique wall with an entrance just on the corner, called *ochavo* (Fig. 2).

The main characteristic of the ensemble is the homogeneity of the architectural language of the different houses, that make the blocks to appear as an unique building, because of the repetition of some patterns, as the horizontal continuity of the facades, the simples one floor volumes of adobe masonry walls, the baseboard of slate stone, the rhythm created by the vertical windows and doors, the heavy tile roof and the absence of decorative elements. It is an austerity language that dominate the landscape of hundreds of rural towns of the Chilean Central Valley; just the different colours of the facades broke this homogeneity.

2.2 *Earthen constructive technologies*

The traditional houses of most rural villages of northern and central Chile, are almost entirely built with earthen construction techniques. The same technologies are recurrent throughout all the country, but there are always local variations, especially for the "mixed techniques".

Figure 2. The *ochavo*, oblique corner wall (Jorquera N., 2011).

In the Cobquecura case, the perimeter walls of the buildings are made of adobe masonry; the Chilean adobe has an average size of $60 \times 30 \times 10$ cm, thereby the walls are of 60–70 cm thick.

The interior division walls, could also be constructed in adobe masonry, or more often are made of mixed techniques, where a wooden framework, with structural function, is fill with raw earth; there are many variations depending on the filling, and so the technique's name changes.

The most common mixed technique is a special kind of *quincha* (Fig. 3), where a wooden main structure (called *tabiqueria*), composed of vertical wooden stakes, is closed with a secondary structure made of horizontal wooden tables, and it is filled with an earthen and straw mixture; everything is covered by an earthen plaster and the wall's thickness is about 15–25 cm.

Another local technique for the interior division walls is the adobe masonry "confined" inside the wooden structure, where the adobe bricks have an incision to ensure a better anchor to the wooden structure (Fig. 4); the wall thickness is about 30–40 cm.

Figure 3. The *quincha* wooden structure (Jorquera N., 2011).

Figure 4. Adobe masonry "confined" inside a wooden structure (Jorquera N., 2011).

Figure 5. The slate stone base (Jorquera N., 2011).

The roof is made of wooden structure, closed with wooden planks and covered by clay tiles fixed with an earthen mortar. In more recent times, many clay tiles have been replaced by metal sheets roofing, changing not just the external aspect of the house, but the weight and then the structural behavior of the house.

Despite of being houses of just one floor, the internal spaces are very tall, and so the wall slenderness is very high, carry out some structural problems in front of the seismic action.

The Cobquecura architecture is finally characterized by the use of the slate stone, fixed in "dry" (without any kind of mortar) or with earthen mortar, extracted in the area. It is used to make the basements of the adobe walls, to build the properties dividing walls, and for the external road and sidewalk pavements (Fig. 5).

3 EARTHQUAKE DAMAGESES AND RECOSTRUCTION

3.1 *2010 earthquake damages in Cobquecura*

Cobquecura has survived to several big earthquakes over the 8º Richter magnitude, those of Talca in 1928, Chillán in 1939 and Valdivia in 1960.

Cobquecura, was one of the most damaged towns after the 2010 Chilean Earthquake because of being near of the epicenter: 95% of the houses had different level of damages, and 50% was declared uninhabitable; however the general architectural language and the physiognomy of the town still remains, but need urgent repair.

The most frequent structural damages were:

- big angle cracks or even the whole separation of adobe walls in the angles, due to deficient wall toothing;
- separation of perpendicular walls, in the union of different techniques (adobe masonry, confined adobe masonry, wooden frame fill with earthen mortar);
- roof collapse due to the bad state of conservation of the wooden beams, that reduces the structural capacity of bearing the overload of the tiles cover and the earthen isolation layer;
- slate stone wall collapse, because of original construction defects (walls set without mortar and without toothing or ties) that make the wall not to be able to resist the horizontal seismic thrust.

During the field research, no diagonal cracks around openings were registered, maybe because of the direction of the seismic thrust (it seems that the earthquake took a direction perpendicular to the main facades, provoking a strong pressure of the orthogonal shorter walls, that made the facade walls to go off their course plan) or because the facades have few openings, and so in that direction the walls have a great inertia mass.

In those few cases of complete collapses, the causes are:

- changes to the original geometry (most of the houses now "L" shaped were originally "C" or quadrangular shaped), that creates problems of torsion and, due to the different construction time, not guarantee the "joint work" of the building during the earthquake;
- changes to the original configuration of the house: orthogonal interior walls demolition for enlarging the spaces, that modifies the entire structural behavior; openings enlarge that reduce the wall section, an so its resistant capacity;
- lack of maintenance that provokes quickly deterioration process: the most typical the presence of excessive humidity (water runoff coming from the roofing, or capillarity humidity) that erodes the earthen walls and thus, reduces its mechanical capacity.

Some other non structural damages were registered, and even if they don't represent a threat for the building stability, they could have been a danger for people's life: tiles fall, ceiling fall, earthen mortar detachment from the wooden frame divisor walls, plaster detachment.

Damages originated in the incompatibility between two materials, like in the case of concrete render applied on earthen walls.

A last damage was very frequent: vertical cracks at the junction of the wooden frame and the earthen mortar fill; this damage represents just the discontinuity between both materials, but not a structural problem, nor a danger for people's life.

3.2 *The process of the reconstruction plan in patrimonial area*

The big damages caused by the last earthquake are not the result exclusively of its great magnitude, but

Figure 6. Damages example in Cobquecura (Baglioni E., 2011).

the consequence of a big chain of external agents, that made Cobquecura to become an already fragile environment before the earthquake.

The nomination of Cobquecura, in 2005, as *Zona Tipica* by the Chilean Monuments Law, means the safeguard of architectural heritage, but at the same time, has become an obstacle to the reconstruction/reparation process, due to many reasons:

– every reparation has to have a project made by a team of professional experts (and there are few professional with the specific competences); the project has to have the National Monument Council supervision, before it can be presented to the municipality for its approbation, then, the entire process is very slow;
– every reparation inside the *Zona Tipica* is understood as a restoration project, and so, the equipment required by the National Monuments Council has to be composed by an historian, an architect restorer, an anthropologist, etc., and therefore, the project become very expensive and affected families cannot afford it;
– the subvention for the reconstruction process is given by the Chilean Ministry of Housing (MINVU), or the Reconstruction Plan in Patrimonial Area, with the objective to restore or reconstruction the habited heritage. The problem is that the subvention is the same given normally for a minimal social habited unit of 50 m^2, ($8,342,634 Chilean pesos = 18,078.49 USD) with a small addition (4,390,860 Chilean pesos = 9515 USD) due to be within the Typical area, but as these houses are very big, that amount of money is very scarce, and very few professional equipments are interested in working at;
– from the technical point of view, there's another problem: the Monuments Law requires the respect for the architectural language and traditional techniques, but the reparations/reconstruction projects have to be according the General Standards for the Construction (*Ordenanza General de Urbanismo y Construcción*) that allows just the use of modern materials, like concrete and steel (no earthen or stone masonry are allowed). Recently, the first Standard for Historical Building has been approved (on July 2010), and with this, the reconstruction scene will surely change, because this new standard at least recognizes the existence of different earthen techniques.

Now, that two years have passed since the earthquake, the Cobquecura community can't make anything by themselves for saving their homes, as they did in the last earthquakes, and this is a big paradox: a protected area with lot of heritage values has to wait long periods for external help, and inhabitants can't live in their own houses until they are repaired. Three winters have passed, and so, the unprotected adobe walls of the damaged homes, are more deteriorated by rain water than just after the seismic action. A lot of houses seem abandoned, but in fact, most owner families are living in a temporary little wooden house built inside their closed courtyard, while the rest of the earthen house continues the decay process.

3.3 *The Chilean intervention techniques for structural reinforce of the patrimonial earthen houses*

Due do the insufficiencies of the reconstruction subvention, the restoration interventions in patrimonial area, consist mainly in the conservation of the façade and the rooms inside the 50 m^2 area, respecting the architectural language, and reinforcing or reconstructing the adobe masonry.

The intervention techniques we will described, are created by two Chilean architecture studies -in which the authors have worked -specialized in earthen architecture, both contemporary construction and patrimonial restoration: Arias Arquitectos and Marcelo Cortes studios.

The structural reinforcement technique used consist in the application of a metal greed in both facade of the same wall, joined with metal connector insert into the adobe masonries, with a distance between them similar to the wall thickness (Fig. 7). These metal greed are superimpose to guaranties the union between them, and are applied in all perimeter of the "restoration" area. This reinforcement technique was created in the old legislative context, where just industrial (and certified) materials were allowed.

The constructions process begin with the removing of all the wall plasters, so if the masonries present structural cracks, they could be closed with a earthen plaster (of an earth with similar

Figure 7. The structural reinforcement technique used by the Chilean architecture studios Arias Arquitectos and Marcelo Cortes (Baglioni E., 2011).

characteristic of the adobe earth) before the greed application.

When reconstructing part of the wall is necessary, a new reinforced adobe masonry is built -with an earth with similar characteristics-, collocating an horizontal metal greed every three adobe courses. This new wall is also reinforced with the metal greed.

In all cases, the greed are applied with a lime mortar, and then covered with a clay plaster in tow coat.

For the interior division walls, generally built in mixed technique -wooden framework fill with raw earth-, it's used the same metal greed technique, after closing the crack or putting in place the missing row earth filling.

In most of the cases, when the wooden structure is in a bad condition, due to the bad maintenance or to the humidity effects, the division walls are reconstructed, and the foundation are reinforced with a concrete basement.

The efficiency of the division walls is fundamental to the correct structural behavior of the buildings, because they contrast the perimetrical adobe walls overturning.

The structural collaboration between the walls (perimetrical and interiors) is guaranty by the collocation of a top beam.

If isn't necessary the roof reconstruction, the beam is realized with angular metal profiles, inserted at the top of the walls, in both sides, and they are connected with transversal metal profiles.

For the ceilings, and the floor, generally in wooden tables, the original techniques are respecting, with the substitution on the necessary pieces; the same criteria is used for the roof.

4 CONCLUSIONS

Unfortunately, after two years of the 2010 Chilean earthquake, there are too many patrimonial towns where there aren't restoration projects, due to the difficulty of the process already described, but also due to the absence of professionals experts in earthen constructions and restoration.

It is clear demonstration of the loss of the know-how about earthen construction, even in a nation when the entire Colonial heritage, and not only, was constructed in raw earth techniques.

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Preventive maintenance of an Himalayan earthen temple and studies on its reduced scale model

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ABSTRACT: Kanji, a village in the Leh district of Ladakh (North India), is caught up in the processes of decay, which has affected some dwellings and religious buildings. A small Kanji earthen temple was in a serious state of decay due to several pathologies related to the freeze/thaw cycle. This phenomenon created the formation of cracks along the joints between the wooden/earthen terrace roof and the vertical parapets, built with mud bricks called *pakbu*. For these reasons, during a mission, the Udine University team carried out some conservation treatments on the temple, in order to construct an *improved joint* in the roof plane-wall. At the University laboratory, the Udine team verified the results of certain technological choices, creating a reduced scale model of the upper part of the temple. The model was then submitted to a set of five freeze/thaw cycles by means of insertion in a dedicated freezer for frost tests.

1 INTRODUCTION

Kanji is a fine earthen village (Bertagnin et al 2010), sited in Ladakh, on the Himalayas Mountains. This area is characterized by earthen buildings used as housing, for worshipping and for public meetings. The traditional building technology foresees the implementation of mud bricks, called pakbu, and the construction of floors as well as roofs, using earth material and wooden elements.

During the last decade, this heritage has been more and more damaged by the growing of heavy rainfalls, which, one time, were occasional, light and concentrated in a specific period in a year (Bertagnin 2005a, Cassar 2005). A small private Buddhist temple was invested by several pathologies most of all due to the atmospheric events. For this reason, in summer 2005, we decided to hold a field mission in Kanji, in order to carry out some preventive conservation treatments on the temple.

The article refers to observations on the degradation which has taken place at the small temple and the solutions actuated in order to eliminate the damages. Moreover, we describe some laboratory studies carried out on a reduced-scale model, representing the upper part of the temple, in order to test the results of the chosen conservation interventions.

The conservation activities were carried out by the Udine University team together with the Achi Association which promotes the conservation of the Buddhist cult architecture of Ladakh.

2 TRADITIONAL BUILDING CONSTRUCTION

Kanji vernacular technology displays typical features of earthen architecture (Bertagnin 2005b).

Over a stone basement, the bearing masonry of the walls is normally made of earthen blocks, called *pakbu*. The earth used for *pakbu* and the subsequent layer of plaster, is very clayey. It is important to observe the totally lack of straw or other strengthening vegetable fibers, in the earthen mixture prepared for the *pakbu* production. In the interior, the vernacular buildings have a wooden structure serving as the support for the roof. The addition of sand and stones in the *pakbu* and the earthen roofing is a normal practice.

Figure 1. Traditional realization of the roof.

The vernacular flat roofs have a first structure, generally consisting of round section poplar trunks, which support a second structure of wooden boards, small branches, or cut willow sticks (Fig. 1). Successive layers of earth and *markallak* are spread on that second structure, in order to form a stratum of insulation and surface protection.

3 PATHOLOGICAL FRAMEWORK

At the time of conservation work on Kanji temple it was possible to observe certain phenomena strictly connected to the degradation induced by atmospheric agents on the earthen structures of the village and particularly on the small temple (Fig. 2).

Highly intense rainfall and freezing and thawing cycles create in built structures, especially in raw earth roofs, phenomena of stress which must be controlled and governed by protective actions (UNESCO 2007). In particular, it was observed how the combined action of freeze/thaw, melting snow during springtime and the following torrential rain were responsible for the penetration, along the line of the temple flat roof and perimeter protective wall, of damp and water of pluvial origin capable of damaging the internal walls of the temple plastered in earth and painted.

The investigation led to the composition of an articulated pathological framework, characterized by the following phenomena:

– Presence of deep cracking in the roof mantle;
– Particular vulnerability in the connection joint (joint broken in several places) between the roof mantle and high walls, with the consequent possibility of penetration of water or melted snow along the joining line between the two perpendicular planes;
– Insufficient sloping in the roof plane for rapid evacuation, towards the outside, of meteoric waters or those resulting from snow melting;
– Insufficient ratio between the surface of the roof and the number of water evacuation points (water shoots);
– Insufficient maintenance of the evacuation points to avoid blockages (accumulation of fibers and debris after the snow mantle has melted, small bird's nests) with consequent roof flooding and penetration of water in the joints through capillarity.

Also observed was how the degrading action on raw earth structures, produced by meteoric waters during the summer and by freeze/thaw cycles during the winter-spring, became particularly evident along the connecting edges between the horizontal plane of the roof and the vertical plane of the external walls.

Penetrations, along such edge, of damp and scouring water, originating from the cracking phenomena described, have caused the underlying paintings in the temple to be particularly damaged (Fig. 3).

It is on such pathologies that we intended to concentrate our efforts for creating suitable preventive conservation solutions which have given interesting results.

Figure 2. Tsuglag-Khang, the small Buddhist private temple in Kanji.

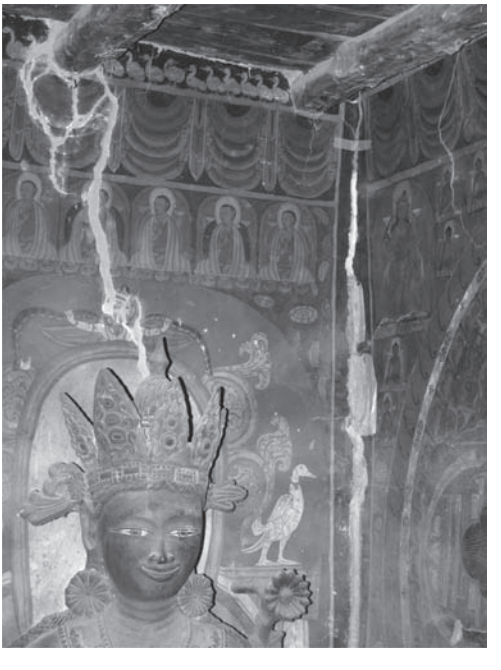

Figure 3. Degrading action on the earthen wall decorations caused by infiltrations of water inside the temple.

4 PREVENTIVE MINTENACE INTERVENTIONS ON THE TEMPLE

Following the traditional building technology which foresees the use of natural materials, we tried to carry out a series of small correctives able to improve the global behavior of the connection between the horizontal structure and the vertical walls (Bertagnin 2005c). First of all we installed an "improved profile of roof plane-wall connection" able to optimize the performance of upper roof protection for a better air- and watertight behavior of such constructive elements. Parallel to such intervention, we actuated the modification of the wall profile at the top of the temple.

We started cutting all the protruding wooden elements presented along the internal edge of the perimeter walls of the roof-terrace (Fig. 4). They were installed during a previous restructuring work on the temple and contributed to possible water infiltration.

Further we realized an "improved roof plane-wall joint", preparing a dedicated mixture of *markallak*, containing finely chopped straw, able to resist the phenomena of contraction-expansion connected to the frequent freeze/thaw cycles. On top of the layer of *markallak*, another layer of flat stones was created. The final phase of this interventions consisted in covering all the surfaces of the vertical parapets and the flat roof with earthen mortar (Figs. 5 and 6). Another intervention was carried out in order to protect the upper edge of the vertical earthen walls. It consisted in realizing a sacrificial layer for the top of the roof-terrace parapets, adding flat stone slivers and another layer made by earth with a curved section (Fig. 7).

With these elements we were able to build a first level of protection during the winter period for the upper edge of the joint. This treatment, in fact, allowed an improvement in defense against erosion caused by rain and wind.

Figure 4. Cutting the protruding wooden elements along the perimeter wall.

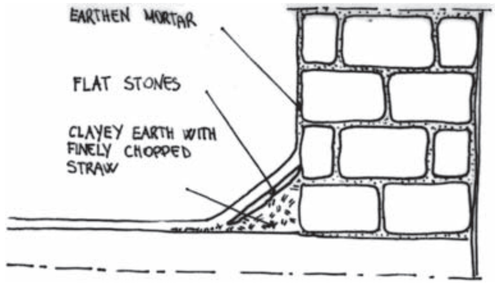

Figure 5. Realizing an "improved roof plane-wall joint".

Figure 6. Creation of the improved joint using *markallak* mixture and finely chopped straw with stone joint cover.

Figure 7. Creation of the protective stone cap.

5 STUDIES ON A REDUCED SCALE MODEL

At the laboratory, in the Udine University, we tried to understand the validity of some hypotheses for improving the constructive details in the important horizontal closure—vertical closure. The adopted solutions were extremely simple but able to limit such degrading phenomena and, at the same time, create a reference for successive actions of preventive conservation to be realized on other raw earth buildings protected by Achi.

In order to verify the results of certain technological choices such as the positive impact of the use of straw in the mixture for creating the improved joint of the roof plane-wall, a reduced scale model of the upper part of the temple of Kanji was realized.

In the laboratory we studied samples of *markallak* used in the maintenance work on the temple roof and we discovered their strong withdrawal and the consequent cracking thereof following repeated freeze/thaw cycles.

On the roof surface of the reduced scale model of the temple was spread a mixture of *markallak* and finely chopped straw in order to reproduce real conditions (Figs. 8 and 9).

The model was then submitted to a set of five freeze/thaw cycles (–20°/+5°) by means of insertion in a dedicated freezer for frost tests. The commonly used test of freezing and thawing at the temperatures –20 °C and +20 °C, was adapted to the reality to make the test more "appropriate" to understand of the behavior of the earthen structures during the late winter-early spring season in Ladakh, when the pathologies happen. During the long Ladakhi winter, in fact, the temperatures are always under the zero and only in case of a sequence of some sunny days the temperatures can overcome the zero.

Figure 8. The reduced scale model of the private temple.

Figure 9. The reduced scale model and the sacrificial layer on the top of the parapets.

The results of the test of freezing and thawing showed how the "improved" solution (*markallak* mixture + fine straw) allows a good seal of the improved profile without cracks along the suture line between the roof and the perimeter wall.

6 FINAL OBSERVATIONS: POSITIVE RESULT OF THE REALIZATION OF THE IMPROVED PROFILE

Despite the realization of the improved joint installed during the intervention campaign in the summer of 2005, during the following winter infiltrations in some points of the realized joint were recorded. These are to be attributed, in our opinion, to a combination of various factors.

In the first place, a defining role for water stagnation on the roof surface is attributed to the lack of maintenance of the evacuation points, which allowed water to accumulate, generating a "roof-pond" effect.

A simple action of cleaning maintenance on the outlet for wastewater, produced by melted snow and ice accumulated on the roof, would certainly have prevented infiltration and relative damage caused inside the temple.

The improved profile for the roof, the experimentation of which, also on the model, has demonstrated a good tightness, above all in relation to the ability to absorb expansions in the raw earth mantle linked to freeze/thaw, was found to be an appropriate solution. The lack of sufficient drainage and discharge of meteoric water and melted snow in the temple's roof-terrace, has contributed determinedly to the recorded infiltration, nullifying the positive performance of the "improved roof plane-wall joint" recorded in the model which underwent repeated freeze/thaw cycles.

7 THE REALIZATION OF A SECOND ROOF AS A CONSERVATIVE OPTION

As said above, the experimental conservation techniques carried out on the temple could not totally solve water infiltration issues of the temple.

For this reason, the team decided to build a second protective roof (Fig. 10). This choice certainly limits the possibility of obtaining "authenticity of form "related to traditional conservation interventions.

On the other hand, this intervention presents a character of "reversibility", providing additional protection. This second roof, even in the absence of ordinary maintenance, can guarantee complete safeguarding of the structure.

Figure 10. The second roof above the old one.

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Cooperation projects for the preservation of earth architecture in Chiquitos, Bolivia

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ABSTRACT: Since year 2000 the Universitat Sense Fronteres (USF) association together with the Polytechnic University of Catalonia accomplishes an all-round cooperation for development program in the region of Chiquitos—Bolivia. This region was declared World Heritage Site by the UNESCO in 1990. The cooperation projects are conceived using local materials such as adobe so as to strengthening the important local heritage. These cooperation projects also introduce technological improvements both in production and in later building work, sharing the knowledge with local actors through a participation process. Different built projects have enabled a comparative analysis of the adobe, Compressed Earth Block (CEB) and hand-made fired brick mechanical behavior, on the basis of compression breakage tests.

1 EARTH ARCHITECTURE IN CHIQUITANIA, BOLÍVIA

1.1 *Jesuit missions*

Communities of the Jesuit missions of Chiquitos, Bolivia, are located in a strategic location in the core of America, rooted in a unique heritage and natural environment.

In 1609 the first Jesuit communities in Paraguay were founded. The first temples were built in a precarious and provisional manner until they could be replaced by new buildings made of stone and brick within academic canons of the European Baroque. Instead, in Chiquitos missions, founded since 1690, the structural conception of walls in the first missions was modified by a wood skeleton structure of distinctly premissional nature, which was stabilized by adobe walls protected from the humidity of the area's climate by large corridors in the perimeter, getting a crossbreed, noble and durable architecture (Fig. 1)

Most of these buildings, built under the direction of the Jesuit and architect Martin Schmid (1694–1772), are not only clearly influenced by the canons of Baroque but by all contemporary constructive traditions in Central Europe. The Jesuit's knowledge of carpentry techniques to assemble, allowed them constructing buildings with much larger spans than done before by native architecture.

Churches have basilical plant of 70–80 m long and 25–30 m width. "*The foundations and part of what from them stands, are made of stone: the rest, made of adobes; and all the wood made roof, lies on wooden pillars... So are the pillars of the walls and of the middle naves. Then the joist, paving and rafters, and the roof are built. Once all this is done, the walls are built from the foundation: and as I said, they are made of adobes, of around four or five cuartas wide (0.801 m): and in the midst of them are the pillars*" (AECI 20012003).

Figure 1. San Miguel de Velasco's Church. (Picture: USF).

Santa Anna's Church, built after 1767, was entirely built by the natives. It is more humble and the foundations are also made of adobe.

Over time and both filtering and capillary moisture problems, as well as the lack of maintenance led these majestic buildings into an advanced state of degradation.

In 1972 the Austrian architect Hans Roth starts the restoration of the missionary complex of Chiquitos, which would last for the next 24 years. Restorations focused on the recovery of the churches' missionary structure, as well as solving all constructive and durability problems. Entire roofs were disassembled for cleaning the wood and recovering their original profile. Buried and rotten parts of wood pillars were replaced by reinforced concrete foundations, as well as damaged parts. Some of the wall embedded pillars were found fully rooted until the top, which affected wall's stability; he opted for removing damaged parts replacing them with concrete, where he would embed metal plattens joined to the wood pillars shafts (Fig. 2).

In 1990, and thanks to the restoration work done in the 1970s and 1980s, the Chiquitos missions were declared World Heritage Site by UNESCO, valuing not only monumental churches architecture but also the popular earth architecture, as well as the intangible value of the crafts that have kept alive this heritage.

1.2 *Stress status of adobe walls*

The enclosing walls of the churches are made of Castilian format adobes, 40 × 20 × 10 cm, which are placed configuring walls between 0.80 and 1 meter width.

A precise descent of loads on the walls, tells us that stress on the underside of the wall is situated about 0.12 N/mm^2.

2 INTEGRATION OF HERITAGE IN THE COOPERATION PROJECT

2.1 *Cooperation and globalization*

Many of the international cooperation projects act from strictly survival aid criteria, and connection with the cultural heritage does not usually appear in their phase of conception or execution. The own values are erroneously associated with poverty and leave aside for the blind faith in what is foreign and "modern". It is sometimes due to the ignorance of the traditional means of the place by technicians from "donor countries".

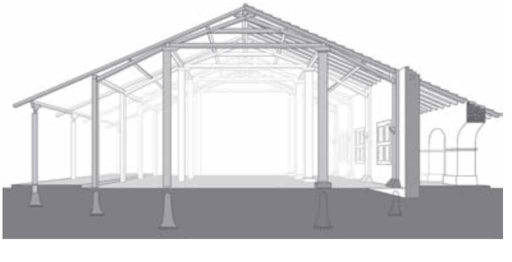

Figure 2. Structural diagram of wood and adobe walls San Miguel de Velasco's Church, Bolivia. (AECI 2001–2003).

Architectural interventions are carried out with imported materials as cement or sheet metal, which distort urban landscape. Cement, symbol of development and progress, is destroying confidence in the architecture of the place. Materials, textures, colors, all bases of cultural heritage are also globalized and, thereby, vernacular cultures are being homogenized losing its richness and diversity.

2.2 *Revaluation of local architecture*

One of the aspects that must be solved by a building in Chiquitos is its durability versus water. In this regard, tradition provides typological solutions like large decks and exterior corridors to protect the building from the subtropical weather. Schools carried out by Universitat Sense Fronteres in this Boli-vian region are characterized by the use of local resources such as the adobe load and fired bricks bearing walls and wood decks. But it has been stressed the protection of the different constructive elements from environment humidity.

Even nowadays, the use of earth in construction is perceived as a symptom of poverty, undervaluing also the techniques and culture associated with this architecture.

The construction of new facilities by cooperation through the use of local techniques provides the opportunity for cooperation actors to work in the revaluation of local architecture and, thus, of the identity and culture of the place.

That is why it is so important that cooperation projects incorporate intervention criteria in clearly coherence with the place, but also desire for innovation and modernization of local techniques, avoiding merely witness projects, with traditional materials tied to tradition in a nostalgic way (Bestraten & Hormias 2012).

3 INTERVENTIONS CARRIED OUT BY UNIVERSITAT SENSE FRONTERES

3.1 *Architectural typologies used*

After an exhaustive analysis of local architecture, new typologies of public educational and socio-sanitary facilities were proposed by the Universitat Sense Fronteres association, with the support from the Polythecnical University of Catalonia, intended to respond to the population of the region needs.

From the beginning the commitment to sustainability is embodied in the realization of *bioclimatic designs* that optimize comfort conditions regarding the surrounding environment, reducing at the both the costs of operation and maintenance of the infrastructure (Bestraten & Hormias 2012).

In turn, *local constructive systems* such as adobe and wood are adopted, which means a clear reduction of CO_2. These materials are used incorporating dimensioning and execution improvements, and quality control. Over time and after gained experience, there have been developed different architectural typologies and different constructive solutions which have been responding to different needs such as reduction in commissioning work time or the resources availability (Fig. 3).

The basic projecting unit has always been the school classroom 9 × 7 m internal gross area with a 3 meters wide exterior covered corridor access. These dimensions have been a constant reference in the generation of different equipments.

All built facilities have started from earth as a building material, making an effort in the understanding of this material's characteristics, from its extraction and manufacturing process to the specific requirements in its design and commissioning work. As shown in the following chapters, it has been investigated the construction through load bearing adobe wall, the combination of brick pilasters with adobe enclosures and, recently, the use of Compressed Earth Block in load bearing walls (Fig. 4).

Figure 3. First module of the Facultad Integral Chiquitana - UAGRM, USF, San Ignacio de Velasco, Bolivia. (Picture: USF).

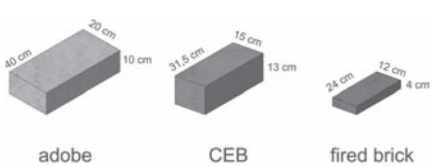

Figure 4. Types of earth masonry used in the construction of public equipments by USF in Chiquitania, Bolivia. (Source: USF).

Roof incorporates a continuous skylight that breaks the traditional gable roof symmetry and with a few wooden braces it goes over the façade line to protect the buildings from the rain. The roof solution with skylight enables a more intense incoming of light inside the classroom, offsetting the reduction of light entry in the center of the classroom caused by the facade corridors. Furthermore, ascendant convection ventilation is powered, enabling a fresh and comfortable environment for work.

Roof is supported with trusses of a single 30% slope made of Tajibo wood and placed every 90 cm, braced with battens, over which sits the *tumbado*, made with wire net, mortar and straw. When the *tumbado* is done, the inside is stuccoed ensuring a correct grip due to the wire net and straw. This white surface becomes a reflector of light that enters through the skylight, to enhance the natural resources and avoid to the maximum the need of electricity for lighting. Different types of structures have been made which will be analyzed to justify the advantages and disadvantages of each one of them: deck of rafters with timber ridge beam, queen post timber truss, structure of roof rafters and collar ties without ridge board or half scissor truss.

Roofs are finished in Arabic ceramic tile, which thanks to firing chamber built kilns ensure a more homogeneous and higher burning temperature that offer a waterproofing improvement (less porous) in ceramic pieces.

Materials have been purchased and manufactured in the same town, contributing to the revitalization of local economy. It has been chosen to distribute commissions among various providers, delivering resources and favoring as many families as possible.

In this paper we will do a comparative analysis of the behavior of each of the three solutions.

4 ADOBE CHARACTERIZATION

4.1 *Constructive solution*

Equipments are built with a 40 cm thick adobe load bearing walls. These pieces of 40 × 20 × 10 cm are handled by the mixture of straw, earth and water, with no firing. Drying process lasts one month. These walls take advantage of the thermal inertia of the material to ensure a fresh atmosphere inside the classrooms despite external temperatures (Fig. 5).

Adobe is finished with umbacá coating, mixture of earth, straw, lime, cow's dung and fine sand from *cutusepes* (ant) nests and a small proportion of cement. The key for maintaining these elements in working order is to keep them away from

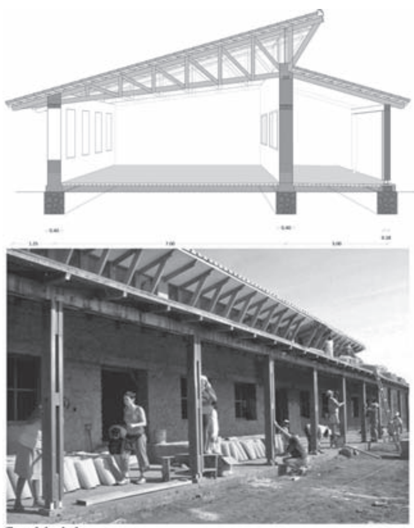

Figure 5. Adobe walls. First module of the Facultad Integral Chiquitana, USF, San Ignacio de Velasco, Bolivia. (Picture: USF).

the humidity of environment and ground, a very important factor considering local climate, characterized by a continuous rainy summer season. So, upper eaves are design to prevent contact with rainwater so as the stem wall, a stretch of 40 cm above the ground of fired brick.

Decks on adobe walls have been solved through the use of light trusses placed every 60 cm on a 18 × 20 cm wood lintel. The latter is placed in the center of the adobe wall guaranteeing an homogeneous load distribution along the wall preventing lesions by point loads and avoiding a possible eccentricity of the trusses on the wall.

4.2 *Compression tests on adobes*

In order to evaluate the quality control of the constructive solution, some classrooms adobes tests have been done. These tests were carried out in the Civil Engineering laboratories from the Universidad Autónoma Gabriel René Moreno, Santa Cruz de la Sierra (Bolivia). Five samples of 20 × 40 × 10 were tested to compression according to the N.B.2.5. -002 (Bolivian Standard). The results show a high variability, with an average test-tubes strength of 1.84 N/mm² and a characteristic compression strength of 1.25 N/mm². To establish the characteristic compression strength of the masonry as a whole, performed by analogy with the spanish *Código Técnico de la Edificación* (CTE), we obtain a value of 0.25 N/mm², considering a material factor of $\gamma = 3$.

Table 1. Test results on adobe bricks*

N.	Load (N.)	Area (mm²)	Breaking stress (N/mm²)
1	180.000	80.000	2,250
2	130.000	80.000	1,625
3	100.000	80.000	1,250
4	150.000	80.000	1,972
5	160.000	80.000	2,104

*Test carried out in the material laboratory of the Universidad Autónoma Gabriel René Moreno, Santa Cruz, Bolivia.

4.3 *Defining maximum loads*

After performing a precise descent of loads of all the elements supported by adobe walls, after applying the permanent load factors and considering a maintenance variable load as defined by the Spanish CTE, we obtain a maximum design compressive stress of 0.14 N/mm². Demands are, therefore 65% lower compared to the material limits.

Note that although the cross-section might be reduced by structural criteria, earth mass is needed considering environmental factors, since it provides a high thermal inertia.

5 BRICK PILASTERS CHARACTERIZATION

5.1 *Background*

Since the schedule is a key factor in any cooperation project, and due to the specific climatology of the area where, as previously mentioned, there is a wet season when one can't build outdoors, it was considered the possibility of a fired brick pilasters structure which supports the roof and, at the same time, some adobe walls contributing to the thermal benefits of Earth. This process lets the deck be built rapidly and to build the adobe walls sheltered from rain, following the conception used in the churches with the wooden structure (Fig. 6).

5.2 *Constructive solution*

Solution is based on the fired brick pilasters placement of 1 × 0.60 m separated 4 m between axes. This pilaster has U shape and supports two large Tajibo wood trusses. To ensure continuous support on the brick, three perpendicular wood lintels are placed into the arms of the U, where trusses rest.

Apart from collaborating in the load distribution, the U shape gives the pilaster some stability against compression buckling or the possible bending moment generated by the deck.

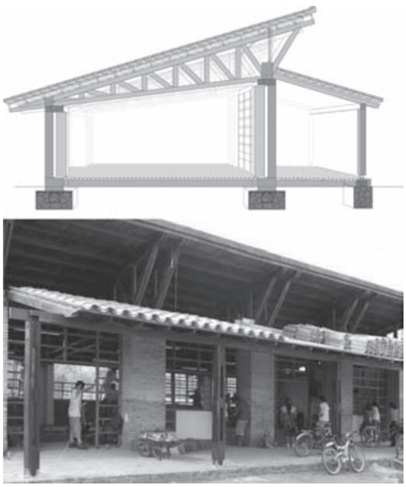

Figure 6. Fired brick pilasters. Second module of the Facultad Integral Chiquitana, USF, San Ignacio of V. Bolivia. (Picture: USF).

Table 2. Fired bricks test results. Test carried out in the material laboratory of the Universidad Autónoma Gabriel René Moreno, Santa Cruz, Bolivia.

N.	Load (N.)	Area (mm^2)	Breaking stress (N/mm^2)
1	12.000	25.850	4,642
2	13.000	25.850	5,029
3	11.000	25.850	4,255
4	12.000	25.850	4,642
5	12.200	26.320	4,635
6	11.000	26.320	4,179
7	13.000	26.320	4,939
8	10.000	24.150	4,141
9	10.200	24.150	4,224
10	10.400	24.150	4,306

5.3 *Performed tests*

Simple compression tests have been done on several samples of fired bricks of the items used in the work of 24 × 12 × 4 cm. This was the same type of test as the adobes one.

In this case, obtained results show a high homogeneity, with maximum deviations below 11% compared to the average 4.49 N/mm^2 strength. From obtained data we can determine a characteristic brick strength of 4.14 N/mm^2. Making an analogy regarding the values determined in the Spanish CTE, the characteristic compressive strength of the whole masonry must not exceed 2.48 N/mm^2. Considering a partial material factor of $\gamma_m = 3$, we obtain a design compressive strength $f_d = 0.83$ N/mm^2.

5.4 *Defining maximum loads*

The performed descent of loads in the wall, shows a stress on the underside of the pilaster of 0.35 N/mm^2, offering a safety margin still 1.65 times the stress currently supported.

6 COMPRESSED EARTH BLOCKS CHARACTERIZATION

6.1 *Constructive solution*

Another considered system has been the construction by Compressed Earth Blocks (CEB). The process consists of the manufacture of earth blocks stabilized with cement through the use of a manual press.

After this process the blocks go into a wet curing process followed by a dry curing process, until 28 days have passed since its manufacture.

The cross section has been solved through continuous walls of CEB where a manual tile deck rests on wood trusses, similar to the adobe wall solution.

To avoid humidity lesions appearing in the length in contact with the ground, the percentage of cement is increased in the first two rows up to 10%.

6.2 *Performed tests*

In order to determine the mechanical properties of Compressed Earth Blocks, 63 compression tests have been carried out, changing different parameters in the pieces manufacture as the amount of cement per piece, the amount of water used in the mix and wet curing time. Total curing time ranged from 23 to 27 days. Tests were carried out by the company COBOCE. CEB samples of 31.5 × 15 × 13 cm were done with different amounts of cement: 4%, 5%, 8% and 10%. The obtained results show a connection between the amount of cement used in the mixture and the strength. Note that, while between 4% and 8% a linear relation can be established between the amount of cement and the compressive strength, the increase of strength by adding 10% of cement is proportionally lower, as shown in table 3.

Table 3. Strength according to the amount of cement.

% of cement	Average strength (N/mm^2)	Characteristic strength (N/mm^2)
4	2,663	2,060
5	3,877	3,132
8	5,129	4,692
10	5,383	4,794

Table 4. Descent of loads in vertical structure.

Thickness (cm)	Adobe (40)	Brick (pilaster)	CEB (30)	Adobe (78) church
Characteristic strength 95% test (f_x) (N/mm²)	1,25	4,14	3,13	1,25*
Design strength (f_d) (N/mm²)	0,25	0,83	0,63	0,25*
Acting stress (σ_d) (N/mm²), so as descent load**	0,15 (safety factor 3)	0,31 (s.f. 3)	0,19 (s.f. 3)	0,12 (s.f. 3)
Safety margin	1,65	2,69	3,27	2,03

*Data from the adobes of churches has been extrapolated by analogy of the adobes tested by USF.
** In these data possible lateral thrusts or second-order effects as buckling have not been taken into account.

6.3 *Defining maximum loads*

The descent of loads performed in the cross-section, shows a stress on the wall's underside of 0.21 N/mm², approximately 2.5 times lower with regard to the maximum permissible material stress, considering a brick containing 5% of cement.

7 CONCLUSIONS

Projects undertaken by Universitat Sense Fronteres and the Polytechnic University of Catalonia, in the region of Chiquitos have strengthened local population's awareness of their own heritage. The construction of more than 10 educational and socio-sanitary equipments since the year 2000 in this Bolivian region, with the voluntary participation of more than 5000 Bolivian families, has helped to revitalize the use of materials and indigenous architectural typologies among the local population and validate its continuity both in the productive and constructive processes. The use and improvement of the production processes of local materials represents another tool for strengthening the economy and the local business. The Cultural Heritage of Chiquitania will continue alive as long as new youth generations are still identified with the essential cultural values transmitted by their parents and through the local heritage.

Tests carried out relative to the vertical structure solutions allow to validate constructive techniques adopted and to propose new solutions. In this regard, a field to investigate in future is the implementation of the CEB in other typologies, beyond the wall, since its results show higher margins with regard to the other materials. Finally, scientific validation of materials as earth and its diffusion strengthens the confidence of the local population in its own materials and heritage.

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Vernacular adobe architecture in Texas: Conservative issues

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ABSTRACT: The Texas adobe vernacular architecture is characterized by an interesting continuity with Mexican tradition, regarding both functional kinds and technical aspects of construction, however it presents relevant and peculiar variations. This eighteenth and nineteenth centuries variegated heritage of religious and residential buildings is specifically suited to an arid climate and a devoid of good building stone land; but its conservation is endangered by rare and violent weather events and by geotechnical problems relating to canyon systems. Abandonment and lack of maintenance works are therefore the primary cause of degradation. The paper reports the experience of a case study regarding adobe vernacular architecture in the Texas National Ranch Big Bend Park, which has an interesting heritage of adobe buildings in serious conservative conditions. For this reason the research proposes a conservation intervention of archaeological kind, in order not to produce significant changes and at the same time to pursue its preservation.

1 INTRODUCTION

1.1 *Texas Big Bend National Park and State Park*

The Big Bend National Park and the Big Band Ranch State Park are two Texas protected area of Chihuahua desert region. The first is one of most visited American national park, is located in Brewest County, covers an area of 3,200 km^2, was founded in 1944 and represents the international boundary with Mexico; the second one is located in Presidio County, covers an area of 1,100 km^2, borders with first one and was founded in 1988. Both are crossed by Rio Grande River. These two parks, characterized by a significant geological and paleontologic value, have desert climate, characterized by strong and severe environmental conditions, above all in terms of day-night hygrothermal variations, which determine peculiar and diversified habitats and ecosystems.

However human presence in this region is ancient and continuous, until the 19th century and during Spanish occupation, and mineral deposits from the early 20th century, with construction of silver mines and related residential non-aggregated settlements, usually consisting of ranches, abandoned since the 50s of 20th century, due to technological obsolescence of mines (Robinson, W. B. 1981). About Big Bend National and State Parks architectures there are a lot of interesting studies (Wolfskill, H. 1950), but above all focused on specific building on site, in fact it was not possible to know studies about this heritage.

2 VERNACULAR ADOBE ARCHITETURE

2.1 *A preliminary census: Mexican and American adobe architectures*

A first step of research was aimed to realize a preliminary census (Fig. 1), done with indirect instruments: maps, pictures, books and on line sources (Harrington, S. L. 1945, Robinson, W. B. 1981) due to really large dimension of areas to investigate. So this census must be considered only a preliminary and not complete investigation. However it was useful not only to have a first approach to an interesting, but complex architecture, in terms of typologies, technical characteristics and conservation conditions, with possibility of show following data. Mexican adobe architecture: typology (houses 60%, churches 10%, others 30%); conservative condition (ruin 35%, no good 25%, good 40%). American adobe cottage: typology (residential 65%, not residential 25%, others 10%); conservative condition (ruin 20%, no good 25%, good 55%). A first data concerns a macroscopic element; these architectures can be classified in two big categories: Mexican adobe architecture, which are vernacular buildings realized generally before 20th century (Fig. 1, top), and American adobe cottage, realized after 20th century (Fig. 1, middle), by US communities, who, for them new settlements, chose this technology considering it better, in comparison to wooden frame technic of prefabricated system, due to environmental condition of this territory, confirming a good perception in time of performances of this constructive system.

A second issue concerns present conservative condition of this architecture, which unfortunately is usually abounded and is often object of inadequate alterations (Fig. 1, bottom).

Concluding, this census was useful to show need by one hand to think up strategies able to incentive economic revitalization of this territory, for example in terms of sustainable tourism, and by other hand to define rules and procedure able to guarantee restorative intervention finalized to preserve identity and history of this heritage. Under this point of view the following Crawford-Smith ranch pilot case aspires to represent a little and simple applicative case of this cultural approach.

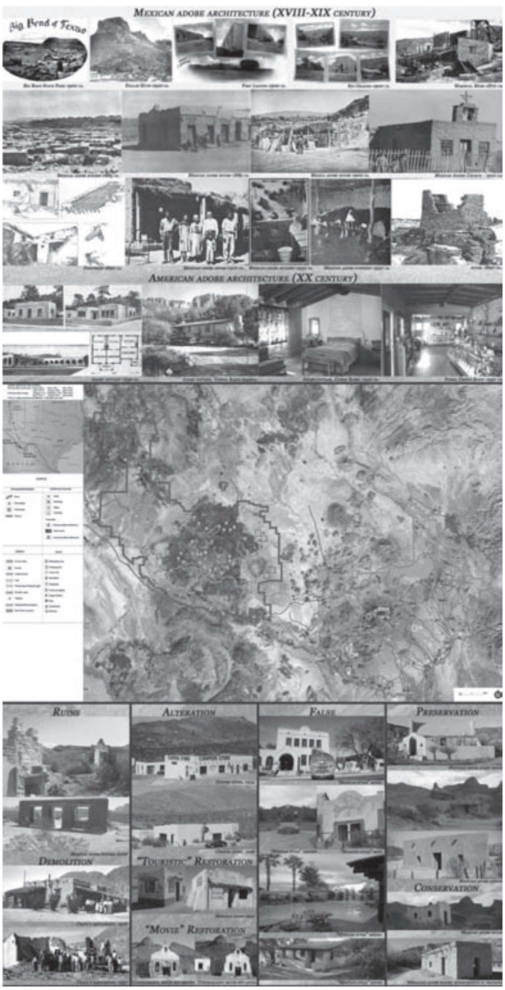

Figure 1. Census, Mexican and American adobe architecture in the National and State Big Bend Parks. Credits for photographs: Harrington, S. L. (1945), Robinson, W. B. (1981), Wolfskill, H. (1950), http://www.nps.gov/bibe (accessed Oct 12 2011), http://www.tpwd.state.tx.es (accessed Oct 23 2011). Credits for map:http://www.earthobservatory.nasa.gov (accessed Oct 16 2011).

2.2 *Typological and technological characteristics*

Considering this preliminary census showed Mexican adobe heritage is, in comparison with America adobe architecture, is more exposed to degradation risk, because it is more ancient and less object of preservation activities, the research was focused on this large category, which consists generally in two typologies: residential and not residential building. First typology (residential buildings) can be divided in single Mexican adobe house, which is composed by an elementary cell, generally isolated and characterized by a little rectangular floor with unburned bricks, one door and one window on facade and wooden plane roof, and admitted Mexican adobe house, composed by aggregation of two or more elementary cells. The admission process can be determined during foundation phase and in this case the entrance in on the short facade, but more frequently it is a result of one or more following constructive phases. Second typology (not residential buildings) concerns above all Mexican adobe churches and it can be divided in little rectangular church, with vault and dome, and large stretched rectangular church, with apse, plane roof and tympanum facade. Variety and articulation of these categories needed to examine closely only one typology, considering this is a preliminary research.

So was chosen the single Mexican adobe house typology, because not only it represents architectural basic identity, but also because is very widespread and for this reason the most vulnerable category; so following consideration description regards only this one. Under the technological point of view, the single Mexican adobe house (Fig. 2), which usually is articulated only on one level, is characterized by irregular stone masonry linear foundations with mortar. The choice of stone masonry is due to need to use a durable material to contact with ground, in order to avoid problems of rising damp and solution of low walls foundation, instead of a continuous foundation, secures at the same time a significant saving and a good ventilation, especially during summer. Exterior walls, with a thickness of two bricks (50 cm) are made of unbaked argil bricks, with a high clay component mortar; corners are generally well made. Floor is generally made with large stones, used to fill mesh through foundation walls, but arranged to act as a ventilated crawl space. On stones is arranged simple clay, as flooring, only in few cases it is constituted by a succession of thin timber beams, warped according to long side of house; so they can be composed by multiple pieces, joined in correspondence of support on

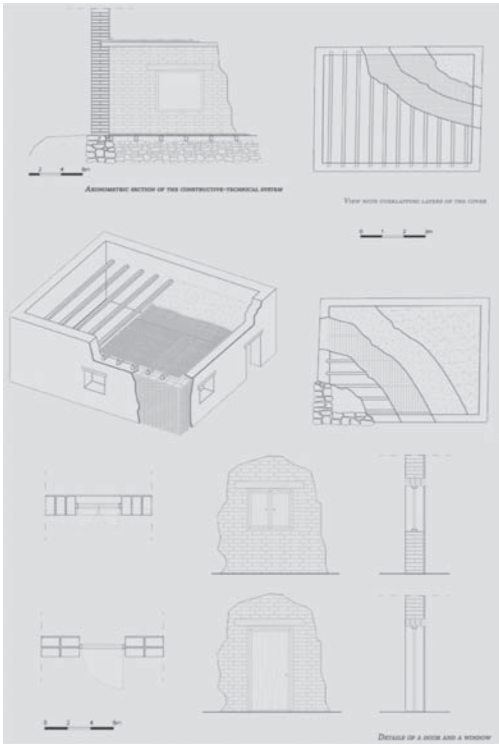

Figure 2. Mexican adobe architecture, technic characteristics.

foundation walls, with an overlying nailed planking, which has also role of floor. Thatching roof is flat with thin little regular wooden beams and rather close together, arranged according to short side of house, so as to be little long and harmonized with floor beams, which are orthogonal to them. On this structure is disposed a double layer of reed, with alternating textile, and finally a layer of mortar, lightened with straw. This layer usually is rather thick, so as to allow to achieve adequate slope for rain water and finally a thin, elastic and rainproof layer. Door and windows, which are generally quite small, so as to allow greater thermal insulation, have good wooden lintels. Finally fireplace, if is not entirely external, is often realized with external bodywork, so to not clutter small inside space of house, and it is made with stones and mortar, because of the inadequacy of unfired bricks to contact for a long time with low temperature heat of domestic fireplaces. The Mexican adobe house is therefore a very simple architectural system, also because done with what it is possible to find in an hostile environment, however, it is very effective in every constructive detail, providing it is guaranteed its maintenance.

2.3 *Energetic and hygrothermal performances*

Adobe Mexican architecture is particularly appropriate to very hot and dry Big Bend National and State Parks climate; however, the strong and short rain storms, which characterize this area during season changes, are a threat to these houses, because the not fired bricks dissolve to contact with water, if not protected by plaster, which deteriorates through this violent runoff action. This requires a careful maintenance of these hoses, which, losing roof and plasters, quickly degrade. This is one of main reason why more than 40% of adobe Mexican houses in Big Bend Park are ruins. However, good performances of vernacular Mexican houses is primarily due to its materials, specially to adobe masonry, because it has a thermal conductivity value (λ = 0.240 w/m°k) similar to fired bricks masonry (λ = 0.248 w/m°k). But they are more breathable, so fully suited to the Big Bend state Park, whose weather is really hot and arid, but characterized by strong day-night thermal variations. In terms of energetic behavior, even more interesting are technical and constructive characteristics with which these materials can express their best. A correct geographical orientation allows to reduce summer sun radiation, affecting mainly two short side and to extend winter sun radiation, affecting mainly two long sides. Adobe walls, with multilayered plasters; masonry without foundations, increase their general thermal mass. Its light and its ventilated roof helps to reduce formation of thermal bridges on top, avoiding condensation and heat loss during winter.

Rainwater harvesting, useful because short and very intense rains (in December Big Bend State Park has a cumulative rain average of 38 mm) alternate with long dry periods (in June Big Bend State Park has a cumulative rain average of 13 mm) (Gamboa Carrera, E. 1993); and so on make this poor and seemingly simple architecture adapt to an inhospitable habitat.

3 A STUDY CASE: CRAWFORD-SMITH RANCH

3.1 *A brief description and a hypothetical reconstruction*

Crawford-Smith ranch is a building complex, located on the East part of Big Bend Ranch State Park in Fresno Canyon was realized on a pre-existing site. Its first owner, J. J. Allen, selected this area thanks presence of water springs, able to guarantee irrigation for the ranch, covering over 41 km^2. In a first phase the ranch consisted of only a long residential wooden building with little wooden provisional buildings for workers. During the years 1929 to 1942 the ranch enlarged with geologist Homer Wilson's help, by Harris Smith; in fact in this period was built the residential adobe house and other little masonry buildings for workers, further lots improving intervention for irrigation system. At the same time the site was chosen to develop a Fresno quicksilver mine oh the Nord-western side of Terlingua district, founding the Buena Suerte associated community. The ranch was abounded by Smith family only few years after, when in 1944 the mine was closed, and through the 1972 was occasionally occupied by other families (Robinson, W. B. 1981). So in less of fifty years the large part of buildings in Crawford-Smith ranch does not more exist (wooden building, Fig. 3), or are in ruin condition (adobe house, Fig. 3) or presents lots alterations (Fig. 3). The first cause of this quick degradation is maintenance lack. This condition needed to purpose an introductive study, aimed to suppose its original thickness state and conservative problems, above all to do a diagnosis of kinematics, useful to guide consequent structural restoration choices. So, study is on focused only on principal adobe residential building (adobe house, Fig. 3-green), whom hypothetical reconstruction describes a building composed by along rectangular cellar, divided in three sectors. This is the result of two different additions, realized in unknown time on two opposite short front. In terms of technical issues, Crawford-Smith ranch conforms to what has been generally described in 2.2 paragraph about Mexican adobe house, with exception of a serious problem in connection for its corners.

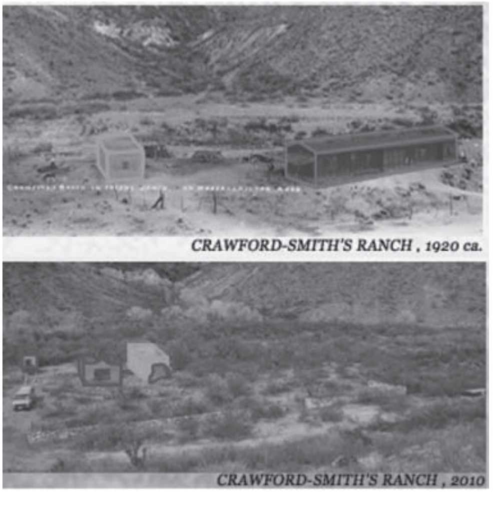

Figure 3. Crawford-Smith ranch in 1920ca. (top) and in 2010ca. (bottom). Credit for 1900 picture: Wolfskill, H. (1950); Credit for 1900 picture: prof. ing. Robert Warden, CHC-TAMU University.

3.2 *Risk factors: environmental events and anthropic activity*

The site, where is located Crawford-Smith ranch, is a large alluvial area, called Lewis Canyon. The site, in terms of environmental risks, is little exposed to environmental hazards of episodic and violent kind, as volcanic eruptions (Index = 0.000 in comparison with an average US Index = 0.002), or earthquakes (Index = 0.001 in comparison with an average Us Index = 1.840) and twisters (Index = 3.130 in comparison with an average US Index = 137.000). However a considerable risk is determined by cyclic and intense weather events (period 1940–1990: ca. 30 thunderstorm, ca. 50 floods and ca. 50 hails) (Gamboa Carrera, E. 1993), really dangerous for adobe architecture not only in terms of material conservation, but also in terms of structural alteration. In fact, although sixty years is a too short period to analyze and value geological issues of a site, doing a comparison between geological and geotechnical characteristic of Lewis canyon in 1940 and 2010, it is possible to watch significant new degradation events. For example the advance of 1 ancient landslide or 3 new growth of erosive phenomenon, despite some improving elements, as a widespread increase of vegetation, determined by ending of human exploration, above all in terms of timber business, with a positive consequence of stabilizing 2 large landslides.

The presence of significant geotechnical problems in Lewis Canyon, partly induced by local geological characteristics and partly by severe weather phenomena affecting this area, produced onset of a serious risk for Crawford-Smith ranch conservation, which in fact, in the current state, is in a ruin condition, to which, inter alia, the building arrived in a fairly short time (Fig. 4, top-left).

3.3 *Conservative and structural conditions*

This situation made it necessary first of all to reconstruct, as far as was possible, Crawford-Smith ranch consistency, before most of the its walls collapsed (Fig. 4, top-right), doing an analysis of current conditions and also using historical images of site, then proceeding with of typological comparisons both in terms of size and proportions of units, both in terms of hypothesis about elements almost lost, as its roof or fireplace. This study allowed to understand how, this ranch, being result of addition of more cells (Fig. 4, top-right), not only does not have adequate corner connections, but has an imbalance between dimensional length and width of its cells, between thickness of walls and possibility of having cross walls, which exposes it more to geotechnical problems described above, although this circumstance is not unusual in this buildings.

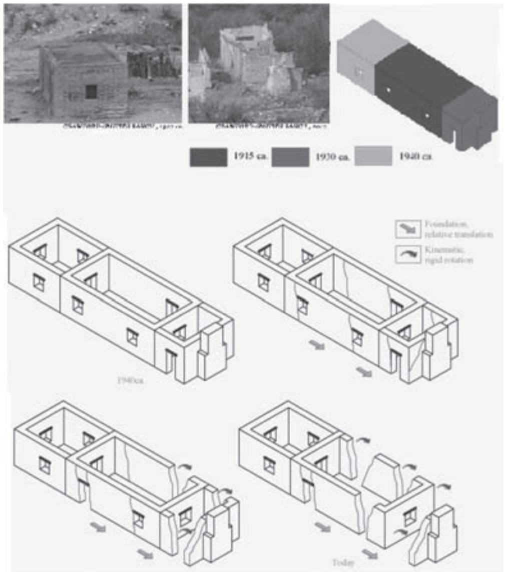

Figure 4. Crawford-Smith ranch, adobe house: phases (top) and hypothetical reconstruction with kinematic scheme and its progression (bottom). Credit for top-left picture: Wolfskill, H. (1950); Credit for top-right picture: prof. ing. Robert Warden, CHC-TAMU University.

To compounding its structural deterioration also contributed roof collapse, which not only produced collapse of window wooden lintels, which were too thin and too close to wall top, but also led to a general decay of structural behavior in the building, respect to which roof has an important role, even in case of light roofs, such as that in question, but provided with close beams. All this set of intrinsic and extrinsic vulnerabilities determined presence and progression of serious related kinematic mechanisms (Fig. 4, bottom), which can be summarized into two categories: a relative translation of foundation and a rigid rotation of walls. It is evident, however, these two mechanisms overlap and merge, allowing, in part because of ruin condition in which the building is now, only a general delineation.

3.4 *Restoration and conservation project: methodology, criteria and solutions*

Choice of Smith-Crawford ranch as a pilot building is motivated primarily by the fact it represents, from technical-construction point of view most of Mexican adobe vernacular characteristics of this territory and secondly by its conservative conditions. They are so extreme that developing a project aimed at its preservation and improvement of structural safety can be a useful strategy to highlight technical feasibility to preserve this rich and interesting Mexican adobe vernacular architectural heritage, although it is very hacked, also in this way demonstrating how this activity is urgency. From this purpose, which can be defined demonstrative, project is based on a fundamental principle: every project decision has, first of all, to start with knowledge about technological characteristics and structural resources of historic building, which itself is summation and evidence of a constructive logic that is as old as sophisticated, because amended, adapted and improved over time, so as to allow its preservation even in severe environmental conditions. But this principle has to be reconciled with need for further improvements, suggested suggests by building and expression of our time; it is precisely this process of knowledge and improvement, conservation and innovation that history shows as a virtuous approach to what it belongs. The choices of the project would be coherent to original ones, but, where necessary, suggest innovative interventions in harmony with building (Fig. 5). A first intervention concerns complex volume of building; its construction history indicated a unbalanced volumetric development in direction of length and it is manifestation of this problem circumstance just most recent cell, that one afferent to fireplace, is more vulnerable to geotechnical kinematics, falling into ruin in a few years. So it was decided to renounce to this cell, suggesting a controlled demolition of its few surviving ruins, except for fireplace. It thus becomes an isolated element, with intent to preserve signs of ranch transformations, without having to intervene with extensive reconstruction works, which, considering scarcity of historical images and tangible elements, could be a falsification.

This solution also determines an improvement of complex structural behavior of house, now more balanced in terms of length-width proportion. Another non-conservative intervention regards foundations, which, although adequate of this environment, as already explained, in terms of thermo-hygrometric and technological aspects, are rather inadequate to ground on which they lie, because of poor connection of these thin and not very deep walls constituting foundations. An innovative, yet respectful, non-invasive and reversible solution suggested in project is consists of a FRP perimeter bordering, which however cannot be considered a definitive intervention, because it is not possible to define its durability in this climate. Also realization of a beams floor allows, anchoring beams heads with little metallic plate anchors, to implement ability of building to contrast translation-foundational kinematics, making mutually collaborative perpendicular walls. Regarding walls, the project proposes a necessary and extended

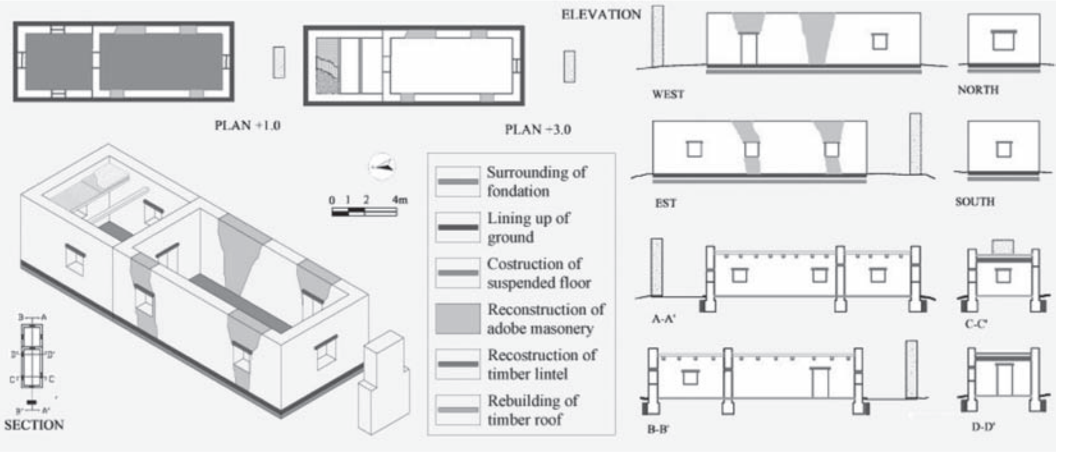

Figure 5. Crawford-Smith ranch, restoration project.

reintegration, with unfired bricks and mortar, to do homologues to the existing one. In this case small improvements are suggested, such as realization of window wooden lintels longer than original ones and composed by a single element and not two adjacent irregular pieces, very diffused in this area. New walls will be completely homologous to existing one, using modern adobe bricks for their recognition. Roof, plasters and regimentation rainwater system will instead be entirely homologous to original ones, typical of this area, already previously described, because they not only are effective, but they still can be defined in their original technical and dimensional configuration studying actual conditions of building.

The last part of project regards a structural and hygrothermal monitoring program. In fact one of main conservative restoration issues, especially in non-monumental buildings, is impossibility to value, in qualitative and especially quantitative terms, the immediate effectiveness and in time efficiency of adopted solutions, because this involves investing not irrelevant economic l resources. These are not actionable in common professional practice. However in case of an experimental study on a pilot-building a verification of what project proposed is really useful, at aim to suggest really effective solutions just in ordinary cases, where factors related to cost, timing and logistics have priority. For this reason, the project includes a diagnostic instrumental plan. This is articulated in a structural monitoring, consisting of eight electronic crackmeters and of six electronic inclinometers, and a thermographic and thermohygrometric monitoring, Scope of this diagnostic plan is but also to define a specific diagnostic protocol.

ACKNOWLEDGEMENT

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)
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Test and device to evaluate the capillary absorption in soil specimens of adobe and rammed earth

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ABSTRACT: Humidity rising up the capillaries is a valuable indicator of the state of conservation of earth structures. This situation is made worse by the condition of seismic zones, because the constructions present weaknesses where they need more resistance: in their bases. The result of this study has been the realization of a patented model of equipment and practice to evaluate the humidity of walls constructed in raw earth. This "Test and device to evaluate the capillary absorption in soil specimens of adobe and rammed earth" allows the characterization of the easiness of the water absorbed or lost in the soil used in construction. Thanks to these studies it is possible to analyze the reaction of the earth against capillary humidity and in relation to this, improve its quality, its texture, compaction density, composition, type and doses of additives. Our main purpose is the structural consolidation of heritage buildings.

1 INTRODUCCIÓN

En el marco de un proyecto sobre "Bienes culturales en el Área metropolitana de Mendoza" se relevaron más de 1200 edificios patrimoniales. El procesamiento estadístico de los datos obtenidos permite afirmar que el 37% de nuestros edificios históricos son parcial o totalmente de adobe, tapia o quincha. Un dato altamente significativo del relevamiento fue que el 96% de los edificios construidos con tierra presentaba humedad a pie de muro, originada por ascenso capilar desde sus fundaciones, cuya altura abarcaba desde los 20 cm hasta 170 cm de altura, con distintos grados de desmenuzamiento y patolo-gías derivadas.

Este efecto se debe al valor elevado de tensión superficial que presenta el agua y que en materiales porosos le permite ascender por encima de su nivel freático entre los poros del material venciendo la fuerza de gravedad. Este mecanismo es natural en los suelos agrícolas y del mismo se valen las raíces vegetales para obtener agua. Este ascenso capilar normalmente finaliza en la capa superficial de suelo donde este realiza un intercambio de humedad con el aire. Sin embargo, cuando en su recorrido encuentra una estructura porosa (fundación edilicia) tratará de continuar su ascenso por dentro de la misma hasta que el peso de la columna de agua se equilibre con la fuerza de ascenso generada por la tensión superficial. Por las características inherentes de las construcciones de tierra (adobe, tapias, quincha) y la composición del material en sí (3 fases: sólido, líquido y gaseoso), la humedad de muros es una patología muy seria, pues no sólo provoca eflorescencias salinas y desmenuzamiento con pérdida de la sección resistente, sino que además modifica la cohesión del material, alteraciones que comprometen sensiblemente la estabilidad estructural de la construcción, máxime en un entorno de alta sismicidad.

De estas premisas surge la necesidad de un estudio científico y crítico del mecanismo de ascenso del agua en tierra. Pues los trabajos existentes se basan en recetas aplicables al lugar y tipo de suelo para el que fueron propuestos y aún así son de relativa o cuestionable eficacia.

Actualmente se ha encarado este estudio a nivel mundial en un entorno científico y de laboratorio. Sin embargo, este mecanismo en estructuras de tierra no ha sido descripto totalmente, y todavía no se han aportado soluciones al campo de la restauración y la consolidación estructural.

En nuestro laboratorio se han diseñado y construido instrumental, técnicas y procesos de ensayos novedosos para evaluar el ascenso capilar en probetas a escala real y reducida. Actualmente, nos encontramos analizando el mecanismo de ascenso del agua capilar en probetas de adobe apoyado en lecho poroso saturado en función de diferentes variables: granulometría y compacidad del suelo usado, velocidad de ascenso, volumen de agua alcanzado, grado de desmenuzamiento, pérdida de capacidad portante, resistencia a la penetración, tipos de agua (cantidad y tipos de iones), temperatura del agua y del ambiente, humedad relativa.

2 DISPOSITIVO DE ENSAYO

La base porosa, consiste en una placa de piedra volcánica (2) *(denominada comúnmente pómez o pumita, $\delta_{aparente} = 0.67 g/cm^3$)* enmarcada por un cuadro (3) de latón (bronce) sostenido por 2 apoyos trasversales (8) del mismo material y una hoja de papel poroso (4) ($80 g/m^2$) que cubre la placa.

Esta base se sumerge parcialmente en una pileta con agua (5), que mantiene su nivel constante (7) (levemente por debajo de la base de la muestra). El marco metálico, conformado en sección "Z" sumado a la elevación que proveen los apoyos transversales (8), permite el franco ingreso de agua por la parte inferior de la base, la cual es transferida a la probeta (1) a través del papel filtro, evitando que la muestra tome contacto directo con el agua y el correspondiente desmenuzamiento.

3 DESCRIPCIÓN DEL PROCEDIMIENTO DE ENSAYO

3.1 *Preparación de la muestra*

Se talla (adobe) o compacta (tapia) para conformar la probeta de ensayo, la muestra se lleva a estufa

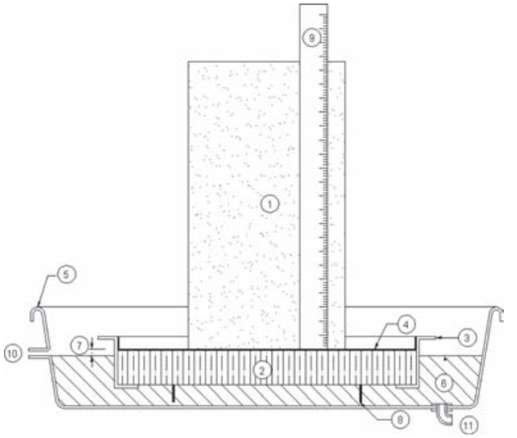

Figura 1. Esquema del dispositivo de ensayo.

1. Muestra (probeta).
2. Placa de piedra volcánica (pómez). Dimensiones: 90 × 220 × alto20mm.
3. Marco base porosa.
4. Papel filtro.
5. Recipiente contenedor (pileta).
6. Agua.
7. Revancha entre el apoyo de la muestra y el nivel de agua (4mm).
8. Apoyo base porosa.
9. Regla graduada.
10. Vertedero para derrame por sobre-nivel.
11. Ingreso de agua.

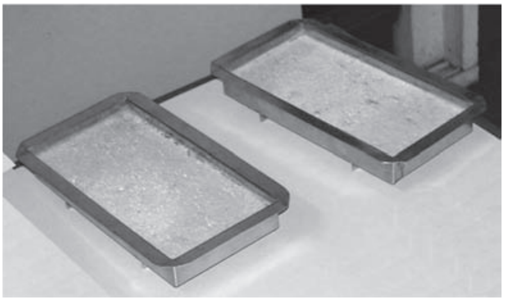

Figura 2. Base porosa (sin papel filtro).

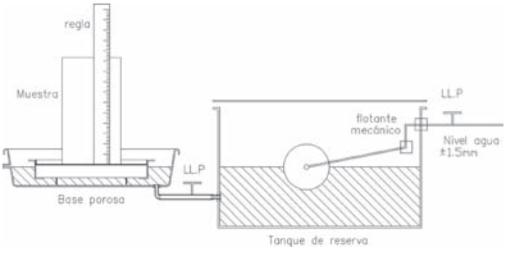

Figura 3. Esquema del montaje del equipo para realizar los ensayos.

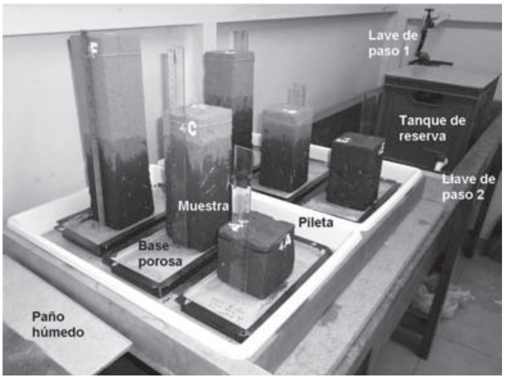

Figura 4. Armado del equipo de ensayo.

a 60º hasta peso constante. A nuestras probetas le dimos dimensiones variables y empleamos suelo tipo SC (IRAM 10509).

3.2 *Armado del equipo*

Se sumerge parcialmente la base porosa en una pileta que mantiene un nivel de agua constante (±1.5mm), controlado mediante un tanque de reserva con válvula flotante. Se deposita la probeta sobre la base porosa (4 mm por sobre el nivel de agua), instante en que comienza el ensayo.

3.3 *Ensayo*

Presenta dos fases: humedecimiento y secado, que constituyen un ciclo de ensayo, permitiendo a su vez efectuar varios ciclos.

a. Humedecimiento: determina en una muestra de abobe o tapia, la velocidad del agua y la tasa de agua absorbida durante el proceso de ascenso capilar.

   Durante esta fase, el conjunto base porosa-muestra se retira de la pileta, reposa 90 segundos sobre un paño humedecido (sin superficie brillante), se pesa y luego, retorna a la pileta. Así se continúa, hasta verificar una variación entre pesadas inferior al 2%.

   Simultáneamente, se lleva un registro fotográfico de la cara con regla de la probeta, lo cual permitirá luego, determinar la variación de altura de ascenso en el tiempo. En efecto, durante el humedecimiento, es claramente observable la línea que separa la parte seca y húmeda de la probeta. Este registro se extiende hasta que el tono pardo oscuro alcanza la cara superior de la probeta o se mantiene estable (altura de probeta > 400 mm, dependiendo de la textura y compacidad del suelo).

b. Secado: durante esta fase, la probeta es retirada de la base porosa y llevada a otra impermeable, permitiéndose el secado natural de la muestra (al aire libre sin asoleamiento directo) registrando su peso en el tiempo, hasta verificar una variación entre pesadas inferior al 2%. Una variante rápida del secado es realizarlo con estufa a 60ºC.

   El registro fotográfico sólo brinda una evaluación cualitativa del proceso de retracción y cierre de las fisuras producidas durante el humedecimiento. Por lo tanto, su uso dependerá de los resultados buscados.

3.4 *Resultados*

Por diferencias de pesada se determina la variación de:

- Cantidad de agua absorbida-perdida por la muestra.
- La variación del grado de humedad medio, en humectación-secamiento.

Por el registro fotográfico, se obtiene:

- La variación de altura capilar en función del tiempo.
- La velocidad media e instantánea de ascenso capilar.

A modo de ejemplo:

A través del registro fotográfico veamos el ascenso de una probeta:

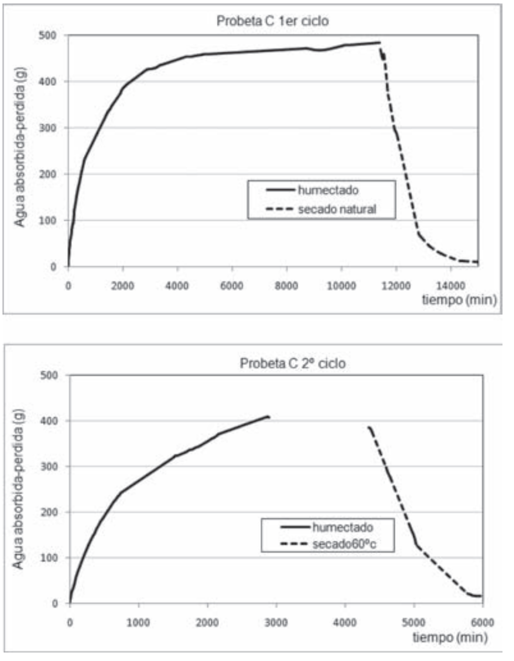

Figura 5. Ejemplo: agua absorbida-perdida en dos ciclos completos de gráficos obtenidos.

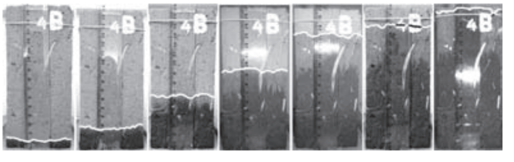

Figura 6. Secuencia fotográfica en ascenso capilar.

3.5 *Variantes del ensayo*

a. Parafinar de una a cuatro caras de la muestra para modelar su comportamiento en diversas posiciones de un plano horizontal dentro de la masa del muro.
b. Incrementar el espesor de la plaza porosa para reproducir el comportamiento de la muestra a diversas alturas dentro de la masa del muro.
c. La recolección de las sales que se produce en la cabeza de la muestra durante el humedecimiento-secado, permite determinar el tipo de sales presentes en el suelo que una vez disueltas producirán luego eflorescencias (el agua de ensayo debe realizarse con agua desmineralizada).
d. Ampliar la escala del ensayo para probetas que permitan representar, la interacción entre el tipo de mampuesto y la argamasa usada. En este caso las probetas tendrían una dimensión de 1 m^2 por el ancho del muro en estudio. En este

caso, el significativo peso de la muestra imposibilita una determinación gravimétrica con la precisión necesaria, sin embargo, mediante la fotografía se realiza el seguimiento de la velocidad de ascenso capilar, permitiendo evaluar tipos de texturas, compacidad y aditivos usados. Este ensayo se encuentra en fase de desarrollo.

3.6 *Validez del dispositivo*

a. Interferencia de la placa porosa: Se verificó que la velocidad media de ascenso capilar, para alcanzar igual altura, es 2.74 veces mayor en la placa porosa que en la muestra. Es decir, que la placa introduce un grado de interferencia necesario para modelar el efecto de a una fundación parcialmente saturada.
b. Perturbación del retiro del conjunto base porosa-probeta: Para evaluar el grado de perturbación que introducía el retiro y reingreso de base porosa-probeta a pileta, se comparó los valores de altura capilar, con aquellos provenientes de probetas patrón que no fueron retiradas de la pileta. La variación obtenida es despreciable (R = 0.999994):

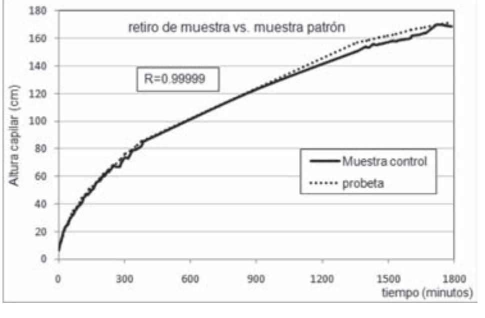

Figura 7. Evaluación del retiro de la pileta de la muestra.

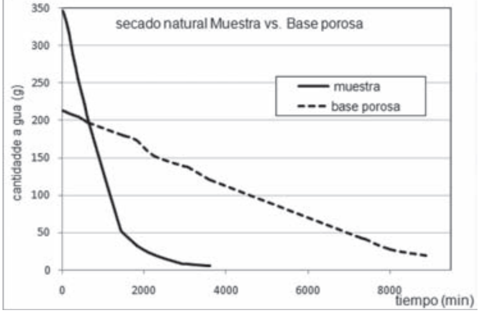

Figura 8. Comparación del secado natural en base y muestra.

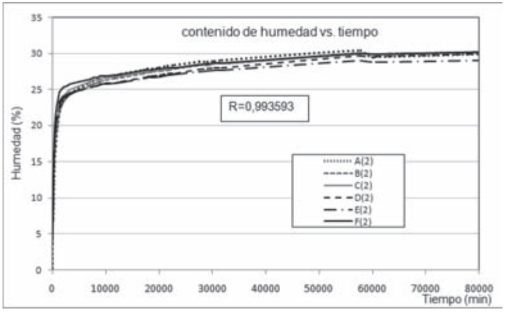

Figura 9. Comparación de resultados entre probetas semejantes.

Esta correlación se explica en que la tasa de secado en la muestra es 7 veces mayor que la base, por lo tanto, durante el retiro-reposo es la misma placa la que durante la operación de retiro, retiene el agua y disminuye la pérdida de agua por goteo.

3.7 *Reproducibilidad del ensayo*

La repetición del procedimiento de ensayo en probetas de iguales características granulométricas y dimensionales nos permitió obtener resultados semejantes. En el ejemplo vemos los resultados obtenidos con seis probetas semejantes.

4 APLICACIÓN PRÁCTICA DEL INVENTO

El trabajo consiste en la invención de un dispositivo y el correspondiente procedimiento de ensayo para la evaluación de la absorción-pérdida de agua de origen capilar en una probeta de suelo empleado como material de construcción de muros (adobe, tapia, etc.)

El conocimiento de parámetros tales como velocidad de ascenso capilar, variación de la cantidad de agua absorbida, de humedad, tasa de secado, permite valorar la respuesta del suelo empleado ante la humedad capilar y así, mejorar su calidad por medio de la modificación de su textura (granulometría), compacidad, composición, tipos y dosificaciones de aditivos (cemento, cal, asfalto, silanos, etc.). En el caso de la labor específica de nuestro programa de trabajo: Consolidación estructural de edificios histórico-patrimoniales, posibilita diseñar procedimientos de consolidación-restauración idóneos, tal que permitan aplicarlos con el pleno conocimiento de su eficiencia, sin poner en riego al bien en estudio debido a una práctica incorrecta.

Cabe recordar que el deterioro de las estructuras de tierra a pie de muro es la patología más frecuente en este tipo de edificación.

Por otra parte, la obtención de valores controlados de humedad con una distribución variable en vertical, brinda muestras representativas del proceso real para la realización de otros ensayos, por ejemplo, resistencia al corte directo, compresión simple, parámetros mecánicos necesarios para cuantificar la capacidad mecánica del muro en estudio.

Es de destacar, el exiguo valor económico del equipamiento de ensayo. En efecto, la fabricación del mismo requiere tecnología simple y materiales de fácil obtención, cualidades que resultan en un equipo de accesible adquisición, cualidad muy importante para los países en donde mayoritariamente se emplean estos materiales constructivos (países emergentes).

5 CONCLUSIONES

Este ensayo tiene por objetivo la evaluación del agua capilar en su proceso de ascenso y secado en muestras que se disgregan fácilmente en contacto con agua (arenas finas limo-arcillosas). Nuestro ensayo emplea determinaciones gravimétricas y fotográficas, empleando equipos económicos en comparación con otros procedimientos que permiten obtener las mismas cuantificaciones pero con equipos sensiblemente más costosos: espectrógrafo nuclear, absorción de rayos gamma, propiedades termales del suelo sobre el contenido de humedad, ondas ultrasónicas, ondas de radar, propiedades dieléctricas.

Nuestro dispositivo se diseñó específicamente para su uso en muestras que se disgregan en presencia de agua. Además, la absorción de agua a través de la base porosa parcialmente sumergida introduce una adecuada interferencia como para simular una fundación de muro parcialmente saturada.

El dispositivo diseñado no confina la muestra ni aplica carga hidráulica, permitiendo desarrollar un gradiente natural de humectación-secado.

Puede aplicarse en obra nueva para optimizar la relación textura-compacidad-aditivos del material usado en la construcción (tapia, adobe), y reducir y/o evaluar la vulnerabilidad al ascenso capilar. Varios países emergentes continúan usando adobe y tapia en edificación nueva (Perú, Bolivia, Brasil, Centroamérica, Asia), otros realizan prototipos para su uso ecológico (Nueva Zelanda, Alemania, Australia). Y puede aplicarse al mantenimiento-restauración de edificios de adobe y tapia con alto valor histórico, un tipo de intervención que despierta el interés de numerosos países, como Argentina, Chile, Brasil, Perú, México, Francia, Egipto, etc.,

Nuestro dispositivo aplicado en restauración-consolidación estructural de edificios históricos brinda un significativo aporte. En efecto, la modelación del proceso capilar permite ensayar técnicas de reparación, uso de aditivos, preparar muestras para otros tipos de ensayos (corte, compresión), etc. También permite normalizar materiales a partir de un ensayo caracterizado como estándar, además de correlacionar la humedad capilar con la pérdida de la capacidad portante.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Earthen domes in Northern Syria: Problems and criteria for the conservation

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ABSTRACT: Northern Syrian dwellings are cell buildings characterized by the presence of corbelled domed roofs built with adobe bricks. In the steppes and the uplands of Northern and Central Syria the availability of earth as the only building material generated this unique architecture, that is an expression of the complex relationship between environment and people spanning thousands of years. This paper aims to describe the earthen dome architecture of northern Syria, that have been the object of the 'Coupoles Et Habitats, une tradition constructive entre Orient et Occident' project (embedded within Culture 2000 programme, funded by EU) analysing the main characters of this building technique, the problems of its conservation, and identifying the strategy for the safeguarding of this amazing heritage.

1 INTRODUCTION

The steppes and the uplands of Northern and Central Syria were for centuries a favourite place for tribes of nomadic and semi-sedentary herders of sheep and goats. The arid climate was a determining factor that influenced settlement, architecture, building culture and use of land. In the conditions of scarce resources, the availability of earth as the only building material generated an unique architecture, where a building technique represents an example of cultural diversity and at the same time, it is the expression of the complex relationship between the environment, people, and habitats over thousands of years. Northern Syrian dwellings are cell buildings characterized by the presence of corbelled domed roofs. Although this type of vernacular construction is common in the Mediterranean area, it is usually built in stone. Less common is to find it built with adobe bricks as a construction technique, forming groups of dwellings or even whole villages.

In the interaction with the natural world, the social and the political, in the capacity to adapt and maintain systems of settlement, we can find the value and interest of this heritage on a global scale: the domed architecture, its form, the construction technique with its variations and adaptations, and the organisation of the houses and villages, give appropriate responses to climate and customs of the inhabitants, reflecting their culture of life.

The strategies and solutions of settlement, and the use of resources observed today, are similar to those developed in past millennia, reflecting a situation of continuity even through the vicissitudes of both natural and social conditions.

2 MORPHOLOGY OF SYRIAN DOME VILLAGES

The architecture of earthen corbelled domes is common in many inhabited villages in the regions of Aleppo, Hama, and eastwards along the Euphrates.

The Northern Syrian villages retain a strong formal expression of the nomadic Bedouin culture, which is manifested in the way the different units are grouped, in the organization of the community space, in the use of housing for basic needs (sleeping, eating) and the predilection of the outer space for the remaining activities.

The principles of transition and self-construction that characterize this culture are crucial prerequisites for understanding the process of evolution of these settlements. In general the agglomeration is not based on any previously thought out plan (Ghiyas 1984). Only few villages present a more structured organization of the housing units, a more regular path system and clear meeting spaces.

The settlement consists of groups of separate but adjoining houses. The units are always composed of enclosed buildings with domes and flat roofs and a outdoor area with a mastaba, a terrace central or attached to one of the facades, for storage and animals. The spatial organization of the dwelling unit can be open or closed: the open unit is a straight building or L-shape, in an area which is not visually defined; the closed unit is enclosed

Figure 1. Representation of the urban morphology of a dome village. (autor: Dipasquale L. 2009).

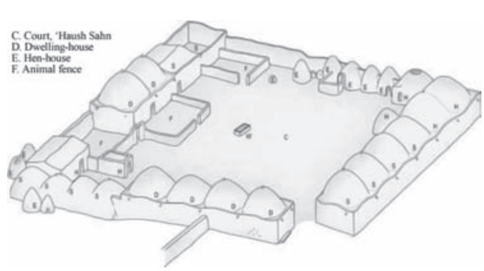

Figure 2. Architectural and functional characters in a housing unit (autor: Dipasquale L. 2009).

by a small fence wall, or by the own buildings, arranged around a central courtyard (Fig. 2).

The lack of urban organization is also confirmed by the scarcity of paved road, public space and services. Public spaces can be defined as spontaneous spaces, residues of a settlement phenomenon without rules of urban organization or hierarchical definition of spaces. The daily use and enjoyment of outdoor spaces has gradually led to the formation of common and meeting areas, the form of which shows the irregularity and randomness that is a consequence of the absence of planning. Schools and mosques have been introduced only recently and built with modern materials.

3 ARCHITECTURAL MORPHOLOGY OF CORBELLED DOME HOUSES

The typological solution adopted is strongly linked to the climate, and to the few local resources available for construction.

The Syrian domes are able to meet the demands of hygrothermal welfare in an arid climate. The thick earthen walls have a naturally elevated thermal inertia and can regulate the indoor humidity through vapour permeability. The ogival shape of the dome determines a low incidence of solar irradiation, create self-shadowing, allows the indoor upwards movement of hot air, and permits the run off of the occasional but torrential rainwater. At the same time the dome shape resists the mechanical stresses of wind pressure and the minor shocks of the frequent earthquakes which afflict the region.

The few openings are designed to maintain the in ternal microclimate: the low ventilation holes permit a constant natural ventilation, minimize the sun's glare and the entry of hot air during the day as well as cold air at night.

The main space of the house is called *Gurpha*: it may consist of a single cell, or two domes communicating by an arch. Orientation is frequently north-south, with the main opening towards the south in order to protect the house from the easterly and north-easterly winds. The main housing cell functionally and spatially organizes the whole of the complex, linking the different functionally complementary service elements. This space has a multifunctional character: by day it serves as an area of residence and shelter from the harsh climate, by night as a sleeping room. The interior has no fixed furniture. Blankets and in some cases thin mattresses are placed in a pile in a corner of the room (*frash*), and only at night are arranged on the floor for sleeping. Objects are placed in niches (*khezana gedaria*), built into the thickness of the masonry.

The tableware and wooden supplies are placed in a specialized dome (*matbakh*); foodstuffs and fruit for winter are preserved in another storage space, or in small holes (*kuara*) in the walls of the main room. Traditionally, meals are prepared outside according to the nomadic custom; In each unit there is an oven for the daily preparation of bread, consisting in a simple circular base in clay, about 60 cm high, with a cavity in the center for the burning of straw and small branches. The cavity is covered by a convex metal disc, on which a layer of dough of variable thickness is placed.

The outdoor area is a highly frequented space where we can find fenced off spaces or shelters for animals, small domes used as chicken coops, fireplace for the preparation of meals, wells for the water supply.

This type of dwelling in multiple structures allows the addition of new blocks, in cases where extra space for production is necessary or to make room for new members of the family. A tent is sometimes set up next to the living unit, used for the storage of straw and firewood, or for the preparation of milk products.

3.1 *Typologies of Syrian corbelled dome houses*

In the vernacular landscape of the Northen villages in Syria the repertoire of dome-shaped structures is found in a wide variety of types and variations, differing from one another in formal aspects and constructional character. The different height of the perimeter and the profiles of the domes allow to identify the following types of domes (Fig. 3):

- *Simple domes*: this is the most ancient type, in which the dome rests on a stone baseboard that rises few cm respect to the campaign floor.

The building has ogival profile; the shell of the dome is entirely visible from the archway soffit or the extrados. The square base measures about 3.0–3.5 m × 3.0–3.5 m, while the height is variable from 4.0 to 6.0 m.

- *Sultanya domes*: the building consists of a wall box, with a dome cover, which profile is ogival-paraboloid. From the outside the two elements, the box walls and dome, are clearly identifiable. The box has a square base measuring from 3.00 to 4.50 m. The height ranges from 4 to 6 m.
- *Domes set on low stone basement*: The building comprises a stone basement, of variable height, and a shaped stone profile at the door. The roof dome is not enclosed by a wall, but its shell is visible from the archway soffit or the extrados. Sizes in plant and height is variable from 2.5 to 4 m.
- *Plan roof Domes*: the dome is not completed, but the top is closed by a cover with a wooden structure covered with earth. This type of construction is widespread in the villages near the Euphrates River, where the availability of wood branches allow the building of flat roof.
- *Smaller domes in cob*: this type of dome is used for the service areas (stock, silos, animal shelters), and the structure is made of earth shaped by hand and stone.

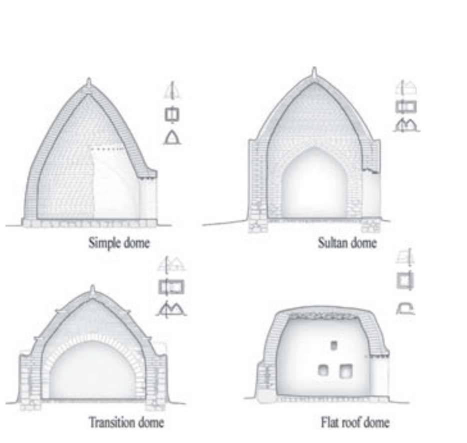

Figure 3. Constructive section view of the main earthen domes tipoligies (autor: Onnis S. 2009).

4 THE BUILDING SYSTEM AND PROCESS

There is a cultural diversity in the building systems resulting from the variety of local resources available, the geomorphology of the places, the position in relation to roads, the knowledge of the builders, the subjectivity that goes to make each individual village.

Differing modes of integrating basalt stone or limestone or wood in relation to their availability generate technical solutions, forms, aspects, and colours of the architecture in each village. Some villages were built on the ruins of ancient villages of the Byzantine period, effectively used as quarries for building materials. In others the earth is mined from alluvial deposits in the riverbeds of seasonal torrents: the people of the villages know the areas where earth to make the bricks can be found.

The manufacture of bricks is still today a family production under the supervision of an experienced builder, the *muallem*. Preparation of the earth mix is done by men, while women shape the bricks with the help of a wooden form: the involvement of the whole family in the construction process, which also involves children with different tasks depending on their ages, significantly reducing the cost of the bricks.

The earthen masonry technique (adobe) is integrated, for buildings of modest structural and functional importance, with the technique of cob, which is an in situ, hand-modeled earthen wall. The mixture in all cases (adobe and cob, mortars and plasters) is prepared with earth, water and vegetal fibres, or wheat and barley straw, grown around the village, using coarse and knobbly straw for the bricks and sieved straw for the plaster.

The mason digs until he finds a solid layer of soil (average depth 40–60 cm) and builds the foundation with stones and earthen mortar.

Above the foundation wall a stone wall of variable height is built, upon which the earthen masonry wall is erected.

The elevation wall is interrupted for openings, niches and for the arch linking two cells. The wall is built in horizontal layers, with particular attention given to the connection between the walls. The stone walls are usually protected by an earthen plaster, often finished with a coat of limewash. The stone walls are always composed of two external vertical layers, not connected by orthogonal stone elements; the space between is filled by a mixture of earthen mortar and small or medium sized stones, in a double wall technique.

The adobe wall, is an elevation wall built on the base, a characteristic of the *Sultanya* dome houses. The wall is usually three-headers, sometimes four, thick. The size of the bricks varies from village to village, having regular proportions of 1:2 between width and length of the brick: the average size is $20 \times 40 \times 10$ cm. The horizontal and vertical joints, which have variable thickness, when skillfully done, are made with sieved earth mortar, often mixed with straw.

The set of building parts realized to achieve the transition from the square base wall or elevation wall to the circular, base of the dome, more or less regular, in is called 'pendentive': the rows of bricks gradually take the shape of the internal perimeter from a square to a circle. The use as a shelf of a piece of wood or a stone in the corner allows a greater overhang, facilitating the creation (i.e. less then 12/15 rows) of a circular base for the first brick layer of the dome. The height of the starting point of the pendentive varies from 20 cm above the floor (Simple dome), up to 1.5 meters (more common) or more (Sultanya dome).

4.1 *The corbelled dome*

The corbelled dome is realized by laying the earthen bricks according to a continuous helicoidally spiral, tapered and often tilted towards the center.

The laying of the bricks according to a spiral permits laying in continuity without interruption and completing the horizontal rings with brick fragments. The mason lays the bricks, perched on the ring of the dome, in an anti-clockwise direction to favor the use of his right hand. This allows the construction process to proceed more efficiently, without any scaffolding or need to adjust the bricks.

The mortar is made with earth (clay and sand) and sometimes straw, as for the mortar of walls. The thickness of the mortar is considerable (2 cm) compared to the thickness of the brick (4–6 cm).

The overhang of bricks in relation to the lower layer is obtained by hand and without instruments. The builder, balancing himself on the ring of bricks backs up as he lays the bricks.

When the top of the dome is approached the working position becomes increasingly awkward, the mason is forced to work from the outside, finding foothold on the protruding stones with arms outstretched to lay the bricks.

The top of the dome is executed with great accuracy, both formal and functional, as this part is the most prone to degradation and the most architecturally expressive.

At the top of the dome when the arrangement of the bricks into a spiral becomes difficult, the mason lays bricks horizontally to close the void, adds layers of clay mortar and fixes in a standing stone, the *tantour*, at the top.

5 PROBLEMS OF CONSERVATION

5.1 *State of conservation of dome villages of Northen Syria*

The conservation of corbelled dome buildings has always been part of a natural process developed over the decades by the population of Northeast Syria, who have passed from generation to generation the tacit knowledge associated with the practice of buildings construction and for a regular maintenance, in order to prolong their useful life.

The corbelled dome structure, from a geometric point of view, is perfectly stable, and if it is well made, it seems an excellent solution both from constructive, climatic and functional aspects.

Practices such as the remaking of the plaster coating every year after the rainy season (Fig. 5),

Figure 4. Domes in a poor state of conservation (autor: Dipasquale, L. 2009).

Figure 5. Traditional practice of plaster maintenance (autor: Lupi, L. 2009).

or making sure that capillary moisture or any kind of infiltration does not affect the walls built of earthen bricks, have been for many decades part of the natural process of maintenance.

If this process is interrupted for any reason (because of cultural and/or technical factors), then the building falls into a progressive state of degradation, which could be stopped only if maintenance is carried out in time, because the earthen material is particularly vulnerable to the degradation produced by environmental agents.

The rain water that infiltrates from a failure, for example, reduce the resistance of the material and can cause the collapse of a portion of the wall, and if not repaired on time, the fall of the whole building.

Nowadays, corbelled dome houses, are in different states of conservation depending on the village: in those where people live and still have a strong care for the maintenance of the houses, they are in good condition; in those where the population has begun a process of migration, and there is no longer an emotional link with the buildings, they begin to deteriorate gradually; abandonment is, therefore, the primary agent of degradation.

5.2 *The impact of cultural factors in the process of degradation*

The corbelled dome buildings in the North of Syria, as seen, represent an adaptation process from the nomadic to the sedentary lifestyle, and therefore from sporadic habitation to permanent house, keeping the concept of a space suitable just for the satisfaction of basic needs. The cultural and architectural heritage of Northern Syria villages is otherwise subject to threats mainly related natural and social factors. The water and resources scarcity, the harsh climate and the isolation lead the inhabitants of villages to graduals change of lifestyle.

Nowadays the villages studied are subject of a new process of adaptation: the advent of modernity has led, on the one hand, to the migration of populations towards the city, and hence the abandonment of the domes, and on the other hand, to the emergence of new constructions with types and techniques that do not comply with the originals, which are gradually changing the character of the villages. This phenomenon is increasing because of a disinclination of the inhabitants to value the heritage that this singular architecture represents, and a lack of legal protection. Most types of deterioration in the corbelled dome buildings are the result of this gradual process of abandonment and lack of care.

So, the first step to stopping the abandonment and the deterioration process must be made from a reflection on the possible adaptation of these spaces to the contemporary needs of the local community, who will ultimately be responsible for maintenance of this outstanding heritage.

5.3 *The impact of technical factors in the process of degradation*

The different degradation forms that characterize the Syrian domed buildings, respond to the weaknesses related to the intrinsic characteristics of the material earth, its vulnerability to environmental actions, and to the mechanical behaviour of masonry construction. The static principles that the earthen bricks system is based on, are the same as for the simple masonry construction: the structural elements (walls) work in compression, the statical behaviour is guaranteed by a correct geometry that ensures the equilibrium, and the material works within certain strength limits. However, unlike the construction of stone or brick masonry, earthen constructions have lower mechanical performances (in terms of strength and stiffness), which can promote the development of certain types of pathologies.

Earthen constructions differ from brick masonry substantially for an especial sensitivity to the effects of water: the water runs down the wall or goes up through capillary moisture, which, if not checked, can produce numerous pathological effects.

Water is an essential element at the moment of the mixture performed for the construction of earthen bricks, but once the material is dried and it behaves as a monolithic entity, the presence of moisture in the structure may cause the brick to return to its plastic state, with the consequent loss of mechanical properties such as strength and stiffness. Water can cause mechanical erosion, surface tension of water soluble crystallised salts that are transported by capillary action, and cracking in the cases where there is an excess of water in the earthen elements that lowers the resistance to compression.

In the earthen domes of Syria, the phenomena of material leak alteration, as washing away and erosion are located predominantly at the base or at the corners of the walls; at the base is a symptom of poor drainage and stagnant water, which causes capillary moisture with a further disintegration of the affected portion. In cases where the loss of material is largely present on the walls, it is the result of prolonged exposure to the elements (rain and wind). The construction element that shows these kinds of symptoms has little cohesive property in its most degraded area; as a result of this, a removal from abrasion and crushing or a lifting followed by the flaking of one or more superficial layers can be originated and can produce some repercussions for the stability of the structure, when a resistant portion of a construction element is reduced.

Other pathologies affecting the earthen domes, due to building method or are linked to the shape and materials used, are:

– masonry comprised of a mixture of unfired earth bricks and rubble stones results in a differential creeping between the two kinds of masonry;
– the pendentive solution cannot support inclined forces transferred by the domes; these forces may deform or break the masonry.
– the brickwork quality is scarce; in consequence damage such as blistering and cracks running can be occur.

It's important to say that any kind of pathological event may remain isolated or, in case of non-intervention, may generate new degenerative processes on the individual components affecting the structural behavior of the whole structure.

5.4 *Interventions for improvement and repairing of damaged elements*

The interventions for improvement and repairing the damaged earthen dome elements will aim to slow the most frequent alteration processes: the partial or total loss of the plaster rendering, the subsidence of certain portions of the wall, and the presence of deep fissures, generally located in the corners where two walls meet at right angles, and in the discharging arc created under the tax line of the dome.

The three main act of intervention are:

– improvement or remake of the existing plaster coating, in order to delay maintenance, for protecting the internal structure of the walls from water and other erosive environmental factors;
– improvement of the weakest structural parts of the construction: the foundations and connection of perpendicular walls;
– improvement of the drainage water system, in order to remove moisture from the walls and protect the coating and the earthen material.

Regular up-keeping, improvements in plaster and hydrated lime techniques, strengthening by the addition of woven strips of organic matter would all be technical improvements that would ease the task of general maintenance.

The economic impact seems negligible given the advantages, but this would need looking at in finer detail. Hydrated lime, sand, fibres, as well as the quantities and method would need to be looked at with the local craftsmen so as to further fine-tune this advice.

The conservation and/or restoration practices may resort to replicate traditional maintenance practices, respecting the original materials, the construction techniques and typology, but can also determine innovation of solutions in order to improve the inhabitants comfort, achieving maximum suitability and compatibility with the existing building.

6 CONCLUSIONS

The chief scientific problem related to this outstanding vernacular architecture, undervalued for the past century or so on account of the difficulty of managing them from a standardized industrial and commercial point of view, lies in the reconstruction of value chains, knowledge and local production. Syrian earthen corbelled dome architecture expresses a consistent levels of local knowledge, of technical and procedural competence and of information on local materials, resources and practices which is of the utmost relevance.

The analysis presented in this research is the first step to increase the perception and consciousness of the value of this local earthen architectural heritage in an effort directed towards the sustainable development of this region.

Insufficient social value and a lack of knowledge is, in fact, at the base of the perceived poorness, inadequacy and unreliability of earthen technology, an 'old' material but, nevertheless, an indomitable expression of cultural diversity, variable in relation to the cultural and natural characters of places, capable of being a strategic material for the future of architecture and human settlements.

The conscious design of new architectures and heritage conservation requires a combination of specific scientific and experimental knowledge, along with both the local and tacit knowledge systems that are at present dispersed, unconnected and, in some respects, lacking.

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Defense tower turned into an artist bottega

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ABSTRACT: What seemed to be the rehabilitation of a home becomes a research and conservation work of an ancient defense tower. The restoration of original features is defined by reading the walls and the different materials: carved stone walls with a thickness of 1 m using fillers, mud walls and earthen plasters. The restoration is performed using techniques of traditional construction, repairing and reusing the own materials, looking for innovation in the proposed interventions, always under the parameters of sustainability.

1 ANTECEDENTES

El edificio está situado en Monzón de Campos en Palencia, adquirido por el artista plástico Miguel Macho, quien deseaba ubicar en él su vivienda y estudio-taller de pintura, con una zona de apertura al público, una Bottega de Artista.

Lo que parecía una casona con mucha envergadura con una de sus fachadas de piedra, prometedora, eso sí… resultó ser una fortaleza defensiva, un torreón, de un castillo o recinto fortificado mayor, que ha llegado intacto hasta la actualidad.

Una vivienda con su cuadra y almacenes se había apoderado del edificio original, lo había parasitado y fagocitado convirtiéndolo en otra “cosa” los nuevos usos dictaron necesidades y de las necesidades surgieron las formas: un baño aquí, una ventana allá, el cierre de huecos preexistentes, una escalera, techos bajos en las habitaciones para conservar el calor, una gloria en la estancia principal, un hueco en el forjado de madera para pasar la única bombilla de la casa… cierres, oclusiones, particiones y revestimientos, tantos que la fortaleza quedó completamente desfigurada, casi irreconocible.

El propietario es Licenciado en Bellas Artes y supo ver y apreciar que detrás de lo que se veía había mucho más.

2 ANÁLISIS DEL EDIFICIO

En un primer análisis podemos identificar diferentes épocas de factura del edificio, que se plasman en el uso de diferentes aparejos y técnicas. También algunos muros carecen de trabazón, identificándose claramente que pertenecen a una época posterior.

Al realizar el levantamiento del edifico la propia planta delata esta situación (Fig. 1).

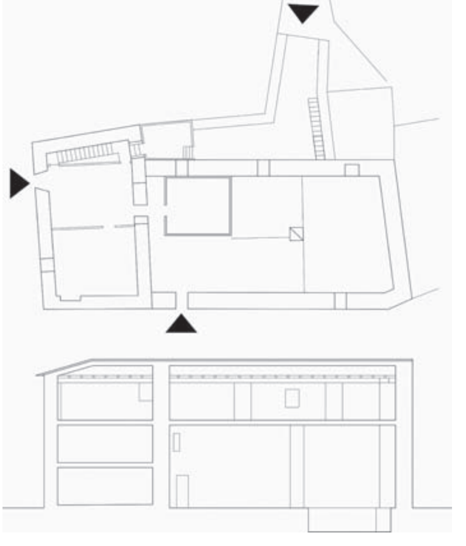

Figura 1. Planta y sección del estado inicial. (Autor: P. Diez).

El cuerpo primitivo, la torre, es muy regular con muros de sillarejo, hacia el exterior manifiesta una ventana de arco de medio punto, tiene una puerta de entrada y un bocarón de pajar que son claramente posteriores. Su interior es prácticamente ciego, la toma de datos se realiza con linterna, carece de ventilación e iluminación, pero se aprecian las marcas de ventanas que se han cerrado en sus cuatro caras.

La gran altura de este recinto había sido aprovechada para realizar otras construcciones en su interior: un baño, las cuadras, el pajar…a través de ellas emergía un pilar central que sustentaba la estructura de madera de la planta superior.

Se comunicaba esta cuadra con la vivienda con una portezuela pequeña, en un muro que tres metros más arriba delataba la traza de un arco.

El segundo cuerpo se adosa al original y en él está instalada la vivienda antigua (Fig. 2). En la calle lateral y en la esquina está ejecutada con sillares de mejor factura, pero el frente, la entrada principal es más confusa, alternándose con zonas de tapial revocado al exterior y con huecos muy pequeños. Por encima de la puerta una grieta muy pequeña pero extrañamente curvilínea delata la posible presencia de un arco. El interior es lúgubre, muy húmedo y con estancias de muy poca altura. Por una escalera se accede a las plantas superiores. En la primera planta una grieta parece marcar la traza del arco que se aprecia desde la cuadra, cortado aquí por el forjado.

Bajo la escalera en la planta baja se sitúa la entrada de la cocina, en un lugar de paso de acceso al patio lateral de la casa (Fig. 3). La cocina se sitúa en otro cuerpo añadido a la construcción primitiva, en el que se está desprendiendo la pintura por la humedad, dejando al descubierto algunos sillares y la posibilidad de que ahí exista otro arco.

El tercer cuerpo en altura, último añadido del edificio, se corresponde con el desván de la vivienda y la panera o almacén, es completamente diáfano. Se levanta sobre los muros de piedra, y unifica todo el edificio bajo una sola cubierta. Este cuerpo es de tapial entre machones de piedra que atraviesan todo el espesor del muro (Fig. 4). El tapial ha perdido su revoco y se encuentra muy erosionado, sobre todo en la cara norte hacia el patio. La cubierta de estructura de madera está en muy mal estado de conservación.

Figura 2. Fachada a la entrada principal. (Autor: M. Macho).

3 EL PROYECTO

La premisa principal del proyecto es conservar y sacar a la luz la estructura original del edificio: la torre, desmontar los añadidos y conseguir que este rescate sea compatible con los nuevos usos.

La propuesta de distribución sitúa la vivienda en la planta superior, a modo de loft, en el espacio diáfano que se dedicaba a almacén, planteando acceder a ella por una escalera situada en el patio lateral que no interfiera con las estructuras históricas. La planta baja será el estudio-bottega del artista que respetará la estructura antigua sin alterar su configuración y un patio delantero, donde antes se ubicaba la vivienda, será el acceso principal. (Fig. 5).

El proponer el vaciado completo de la antigua vivienda permitirá crear este patio, resolver los accesos independientes a la vivienda y al estudio, conservar los muros de sillar, liberar los arcos ocultos en el muro permitiendo que se vean en toda su envergadura y permitir una lectura clara del edificio original y el proceso de añadidos que ha sufrido.

Figura 3. Fachada lateral al patio. (Autor: M. Macho).

Figura 4. Fachada lateral a la calle. (Autor: M. Macho).

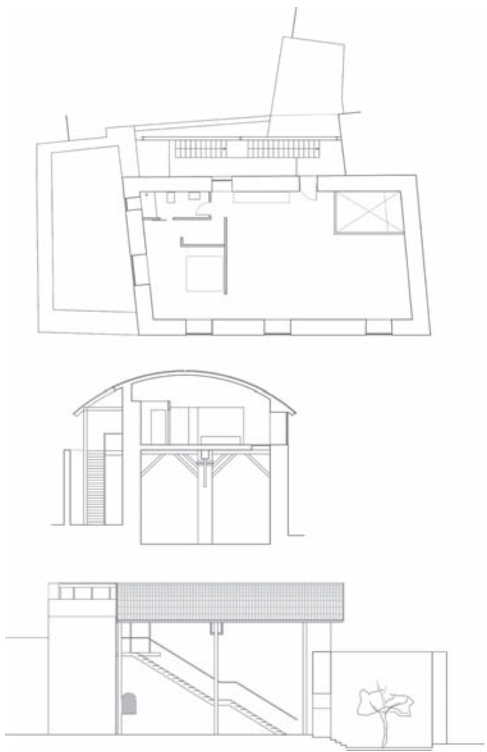

Figura 5. Planos de proyecto: planta de la vivienda, sección transversal y alzado al patio lateral de acceso a la vivienda.

Figura 6. Arcos de acceso. (Autor: M. Macho).

Figura 7. Arcos de acceso. Interior. (Autor: M. Macho).

4 DESCUBRIMIENTOS Y DATACIÓN

Comienza la rehabilitación y con ella los descubrimientos: el edificio manda, vamos leyendo los paramentos y eliminando los añadidos, abriendo, quitando, retirando y a la vez seleccionando y catalogando, todo es reutilizable y reciclable: la piedra, la teja, las baldosas, la madera, las puertas…también en el medio rural esto tiene su propio mecanismo, tu lo pones en la puerta y antes de un día si alguien no te lo ha pedido es porque ya algún otro lo ha "reciclado".

Al eliminar la vivienda delantera y las construcciones de la cuadra aparece un arco gótico de 3 m. de altura que da acceso al recinto prácticamente rectangular de la fortaleza. El arco está intacto (Fig. 6) y tiene una marca de cantero que coincide con las que aparecen en los sillares de los arranques de la parte más baja. Estas marcas de cantería coinciden con la Abadía de Husillos, muy cercana, con lo que podemos datar la construcción de la torre en el s. X periodo en el que se produce un asentamiento de población en esta zona cercana a la Iglesia.

Posteriormente a la torre se le adosa un muro, que como el pilar del interior son del s.XIV. Este pilar soporta la estructura de madera del forjado de la primera planta que también es la original (Fig. 8). Cercana a la base se encontró el arranque de una columna que podría haber sido el soporte original.

Desde la entrada el suelo va en desnivel, seguramente este era el refugio de los caballos, y la altura final, eliminados los escombros, llega hasta 5 m libres. En las cuatro fachadas se abren ventanas saeteras y aparecen otras menores con arco de medio punto la última en descubrirse provista de un orificio defensivo. Toda la construcción es de piedra de sillería de mayor o menor entidad, con los morteros de rejuntado de tierra y de relleno, aunque el cuerpo superior es de tapial, puede leerse como proviene de una factura posterior de integración de los dos cuerpos bajos.

El edificio se encuentra situado en el centro del pueblo con orientación suroeste, y claramente formó parte de un asentamiento defensivo mayor, de tiempos de la reconquista del Conde Ansur fundador, más delante, de la ciudad de Valladolid.

Figura 8. Interior de la fortaleza. (Autor: M. Macho).

5 LA REHABILITACIÓN: CRITERIOS DE INTERVENCIÓN-ACCIONES

Una vez eliminados los elementos distorsionantes, cuando el edificio muestra ya su forma original comienza la restauración de los muros: se consolidan las fábricas de mampostería, sillares y tapiales, se cosen las fisuras, se picotean las juntas y se rejunta utilizando morteros de cal.

Las zonas con morteros antiguos de tierra se respetan lo máximo posible consolidando las zonas exteriores.

El criterio a seguir es mostrar de la forma más respetuosa las diferentes técnicas constructivas existentes incluso en el mismo paramento, poner de manifiesto su morfología dando como resultado el collage de la historia del edificio. De hecho mantener la “estética de la ruina” y su poder evocador favorece al edificio.

5.1 *Planta baja*

En la planta baja una vez eliminada la parte delantera de vivienda aparece otro arco de tres metros de altura, le faltaba la clave y algunas dovelas, que se reponen para conservarlo (Fig. 9).

Habían sido cortadas para abrir una ventana en la planta primera. Esta fachada está muy dañada, los muros de sillar al exterior en el interior son de tapial y existen grietas entre las hojas.

Figura 9. Restauración del arco de entrada. (Autor: P. Diez).

Probablemente se derrumbó una parte que después se rehízo solamente con tapial. El agua que ha ido entrando aumentó el tamaño de las grietas, se retacan y se traban reponiendo posteriormente los morteros de protección y acabado, se utiliza mortero de cal y las esquinas se cosen con varillas de acero inoxidable de hasta 1 m de longitud.

En el interior de la torre se sanea el suelo y se limpian los muros, pero sobre todo en la que corresponde con la cara norte se ha perdido parte del mortero del rejuntado.

Figura 10. Fachadas exteriores restauradas. (Autor: J. Muñoz).

5.2 *Estructura de madera y cubierta*

El mal estado de la cubierta hizo que alguna de las vigas de madera estuvieran dañadas y fuera necesario sustituirlas. Las que se mantienen reciben un tratamiento antixilófagos.

Para la realización del forjado se reutiliza la estructura existente, realizando un sándwich in situ con doble panel de madera con costillas interiores para nivelar y formar una cámara de aire y aislamiento de lana en su interior. El solado es de tarima sobre rastreles.

La solución de la cubierta es un ejercicio de innovación y experimentación, buscando por un lado reducir los costes lo máximo posible y por otro un efecto plástico necesario para solucionar la estética del edificio. Se proyecta una cubierta curva que cubra de una forma asimétrica el interior de la vivienda que se sitúa en la planta de arriba y el patio cubierto donde se sitúa la escalera de acceso. (Figs. 10 and 11).

Está realizada con panel de madera contralaminado de 13 m. de longitud curvados in situ para adaptarse a la forma deseada, el montaje de todo ello ¡2 días! con tres personas. Las prestaciones térmicas de la cubierta se mejoran añadiendo aislamiento térmico (lana de roca) y una lámina impermeable difusora del calor. Por último el material de cobertura es acero corten que se adapta a la curvatura y se pliega para resolver los remates laterales y el canalón.

Figura 11. Fachada lateral al patio. (Autor: M. Macho).

5.3 *Planta primera*

En el interior de la planta primera se reutilizan y reciclan materiales de la propia casa, las puertas y solados.

Se descubren los antiguos yesos sobre el tapial y se consolidan, conservando también los pictogramas y escritos de las paredes (en uno de ellos aparece una @ del año 1872). Para ello se limpian a esponja y se les aplica un consolidante. En la actualidad se está transcribiendo el contenido.

Se recuperan los huecos originales de las ventanas en el tapial y se realiza un tratamiento exterior, con la apertura de las ventanas del cuerpo superior y el revoco con mortero de cal y restauración del tapial (Fig. 12). Aparece embebido en el muro un dintel mudéjar, madera labrada con decoraciones y restos de pintura blanca y rojiza. Se limpia y se le aplica un tratamiento protector y antixilófago.

6 AHORRO ENERGÉTICO

La planta primera de la vivienda se calefacta, su orientación es óptima (norte cerrado y abierto al sur) protegida con la envolvente de los muros de carga de tapial de 1 m de espesor. (Fig. 13)

Figura 12. Interior de la planta primera. (Autor: J. Muñoz).

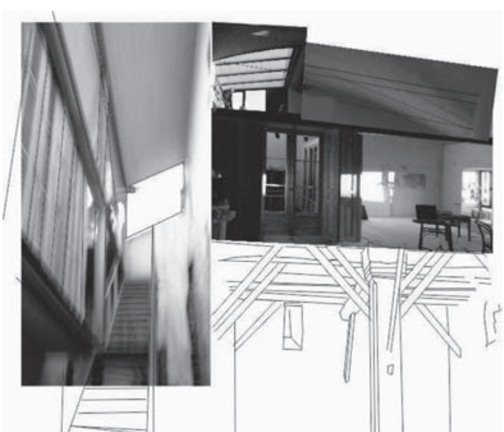

Figura 13. Montaje sobre la sección transversal. (Autor: M. Macho).

El sistema de calefacción y producción de agua caliente es una caldera de biomasa que se sitúa en el cuarto de instalaciones en la zona de acceso.

7 PARÁMETROS DE SOSTENIBILIDAD

El Proyecto de rehabilitación se basa en uno de los primeros parámetros de la sostenibilidad que es la reutilización como base de la prolongación de la vida útil de una construcción - consumo ya realizado.

Reutilización y reciclaje de lo construido.

Reutilización y reciclaje de la arquitectura.

El proyecto utiliza estrategias como la reducción del consumo, la reparación en lugar de la sustitución y el reciclaje. Construcción como unión de soluciones tradicionales y sencillas con avances tecnológicos.

Ecodiseño.

La vivienda se sitúa en lo que era la antigua panera o almacén de grano de la casa, reutiliza sus antiguos muros de tapial de un metro de espesor aportando una solución de cubierta novedosa en cuanto a la forma de utilización del material (tablero de madera contralaminado) para cubrir grandes luces sin necesidad de estructura de soporte adicional, economizando al máximo el consumo.

La flexibilidad del espacio creado la hará ser capaz de albergar cualquier uso, presente o futuro con lo que se consigue la máxima eficiencia de los recursos empleados.

8 CONCLUSIONES

El proyecto no es sólo una rehabilitación, es un descubrimiento, o mejor dicho, redescubrimiento. La Torre defensiva aún estando situada en el centro del pueblo había pasado inadvertida, oculta bajo la apariencia de otro edificio.

La restauración realizada ha puesto ante nuestros ojos una gran cantidad de interrogantes, de momento sólo hemos podido responder a sus patologías, los tratamientos que la lectura del edificio pedía de la forma más sencilla y económica, pero se han abierto muchas posibilidades y sobre todo un lugar para la creación.

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Earth-based repair mortars: Experimental analysis with different binders and natural fibers

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ABSTRACT: This work is an excerpt of the first author's PhD work, and intends to contribute for a better knowledge of earth-based repair mortars. The studied mortars are made of a commercial earth (consisting mainly of clay), and other components namely: sand; powder hydrated air-lime; natural hydraulic lime; Portland cement; Roman cement and natural fibers. The experimental analysis of the mortars in the fresh state consisted in the determination of the consistence by flow table and bulk density. In the hardened state the tests conducted were: linear and volumetric shrinkage; water absorption capillary coefficient; drying test; dynamic modulus of elasticity by measuring the fundamental resonance frequency; flexural and compressive strengths.

1 INSTRUCTION

Rammed earth is one of the most important earth building techniques, both in traditional construction and modern earth architecture. In Portugal, the number of buildings being built with this technique or simply rehabilitated is increasing. However, it is common to find anomalies, often due to the use of incompatible materials, in both types of interventions.

Degradation of the exterior surface of rammed earth constructions is very common. It is also frequent to find rammed earth constructions repaired by applying cement-based mortars in the attempt to overcome the decay; but these mortars normally end up causing additional problems to the construction, especially when used in unstabilised earth constructions (Guelberth & Chiras 2008; Walker & Standards Australia 2001).

The surface repairs should be made of mortars with physical, mechanical and chemical properties similar to those of the walls. Indeed, the main requirement of repair mortars should be the protection of the original material of the walls. The durability of the repair mortar itself should come only as a second order requirement, but this is often not respected. Mortars have to ensure the long-term integrity of the bond to the earth substrate; this property is very important but also difficult to achieve.

This article intends to contribute for a better knowledge of earth-based repair mortars. An experimental campaign was conducted aimed at the development of earth-based mortars for the repair of rammed earth walls. It consisted of the following types of laboratory tests: (i) in the fresh state: determination of the consistence by flow table and bulk density; (ii) in the hardened state: linear and volumetric shrinkage; water absorption capillary coefficient; drying test; dynamic modulus of elasticity by measuring the fundamental resonance frequency; flexural and compressive strengths.

2 MATERIALS

A commercial earth, herewith designated "reference-earth", with a large percentage of clay, was used as binder. Sand, mainly composed by quartz and with dimensions in the range of 0.6 to 2.0 mm, was also used in the mortars subjected to the present experimental campaign. Figure 1 shows the particle-size distribution of the reference-earth and the sand. The addition of sand had the main objective of reducing the shrinkage which otherwise would be very high because the reference-earth consists essentially of clay. The basic volumetric composition of the mortars was 1:3 (reference-earth: sand).

The mortars included also the addition of 0%, 5%, 10% or 15% of binder, and 0% or 5% of hemp fibers (F) (percentages by weight in relation to the earth). Four types of binder were used: powder hydrated air-lime (AL) EN 459-1 CL 90-S; natural hydraulic lime (NHL) EN 459-1 NHL5; Portland cement (PC) CEM II/BL 32.5 N and Roman cement (RC).

The compositions of the ten distinct groups of earth-based mortars that resulted from these mixtures are presented in Table 1.

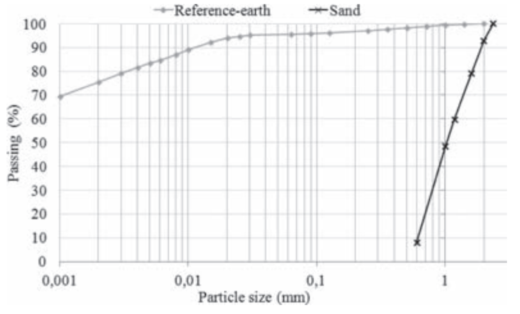

Figure 1. Particle size distribution nomograms for the reference-earth and sand.

3 EXPERIMENTAL METHODOLOGY

The experimental analysis of the mortars in the fresh state consisted in the determination of the consistence by flow table (CEN EN 1015-3 1999) and the bulk density (CEN EN 1015-6 1998). In the hardened state, the following tests were conducted: linear and volumetric shrinkage (Alcock's test); capillary water absorption (RILEM TC 25-PEM 1980b) and drying (RILEM TC 25-PEM 1980a) which were carried out sequentially using the same six cubic specimens (dimensions 50 × 50 × 50 mm) for each mortar; the dynamic modulus of elasticity by the fundamental resonance frequency (CEN EN 14146 2004), the flexural and compres-

Table 1. Composition of the ten groups of mortar.

Group of mortar reference-earth (MRE)	Designation	Binder (%)* AL	NHL	PC	RC	F (%)*
Reference-earth	MRE	-	-	-	-	-
Reference-earth with fibers	MRE_F	-	-	-	-	5
Reference-earth with hydrated air-lime	MRE_AL5	5	-	-	-	-
	MRE_AL10	10	-	-	-	-
	MRE_AL15	15	-	-	-	-
Reference-earth with hydrated air-lime and fibers	MRE_AL5_F	5	-	-	-	5
	MRE_AL10_F	10	-	-	-	5
	MRE_AL15_F	15	-	-	-	5
Reference-earth with natural hydraulic lime	MRE_NHL5	-	5	-	-	-
	MRE_NHL10	-	10	-	-	-
	MRE_NHL15	-	15	-	-	-
Reference-earth with natural hydraulic lime and fibers	MRE_NHL5_F	-	5	-	-	5
	MRE_NHL10_F	-	10	-	-	5
	MRE_NHL15_F	-	15	-	-	5
Reference-earth with Portland cement	MRE_PC5	-	-	5	-	-
	MRE_PC10	-	-	10	-	-
	MRE_PC15	-	-	15	-	-
Reference-earth with Portland cement and fibers	MRE_PC5_F	-	-	5	-	5
	MRE_PC10_F	-	-	10	-	5
	MRE_PC15_F	-	-	15	-	5
Reference-earth with Roman cement	MRE_RC5	-	-	-	5	-
	MRE_RC10	-	-	-	10	-
	MRE_RC15	-	-	-	15	-
Reference-earth with Roman cement and fibers	MRE_RC5_F	-	-	-	5	5
	MRE_RC10_F	-	-	-	10	5
	MRE_RC15_F	-	-	-	15	5

*Percentages by weight in relation to the reference-earth.

sive strength (CEN EN 1015-11 1999) were also performed sequentially on the same six prismatic specimens (dimensions 40×40×160 mm) of each mortar. These test methods are discussed in detail in Gomes et al (2012a).

Figures 2 to 5 shows the capillary absorption test, dynamic modulus of elasticity test, the flexural strength and the compressive strength tests, respectively.

Note that several of the tests are not easily applicable to earth mortars due to the low mechanical strength and sensitivity to the action of water of earth materials. Therefore, numerous preliminary tests and the adaptation of existing testing protocols were often necessary.

3.1 *Preparation of the earth-based mortars*

In the mixing of the mortars, CEN EN 196-1 (2005) was followed as closely as possible. However, this

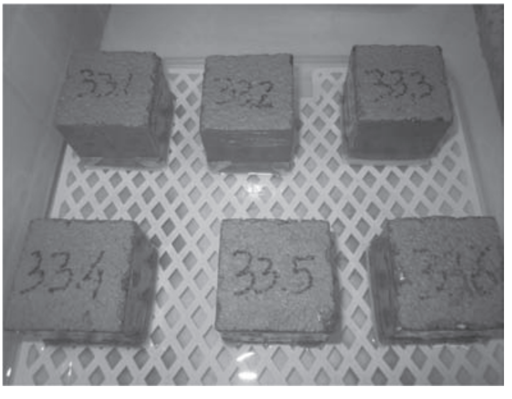

Figure 2. Capillary absorption test on the MRE_RC10 specimens.

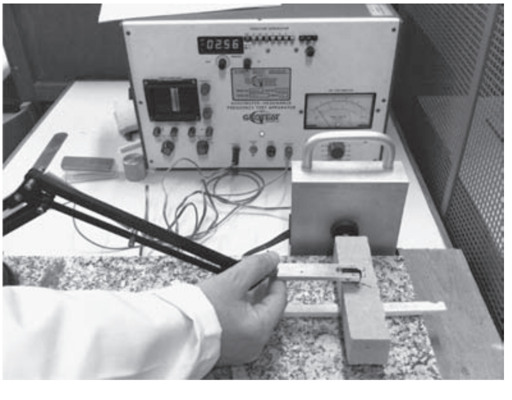

Figure 3. Dynamic modulus of elasticity test on the MRE_PC10 specimen.

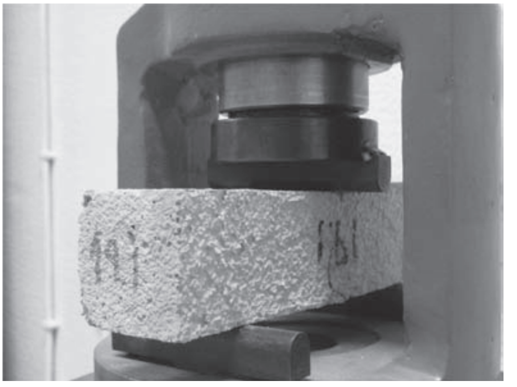

Figure 4. Flexural strength test on the MRE_AL15_F specimen.

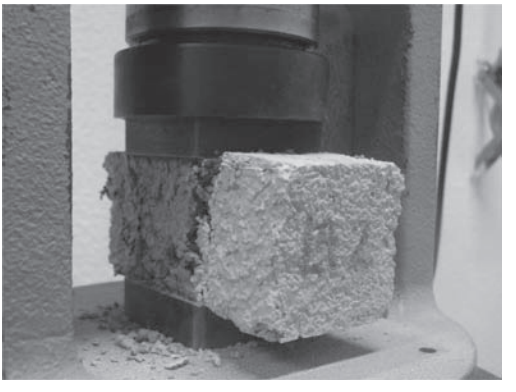

Figure 5. Compressive strength test on the MRE_AL15_F specimen.

standard is not specific either for repair mortars or for earth-based mortars, thus some adjustments had to be made.

A mechanical mixer was used, composed by a vat of stainless steel with a capacity of 3 l and a paddle mixer driven by an electric motor. It was necessary to increase the mixing time in relation to that specified in the standard because the mixtures have a large percentage of clay and, else, a good homogenization would be difficult to achieve.

The methodology was as follows: manual homogenization of the material; introduction of water into the vat, followed by introduction of the material; manual mixing for 2 minutes (to assure a uniform wetting of the mixture, otherwise, even in low speed, the mixture would splash); mixing at slow speed for 150 seconds; a 90 second halt (in the first 15 seconds, the adhering mortar was removed from the walls of the vat with a rubber spatula and added to the remainder mortar); finally, continued mixing at slow speed for an additional 60 second period.

3.2 *Curing conditions*

CEN EN 1015-11 (1999) specifies the curing conditions of various types of mortar (cement, lime) but not those of earth-based mortars. However, since there was no alternative, the method recommended for lime mortars was followed, albeit with some adjustments. The specimens were kept in the mould during 7 days, in a sealed polyethylene bag. After this period the bag was removed. The specimens remained in the mould for 7 additional days, in a conditioned room (20 ± 2 °C and 50 ± 5% RH). After this period the specimens were demoulded and remained in the same room until they reached the age of 90 days. When they reached the age of 28 days, the mortars with hydrated air-lime (AL) were placed for 7 days in a carbonation chamber (5% CO_2, 21 ± 2 °C and 71 ± 2% RH) to ensure complete carbonation.

4 RESULTS AND DISCUSSION

4.1 *Tests on fresh mortars*

The flow values were adjusted to the target 160–176 mm interval which, as previously shown (Gomes et al 2012c), corresponds to earth-based mortars with excellent workability. Table 2 shows the flow values obtained for the earth-based mortars, which ranged from 159 to 180 mm. The bulk density of the fresh mortars and the water/dry material ratio are also reported in Table 2.

As seen in Table 2, the water/dry material ratio was systematically higher for the mortars with fibers. Thus, fibers appear to increase the amount of water needed to achieve good workability. This can be clearly observed for the MRE mortar which had a higher water/dry material ratio than the MRE_F mortar, while having equal flow. This is probably due to the fact that hemp fibers absorb part of the water used in the mixture. The variation of flow with binder content did not show a clear trend, which suggests that the slight differences in binder

Table 2. Flow, bulk density and shrinkage of the earth-based mortars.

Designation	Water/dry material (%)	Flow (mm)	Bulk density (kg/m³)	Shrinkage (%)	
				LS	VS
MRE	31	170	1872	1.15	4.06
MRE_F	34	170	1783	0.90	0.95
MRE_AL5	30	172	1873	1.59	7.83
MRE_AL10		172	1871	1.77	6.39
MRE_AL15		170	1854	1.36	6.21
MRE_AL5_F	33	165	1787	0.48	4.18
MRE_AL10_F		163	1776	0.23	6.03
MRE_AL15_F		163	1770	0.27	6.02
MRE_NHL5	29	171	1878	0.70	4.65
MRE_NHL10		172	1879	0.61	3.77
MRE_NHL15		172	1880	0.57	5.49
MRE_NHL5_F	32	169	1793	1.40	4.57
MRE_NHL10_F		166	1794	1.65	2.80
MRE_NHL15_F		166	1798	1.51	4.30
MRE_PC5	29	176	1893	0.86	2.52
MRE_PC10		176	1897	0.30	2.43
MRE_PC15		180	1902	0.37	3.19
MRE_PC5_F	33	169	1796	0.50	2.60
MRE_PC10_F		173	1798	0.22	1.84
MRE_PC15_F		173	1800	0.18	2.14
MRE_RC5	29	172	1889	1.37	4.88
MRE_RC10		173	1892	1.94	5.17
MRE_RC15		159	1876	1.72	4.07
MRE_RC5_F	32	168	1811	1.00	1.12
MRE_RC10_F		172	1807	1.21	2.01
MRE_RC15_F		163	1786	1.41	1.55

LS: Linear shrinkage; VS: volumetric Shrinkage.

content do not significantly affect the workability of the mortars.

Fiber containing mortars have also lower density (Table 2) due to their higher water content and to the fact that hemp fibers exhibit very low density.

4.2 *Linear and volumetric shrinkage*

The results of the linear and volumetric shrinkage, summarized in Table 2, were quite variable. Interestingly, linear shrinkage does not appear to be representative of total shrinkage. Also, no clear relationship was observed between binder content and either linear or volumetric shrinkage. The use of fibers reduced the linear and volumetric shrinkage for all mortars, with the exception of the linear shrinkage of natural hydraulic lime mortars.

Figure 6 shows the total shrinkage of the MRE_PC15 material, following the Alcock´s test.

The mortars of Portland cement and hydrated air-lime with fibers showed the lowest linear shrinkage, while Roman cement and Portland cement mortars with fibers showed the lowest volumetric shrinkage.

The linear shrinkage did not exceed 2% in any of the mortars. New Zealand Standard 4298 (1998) considers 3% as the limit for linear shrinkage of earth mortars, as obtained in the Alcock's test. Thus, it can be concluded that all tested mortars had acceptable shrinkage.

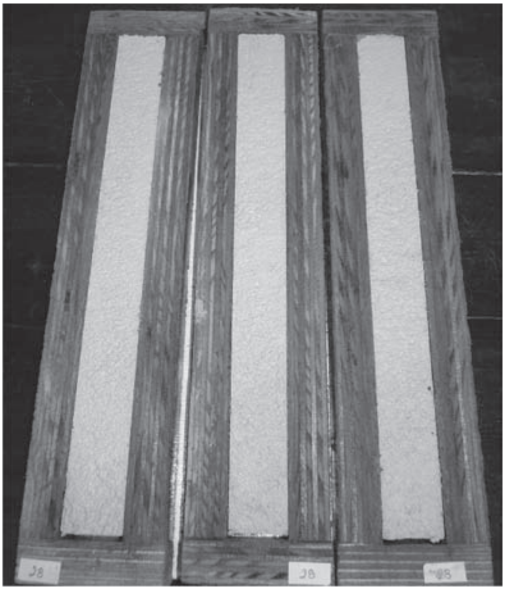

Figure 6. Alcock's test on the MRE_PC15 material.

4.3 *Capillary water absorption*

Capillary water absorption curves express the amount of water absorbed per unit area ($kg.m^{-2}$) as a function of the square root of the elapsed time ($s^{1/2}$). The slope of the linear portion of these curves corresponds to the capillary absorption coefficient (CC), shown in Table 3.

It can be concluded that: (i) the water absorption coefficient increases with the percentage of binder; (ii) there is not a clear or significant influence of the fibers on the capillary absorption coefficient; (iii) the highest results of the water absorption coefficient were observed for the Portland cement binder, when compared to the mortars with the same content of other binders, both with and without fibers.

4.4 *Drying test*

The results of the drying test can be expressed by a single quantitative parameter, the Drying Index (Normal 29/88, 1991). The Drying Index (DI) values obtained for the tested mortars are listed in Table 3.

For the same type of binder and considering similar binder content, it can be conclude that drying was slower for the mortars with fibers (with the single exception of the MRE_PC10 mortar).

Generally, for the same binder content, drying was faster in the reference-earth mortars (MRE and MRE_F), natural hydraulic lime without fibers and Roman cement mortars without fibers. The slowest drying was observed for the Portland cement mortars, with or without fibers.

A general trend was found for drying to become slower as the binder content increased.

4.5 *Dynamic modulus of elasticity*

The test results for the dynamic modulus of elasticity are shown in Table 3. The introduction of fibers did not appear to significantly affect in a clear way the modulus of elasticity.

The highest modulus (lower deformability) was verified for the Roman cement mortars with fibers.

The dynamic modulus of elasticity decreases with the binder content for all mortars, with the exception of the hydrated air-lime mortar, whose values increased, for the mortars with and without fibers.

4.6 *Flexural and compressive strength*

The results for both the flexural and compressive strength tests are also given in Table 3.

For the same binder content, the introduction of fibers: (i) increased the flexural strength in all cases except for the hydrated air-lime and reference-earth

Table 3. Capillary absorption coefficient, drying index, dynamic modulus of elasticity, flexural and compressive strength of the tested mortars.

Designation	CC (kg/($m^2.s^{1/2}$))	DI	E_{DM} (MPa)	FS (MPa)	CS (MPa)
MRE	0.138	0.122	1065	0.17	0.51
MRE_F	0.226	0.130	967	0.14	0.47
MRE_AL5	0.226	0.139	576	0.08	0.11
MRE_AL10	0.473	0.156	609	0.11	0.20
MRE_AL15	0.509	0.154	683	0.13	0.28
MRE_AL5_F	0.208	0.154	532	0.06	0.25
MRE_AL10_F	0.339	0.173	551	0.08	0.31
MRE_AL15_F	0.465	0.184	597	0.12	0.45
MRE_NHL5	0.102	0.121	1190	0.12	0.31
MRE_NHL10	0.120	0.128	821	0.09	0.26
MRE_NHL15	0.381	0.133	604	0.08	0.19
MRE_NHL5_F	0.050	0.131	1160	0.17	0.44
MRE_NHL10_F	0.114	0.151	954	0.15	0.36
MRE_NHL15_F	0.262	0.164	759	0.12	0.38
MRE_PC5	0.259	0.148	537	0.09	0.18
MRE_PC10	0.449	0.183	312	0.06	0.17
MRE_PC15	0.566	0.181	183	0.04	0.18
MRE_PC5_F	0.333	0.150	564	0.11	0.29
MRE_PC10_F	0.505	0.178	286	0.06	0.25
MRE_PC15_F	0.682	0.187	214	0.06	0.27
MRE_RC5	0.058	0.121	1129	0.20	0.39
MRE_RC10	0.147	0.130	1105	0.20	0.39
MRE_RC15	0.205	0.136	775	0.19	0.33
MRE_RC5_F	0.096	0.142	1239	0.20	0.48
MRE_RC10_F	0.238	0.150	1214	0.25	0.58
MRE_RC15_F	0.395	0.150	967	0.23	0.53

CC: capillary absorption coefficient; DI: drying index; E_{DM}: dynamic modulus of elasticity; FS: flexural strength; CS: compressive strength.

mortars, where the values decreased; (ii) increased the compressive strength, except for the reference-earth mortars.

There was no clear relationship between binder content and flexural or compressive strength. The authors think that, because the binder content values are always small, they do not result in significant differences in terms of mechanical strength.

For the same binder content, the reference-earth mortars and Roman cement mortars presented the highest flexural and compressive strengths, with and without fibers.

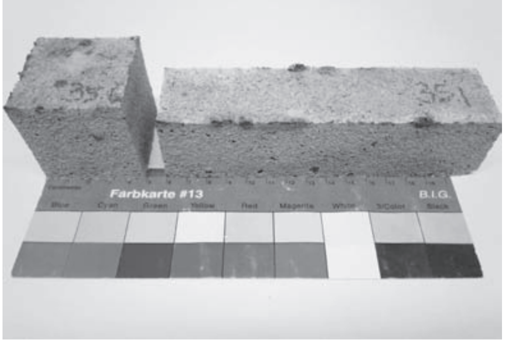

Figure 7. Fungus on the MRE_RC5_F specimens.

4.7 *Biological growth*

In three out of the four groups of binders, fungi appeared in the mortars with hemp fibers. The hydrated air-lime mortars were the exception. The highest amount of fungi appeared in the mortars with the lowest binder content, decreasing with increasing binder content.

Fungi appeared on the surface of the MRE_NHL5_F and MRE_RC5_F mortars (Fig. 7) while the specimens were still in the respective moulds. For the following mortars, fungi appeared during the course of the tests: (i) in MRE_NHL15_F, MRE_PC10_F and MRE_RC15_F, biological growth had no great significance, as it was hardly noticeable; (ii) differently, MRE_NHL10, MRE_

PC5_F and MRE_RC10_F showed a large amount of fungi.

It is believed that such occurrences are linked to the presence of the hemp fibers. The fibers may enhance the biological growth, which is inhibited or hindered in some cases (in mortars with hydrated air-lime and mortars with the highest percentage of other binders), possibly due to pH changes. Traditionally, air-lime was used for health purposes, which is consistent with the fact that no fungi were found in the hydrated air-lime mortars.

5 WORK IN PROGRESS

To verify the compatibility, the applicability and effectiveness of the earth-based repair mortars on a rammed earth substrate, rammed earth blocks were manufactured.

The material used in these blocks was obtained from non deteriorated parts of walls of old rammed earth buildings in south Portugal (Alentejo region). Earth with three different compositions was collected, with each composition corresponding to a different building. The three earth materials were chosen to represent different grain size distributions and types of clay used in rammed earth walls, in the Alentejo. The characteristics of the collected material and the location of the respective buildings are described in Gomes et al (2012b).

The rammed earth blocks had dimensions of 30 × 20 × 28 cm. Two types of anomalies commonly found in the exterior surfaces of rammed earth walls were recreated, in a typified manner, on the sides of the rammed earth blocks: (i) deep holes; (ii) superficial loss of material. The blocks are being kept at 20 ºC and 50% RH for two years. Their manufacturing procedure is described in Gomes & Faria (2011).

The earth-based mortars will be applied in both types of anomalies in order to verify their applicability and evaluate its behavior as repair mortars. These will then be subjected to artificial ageing tests.

6 CONCLUSIONS

Regarding the addition of fibers in the mortars, it was found that: (i) shrinkage, both linear and volumetric, decreases for all mortars with the exception of the linear shrinkage of natural hydraulic lime mortars; (ii) there is no clear influence on the capillary absorption coefficient; (iii) the drying index increases; (iv) there is no clear influence on the dynamic modulus of elasticity; (v) the flexural and compressive strength decrease in most cases (vi) biological growth appears recurrently associated to the hemp fibers, except in the case of the hydrated air-lime mortars which seem to hinder such development.

Regarding the binder type, it can be concluded that: (i) there is apparently no relationship between linear and volumetric shrinkage and binder content; (ii) the capillary water absorption coefficient increases with the percentage of binder; (iii) generally, drying becomes slower as binder content increases; (iv) the dynamic modulus of elasticity decreases with increasing binder content for all the mortars, except the hydrated air-lime mortars with and without fibers; (v) there is no clear relationship between the variation in binder content and the flexural and compressive strength.

The present work is part of an ongoing effort to assess the adequacy of earth-based mortars as repair mortars for rammed earth materials and further studies will define their most appropriate application conditions.

This work is an excerpt of the first author's PhD work. The mortars with the best results will, in a second phase of the work, be applied on rammed earth blocks manufactured for this purpose, and then subjected to artificial ageing tests.

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Rammed Earth Conservation – Mileto, Vegas & Cristini (eds)

Buddhist clay sculptures in Central Asia: Conservation and restoration problems

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ABSTRACT: The so-called "Greco-Buddhist art", originated by the fusion of Hellenistic and Indian influences, represents one of the most significant aspects of transfer of knowledge along the Silk Road. This artistic expression is strictly related to the diffusion of Buddhism in Central Asia, which is reflected on the appearance of several Buddhist monasteries and temples along the main geographical routes. In the last century, several research teams have conducted archaeological excavations in these buildings. These excavations have revealed an amazing but extremely fragile heritage of earthen architecture and related decoration, including paintings, high reliefs and monumental sculptures in clay. In the last decade the investigation in restoration practices has increased with respect to earthen architecture and paintings, however, an improvement of the practices related to sculptures conservation is still needed. This paper focuses on this gap, discussing conservation and restoration practices of clay sculptures, and proposing future research directions.

Monumental clay sculptures of Bamyan, first half of 6st century AD (Bamyan Valley, Hazarajat district, Afghanistan) were well known by historians and archaeologists, but after their destruction in 2001 have become world-famous, generating numerous debates and fruitful researches (Petzet, 2009). However, the previous manifestations of such colossal artistic expression, which has as basic materials for their creation stone, but also clay, are yet poorly known.

Between the 1st-3rd centuries AD, the establishment of Kushan Empire in Central Asia favored the consolidation of long distance trade routes between Asia and Europe, known as the Silk Road.

Kushan kingdom brought politic stability to this area and generated a period of economic prosperity which favors commercial trade and cultural exchanges. Within the sphere of cultural interactions, should be remarked those concerning Hellenism and Buddhism traditions. Hellenism was brought by Alexander the Great to Central Asia in the 4th century BP and consolidated during the 3rd and 2nd centuries by the establishment of the so-called Greco-Bactrian kingdoms, principally located between the current north of Afghanistan and south of Uzbekistan and Turkmenistan; on the other hand, Buddhism spread from the northeastern Indian continent towards Central Asia since the 3rd century BP. From the relationship between both, emerged a new artistic expression, known as "Greco-Buddhist" (Foucher, 1905).

This art represents the first figuratives sculptural manifestations of Buddha and reflects a strong inspiration of elements inherited by the Hellenistic sculptural tradition (Galli, 2011; Kramrisch, 1966).

This syncretism led to the spreading of spectacular and refined decoration of Buddhist architecture in a great part of Central Asia. Examples of this decoration are represented by numerous sculptures in temples and monasteries. However, while in the north of the Indian subcontinent the material used was stone, in the major part of Central Asia, raw earth is the essential sculptural material. Many of these buildings were discovered during archaeological interventions conducted since the end of 19th century. However, unlike has been made an international effort in recent decades towards the preservation of earthen architecture, it is still missing a research program considering the clay sculptures as a specific conservation problem but in the same time an integrative part of the architecture.

This paper aims to make aware to this conservation problem and is organized around: a) the examination of the clay sculpture artistic tradition and production techniques, b) a state of the art of the researches which have attempted to solve the problem, c) a review of recent methodologies related to the preservation of archaeological materials in clay which might be adapted to the monumental clay sculpture.

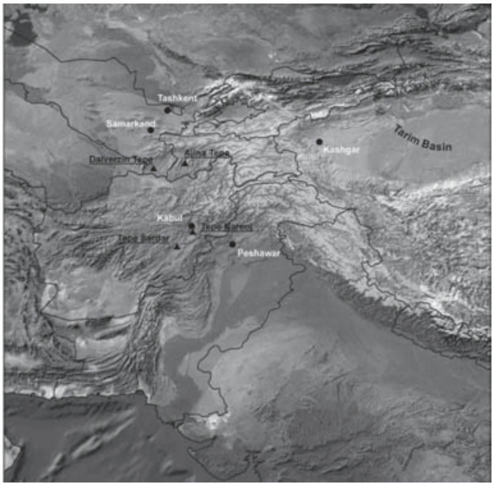

Figure 1. Kushan Empire influence (in red) and sites mentioned in the text.

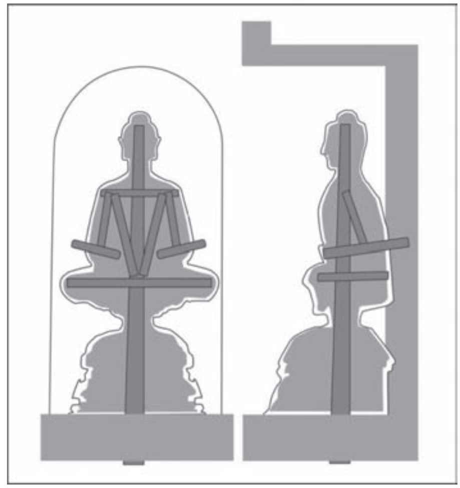

Figure 2. Scheme of sculptural structures. Picture modified after (Tarzi 1986, p. 75).

1 THE OBJECT OF STUDY

The clay sculpture of Greco-Buddhist art consists of figurative high-reliefs and low-reliefs, which were the principal decoration in mudbrick and *pakhsa* (rammed earth) temples and monasteries. These sculptural reliefs were realized by groups of specialized ateliers that moved through Central Asia trade routes (Tarzi, 1986). Their production styles resulted in varied trends and influence areas, contributing at the emerging of a common artistic tradition during the Kushan Empire(Dani, 1999).

Among this sculptures, the dimensions could vary between high-reliefs of human-size or larger than human-sizeup to several meters. The world's largest known Buddha statue made of clay measures 13.5 m (Ajina-Tepa temple—south Tajikistan). To make it, the artist started with a wood skeleton, which was fixed to the walls and/or to the floor. On the outer part of the skeleton, the artist wrapped vegetal fibers to fix the clay and model the shapes. The modeling process was made overlapping layers of clay, from the coarsest one (with and high proportion of vegetable fibers or fine gravel) for the main structure to the finest (more homogeneous and dense) for clothes details, facial and ornaments. Once finalized the modeling process, the sculpture was covered with lime or plaster-based stucco. Once the stucco was dry, the sculpture was finished with polychromatic and/or golden decorations (Tarzi 1986).

The result of this articulate process is the creation of large and heavy sculptures, but extremely fragile.

Figure 3. Sitting Buddha. Monastery of TepeNarenj (5th–6th centuries AD), Kabul, Afghanistan (Photo: Z. Paiman, 2011).

2 A REVIEW OF CONSERVATION METHODOLOGIES

The ideal conservation strategy of any architectural element of a site would be conservation"in situ". This is especially evident for the sculptures we are discussing. However, this strategy is difficult to perform. The most evident reason is that the archaeological excavations of Buddhist temples and monasteries in clay are located in countries where heritage preservation is often not assumed as a political target, determining an evident lack of investments in resources and studies. Consequently, conservations interventions depend mainly on resources (economical and expertise) provided by International Organisms. Another reason is the insufficient attention paid by archaeologists to the conservation. Central Asia has testified in the last 50s years and is still witness of extensive excavations of archaeological Buddhist temples and monasteries, but conservation has been and still remains a secondary target, often limited to risk intervention without a preventive strategy.

The problem of the conservation of architectural clay and the decoration associated is still an open issue. The absence of specific conservative strategy of monumental clay sculpture has often resulted in the incredible "disappearing" of these cultural expressions after their archaeological "discovery". An example is what occurred during the end of 19th century and beginning of 20th century due to British, French and Soviet interventions in the present Chinese Xinjiang (Maillard, 1983). These expeditions, mainly promoted by geopolitical interests (mapping of resources and routes), have realized numerous archaeological fieldworks throughout the Tarim basin. Many Buddhist temples were discovered and excavated with the aim of identify old Buddhist manuscripts (Hopkirk, 1980). Archaeologist and adventures diaries explain that impressive monumental sculptures were discovered, but nowadays only a photographic documentation remembers their past existence (Maillard, 1983).

Different cases are archaeological sites excavated during the Soviet Union. During the 60s and 70s with the improvement of the archaeological investigations was defined also a strategy for the preservation of monumental clay sculptures (Fedorovitche, 1969; Kostrov & Sheinina, 1961; Lunev & Musnitdinnodjaev, 1975). This strategy was based on extractive technique, which permits moving the sculpture from the archaeological site to the museum and then start the preservation there. The preservation technique included high concentrations of Polybutylmethacrylate (PBMA) dissolved in xylene. Thanks to this resin, the sculptures gained the sufficient consistence to allow the subtraction from their original location. Hence, after applying various layers of PBMA on the original support, the sculpture was cover with foil paper to protect the original from an external cask in plaster or polyurethane foam. Once separated from their architectonic support/basis, in some occasions, the inner of the cask was emptied, reducing its weight and facilitating its manipulation. This technique has been certainly useful to preserve an important amount of Buddhist monumental clay and stucco sculptures found throughout numerous archaeological interventions conducted in Central Asia republics during the soviet period.

However, this "rescue" paid a high price: the process of extraction and emptied from the original architectonic supports generated remarkable deformations, fragmentation and loss of polychrome and golden finish.

Fig. 4. Sculptural remains from DalverzinTepe (2nd–3rd century AD), Caraban Sarai Fine Arts Institute, Uzbekistan (Photo: M. Lopez Prat, 2010).

Currently, the "rescued" remains are mainly housed in the Hermitage or in Uzbekistan and Tajikistan national museums.

This is the case of the sculptural remains of Dalverzin Tepe (Uzbekistan, 1st–2nd century AD). Hundreds of fragmented sculptures are stored between the Fine Arts Institute of Tashkent and the Archaeological Institute of Samarkand, inaccessible (and mainly unknown) to the general public. The reason is that the local conservators and restorers do not dispose of the knowledge and media to perform treatments that could improve the soviet interventions and could permit their manipulation, without risking their state of preservation.

Apart from Soviet School, there was not any other real tentative to tackle the conservation-restoration of Greco-Buddhist monumental clay sculptures. The few publications focused on this matter are limited to cleaning or desalting of some remains recovered by the several European expeditions from the beginning of 20th century. For example those preserved in the Musée Guimet (Paris, France) and recovered by P. Pelliot's expeditions in Chinese Turkistan. These sculptures were consolidated with ethyl silicate (Lefevre & Pre, 1996), a treatment inspired by G. Chiari trough his research about the use of this product on earthen architecture. Chiari also experimented with ethyl silicate on some of the principal monumental clay sculptures from the Italian expedition "Old Nisa" in Turkmenistan (Chiari, Invernizzi, & Bertolotto, 1993).

Due to the lack of specific research in the field of preservation of clay sculptures, the techniques currently applied derive from personal experience/knowledge and the information is transferred among professionals. In this sense, in the afghan sites currently excavated, the conservation products used by archaeologists and conservators have not been previously tested on these materials. Thus, the sculptural works are protected from weathering through provisional shelters and wood mainstays, but they are also consolidated with the most commonly used in conservation field acrylic resins, such as Paraloid B-72 and Primal AC-33. This happened in Tepe Narenj (personal communication of Z. Paiman, archaeologist, Afghan Institute of Archaeology, Kabul) and Tepe Sardar (personal communication of F. Colombo, conservator-restorer of Italian State Institute for Africa and Orient, Rome). Furthermore, in those cases in which the approach in situ is unavoidable, the sculptures are taken to the National Museum of Afghanistan (Kabul), where Primal is used as adhesive to glue fragments or as reintegration filler, mixed with clay from the original site.

2.1 *A proposal for a specific research*

The bibliography referred to the preservation-conservation of sculptural clay decoration is rare. However, there are several references related to the preservation of archaeological earthen remains, which could represent an important orientation also for the here-discussed problem. In this sense, should be remarked the large quantity of researches about the analysis and preservation of earthen architecture, field in which there is a vast and growing debate, as reflected in diverse internationals symposia, shedding light on in numerous problems that should be assessed. For example, these subjects deal with the suitability of Synthetic materials and Silicates or the effectiveness of natural materials like Agave juice or Linseed oil as consolidate; the use of Capping or Encapsulation as protection or the need of building fix shelters as an essential technique in archaeological contexts (Cooke, 2010). The problematic is still open and researches are still ongoing, searching advances in the preservation of earthen architecture.

An example of the potentiality offered by the researches done in the field of earthen architecture preservation, are the cases of some prehistoric objects (Bollati, Ceroli, & Huber, 2006) and sculptures in clay (Chiari et al., 1993; Lefevre & Pre, 1996; Rava & Bertone, 2005), where the ethyl silicate has been used to facilitate the desalting.

Another possible element of reference is the conservation of wall paintings in earthen architecture (unlike the clay sculpture, worldwide diffused). In this perspective, recent researches conducted for conservation of decorated surfaces in Yemen (Jerome, 2006) and wall paintings in China (Garland & Rogers, 2006; Zheng, 2006) could represent a useful parallelism due to the handling with technical equivalences with the clay sculptures: support and overlapping, presence of stucco and polychrome finish. In the same perspective, a fundamental suggestion came from the use of Cyclododecane (CDD) (Singleton & Miller, 2006), for the temporal consolidation and protection. CDD could represent the best solution when the extraction of the sculptures is unavoidable, for its characteristic of temporality and vanishing.

Finally, should be especially considered the ongoing research project on the Shuili'an Buddhist Temple (Lantian, China). The work carried out by the Chinese-German cooperative Project for the preservation of Shaanxi Province (Blaensdorf & Tao, 2010) is focusing on the preservation of the polychrome clay sculptures of the great hall. Even if in this context the clay sculptures are integrated in fired brick architecture, the conservation products applied for consolidation (polyvinyl alcohol Mowitol diluted in water) and reintegration (mix of clay from the site, cellulose and sand dissolved in water) should be considered as possible solution also for sculptural decorations on earthen architecture. In this perspective, the monitoring and publication of the interventions results and conservation trends is particularly relevant.

3 CONCLUSIONS

Archaeological interventions in Central Asia sites, in which Buddhist monumental clay sculpture is present, don't have considered a preventive strategy of conservation and restoration. This often has generated and still generates an important loss of heritage and its value. Sometimes this loss is partially mitigated by isolated actions depending on the resources and expertise of the single restorer.

Nevertheless, the progresses experimented in recent years in the preservation of earthen materials (not only earthen architecture but also clay objects) set a starting point to propose solutions for the preservation of Buddhist monumental sculptural decoration on clay.

This said, the current lack of international research lines focused on this problem prevents the application of those advances reached in relation to the preservation of earthen Cultural Heritage. This problem may be due to the fact that we are, apparently, dealing with a very specific thematic, characteristic of a particular area, unknown for the main lines of research about the preservation of earthen cultural assets. However, if we consider the magnitude in term of space and time, and the great patrimonial value of these remains, we should, probably, rethink the concept of "specificity" of this problem.

This paper attempts to bring to the attention of the scientific community this open issue and to begin analyzing it. It is needed a scientific approach, resulting in an international debate to search for specific solutions, as well as assess the suitability of applying the advances reached in other field of the preservation of earth architecture. If this debate is not tackled, the most suitable solution may be to rebury the monumental clay sculptures, until the development of a favorable context, which enables their sustainable preservation.

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Energy rehabilitation of buildings of earthen construction

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ABSTRACT: There is a high percentage of the population that lives in earthen houses. Persists through the ages the idea that the earthen architecture has an excellent thermal performance. Nevertheless the standards of comfort of the most developed countries have reached such high levels that the constructive solutions are required to comply with measurable minimum standards, beyond the sensory perception. However, no known diagnostic tools or values are available that allow for adequate study in terms of both energy and environmental assessment certification and sustainability. Earth walls themselves are unable to achieve these values in their usual thicknesses, needing to be insulated. Through the study of a typical earthen wall, either built with rammed earth or compressed earth blocks, methods of intervention are planned in order to update their performance levels.

1 INTRODUCTION BACKGROUND

1.1 *Performance requirements in the condition of heritage*

UNESCO recognized the importance of rammed earth architecture by declaring the cities of Shibam and Sana'a Yemen as world heritage sites. The cities and the set of the Citadel and the Nasrid Palaces of the Alhambra are built entirely of earth. We mean by extension, that the earthen architecture acquires a condition of heritage inherent in its construction process, which is strongly linked to its typological and formal repertoire (Fig. 1).

Among its greatest advantages, especially from the standpoint of sustainability (Maldonaldo & Vela 1999; 7–10; 2002), it highlights the perfect integration with the environment, to be used almost as the only visible material of the place itself, strengthening the palette of existing colors and textures. On the other hand, if such buildings should be left to abandonment, the step towards ruin does not alter its qualitative primal integration since it prolongs until the complete disappearance of the construction and the consequent restitution of the previously occupied environment. It turns out to be a circular life cycle with the same point of departure and arrival gives convergence (Fig. 2).

However, the regulatory framework for the more developed countries tend to establish a minimum performance threshold in buildings that show technical requirements which are difficult to achieve in these traditional architectures (Goodhew & Griffiths 2005, 451–457). Updating would inevitably pass to the comprehensive compliance of these performance levels, especially with regard to health and

Figure 1. Old Kasbah, Morocco. 11th Century. World heritage site since 1987. Lozano, A.

Figure 2. Old Kasbah, Morocco. 11th Century. World heritage site since 1987. Lozano, A.

indoor air quality and energy savings, both related to the configuration of the surrounding area and the surface of the exchange with the exterior, responsible for lighting and ventilation levels.

No other work is known in this area, neither in its formulation of theory or materialization despite a major park having been built with earth in Spain.

Therefore, the object of the present study is to set some guidelines for energy rehabilitation of earthen buildings within the framework of performance based requirements established by Spanish legislation. To do this, a model-study will be adopted with a very extensive typology to extract general configuration elements that will address specific aspects of their energy behavior within a framework of required demand. From there, methods can be orientated to the values obtained in order to reach these thresholds.

1.2 *Contextualization*

The penetration of earth architecture in the world is extremely important: more than thirty percent of mankind lives in houses built with sun-dried bricks. (Sánchez-García 1999, 162)

In Spain, earthen buildings can be regarded as old as the buildings themselves, some of the having lasted until today. Magnificent examples of Roman, and Arab walls and fortifications were built with rammed earth. Through the chronicles of Gaius Sallustius Crispus we learn that the roman Valentia, founded in 138 BC was a walled city, and that the walls in times of the Roman Republic would be built of mud.

We chose to focus the study on the Spanish regulations as it is currently one of the most demanding in the international scene. The procedure would be exportable to other regulatory codes as only allowable limits may vary, which would alter the solutions recommended for the performance levels given from those proposed herein.

2 HETEROGENEITY FEATURES TYPE

2.1 *Earth as a building material: Key features and typical deficiencies*

This study arises from a systematic approach, without the need for defining or assessing in detail the various solutions and procedures unique to each geographic location.

The main objective is to verify the compliance with the thermal conditions of the material and to place it in its due general framework (Figs. 3 and 4).

The thermal behavior is closely related to the thickness of these walls, which being an important mass, has a high heat resistance factor and

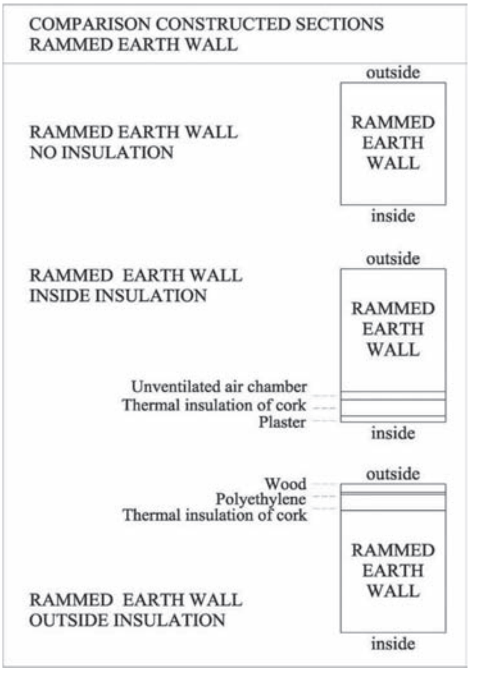

Figure 3. Compared possible sections of a rammed earth wall. Lozano Portillo, A., Lozano Velasco, J.M. & Ruiz Taroncher.

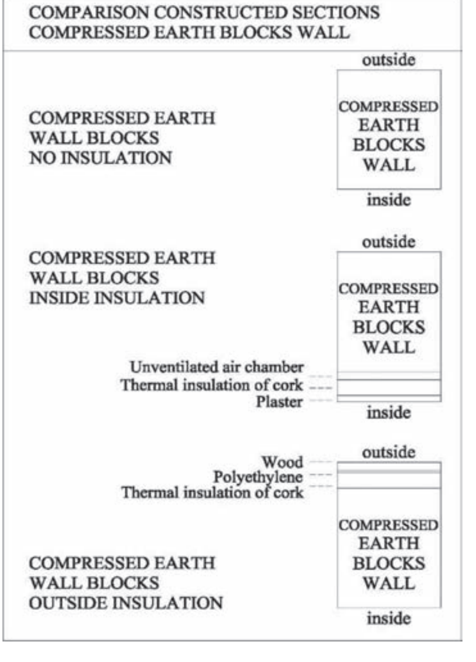

Figure 4. Compared possible sections of a compressed earth blocks wall. Lozano Portillo, A. et al.

therefore a co-efficient reduction of conductivity. (Heathcote 2011, 117–126).

Based on the findings of an earlier study on the verification of the limit values of transmittance, it is deduced that no section of wall less than one meter thick (in the case of compressed earth blocks) comply by itself with the transmittance limit for a large geographical area of southern Spain, and thicknesses greater than seventy-five cm. are necessary (in the case of the rammed earthen wall) to reach these levels of reference.

3 ENERGY CERTIFICATION

3.1 *Reference regulation framework: Testing tools.*

The Código Técnico de la Edificiación (Spanish Technical Building Code) does not contemplate the construction of adobe or the use of compressed earth blocks, although the material is mentioned in Catálogo de Elementos Constructivos (Catalog of building elements) under a single heading of orientative values.

In the same way as the verification of conductivity, thermal resistance and transmittance resulting from the previous study, we use the procedures coined by the Instituto Valenciano de la Edificación (Valencia Institute of Building), and endorsed by the consideration of recognized documents for energy rehabilitation.

Report of conservation and energetic evaluation of the building, catalog of construction solutions, CERMA rehabilitation, quality profile rehabilitation, for the detailed study of the improved sections (Figs. 5 and 6).

CERMA, Calificación Energética Residencial Método Abreviado (Residential Energy Rating Brief Method) is a free application of design and prediction of the energy efficiency rating, elaborated by ATECYR, Asociación Técnica Española de Climatización y Refrigeración (Spanish Technical Association of Air Conditioning and Refrigeration).

It has been regulated as a Document Recognized for energy efficiency certification, as arranged in Article 3 of Royal Decree 47/2007 of January the 19th, which approves the basic procedure for the certification of energy efficiency of new constructions.

The program offers level results of: details of skills, demands and consumption, CO_2 emissions (kg/m^2) monthly and annual heating, cooling and plumbing, detail emissions associated with each of the elements of the building, and parametric study improvements in both the application and in systems and combination of both.

RAMMED EARTH WALL
NO INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Rammed earth wall	0,30	0,70	0,429
Rse			0,04
			R=0,599
			U=1,666

RAMMED EARTH WALL
INSIDE INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Plaster	0,015	0,25	0,06
Thermal insulation of cork	0,04	0,04	1,00
Unventilated air chamber	0,02	0	0,17
Rammed earth wall	0,30	0,70	0,429
Rse			0,04
			R=1,829
			U=0,546

RAMMED EARTH WALL
OUTSIDE INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Rammed earth wall	0,30	0,70	0,429
Thermal insulation of cork	0,04	0,04	1,00
Polyethylene	0,002	0,5	0,004
Wood	0,02	0,13	0,154
Rse			0,04
			R=1,757
			U=0,569

Figure 5. Compared transmittance values for a rammed earth wall. Lozano Portillo, A. et al.

These tools allow us to approach the material behavior within the range required for new construction materials.

3.2 *Improving the performance of the enclosure walls*

As we have previously seen the walls by themselves in the sections of more widespread use, this is where the thickness ranging between thirty and

COMPRESSED EARTH WALL NO INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Compressed earth blocks wall	0,30	1,1	0,273
Rse			0,04
			R=0,443
			U= 2,257

COMPRESSED EARTH WALL INSIDE INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Plaster	0,015	0,25	0,06
Thermal insulation of cork	0,04	0,04	1,00
Unventilated air chamber	0,02	0	0,17
Compressed earth blocks wall	0,30	1,1	0,273
Rse			0,04
			R=1,673
			U=0,597

COMPRESSED EARTH WALL OUTSIDE INSULATION

Materials	e(m)	λ(W/mK)	R(m²K/W)
Rsi			0,13
Compressed earth blocks wall	0,30	1.1	0,273
Thermal insulation of cork	0,04	0,04	1,00
Polyethylene	0,002	0,5	0,004
Wood	0,02	0,13	0,154
Rse			0,04
			R=1,601
			U=0,624

Figure 6. Compared transmittance values for a compressed earth blocks wall. Lozano Portillo, A. et al.

forty cm. fall short of the required parameters. We must therefore make this kind of enclosure walls double sided with an air chamber and insulation, in order to reach these thresholds.

In order to check, we have studied two possible improvement scenarios: acting on the interior or exterior, always with natural materials with low embedded energy, recyclable or reusable, such as cork or wood.

Below are the values obtained for an earthen wall and a wall of compressed earth blocks for a typical geographical area of southern Spain, and therefore representative of the areas of increased presence of these buildings, for which sets a required transmittance U = 0.82 W / m² K (Figs. 7 and 8).

As we can observe, with the contribution of a second sheet with insulation and air chamber can be rapidly reached improvements of up to forty percent over baseline values.

4 GOOD ENVIRONMENTAL PRACTICES

4.1 *Quality profile in the Community of Valencia (Spain)*

Beyond the complied wall of the performance requirements, the constructive practices are valued through the tools of environmental certification that could improve the overall energy

COMPARISON RAMMED EARTH WALL TRANSMITTANCE λ(W/m²K)

cm	RAMMED EARTH WALL NO INSULATION	RAMMED EARTH WALL INSIDE INSULATION	RAMMED EARTH WALL OUTSIDE INSULATION
	outside / RAMMED EARTH WALL / inside	outside / RAMMED EARTH WALL / inside	outside / RAMMED EARTH WALL / inside
25	1,90 Fails	0,57 Ok	0,59 Ok
30	1,67 Fails	0,55 Ok	0,57 Ok
35	1,49 Fails	0,53 Ok	0,55 Ok
40	1,35 Fails	0,51 Ok	0,53 Ok
45	1,23 Fails	0,49 Ok. Better 40%	0,51 Ok
50	1,13 Fails	0,47 Ok. Better 40%	0,49 Ok. Better 40%
75	0,81 OK	0,40 Ok. Better 40%	0,42 Ok. Better 40%

CUMPLY CTE FOR THE CLIMATIC ZONE B4 → TRANSMITTANCE U≤0,82 W/M²K

Figure 7. Comparison of Transmittance values for different thicknesses for Rammed earth wall.. Lozano Portillo, A. et al.

COMPARISON COMPRESSED EARTH BLOCKS WALL TRANSMITTANCE λ(W/m²K)			
	COMPRESSED EARTH BLOCKS WALL NO INSULATION	COMPRESSED EARTH BLOCKS WALL INSIDE INSULATION	COMPRESSED EARTH BLOCKS WALL OUTSIDE INSULATION
cm	outside COMPRESSED EARTH BLOCKS WALL inside	outside COMPRESSED EARTH BLOCKS WALL inside	outside COMPRESSED EARTH BLOCKS WALL inside
25	2,52 Fails	0,61 Ok	0,64 Ok
30	2,26 Fails	0,60 Ok	0,62 Ok
35	2,05 Fails	0,58 Ok	0,61 Ok
40	1,87 Fails	0,57 Ok	0,59 Ok
45	1,73 Fails	0,55 Ok	0,58 Ok
50	1,60 Fails	0,54 Ok	0,56 Ok
75	1,17 Fails	0,48 Ok. Better 40%	0,50 Ok
CUMPLY CTE FOR THE CLIMATIC ZONE B4 → TRANSMITTANCE U≤0,82 W/M²K			

Figure 8. Compared transmittance values for different thicknesses for compressed earth blocks wall. Lozano Portillo, A. et al.

balance of buildings and the reduction in energy consumption.

Most of the Building Sustainability Assessment tools internationally recognized (LEED, BREEAM, VERDE) handle relative values whose acquisition supposes a complex analysis not only of the constructive process, but also of the energy balance of the entire building. Its application would therefore require a detailed study of each earthen architecture typology, and for every specific site.

We consider it essential to address the specific study and previously isolated from the energy behaviour of the envelope based on earth walls, for which absolute data are available and therefore of easiest comparison.

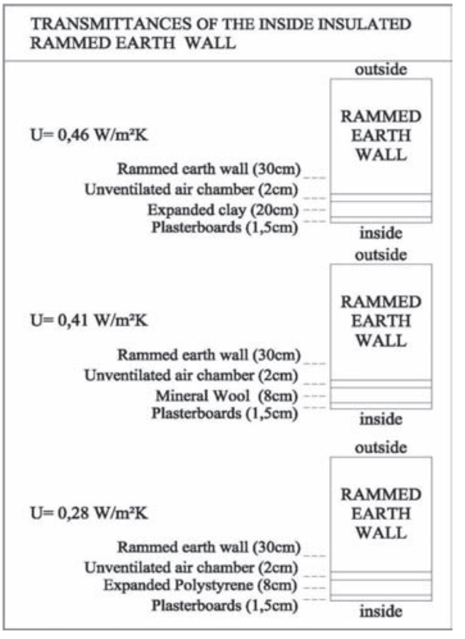

Figure 9. Compared transmittance values of the insulated rammed earth wall. Lozano Portillo, A. et al.

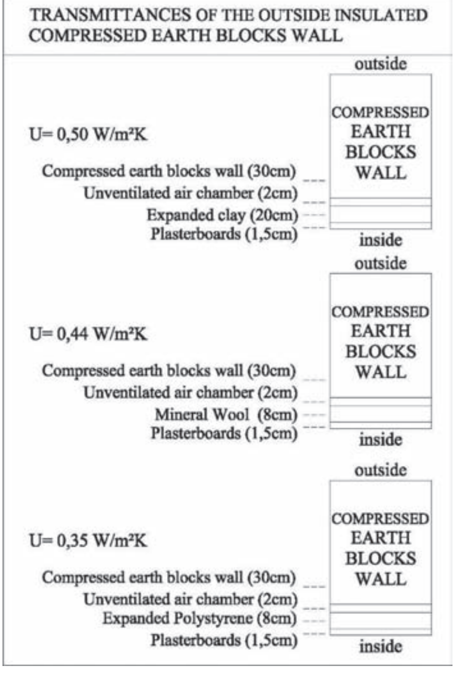

Figure 10. Compared transmittance values of the insulated compressed earth blocks wall. Lozano Portillo, A. et al.

The improved performance of the envelope will have later a direct impact in improving the overall building energy balance, which allow to approach the more complete second phase of study for a given typology. It is particularly effective and easy to apply the profile contained in the agency responsible for quality which is the Instituto Valenciano de la Edificación (Valencia Institute of Building), in regard to energy saving by improving the transmittance of the façade enclosure, referred to the demanded levels of the current regulation framework Spanish Technical Building Code.

An improvement of forty per cent is considered to be a good practice, of high level, whereas the improvement of sixty per cent will be considered to be an excellent practice, of very high level.

We study the behaviour of a thirty cm. thick wall, built with rammed earth and with compressed earth blocks, insulated in the interior side with different materials, in order to compare the results obtained. The following summarizes the actions that would be needed to achieve the required values (Figs 9 and 10).

5 CONCLUSIONS

Comfort standards are increasingly stringent, so in the traditional earthen architectures the only passive conditioning reveals itself to be dramatically insufficient.

Action is needed in the walls creating a new sheet with insulation, separated from the first by an air chamber to mitigate the formation of condensation. Only in this way will it achieve transmittance levels comparable to those required of the new construction.

The results of the studies presented above show that the differences between isolate on the interior or on the outside are not significant; being more effective in all cases the insulation on the inside.

The intervention of the exterior involves the absolute alternation of the formal structure of earthen architecture and introduces a new element of weakness, by using a material that requires maintenance and has an ineffective behaviour on our climate.

In the later phase of study also mentioned, relative to overall energy balance of the building would require a behaviour comparable to the passive house, which emissions arising from energy consumption were compensated by own systems of production.

In this scenario even lower level of transmittance than the studied here would still be needed to do away with performance correction equipment, involving high-energy consumption, and not to mention a difficult integration into these architectures.

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Aït Ben Haddou—Fortified City, Ouarzazate, Morocco

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ABSTRACT: The Aït Ben Haddou *ksar* is an extraordinary group of buildings that provide an overall vision of different construction techniques and a few examples of an impressive pre-Saharan architectural type from the south of Morocco. It consists of two neighborhoods, one popular and one aristocratic. The latter includes half dozen *tighrematín*, from the XVIII century. In the fifties began the exodus of the *ksar*, and only seven families remained. It was at that time, that the film industry started. Different principles provide guidance on recommendations for conservation. One of these principles is Universality, and is applied from the Paris Convention. It's there where cultural property of outstanding meaning is classified as world heritage, belonging to humanity and acquiring consequently universal value. The principle of universality is the base for the defense of the heritage and the responsibility of all to preserve it for future generations. This is the case of Aït Ben Haddou.

1 ANTECEDENTES

El norte y el sur de Marruecos se encuentran separados por el Gran Atlas. Esta cordillera que atraviesa todo el país desde el Atlántico hasta Argelia, no sólo lo divide en cuanto a su orografía sino también en cuanto a su clima. El norte es fértil y el sur es árido.

En el sur, entre la imponente cordillera y el auténtico desierto, se extiende un territorio ayermado donde la vida se concentra en los ríos y sus afluentes, son los valles presaharianos y aquí es donde se encuentran gran cantidad de construcciones de tierra, típicas de la arquitectura bereber.

Uno de estos ríos es el Ouarzazate que desemboca en el pantano de Al Mansour Eddahdi junto con el Dadès. El Marghene es uno de sus afluentes y es en su orilla donde se eleva la impactante Aït Ben Haddou, objeto de una protección global desde 1953 junto con todos los valles de los oasis. Representa la mejor síntesis de la organización del espacio, la cual se ilustra por un tipo de hábitat rural vernacular adaptado al clima y a las condiciones de vida social y utilizando los materiales proporcionados por la naturaleza, mostrando una gran capacidad tecnológica.

Tras la Independencia en 1956 este modo de vida ha conocido profundas mutaciones. Los habitantes del *ksar* abandonaron sus antiguos lugares de ocupación sobre la ribera izquierda del río Marghene para construir un nuevo pueblo sobre la ribera derecha, con espacios más amplios y calles más anchas. Comenzó el éxodo, permaneciendo tan sólo unas pocas familias y empezó su explotación como industria cinematográfica.

Figura 1. Valles presaharianos. (Vicent Soriano Alfaro, 2006).

Aquí se han rodado multitud de películas, desde “El hombre que pudo reinar”, “Lawrence de Arabia”, “La joya del Nilo” hasta “Gladiator”.

Así, se produjo el abandono del antiguo *ksar*, extraordinario conjunto de edificios que proporcionan una visión global de las técnicas de construcción presaharianas y un resumen impresionante de la tipología arquitectónica del sur de Marruecos.

ICOMOS *(International Council on Monuments and Sites*) que sigue con mucha atención los esfuerzos del gobierno marroquí para inventariar, proteger y rehabilitar las arquitecturas de tierra de la zona presahariana, estimó que el *ksar*, con muchos edificios que aún están en bastante buen estado,

Figura 2. *Ksar* Aït Ben Haddou. Valle del Marghene y del Ounila. (Pepa Martínez Barranco, 2010).

Figura 3. *Ksar* El Khorbat. Valle del Todrha. (Pepa Martínez Barranco, 2002).

podría servir como banco de pruebas para una política de conservación basada en el retorno a las técnicas tradicionales de trabajo de la tierra y en segundo lugar de la madera.

Se designa entonces para su inclusión en la Lista del Patrimonio Mundial, principalmente por las cualidades intrínsecas del sitio, de la organización del espacio y de la arquitectura. ICOMOS sugiere que la protección—que implica severas medidas non aedificandi en torno al *ksar*- no sea puntual, sino que se extiendan a todo el valle del Ounila.

En Mayo de 1987, ICOMOS, previo acuerdo del gobierno marroquí a estas recomendaciones, da el visto bueno a la inscripción de Aït Ben Haddou en la Lista del Patrimonio Mundial, sobre la base de criterios IV y V:

Criterio IV. Aït Ben Haddou es un ejemplo sobresaliente de *ksar* del sur de Marruecos que ilustra los principales tipos de estructuras que se observan en los valles del Drâa, del Todgha, del Dadès y del Souss.

Criterio V. Este hábitat tradicional, representativo de una cultura, se ha vuelto vulnerable bajo el efecto de mutaciones irreversibles. (Unesco, 1987).

2 TIPOLOGÍAS ARQUITECTÓNICAS

En los valles presaharianos existen diferentes tipologías arquitectónicas y multitud de términos con el que denominarlas, dependiendo de si la lengua utilizada es el árabe, el bereber, el tamazight, el francés, o incluso el castellano.

2.1 *El ksar*

El *ksar*, cuyo plural es *ksur* en árabe, es un poblado amurallado protegido por torres de vigilancia. En bereber se denominan *ighrem*, y su plural es *iguermán*, siendo su sentido más amplio ya que se denomina así a cualquier tipo de población y también a un granero colectivo aislado.

Estos poblados pueden ser, tanto de planta cuadrada o rectangular, como de planta totalmente irregular. Su trama puede ser, tanto en cuadrícula, con una calle principal y otras secundarias perpendiculares, como típicamente árabe. Pero en ambos casos, las calles pueden aparecer cubiertas por las edificaciones de las primeras plantas. Dejando en ocasiones pozos de luz que atraviesan la totalidad de las alturas como chimeneas de ventilación e iluminación.

La mezquita y el *hammam* son edificaciones que no pueden faltar en ningún poblado, a las viviendas se les denomina *daar* en árabe y *taddart* en bereber.

2.2 *La tighremt*

La *tighremt*, cuyo plural es *tighrematín*, es el diminutivo de *ighrem* en bereber. Su aspecto es similar a los *ksur* pero de menor tamaño ya que es una vivienda familiar fortificada. Es una construcción de planta cuadrada y torres en las esquinas que sobresalen del plano de fachada y en altura del resto del edificio.

Algunas poseen un patio interior concéntrico también de planta cuadrada, o en su defecto, un pequeño pozo de luz.

Cada planta tiene un uso diferenciado. La planta baja se destina a los animales y al almacenaje, en la planta primera se ubica la cocina y el almacén de alimentos y en la planta segunda se instalan las estancias dormitorio y de estar masculinas.

En la terraza también se suelen ubicar estancias para dormitorio de invitados. Sobre todo ello se alza las torres de defensa y vigilancia.

Figura 4. La *tighremt* Ben Moro. Skoura. (Pepa Martínez Barranco, 2010).

Figura 5. *Kasba* Amridil. Skoura. (Pepa Martínez Barranco, 2002).

Esta tipología se construía en un principio dentro del *ksur*, posteriormente en el exterior pero cerca de ellos y finalmente aisladas y de forma independiente.

Existe una variante de las *tighrematín* en la que a partir del modelo básico se le añade un recinto a la fachada principal que también tiene torres en las esquinas aunque de menor tamaño que las principales. Otra variante es la agrupación de varias *tighrematín* compartiendo muro y torres. Y una variante de uso es la existencia de las *tighrematín* colectivas, compartidas por varias familias.

2.3 *La kasba*

La *kasba*, cuyo plural es *kasabat* en árabe, es el conjunto residencial fortificado que pertenece a un personaje pudiente. Existen dos tipos diferenciados de *kasabat*, unas de tipología de palacio urbano y otras con origen en una *tighremt* con posteriores ampliaciones.

El *ighrem*, y su plural *iguermán*, es también un granero colectivo como se ha explicado anteriormente. En algunas zonas se llaman también *agadir*. Sirven para almacenar reservas de alimentos y a su vez como lugar donde protegerse la población de posibles ataques. Cada familia posee un compartimento con puerta y está vigilado por un guardián. Los hay de piedra, de tierra y de una combinación de ambas.

3 ÚLTIMAS INTERVENCIONES Y ESTADO ACTUAL

3.1 *Últimas intervenciones*

A principio de los años noventa, en Aït Ben Haddou, un nuevo dinamismo se instala para cambiar el alma al lugar. Los trabajos llevados a cabo por el *Centre de Conservation et de Réhabilitation du Patrimoine Architectural des Zones Atlasiques et Subatlasiques* (CERKAS) con la colaboración del Departamento de Asuntos Culturales de Marruecos y el PNUD se inscribieron en una visión integral para la conservación de diferentes espacios de acuerdo a las técnicas y materiales utilizados anteriormente por los habitantes. Manteniendo así, la adaptación a las condiciones climáticas, la fusión y la integración en el paisaje natural, la sencillez y la antigüedad de los procesos arquitectónicos, las proporciones y los volúmenes, y la sencillez y la belleza del paisaje.

A pesar del abandono y la despoblación del *ksar*, las condiciones de autenticidad y de integridad se mantienen. Los espacios mantienen su morfología y algunas familias los gestionan por razones económicas (tiendas bazar). Ya que las viviendas y los *tighrematín* son de propiedad privada, frente a la mezquita, plaza y calles, que son de propiedad pública.

Los trabajos realizados fueron la restauración de la mezquita (11/01/1991 a 06/01/1992), pavimentación de las calles (10/01/1992 a 12/31/1992), limpieza y restauración de caminos o estabilización de las riberas (21/07/1993 a 09/03/1993) y rehabilitación de los motivos decorativos de cinco *tighrematín* (10/05/1995 a 02/05/1996).

Se echaba en falta una visión global y un plan de gestión que no se había elaborado. Existiendo una falta de control de los edificios ya restaurados, de hecho, se encuentran en desuso debido a la falta de diseños de rehabilitación y de seguimiento.

Figura 6. *Ksar* Aït Ben Haddou. (Pepa Martínez Barranco, 2010).

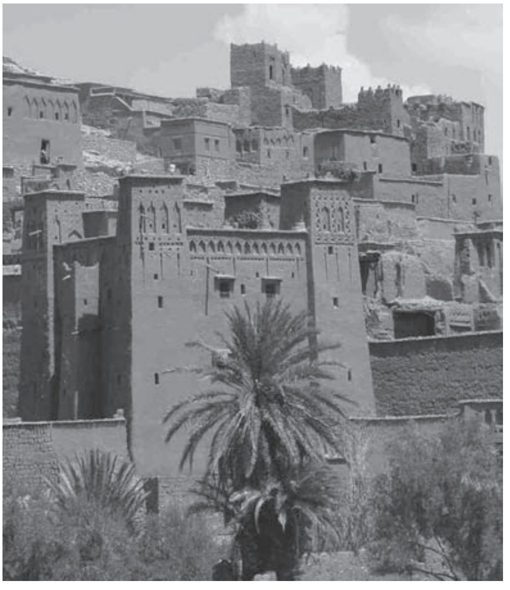

Figura 7. *Ksar* Aït Ben Haddou. (Pepa Martínez Barranco, 2010).

Figura 8. *Ksar* Aït Ben Haddou. Barrio popular. (Pepa Martínez Barranco, 2010).

Figura 9. *Ksar* Aït Ben Haddou. Barrio aristocrático. (Pepa Martínez Barranco, 2010).

Así, por ejemplo, la mezquita después de su restauración en 1991, no es funcional hoy en día. La ausencia de un puente o pasaje que conecte el *ksar* con el pueblo nuevo impide el funcionamiento de esta institución, sobre todo en las épocas en las que el río va crecido. Al marchar los habitantes al nuevo pueblo, sus viviendas son alquiladas a "bazaristas" que las modifican. No existen recursos para dicho seguimiento. Además, las nuevas construcciones del pueblo nuevo, actúan negativamente sobre la integridad visual del *ksar*.

Durante muchos años, preocupa el estado de abandono y de degradación del *ksar*. Así como el recorrido que deben seguir los visitantes para acceder a él, atravesando un río que en ocasiones va seco y en ocasiones lleva agua.

Incluso se plantea la posibilidad, ya que cumple con los requisitos, de incorporarlo en la Lista del Patrimonio en Peligro, incompatible con el ingreso en 1987 en la Lista de Patrimonio Mundial.

3.2 *El poblado en la actualidad*

El *ksar* Aït Ben Haddou es un poblado amurallado protegido por torres de vigilancia, en cuyo interior encontramos numerosos *tighrematín*. Se encuentra en la orilla del río aprovechando la falda de una colina, en cuya cima encontramos restos de una fortaleza preislámica.

Existen dos barrios claramente diferenciados, el primero popular con viviendas de una o dos plantas y el segundo aristocrático formando por diferentes *tighrematín*. Las viviendas del barrio popular son de un tamaño considerable comparadas con las de otros valles. Cuentan con una superficie aproximada de 200 m². En ocasiones poseen patio central. El techo suele ser de cañas apoyadas sobre vigas de álamo. Diferentes callejuelas comunican las diferentes edificaciones.

Las viviendas del barrio popular son de un tamaño considerable comparadas con las de otros valles. Cuentan con una superficie aproximada de 200 m². En ocasiones poseen patio central. El techo suele ser de cañas apoyadas sobre vigas de álamo. Diferentes callejuelas comunican las diferentes edificaciones.

Este barrio se encuentra separado del barrio aristocrático por la avenida principal del *ksar* que comunica las dos entradas al mismo, *Imi n'Ighil* e *Imi n'Tagura*. Esta avenida se introduce en el barrio aristocrático creando una plaza, espacio de relación entre las distintas edificaciones.

Las *tighrematín* se componen de cinco plantas alrededor de un patio central, cubierto a veces hasta la planta segunda. Su abundante decoración se basa en rombos con flores en su interior y

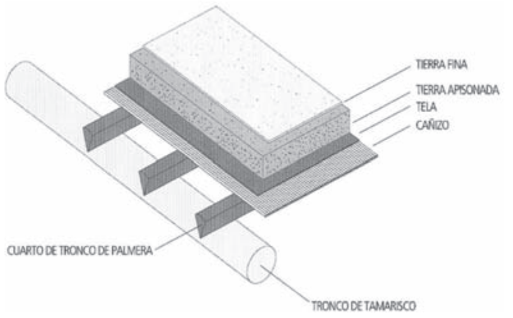

Figura 10. *Ksar* Aït Ben Haddou. Detalle forjado. (Vicent Soriano Alfaro, 2006).

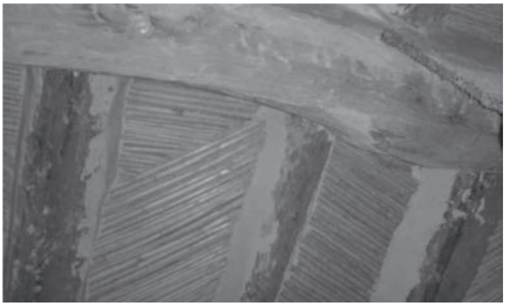

Figura 11. *Ksar* Aït Ben Haddou. Detalle cañizo. (Pepa Martínez Barranco, 2010).

medios rombos, y arquerías y almenas triangulares rematando los muros.

3.3 *Materiales y sistema constructivo*

Los materiales utilizados para la ejecución de las edificaciones son, la tierra cruda para la ejecución de tapia y adobe, la piedra que se utiliza en los arranques de los muros de tapia y la madera en la ejecución de forjados, cubiertas y carpinterías. Estos materiales se encuentran muy cerca del sitio donde se trabaja, por eso los edificios guardan el mismo color que el entorno.

El sistema constructivo utilizado, tanto en las edificaciones del barrio popular como en las del barrio aristocrático, es el tapial. Una vez terminado el muro se procede al embarrado de la superficie mediante una mezcla de barro y paja que da uniformidad, cubre juntas y desperfectos protegiendo los paramentos. Es imprescindible mantener en buen estado este revestimiento para una mayor durabilidad de la tapia.

También es importante rematar superiormente los muros con cañizo a modo de vierteaguas.

Los forjados se sustentan sobre los muros de tapia y vigas de tronco de álamo, se componen de viguetas que están formadas a su vez por troncos más finos del mismo tipo de madera. Sobre éstas se coloca perpendicularmente un cañizo cubierto por telas viejas, en la actualidad han sido sustituidas por láminas de plástico cuya misión es dar base a la tierra apisonada de unos 20 cm, que remata el forjado y es el pavimento del piso superior.

Se dan casos en los que el cañizo que apoya sobre las viguetas se trabaja en malla formando figuras geométricas en relieve, estos techos se reservan para las habitaciones principales.

Las cubiertas se realizan del mismo modo que los forjados pero con una cierta inclinación para la evacuación de las aguas.

Figura 12. *Ksar* Aït Ben Haddou. Remate *tighremt*. (Pepa Martínez Barranco, 2010).

3.4 *La ornamentación*

Las edificaciones de ambos barrios se diferencian en cuanto al sistema constructivo en que las *tighrematín* se rematan con abundante ornamentación. Esta decoración está realizada mediante adobe en diferentes posiciones respecto al plano de fachada, dejándose las juntas de manera que los huecos producen sombras.

También se adopta el motivo de las arquerías ciegas, para la formación de frisos en la parte superior de la fachada y de las torres. Siendo más esbeltas en estas últimas.

La solución del arco también es diferente, mientras que en las fachadas el arco es angular de líneas quebradas resuelto con adobes colocados de forma escalonada, en las torres se prolonga mediante una ranura que convierte el lóbulo superior en una especie de aspillera ciega. El fondo ciego de los arcos se encuentra decorado con figuras geométricas o posee alguna apertura de ventilación.

Las arquerías se delimitan superior e inferiormente por cenefas en diente de sierra que son adobes colocados en ángulo.

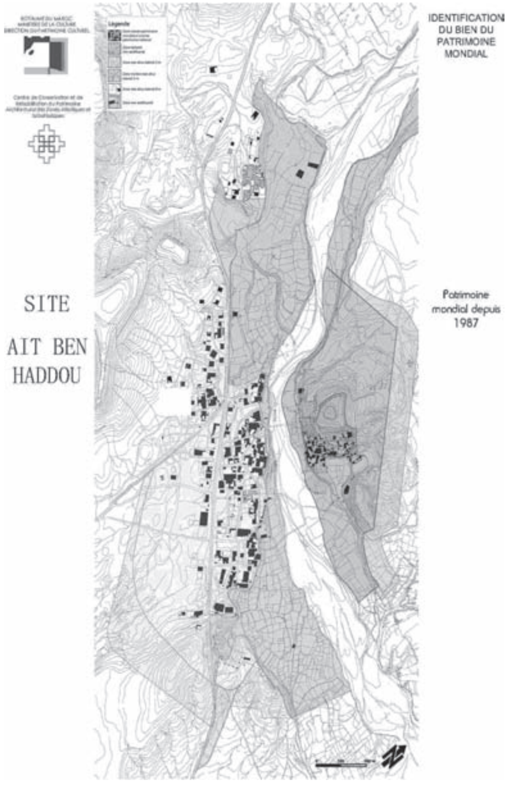

Figura 13. Sitio de Aït Ben Haddou. (Ministerio de Cultura del Reino de Marruecos, 1987).

Finalmente, tanto fachadas como torres, se coronan en sus esquinas con almenas o merlones triangulares que se construyen colocando adobes en horizontal formando una pirámide, son una reminiscencia de origen defensive.

4 CONCLUSIONES

Sería clave para medir el estado de conservación, controlar el estado de los edificios, el regreso de los habitantes al antiguo *ksar* y la rehabilitación y la creación de actividades socio-económicas, como por ejemplo, un museo.

Debería establecerse un plan de gestión adecuado y crear una oficina permanente del Centro de Conservación y Rehabilitación del Patrimonio Arquitectónico en el lugar, con todos los medios necesarios para su funcionamiento.

En estos últimos años se ha finalizado el Plan de Gestión del *ksar*, aunque siguen sin funcionar los mecanismos de financiación sostenibles para la conservación y gestión de la propiedad. Se deben establecer mecanismos para la recaudación de ingresos en el lugar, con los que poder realizar el mantenimiento del mismo, que junto con los ingresos por el rodaje de películas hagan de este lugar un monumento sostenible.

Existe, así mismo, la iniciativa Plan de Acción 2007–2012, con la cual y financiado por diferentes entidades, se pretende realizar la restauración de las murallas, un plan de mejora de la calidad del agua, el desarrollo de un Centro de Ayuda y un plan de restauración de las casas del *ksar*.

Parece que tras largos años de espera y agonía, estas maravillosas construcciones, que han perdurado en el tiempo, como imagen de una forma de vida, van a recuperar su antiguo esplendor. *Inshallah*!

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Conservation of earthen constructions: Earth-gypsum plasters

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ABSTRACT: Earthen constructions represent an interesting and important architectural heritage, whose conservation is necessary in order to make possible the transmission of a technological culture which keeps values of the uniqueness of the landscape as well as of its history. The preservation of this heritage calls for the definition of effective techniques able to mitigate and to prevent processes of alteration, ensuring a long-term conservation. The application of plasters on earthen constructions can guarantee their adequate safeguard. A testing campaign was conducted on different plasters prepared mixing earth and gypsum or earth, gypsum and additives, which intend to offer an effective way of protection against the atmospheric agents. The testing campaign, including chemical and mineralogical characterization (XRD and FTIR), color evaluation (spectrophotometry) and performance tests as capillary absorption, erosion spray tests and Geelong tests made it possible to assess effectiveness and performances of the different plasters.

1 INTRODUCTION

Earthen architecture, although its widely spread presence in the world, has not been subject of actions aiming to enable its appropriate conservation over time, except for some rare cases. These are mostly traditional buildings, often historical, but not covered by protection laws, that constitute an interesting example of knowledge, building techniques, technological cultures intended to be irremediably lost if not properly protected.

Unfortunately, because of the widespread lack of interest of these architectures and the lack of appropriate interventions of preservation and maintenance has led, over the years, to a fast degradation of an important part of such an expression of culture, both material and immaterial, heritage of knowledge and ancient traditions.

Although earthen buildings were built and are still today made with a particular attention to adopt measures that will ensure an effective protection against aggressive actions exerted by the weather, they often exhibit several damages of natural origins (as, for example, the damages caused by the pouring water during rain and the erosion caused by the wind). In particular, the examination of the conservation status of many buildings has highlighted the need to carry on the testing campaign of procedures and actions aiming to mitigate the alteration and/or degradation process of the earthen buildings.

2 EARTHEN BUILDINGS PROTECTION

Earthen building protection could be achieved through measures involving the application both of protective products, of natural or synthetic origin, on the surface, both of plasters. The latter can be simply constituted by earth, and therefore poorly durable and requiring constant and continuous maintenance, or can be made with a mixture of sand and binder (usually air or hydraulic lime, and sometimes even cement). This second type of plasters, especially when the cement is used as binder, has different deformation characteristics compared to the surface where has been applied, so to compromise the adhesion to it. Moreover, it also make it difficult to understand the real material consistency of the earthen structure.

Over the last few years new plasters have been tested, with the purpose to add earth to the mixture, aiming to overcome these problems. Further tests were also carried out using gypsum as a binder, since, thanks to its physic and chemical characteristics, allows to control the shrinkage of the clay and, therefore, the possible formation of cracks.

Aiming to develop appropriate methods of intervention for the protection of earthen buildings heritage, preventing the occurrence of defects, an experimental campaign has been started at the Laboratory Prove Materiali e Componenti

"Roberto Mattone" of the Politecnico of Torino and the Laboratory MaMeCH of the Politecnico of Milano, aiming to identify and evaluate the performances of different plasters made of earth and gypsum to which were added various additives.

3 EARTH AND GYPSUM PLASTERS: EXPERIMENTAL ACTIVITY

The experimental activity aimed to evaluate the effectiveness of plasters made of earth and gypsum (calcium sulfate hemihydrate), admixed with both products available on the market, both products of natural origin adopted in various contexts, with low or totally no environmental impact, meeting sustainability requirements.

Figure 1 shows the particle size analysis of the earth, from the Natural Park of Valleandona in the Asti region (Piedmont, Italy), used during the testing campaign.

The compositions of the different plasters mixtures tested are shown in Table 1. The additives percentages refer to the weight of the dry earth.

The plasters, three samples for each type of mixture, were tested for capillary absorption and surface erosion (Geelong test and erosion spray test as provided by New Zealand legislation NZD 4298) and examined to determine their chemical and mineralogical characterization using XRD and FTIR. Moreover, their color has been evaluated thanks to spectophotometry. The results have been compared with those coming from tests performed on the plasters samples made of only earth and gypsum, without any additive.

3.1 *Water capillary absorption test*

The tests have been carried out using a Karsten pipe (Fig. 2) and by measuring, at regular intervals of one minute, for a maximum of 15 minutes, the rate of absorption of the water introduced in the graduated pipe.

As it is made clear by the diagram in Figure 3, the products as linseed oil (B), beeswax (E) and acrylic emulsion (G) have determined a moderate reduction of the plasters capillary absorption capacity, while much more important results were obtained from the samples of plaster admixed with casein (D). Vice versa is extremely limited the reduction determined by products as wheat gluten (C), cactus mucilage (F) and vinyl powder (H), whose behavior is not very different from that of the plaster made exclusively of earth and gypsum.

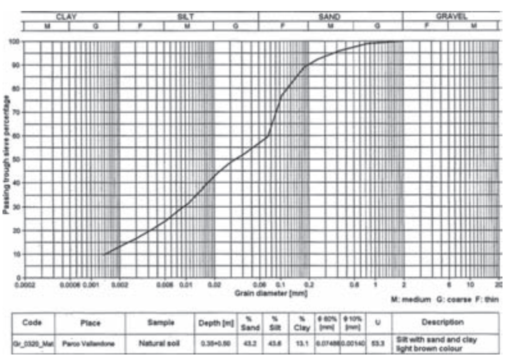

Figure 1. Particle size analysis of the earth used.

Table 1. Plasters composition.

Mixture composition			Additive
A	Earth	Gypsum20%	
B	Earth	Gypsum20%	Linseed oil 6%
C	Earth	Gypsum20%	Wheat gluten 2%
D	Earth	Gypsum20%	Casein 9,6%
E	Earth	Gypsum20%	Beeswax 3% + Linseed oil 3%
F	Earth	Gypsum20%	Cactus mucilage
G	Earth	Gypsum20%	Acrylic emulsion 4,8%
H	Earth	Gypsum20%	Vinyl powder 1,8%

Figure 2. Water capillary absorption tests.

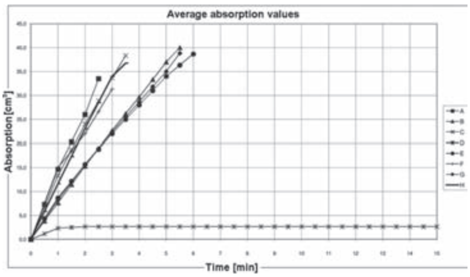

Figure 3. Diagram showing the results of the water absorption test.

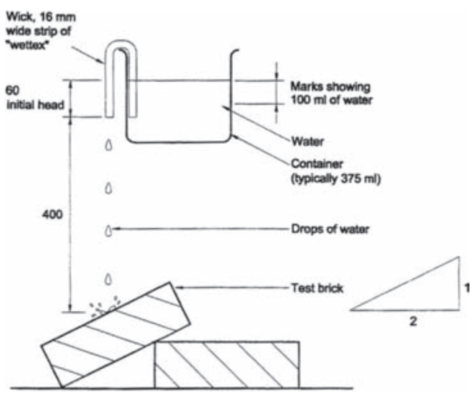

Figure 4. Geelong test implementing rules (NZD 4298).

3.2 *Geelong test*

The Geelong test is based on the measurement of the erosion of a sample's surface, placed at an angle of 30° to the horizontal, caused by the continuous and repeated falling of a water drop from an height of 40 cm and for a total of 100 ml (Fig. 4).

Here below are shown the erosion index list established by the New Zealand legislation (Table 2).

The tested plasters were affected by none or really low erosion, corresponding to an erosion index of 2.

3.3 *Spray test*

The erosion spray test involves the measurement of a sample's erosion after it has been exposed to a water jet with a pressure of 0.5 bar and projected from a distance of 470 mm. The test lasts up to one hour, or until complete erosion of the sample, and is interrupted at regular intervals of 15 minutes to assess the entity, in term of depth, of the erosion caused by the water jet (Fig. 5).

The results obtained after the experiments (Fig. 6) show that all the plasters containing additives have a greater ability to resist erosion, except for those admixed with cactus mucilage (F) and wheat gluten (C). Particularly interesting results were obtained from samples containing casein (D) and linseed oil (B) which have demonstrated a level of erodibility none or really low.

Table 2. Erosion index (NZD4298).

Hole depth (D)	Erosion index
$0 < D < 5$	2
$5 \leq D < 10$	3
$10 \leq D < 15$	4
$D \geq 15$	5

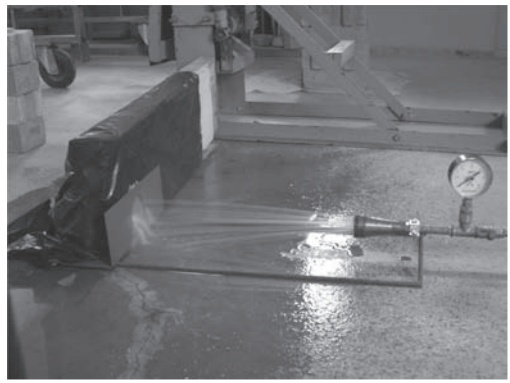

Figure 5. Erosion spray test.

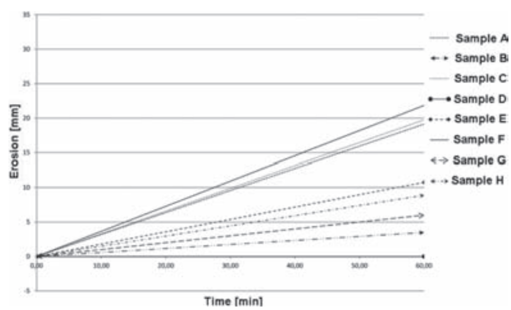

Figure 6. Diagram showing the results of the erosion spray test.

3.4 *Spectrophotometry*

The color of the various samples has been defined in form of an absolute number using a spectrophotometer. The values thus obtained have been used to evaluate the color differences between them, with particular attention to the possible color variation caused by the use of additives. To do that, the color value of sample A, made with only earth and gypsum, has been used as a standard to be compared with the values of the samples from B to H (plasters with additives). The color measurements have been made with a reflectance spectrophotometer in VIS light Minolta CM2500D, with color space CIE L*a*b*, where L* is the brightness and a* and b* the chromaticity coordinates. For each specimen have been conducted ten measurements, from which the average value has been obtained.

The values of chromaticity variations ΔL*, Δa* e Δb* have been calculated for each plaster in relation to plaster A (Fig. 7), used as standard, and then the value of total color difference ΔE* was mathematically obtained (Fig. 8).

The charts, and in particular Fig. 7, show that by analyzing the results of the test is possible to observe that the component that the brightness parameter ΔL* has undergone the most consistent variation compared to the standard sample A, indicating thus a general darkening of the plasters containing additives. Moreover, the general arise of the values of Δb*, indicating an increase of the yellow component's saturation, highlighting a widespread phenomenon of yellowing of the surfaces of the plasters mixed with additives.

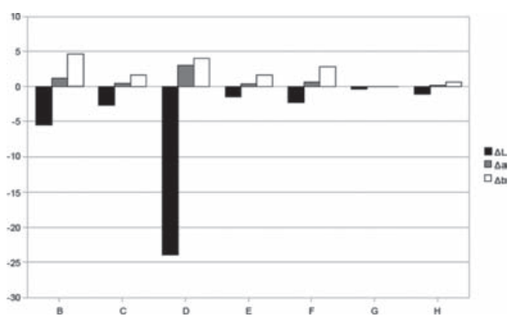

Figure 7. Chart of the average variation of brightness ΔL* and chromaticity coordinates Δa* and Δb* of the plasters B-H compared to plaster A.

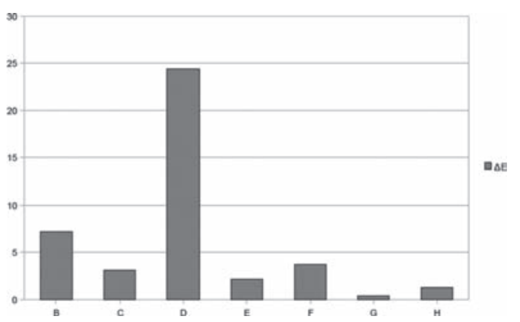

Figure 8. Chart of the total color difference ΔE* of the plasters B-H compared to plaster A.

3.5 *X-ray diffraction (XRD)*

The analysis was performed on powder of the samples by using a X-ray diffractometer Philips PW1830. The XRD analysis has been used to identify all the crystalline mineral phases contained in the earth and in the gypsum used for the realization of the plaster mixtures, in order to characterize them from the mineralogical and petrographic point of view.

This analysis was fundamental to define, above all, the minerals composing the earth used, until now distinguished only by the grains size thanks to the particle size distribution analysis. The clay contained in the sample has been recognized as montmorillonite, while the sandy component has been identified by the presence of albite, muscovite and, most of all, quartz.

The purity of the gypsum employed in the experimentation has been confirmed by the XRD exam, which highlighted it to be calcium sulfate hemihydrated, totally composed by bassanite.

3.6 *Fourier transformed infrared (FTIR)*

The characterization of all the raw materials in their compositional and chemical aspects has been completed thanks to the FTIR analysis. Afterwards also the individual compounds in the mixtures of dry plasters have been determined. It has been used a FTIR spectroscope Thermo Nicolet 6700 with detector DTGS between 4000 and 400 cm^{-1}. Every samples of both raw materials and plasters have been grounded, homogenized and analyzed in KBr pellet. The samples of raw materials in liquid form were applied directly on KBr pellet and then analyzed.

A strong influence on the possibility to identify correctly all the compounds in the plasters came from the quantitative proportions between the main components of the mixtures (earth and gypsum) and those in smaller quantities (additives). In fact, in particular for plasters C, F and H, respectively admixed with wheat gluten, cactus mucilage and vinyl powder, the presence of the additives has not been detected in the FTIR analysis. The hypothesis is that this outcome is due to the low percentage of the additive introduced, but further tests are required.

4 CONCLUSIONS

The conservation of earthen constructions, intended to be irretrievably lost if not properly protected, requires the identification and development of appropriate measures to prevent the occurrence of "risk situation related to the cultural assets in its context (Ministero per i Beni e le Attività Culturali, 2004).

The testing campaign starts, in fact, from the desire to identify products and methods of intervention to ensure an adequate protection of surfaces in order to prevent, as far as possible, the onset of degradation. He examination of the results obtained allows to highlight that products as linseed oil (B) and, even more, casein (D) seem to be able to determine a significant increase in the plasters erosion resistance capacity, while products such as beeswax (E), vinyl powder (H) and acrylic emulsion (G) offer a good protection as well, even if more limited.

For what concerns the absorption tests, all products used have determined a reduction of the phenomenon, in particular in the plaster admixed with casein (D). The influence of this additive on the color changes, moreover, is an important parameter to consider, especially in the case on intervention on historical structures. Although this one has shown also problems during its realization, because of the numerous cracks on the surface of the samples, its results obtained during the tests induce to make further research on this plaster mixture, by varying the percentage ratio of the materials composing it and the mode of execution.

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The ksour of the Saharan Atlas of Algeria: Reflection on conservation issues

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ABSTRACT: Being aware of the conservation of its cultural and architectural heritage, a preservation plan was launched by the Algerian ministry of culture, with a full commitment of local authorities and the civil society to promote the earthen architecture of the ksour of the Saharan Atlas of Algeria. The paper presents description of the ksour architecture as a particular style of earthen architecture, and a reflection on issues of the conservation initiative, likes: the role of different stakeholders, the economic and touristic promotion of the heritage, the training of qualified manpower, the development of adequate techniques and materials of earthen construction in the ksour region.

1 INTRODUCTION

The ksar is a set of attached built-up houses, forming a compact housing environment, surrounded with an outer wall and marked out by watchtowers. Though, it is difficult to specify the date of its appearance, this type of architecture is spread in the Saharan Atlas mountain chains of North Africa, predominantly in the West of the Saharan Atlas, where this part of the mountain chain took its name "The mounts of ksour".

The setting-up of the ksar depends on two important criteria that are: the availability of water resources, and the defensive site (Moussaoui 2006).

The construction of ksour obeys to several architectural rules: on stone foundations, thick bulwarks, walls in Adobe and stones, mixture of earth and straw are the main materials of construction.

This process has proved its thermal isolation efficiency in hot and dry climatic conditions (Mebarki 2007).

Architecture of the ksour, is mainly of a Berber style, which appears typical to this region, with little or no influence of the Arabic or Spanish-Moresque art (Choay 1992). The Atlas ksour expresses a type of rural art, which have many similarities with the Yemenite traditional housing environment (Mebarki 2010).

These buildings in earth played a fundamental role for centuries, as houses of Lords. Isolated and placed on a dominant position, they expressed the authority of the chiefs (representatives of the sultan) or Pasha (governors of an imperial city). Beside their role in controlling oasis and their access roads, the ksour served as refreshment points for the inhabitants of the desert (Naciri 1988).

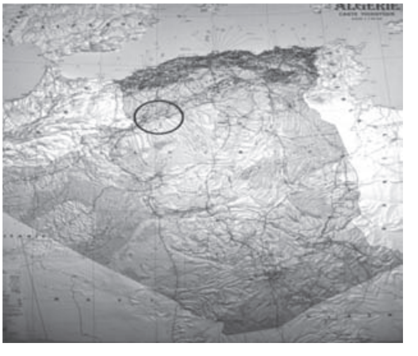

Figure 1. The west part of the Saharan Atlas in Algeria, which represents the geographical space of our study (Center of cartography, Oran Algeria, photo taken by the author, 2008).

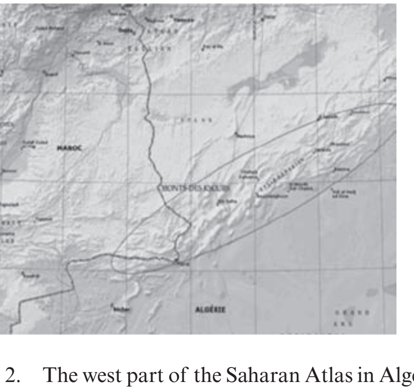

Figure 2. The west part of the Saharan Atlas in Algeria, which represents the geographical space of our study (Encarta. 2004).

Figure 3. The traditional tissue of earthen architecture, Ksar of Bousemghoune (Mebarki 2009).

Figure 4. The façade of house with the earthen architecture, Ksar of Tiout (Mebarki 2009).

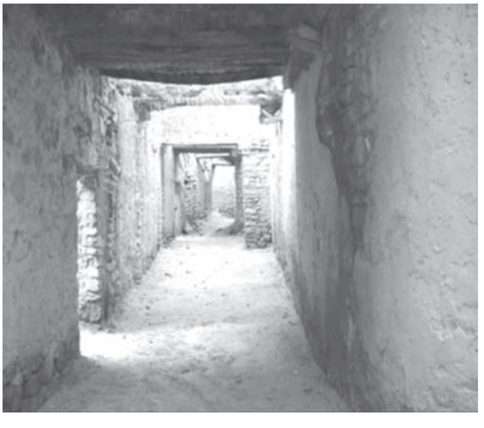

Figure 5. The alleys of earthen architecture, Ksar of Tiout (Mebarki 2009).

2 CHALLENGES THAT ARE FACED BY THE EARTHEN KSOUR

Since the independence of the country in 1962, industrial building materials and techniques were adopted by the Algerian policy makers, in order to overcome the shortage in the housing and equipment sector. But along the years, this choice was to the detriment of the construction in earth, in all aspects: shortage of traditional earthen construction materials, techniques, qualified manpower and craftsmanship, which abandoned the traditional earthen construction to the new trend of construction. Hence, the construction style of the ksour, its cultural heritage and life style started to disintegrate.

A few years ago many parties and actors activating in domains of cultural and architectural heritage became aware of the importance of the ksour in the sustainable development of the region (Marouf 1980).

Hence, a new dynamic was triggered at different levels of intervention: national authorities (Ministry of Culture), regional and local authorities, schools of architecture and associations of the civil society involved in the field, in accordance with international bodies (UNESCO 2006).

The aim was to invert the trend, by boosting the construction in earthen architecture. A task which is not easy to accomplish in a few years, for reasons like:

– The scarcity of the qualified manpower, craftsmanship and technical expertise, which implies the design of updated and adequate skills training programmes.
– Processes and techniques of the production of traditional construction materials and equipment have to be developed according to the particularities and specifications of the region.
– Techniques and methods of conservation and rehabilitation of the architectural heritage in earth have to be developed, as well.
– At the same time, financial resources have to be provided.

3 THE PRESERVATION PLAN

In 2003, the national authorities in Algeria have issued a number of rules under the preservation plan called "*The procedures for establishing the permanent plan of safeguarding the cultural heritage*" (Décret n°03-324, 2003). The preservation plan determines the general rules for the restoration and rehabilitation of old urban tissues, and historic monuments that belong to the cultural heritage, these rules should be applied at national and local levels.

3.1 *At a national level*

Under the initiative of the Algerian Ministry of Culture, national authorities have engaged an action plan to preserve the cultural and architectural heritage. The main guidelines are:

1. Issuing the manual of rehabilitation techniques and methods of preservation of the architectural heritage.
2. Identifying the legal, land and real estate obstacles to the rehabilitation and describe the means to surmount them.
3. Appealing to experts to improve the quality of actions aiming at restoration of the Ksour heritage.
4. Strengthening the legal protection of earthen architectural heritage, which in turn, have slowed down the degradation process of many historic monuments and sites.
5. The different actions of the plan were financed by special founds. As for the case of the ksour architectural heritage, a special founds called "*The development of southern region special found*" provided all the financial resources for the different action of the plan (Décret n° 98-172, 1998).

3.2 *At a local level*

The preservation plan is concretized on the ground through many actions implemented by the local authorities:

– Adapting the national policy on preservation of the cultural and architectural heritage to local realities.
– Developing economic activities in and around the ksour, particularly those activities that generate income for the local population (tourist development of the heritage, craftsmanship and traditional activities).
– Encouraging initiatives of the civil society to act as the main stakeholder in the long term process of the conservation plan.
– Cultural tourism goes side by side with other facilities that can be provided by local authorities (services, communication, infrastructure, and so forth).

3.3 *The civil society*

The role of the associations concerned by the protection and development of the heritage is impressive in the Algerian Saharan atlas. Nothing could be made without their presence. Most of them are associations, established by volunteers, created to defend and promote the heritage of the region. They are a real vector for the preservation of the

Figure 6. The Adobe materials of construction and restoration, Ksar of *Tiout* (Mebarki 2006).

ksour, as an identity of the territory (Ravereau 2003). Although, the role of such associations is quite visible in some events, and in local businesses for certain periods, they actively contribute in:

– Protecting many aspects of the cultural and architectural heritage of the ksour against its disappearance.
– Promoting the heritage to become known on local, regional and national scales, by creating web sites and other means of dissemination.
– Contributing to the program of restoration and protection of monuments.
– Engaging research activities and train youth on the preservation and continuous promotion of their heritage.
– Contributing to local and notional initiatives (preparing local maps of monuments, providing ample information on the ksour architecture, etc.).
– Establishing relations of mutual cooperation with the similar associations, in the nearby governorates and in all the country to exchange the information.

4 THE IMPACT OF THE PRESERVATION PLAN ON THE KSOUR OF SAHARAN ATLAS

Under the preservation plan (Décret n°03-324, 2003) four ksour out of a total of thirty ksour were chosen in 2003, for their cultural, spiritual and historical importance to be subject to operations of restoration. These ksour are *Tiout, moghrar,*

Figure 7. The minaret of restored mosque, Ksar of *Bousemghoune* (Mebarki 2009).

Figure 10. *A ceiling of a palace,* Ksar of *Bousemghoune* (Mebarki 2009).

Figure 8. The interior of prayers' room in The mosque, Ksar of *Bousemghoune* (Mebarki 2009).

Figure 9. Façade of a restored mosque, Ksar of *Tiout* (Mebarki, 2009).

chellala, bousemghoune. The restoration action were taken mainly on spiritual cites, mosques, ancient palaces (Riyadh), alleys, plots and squares.

But after evaluation of the quality of woks the authorities have perspouned the operation in 2006, for the following reasons:

1. Conflicting policies of the parties involved in the restoration process at local level (cultural, tourism, urbanism and construction services).
2. The non respect in a number of cases of current legislation of the preservation plan.
3. The bad quality of restoration work was mainly due to workers' lack of technical mastery.
4. The restoration technical studies require skilled architects who are well trained for such duties, but in the ksour situation, these skills are scarce.

5 CONCLUSION

The national conservation plan of the architectural heritage -especially that of the ksour region-, is a long term plan, for the immensity of the concerned geographic territory and the degradation of many aspects of this heritage.

But the main challenge facing is the lack of the required know-how among the different actors (national and local authorities, architects, skilled manpower). Construction materials, methods, techniques and qualified manpower are the main challenges facing the concerned stakeholders in this domain.

Re-qualifying inhabitants of the ksour, aspiring to live the modernity, but at the same time preserving their identity, seems to be the best solution in this situation.

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Earth and bricks architecture: For a conservation of stratigraphical traces

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ABSTRACT: This paper discusses the issue of restoration interventions on earth based techniques, including both earth, earth-made bricks and baked bricks. Walls of this type are very interesting for materials variety, processing craft and assembly to other elements. Degradation is very different in these cases, it is more evident in earth walls but it occurs also in the other situations. Restorations and micro-substitutions were frequent since the ancient times. How can we interpret them now, with current archaeology architecture methods and tools? Do we have enough tools for this today? And… How any can intervention be possible without erasing the traces and the variety that are inside the object? Some very interesting experiences occurred recently in northern Italy, and this paper deals with these examples in answering the questions above. The solution adopted chooses an ever deepening knowledge of the materials and the techniques as a guideline for an ever more respectful restoration.

1 EARTH STRUCTURES DECAY

1.1 *Earth buildings*

The duration of earth construction is not different from that of the baked brick buildings. In many parts of the world there are still earth structures dating back 40 centuries ago. It is also true that many buildings disappeared in less than a century, but this also happens to brick-based buildings (Pagella 1986).

There are several earth based techniques that historically have been used especially in construction in Piedmont (Italy):

– earth bricks
– rammed earth
– mixed structures (bricks and pisé, …)

In Piedmont the study with the tools of archeology of architecture (Pittaluga 2009a) has shown that the oldest buildings in rammed earth or mud bricks date from the seventeenth century and are still in good condition: the external unprotected wall layer reduced by less than 6–8 cm in more than four centuries. “These data help explain why the ancient authors would appreciate so much the works in earth, that have a very long life even longer than stone-based ones” (Cagnana 2000).

Despite these ideal examples, however, we need to reflect on the phenomena of degradation that can invest these structures. If restoration is not applied correctly, it risks to remove these structures or lead to an elimination of precious signs engraved on their surfaces.

1.2 *Deterioration causes for mud brick buildings*

The rammed earth particles are the alloying elements of mud brick. The clay minerals coming in contact with increasing amounts of water, start increasing their volume, then they become loose (higher plasticity) and at the end they are dispersed in a suspension of water. For these reasons, the most damage to adobe structures are attributable to water, especially when it is abundant and in liquid form (rain and standing water). The wet clay becomes impermeable and the excess rain flows over the surface, carrying away suspended material and digging preferential channels that are eroded more and more quickly because they are subject to a greater concentration of water.

The high moisture content may lower the tensile and compression strength of the adobe. Thus the bases of the walls, in particular, which must bear the entire weight, tend to collapse once they are impregnated with water. When clay gets dry, it shrinks and cracks appear on the surface.

The movement of water (in liquid form) from wall inner section to surface, caused by evaporation, can carry dissolved salts. Depending on the evaporation speed, these can crystallize on the surface (efflorescence, often hygroscopic) or, even more dangerous, below the surface (sub-efflorescence or cripto-efflorescence) causing the disintegration of the portion of material between the salts and the surface itself.

At last rain produces the most damage in mud brick structures.

Other causes of deterioration are:

- Rising damp, limited to 40–60 cm since the capillarity has no greater effect on the mud brick because of the large pore size,
- Condensation: cyclical contractions and expansions, due to micro-cracks, resulting in detachment of flakes of material,
- Sun: it produces an indirect action, in combination with rain, that produces cracks. The detachment of the chips may be caused by different thermal expansion between the surface and the inner layers,
- Wind: it may cause detachment of the loose parts or it may be responsible for abrasion and heavy rain. It increases the surface evaporation rate of a damp wall, preventing the formation of a liquid water veil on the surface: then evaporation occurs immediately below, in the pores; the disruptive effect of the crystallization of the salt is maximum, creating cavities (cellular erosion).

1.3 *Deteroration causes for rammed earth buildings*

The deterioration causes for construction in rammed earth are similar to those for the mud brick structures. In this case, however, exogenous agents attack a surface with a different structure. The great quantity of stones contained in the clay provides a protection surface for the wall itself. Even heavy rain and streaming effect carry away only a minimum quantity of clay elements because water is continuously diverted from the stones in their flow. Also rising dump is limited by the same obstacle.

The abandonment of many buildings is the cause of the detachment of the plaster. This situation is less critical for buildings in earth, often born with no plaster at all, and in some cases plastered only later on, after subsequentes transformations.

1.4 *Decay causes for rammed earth and mud brick buildings*

This is an intermediate situation and the vulnerabilities of a construction system are often added to those of the other.

1.5 *Other decay causes for clay structures*

Other deterioration causes are earthquakes, fire, cracks due to materials wear and aging, improper use of the buildings etc.

It has to be noticed that many studies found mud-brick buildings very resistant to movement and jerky oscillations, because they are more elastic. Fire is a danger everywhere, it causes crumbling and glazing of the walls.

2 FINDING DATES FOR STRUCTURES

Both baked and mud bricks and rammed earth structures often went through series of operations performed in different times and periods as a consequence of degradation problems and repairs.

Finding the date of the different elements of the structure, therefore, is not a theoretical exercise: it is an operational tool to better understand the history of the architectural work.

However, at present, there are still significant differences with the easier "baked bricks" structures.

2.1 *Finding dates in baked bricks structures*

In the dating of baked bricks, several advances have been made, particularly since the seventies. It is possible to date the building blocks of a structure with the help of thermoluminescence of bricks or "mensio-chronology" (Mannoni et al. 1988; Pittaluga et al. 1992; Pittaluga 2009b). Another dating technique is the analysis of masonry technique, that in some areas can also give significant results.

2.2 *Finding dates in clay structures*

These structures have different conditions, and finding dates is more difficult.

Rosa Pagella describes the situation in this way: "Many indicators were tracked on down on clay walls. Some are difficult to be found, as the case of ceramic findings: these fragments were thrown in the soil and then incorporated into clay material. These are to be found with patience in the surface of the masonry. Sometimes these objects are bigger and in good condition, as bottles or parts of them, and they were inserted in the wall to adorn it. Obtaining a date indication from these findings is a task for expert archaeologists. The wall can be recognized as been built after the object was manufactured, this is a post-quem date. It is also possible to obtain dates from the plasters. This is less complex but it still requires attention. The date of the plaster definitely identifies the era of its realization, and this tells us that the wall was built before (ante-quem). Certainly the date of bricks put inside the wall is even more precise … Sometimes doors and windows shapes succeed in dating buildings … Also roof shapes can be a dating tools, for example a pavilion roof provides us chronological indications regarding the Thirties …" (Pagella 2008).

3 OTHER SIGNS TO BE READ

Earth bricks or rammed earth have signs and traces of the work sustained imprinted on their surfaces, including traces of the tools used, etc. Structures can tell different stories when analyzed with the rigor of the archaeologist (Mannoni 1994, Manacorda 2008). The table attached below are some signs on the bricks, who report phases and different tools used and who denounce phases and different tools used; in some cases, the expression of different chronological periods.

The same color of the clay and, in structures with baked bricks and, the final appearance of the elements, can be an expression of the type of cooking (e.g. oxidizing or reducing atmosphere) (Pittaluga 2009c).

A similar situation can be for adobe, even if with some differences. In the structures in pisè, the careful eye can observe the passage of the tables, their length, sometimes also the essence of the wood used the progression of the work….

Table 1. Signs related to main workmanship techniques for baked bricks (Pittaluga 2010).

Operation	Technique	Signs
Moulding	Grill/single mould	Cross strips
Moulding	Fixed "comb"	Narrow ribbon signs *fungus* execess*
Moulding	Simple wood mould	Deformation of the form imprint of the wood
Moulding	Iron mould	Execess
Moulding	Chalk mould	*Volatina di cenere* tracks
Smoothing	By hand	Sub-parallel grooves
Smoothing	With rule	Tracks for conveying—crest *, depressed area
Pressing	With hydraulic presses	Sharp edges, smooth—surfaces, flat surfaces
Pressing	With a mechanical press	Higher density-perfect details-concavity of the face*
Clinch	By hand or by machine	Depression -in the central part
Extrusion		Parallel tracks, clean and precise edges

*May occurr.

4 RESTORATION

4.1 *Missed and incorrect interventions*

Lack of maintenance and neglect are most often the causes of degradation of these structures. Restructuring interventions are often accompanied by the complete destruction of the earth parts of the building and replacing them with modern materials.

4.2 *Conservation interventions*

Conservation is a crucial issue for the life of a building, both in raw and backed bricks. Some measures taken at building initial construction time help to prevent some failures.

Rising water from the subsoil is a very dangerous problem in Piedmont's Alexandrian "resurgences" area. A good solution against it is to have stone foundations or a base in baked bricks and stone.

In mud-brick buildings the plaster is a very important protection from rainfall. For earth building conservation, it is also recommended (ICOMOS-ICCROM 1977) to use chemical and consolidation treatments that are compatible with the original materials. This is more important when the restoration intervention uses ancient techniques. However it is also important to avoid to homologate the restored part to the historical one. In my opinion, indeed, it is important to keep track of the intervention performed, albeit with similar and compatible materials.

4.3 *Conservation interventions for plaster-less buildings*

On clay based buildings, in case there is no plaster, it is possible to arrange surface protection by application of products that slow down the degradation process. Experiences in this directions involved the use of:

– Inorganic materials
– Organic materials of synthetic origin
– Silicic acid esters
– Natural origin products (e.g. cactus pulp)

Inorganic materials: produce their consolidation action by means of deposit of very small crystals in the interstices between the granules. They have the inconvenient of releasing soluble salts, as secondary products.

Organic materials of synthetic origin (acrylic resins Acriloid type B72 and Primal AC33, silane monomers etc.): have this disadvantage. They produce a surface film, darken the color, increase the gloss, their thermal expansion coefficient is much different from the untreated material, they are subject to rapid deterioration when exposed to sunlight. "In the class of consolidating materials of synthetic origin we can count products based on alkyl-alkoxy silanes, silicon organic derivatives, whose recommended application for raw clay walls consolidation is by the Italian norm: Raccomandazione Nor.Mal.L 20/85 (*Interventi conservativi: progettazione esecuzione e valutazione preventive*), but this have not been up to now the subject of extensive experimentation. Recent tests conducted at the Laboratory Prove Materiali e Componenti del Politecnico di Torino have shown how such product appears to be suitable for consolidation and a greater ability to resist erosion of the earth surfaces ...".

Silicic acid esters: The action of ethyl silicate, which has proven its effectiveness over time, does not change the chemical-physical and mechanical properties of the material. It gives water-resistance capability and it has a consolidating effect. According to some authors, this product is excellent even in damp (Mattone 2008). Manuela Mattone always shows evidence of consolidation of Neolithic remains of walls in China with potassium silicate great product, but on dry masonry (Mattone 2008).

Natural origin products (e.g. cactus pulp and linseed oil): cactus pulp has characteristics of porosity, plasticity and very good absorption capacity and compatible with the clay. Tests at the Laboratory Prove Materiali e Componenti del Politecnico di Torino have shown that the mucilage of cactus applied immediately after a short period of fermentation is able to reduce the absorption capacity of the earth and, at the same time, makes it more resistant to erosion (Mattone 2008).

As regards instead the linseed oil, although pairs to be able to offer a greater capacity for resistance to erosion of the surfaces in earth, it has the drawback of change from the point of view of color the surfaces on which is applied, which in fact assume a darker color. (Mattone 2008).

4.4 *Special hints for restoration*

Everywhere, both for the backed brick-structures and for those adobe-structures, it is good, when, for example, be taken to compensate for mortar joints, to use mortar compatible with the existing, and in the drafting of same, does not cover the edges of the bricks to leave intact the possibility to read well the building technique and to perform analyzes *mensiocronologiche* (Pittaluga 2009a).

Try to avoid as much as possible the practice with replacement of elements, as much as possible, work with consolidants of chemical type.

If you must work with a consolidator/protective chemical (see 4.3) it is preferable to use products that do not alter in any way the material, even in color, in order not to lose the opportunity to read the choices made. The color can give us information on both clays used for structures in mud bricks and backed bricks, both of the conditions for firing brick structures, and very often baked bricks were used in the facilities that had more endurance...

5 CONCLUSIONS

All interventions try to reduce the speed of the degradation process by removing the causes and/or repairing small defects of the structure that behave as catalysts.

All interventions try to reduce the speed of the degradation process by removing the causes and/or repairing small defects of the structure that behave as catalysts. Even if several scientific meetings were held on this subject, the conclusion was that no "final solution" was found for mud brick conservation problem, and no one will be found (ICCROM 1986), and its instability characteristics must be compensated with regular maintenance: the only effective remedy is a continuous and careful maintenance of the building.

It is desirable that thorough research will be realized on techniques, building types and towns, in relation with the historical, social and cultural situation of each zone; a continuous exchange of information on this issue is also required.

It is important to promote the awareness of local residents not to destroy their cultural heritage with inappropriate interventions (Pagella 1986).

"*The focus on the theme of sustainable development and eco-compatible technologies related to anthropical changes increased very much in recent years in the national and international scientific community*" (Saracco 2010). Given this increased attention, it is even more important to pay much attention to avoid that wrong interventions jeopardize our heritage.

This paper also deals with the signs that are visible on historic structures of backed brick and still in earth structures (mud bricks etc.). These signs are related to workmanship and they can provide us information on the dating of these structures and the level and degree of knowledge of workers who realized them. This paper also explains how these signs are unstable, sometimes barely perceptible (a slight incision, a special shade of color ...). Therefore it is important that the restoration yard takes all cautions to avoid damages.

"*... The path of discovery of the data on the history of knowledge construction and transformation that are hidden in the complex web of signs engraved into matter. The understanding little by little how those signs are the strong*" words "*of a story that* *was not written but was built, as signs of a seemingly random arrangement they are a writing. Amazement when meanings appear in signs that were apparently meaningless, when you can describe the relationships between these signs. Curiosity, more and more involving, as the observation continues. The labor of observation. These are the experiences related to the story and contribute to generate a natural respect toward what is slowly learned and understood in the matter. Comprehension indeed comes from self-experience, and the knowledge of such a multi-layered context provides the lifeblood for an attitude to respect, care and partecipation to the destiny of these things, even to responsability. The unveiling of the meaning that can be hidden in a material trace ... can contribute to the education to see the discontinuity and to accept it as a carrier of a signifiance ... Recognition of character where these signs help to define that unrepeatable hic et nunc which identifies specifically this work and no other one. If this artifact was lost, also its value as a witness is lost, and its authority as an object, its authenticity ...*" (Quendolo 2006).*"... The contribution that a stratigraphic mentality can lead to a culture of conservation and to the design of the intervention ...*"

This mindset "*becomes the occasion for a particular analytical attention which enables the design of minimal intervention and targeted both from the point structurally both from the point of view of conservation of the authentic material ...*" (Quendolo 2006).

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Repair of rammed earth walls in the walled enclosure of Daroca (Zaragoza, Spain)

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ABSTRACT: The walled enclosure of Daroca (Zaragoza, Spain) was built in the 8th century of the Middle Ages. It has been preserved to a large extent but is still in a dilapidated state of conservation. It has a length of 2960 m and is formed by rammed earth walls with towers, of the same material, every 20–25 m. It is the biggest walled enclosure entity in the Aragon region. A master plan is needed to allow the development of various proposals and intervention criteria depending on the specificities and conservation status of each stretch of the enclosure.

1 INTRODUCCIÓN

El primitivo núcleo urbano de Daroca, fundado por los musulmanes a mediados del siglo VIII, se sitúa junto río Jiloca en la ladera del cerro de San Cristóbal.

En el siglo XII fue conquistado por el rey Alfonso I y se incorporó al reino de Aragón convirtiéndose en un enclave fronterizo con los reinos de Valencia y Castilla y creció rápidamente hasta el siglo XIII pasando a ocupar también la parte baja de la ladera del vecino cerro de San Jorge (Fig. 1).

Al tratarse de una zona fronteriza, su recinto amurallado se fue transformando, ampliando y mejorando continuamente, alcanzando su máximo esplendor en el siglo XV a partir del cual empezó su lento deterioro.

Figura 1. Recinto amurallado.

2 DESCRIPCIÓN DEL RECINTO AMURALLADO

El recinto amurallado se desarrolla entre las cumbres de los cerros de San Cristóbal y San Jorge, ocupa una superficie de 435,000 m^2 y tiene un perímetro exterior de 2960 m de longitud que lo caracterizan como el más amplio de Aragón. En su interior destacan el castillo Mayor y el pequeño castillo de San Cristóbal. En el Sur, en el cerro de San Jorge se emplazó otro pequeño castillo desaparecido.

Está constituido por lienzos, que tuvieron una altura aproximada de 8 m, de tapia de tierra calicostrada con mortero de cal de espesores variables que oscilan entre 1.00 m y 1.70 m, y con torreones cada 20–25 m, del mismo material con unas dimensiones aproximadas en planta de 3.00 por 3.00 m (Fig. 2). Los muros se coronaban con un paso de ronda y almenas.

Figura 2. Tramo de muralla erosionado.

3 ESTADO DE CONSERVACIÓN

El estado de conservación de los muros y torreones del recinto es muy deficiente. En muchos tramos ha desaparecido, en otros está tan erosionado que a duras penas conserva pequeños restos de su masa interior, en otros se encuentra en estado ruinoso con importantes amenazas de vuelcos y colapso, y sólo en unos pocos tramos relativamente bien conservados su aspecto permite intuir cómo fue el conjunto.

Tiene un gran interés paisajístico y plástico, al margen de su reconocido valor como Bien de Interés Cultural.

Desde el inicio de su construcción estuvo sometido a obras de reparación, conservación y mantenimiento como consta en documentos de época medieval y se comprueba con la mera observación de sus muros. Estas obras generalmente consistieron en el enlucido de los muros y en la reparación de la parte superior para evitar la erosión.

Cuando perdió su importancia defensiva cayó en un largo periodo de abandono lo que motivó, con el paso del tiempo, su actual estado de ruina generalizado agravado por las características de los materiales con que construido.

A lo largo del siglo XX se han realizado obras puntuales de restauración de los portales, torreones, elementos más significativos e importantes y algún tramo de lienzo próximo a los mismos, y obras de consolidación con aplacados de mampostería a modo de zócalos y muros de mampostería en las partes bajas de torreones para mantener su estabilidad.

Las obras realizadas esos años han servido para paliar en pequeña medida algunos problemas de conservación, pero lo más importante es que han supuesto el inicio de la concienciación por parte de los vecinos y Ayuntamiento de que el recinto amurallado de Daroca, por su configuración, peculiaridades, tamaño y materiales, es una singularidad única dentro del conjunto de los recintos amurallados de Aragón, en la que es necesario detener su progresiva ruina, consolidarlo para hacerlo lo más duradero posible en el tiempo (eterno dentro de lo humano), reponerle en casos justificados el esplendor perdido, y convertirlo en un recurso patrimonial muy importante del municipio.

4 TÉCNICAS CONSTRUCTIVAS DE LOS MUROS

El recinto amurallado está mayoritariamente construido utilizando la técnica de la tapia de tierra calicostrada con mortero de cal.

Los muros están formados por un zócalo de tapia de piedra y mortero de cal encofrada, de 1.00 m a 1.60 m de anchura y de altura variable, dispuesto sobre el terreno natural como base para regularizar el arranque de la tapia de tierra y para aislarla de la humedad. Sobre este zócalo se desarrollan hiladas horizontales superpuestas, a rompejunta, de tapiadas de tierra calicostrada de la misma anchura que el zócalo, con unas dimensiones aproximadas de 2.10 m de longitud y altura de 0.90 m.

Las tapiadas están formadas por sucesivas tongadas de tierra apisonada de 7 a 9 cm de altura con una junta entre ellas de mortero de cal de 1 a 2 cm (Fig. 3), y su superficie estuvo calicostrada con una capa de mortero de cal.

Las tapias presentan dos tipologías constructivas diferentes que, aunque semejantes superficialmente, han demostrado un grado de deterioro muy distinto (Figs. 4 and 5).

Las tapias realizadas con la tipología de agujas pasantes entre las caras de cada tapiada presentan un nivel de conservación mucho mejor que los muros realizados con la tipología de agujas no pasantes o medias agujas y tirantes de cuerda (Fig. 6), que están mucho más erosionados, prácticamente desaparecidos y con unos desplomes muy importantes.

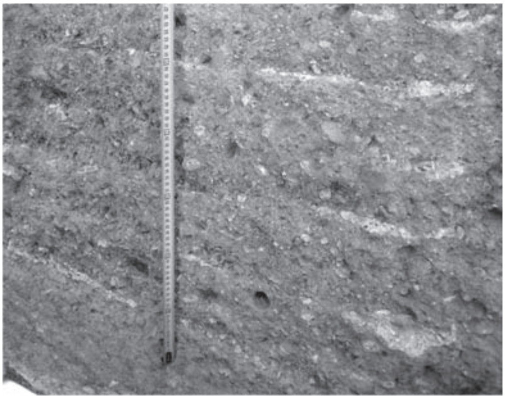

Figura 3. Corte de tapia con tongadas de tierra apisonada y cal.

Figura 4. Muro mejor conservado con agujas pasantes.

Figura 5. Muro peor conservado con semiagujas.

Figura 6. Restos de medias agujas.

5 NECESIDAD DE INTERVENIR EN EL RECINTO AMURALLADO

Del deficiente estado de conservación de las murallas se desprende la necesidad de su consolidación.

Por sus características, debe realizarse un Plan Director que permita conocer en su totalidad el recinto, su historia, evolución, morfología, materiales y técnicas constructivas, arqueología, estratigrafías, patologías, etc., para poder plantear futuras propuestas y criterios de intervención, además de un plan de usos, gestión y difusión.

Como apoyo a este trabajo pendiente y con la finalidad de ayudar a establecer futuros criterios sobre la consolidación del recinto, en el año 2007 a través de un Taller de Empleo se inició la investigación sobre distintas técnicas de consolidación, reparación y restauración de las tapias, cuya experiencia, rendimientos, resultados y conclusiones pudieran aportar una información útil para las posibles intervenciones futuras que pudiera recoger el Plan Director, y también se inició la formación de trabajadores conocedores de esas técnicas.

6 TÉCNICAS DE CONSOLIDACIÓN Y RESTAURACIÓN REALIZADAS

Antes de iniciar los trabajos, para aprender a manejar la tapia de tierra se realizaron en el suelo tapias de tierra calicostrada, primero de pequeño espesor y después del espesor de los lienzos de la muralla fabricando los tapiales, costillas, agujas y pisones necesarios (Figs. 7 and 8).

Con carácter general el gran problema que presenta la incorporación de nuevos volúmenes a las tapias de tierra degradadas es lograr la adherencia de la nueva masa con la existente. Para lograrlo se han utilizado a lo largo de la historia diversas técnicas consistentes casi todas ellas en realizar cajones de tapial nuevo de tierra, colocando previamente llaves de atado o anclajes con ladrillos, rollizos de madera u otros materiales empotrados parcialmente en la tapia vieja.

Las intervenciones previas que se realizaron en todas las pruebas posteriores consistieron en:

Figura 7. Fabricación de tapia de pequeño espesor.

Figura 8. Fabricación de tapia del espesor de la muralla.

– Consolidaciones con rellenos de lechada de cal en los vacíos interiores de muros a través de las grie-tas para evitar desprendimientos, y la eliminación de elementos sueltos en las partes altas para evitar accidentes.
– Saneado del terreno en los arranques de muros para evitar humedades de capilaridad en su base.
– Saneado de los zócalos de mampostería, atando las grietas con grapas de acero o fibra de vidrio tomadas con mortero de cal, y rejuntados con mortero de cal.
– Saneado de las dos caras y la coronación de las tapias de tierra descompuestas y disgregadas, acopiando la tierra para reutilizarla posteriormente en las reintegraciones volumétricas, con el propósito de que los restos de los muros actúen de cantera de sí mismos en su reparación.
– Varias manos de jabelga de agua de cal sobre la superficie saneada.

En todas las pruebas se utilizaron tapiales de madera de las mismas dimensiones que los originales para que las juntas finales resultantes fueran iguales a las existentes.

Las distintas pruebas de consolidación y restauración realizadas pueden clasificarse en cuatro grupos:

6.1 *Regularización de niveles de lienzos de muralla en todo su espesor*

Estas pruebas se hicieron utilizando los mismos materiales con que estaban construidos con pequeñas diferencias.

Para estos casos, que son los más sencillos ya que la intervención alcanza a todo el espesor del muro y en una altura limitada, el problema de la adherencia del nuevo material con el existente se minimiza dado que la nueva tapia se hace sobre la vieja, y para resolver su unión se dispuso sobre ella una capa de mortero de cal y a continuación se realizó la nueva tapia de tierra calicostrada con mortero de dos maneras distintas.

En una, se dispuso una malla de fibra de vidrio en el interior del mortero de unión y en la calicostra superficial de ambos lados, para controlar las fisuras de retracción del mortero, diferenciar la nueva tapia de la vieja y facilitar la adherencia de las futuras reparaciones con un nuevo mortero en las calicostras desprendidas.

La ejecución de esta solución es lenta por la complejidad en el manejo de la malla en el interior de la masa del mortero en las sucesivas tongadas con que se realizan las tapiadas. (Fig. 9).

La otra consistió en amasar el mortero de las calicostras de cal con fibras de polipropileno como solución a las fisuras de retracción y como elemento que diferenciase los morteros nuevos de los viejos. Esta solución es más rápida que la anterior (Fig. 10).

Figura 9. Tapia regularizada con malla en la calicostra.

Figura 10. Tapia regularizada con fibras en la calicostra.

6.2 *Reposición del extradós de lienzos de muralla para regularizar su superficie*

La patología más frecuente que presentan los muros es la pérdida de sus caras exteriores dejando su masa interna de tierra expuesta a las inclemencias meteorológicas que van progresivamente erosionando el muro de arriba a abajo y finaliza con su colapso.

Con la reposición de su extradós se recupera la verticalidad de los muros y se logra el rápido deslizamiento del agua por su superficie. Para ello se realizaron distintas soluciones en muros de 1.60 a 1.70 m de espesor. Se realizaron varias pruebas de reposiciones en las que el espesor osciló aproximadamente entre los 10 y 40 cm.

El gran problema que presenta este tipo de intervención es lograr la adherencia de la tapia nueva con la vieja en superficies verticales y de poco espesor. Para ello, en nuestro caso, dado que los muros en los que se iba a intervenir tenían los mechinales o huecos pasantes de las agujas con que se construyeron las tapias, se reutilizaron para disponer tirantes de varillas de acero inoxidable o de fibra de vidrio que unieran las nuevas tapias por ambos lados.

La primera consistió en utilizar hormigón de cal, es decir, arena, grava y cal con una dosificación semejante a la de los hormigones de cemento, con una armadura en su masa de varillas de acero inoxidable o de fibra de vidrio dispuestas a modo de mallazo vertical de las dimensiones de las tapiadas (Figs. 11–13), realizando distintas pruebas de integración cromática con los aditivos necesarios en distintas dosificaciones (Fig. 14). Este tipo de intervención es de rápida ejecución y permite realizar varias tapiadas simultáneamente. En caso necesario una vez terminada permite realizar distintos tipos de abujardado y darle un tratamiento superficial con jabelga de cal teñida para lograr la entonación cromática (Fig. 15).

Otra prueba consistió en utilizar el hormigón de cal sin ningún tipo de tratamiento cromático y disponiendo exteriormente una calicostra de mortero de cal semejante a las conservadas. Para ello se hicieron diversas pruebas con distintos tipos de arena para lograr una integración cromática adecuada (Fig. 16).

Esta prueba tiene el valor añadido de que al tener una costra exterior de mortero de cal, su textura superficial es semejante a la de las calicostras antiguos, y también permite jabelgas posteriores. Su ejecución es más lenta que la anterior.

A los morteros se les realizaron los dos tipos de tratamiento que a las pruebas del primer grupo con malla de fibra de vidrio y con fibras de polipropileno.

Figura 11. Mallazo de acero inoxidable.

Figura 12. Tapia de cal con mallazo de acero inoxidable.

Figura 13. Tapia de cal con mallazo de fibra de vidrio.

Figura 14. Pruebas cromáticas del hormigón de cal.

Figura 15. Muro con reposiciones de hormigón de cal.

Figura 16. Muro de hormigón de cal con calicostra.

Figura 17. Consolidación como ruina de coronación de muro.

6.3 *Consolidación de coronaciones de lienzos de muralla manteniendo su estado ruinoso*

Se realizó mediante el extendido sobre los restos de tapia de tierra saneada de una capa de mortero de cal con fibras de polipropileno y una malla de fibra de vidrio en su interior, y sobre ésta todavía fresca se echó tierra de la tapia ligeramente apisonada y humedecida para adherirla al mortero (Fig. 17). Se trata de un tipo de intervención de rápida ejecución que puede ser adecuada para pequeñas superficies, pero que para intervenciones de mayor entidad requeriría realizar alguna prueba previa de mayor superficie antes de tomar la decisión final.

Otra opción para los casos en los que los problemas de la erosión y del estancamiento del agua sean limitados, consistiría en echar sólo tierra humedecida de la propia tapia sobre la tapia ruinosa previamente saneada y posteriormente hacer un seguimiento sobre su conservación y grado de erosión para ir reponiendo nueva tierra conforme evolucione la erosión, lo que supone la obligación de realizar un seguimiento constante.

La solución más adecuada para estos casos consistiría en utilizar las dos opciones, la primera en las zonas con graves problemas de erosión y de acumulación y estancamiento del agua, y la segunda para el resto de zonas.

Figura 18. Consolidación de muro de tapia de piedra.

Este tipo de intervenciones permitiría mantener el gran interés plástico y paisajístico de los lienzos ruinosos evitando su colapso.

6.4 *Consolidación de muros de tapia de piedra calicostrada*

En estos muros para lograr su consolidación es suficiente plantear unos niveles de intervención "blandos" debido a las características más resistentes y duraderas de los materiales que lo componen, piedra y mortero de cal.

Estas consolidaciones se realizaron en la torre del homenaje consolidando las calicostras con lechada de cal con fibras de polipropileno y la aplicación de varillas de fibra de vidrio para adherirlas a la masa del muro en las zonas necesarias, y en las superficies donde habían desaparecido las calicostras sólo se rejuntó la masa de la tapia expuesta con mortero de cal con fibras de polipropileno para evitar el estancamiento del agua y proteger las piedras de la erosión.

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Linhas de Torres historic route rescuing and enhancing earthworks

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ABSTRACT: Around 50 Km from Lisbon, over a hundred military earthworks located up the hills between the river Tagus and the Atlantic Ocean survived after 200 years. They are at the origin of a project of rehabilitation, interpretation and fruition that has been named Linhas de Torres Historic Route. A decade of research and intervention works on around 30 military structures led to more information about building materials and techniques used, whilst also enabling the testing of rehabilitation techniques / structure stabilization, and monitoring the effects of men and the elements on earthworks built in between invasions so as to halt the advance of Napoleon's army.

1 WHAT THEY ARE AND WHAT IS LEFT OF THE LINES OF TORRES VEDRAS?

The Lines of Torres Vedras are the world's largest known defense system, playing a major role in the geostrategy of the Peninsular War. This group of forts was raised as a result of a joint effort of British and Portuguese military engineers combined with the hard work of local people.

In order to halt the succession of Napoleon Army's invasions (1807, 1809), a defensive plan was devised by Arthur Wellesley, future duke of Wellington and commander in chief of the Anglo-Portuguese forces. The plan assumed a defensive perspective aimed at controlling all accesses to Lisbon, establishing an efficient communication network, stopping food supply by the Napoleon army and reorganizing the Portuguese Army.

The Lisbon peninsula, sticking out between the river Tagus and the Atlantic Ocean in a terrain punctuated by hills played a major role as a defensive barrier. Two major fort lines for Lisbon's defense were built based on a study of access possibilities by the French army and the features of the soil.

Building works began in secrecy in the autumn of 1809 and, within a year, 126 forts and redoubts equipped with 397 artillery pieces were built. Barricades and palisades were raised, ditches and trenches dug, shooting fields were cleared and, in some areas, escarpments were sharpened. Military roads, bridges and pathways were built on the hills and along fortified lines in order to connect different earthworks.

Figure 1. Military and topographical map of the "Linhas de Torres Vedras e a sua ligação com Lisboa nos anos de 1810 e 1811"; In Soriano, Simão Luz—História da Guerra Civil e do estabelecimentos do governo parlamentar em Portugal 2ª época; Lisboa: Imprensa Nacional, 1874.

When the French army invaded Portugal in November 1810 the defensive lines were completed and military garrisons protected. Following sporadic clashes and withdrawal of the French army that was in Portugal between 10 October and 14 November 1810, works proceeded until 1812, when there were 152 redoubts.

Redoubts were built out of local materials (earth, wood and stone) for a specific purpose and on a temporary basis.

Results of a survey made about 10 years ago confirmed the existence of 80% of the original redoubts. Such fortifications, that were built and had no use since the fall of Napoleon's empire, were paradoxically protected by neglect and abandonment.

2 EARTH FORTIFICATIONS

In addition to acting as barriers between the allied forces and the enemy, military forts were also used as watch towers. They had a geometric layout, adapted to the territory's physiognomy and comprising ramparts with an average height of over 1.5 m surrounding the place of arms, where earth traverses protected the garrison and the magazine from the enemy. Ramparts were often built using earth lifted from ditches surrounding the front that was exposed to the enemy.

This rational use of local resources contributed to the swift building of structures, whilst also minimizing the effort of transporting building materials.

In order to confirm soil composition, origin and compaction, a number of soil boring tests were conducted in ramparts and traverses. Preliminary results provide information about the process of restoring and consolidating such structures.

The soil structure affects aeration, water movement, resistance to erosion and plant roots in vascular plants. Soil structure analysis can lead to precious data about the sedimentary origin, and the organic and inorganic matter content of soil. It can also provide information about past soil evolution in terms of biological activity and human use,

Figure 2. Collecting samples for laboratorial analysis, Forte da Feira, Mafra, 2011 (Ana Catarina Sousa).

Figure 3. Land Clearing, Forte Grande da Enxara, Mafra, 2008 (Marta Miranda).

and chemical and mineralogical conditions under which the soil formed.

This type of construction, that is particularly exposed to the elements, to the inclination and orientation of structures and earthen surfaces, combined with exposure to the wind, humidity and temperature, determine the wearing of the original material.

Leaning structures (parapets, traverses) are more susceptible to phenomena such as surface drainage, land sliding and landfall, where vegetation acts as a protection and containment element.

Biological factors are equally determining in the conservation of earthen structures, particularly when they are not regularly visited by humans. Plants, animals, fungi and bacteria affect the formation, aeration and mechanical resistance of soil. Plant roots and soil microorganisms allow moisture and air to infiltrate into deeper areas of the earth.

Vegetation growth cycles and decomposition combined with the action of microorganisms, including fungi and bacteria, form organic compounds that will create new layers of protection for earthen structures and surfaces. Considering that the bulk of these military earthworks are located in rural or peri-urban areas, the action of animals inhabiting these areas (rabbits, moles and rodents) is often harmful for structure conservation.

Vegetation clearing and cleaning operations made in some structures a decade before the Route project began and involving complete vegetation suppression, removal of roots and application of systemic biocides created serious impacts on earthen structures, leaving them completely at the mercy of erosion and infestation.

Complete abandonment for decades coupled with the growth of medium to large trees next to earthen structures accelerated erosion leading to inexorable destruction caused by excessive root growth and wind.

Erosion is perhaps the greatest menace to earthen structures. The combined action of water, wind and gravity can seriously damage them.

Apart from reducing their volume and destroying the shape of parapets and traverses, soil repositioning, as a result of digging trenches and ditches, may irreversibly damage a military earthwork. In some peri-urban areas, this situation led, in recent years, to some inadvertent earthmoving to make pathways or even for littering or informal motocross tracks.

Human impact, particularly in areas that are open to the public, can also influence protection of earthen construction. As parapets typically stand higher than the place of arms, visitors tend to go up and walk over traverses and parapets in order to take a look at the outer walls.

Unfortunately, this repeated and uncontrolled action may cause greater damage than erosion. The solution to this problem was the clear delimitation of walking circuits inside the structure, and sign posting to make people aware of the potential damages to structures.

3 PROJECT PREMISES

A multi-disciplinary team is involved in this project including heritage conservation experts, History and military researchers, municipal officials, archeologists and researchers with different scientific backgrounds.

The project guidelines stem from a deep knowledge of the area and its settings, and were inspired by good practices in the conservation of historic built heritage, according to legislation in force and international charters and recommendations.

Considering the large number of participants involved, an attempt was made to set out common guidelines through the implementation of theme workshops covering different areas such as Archaeology, History, Restoration and Landscape Architecture.

Drawing on pilot experiences conducted by the municipalities and the Army personnel involved in the Route Project, a handbook of good practices was developed for cleaning, clearing and recording/characterizing vegetable species and establishing guidelines for restoring and rehabilitating earthen structures.

Considering the vast number of earthworks needing intervention, their territorial dispersion and the existence of six entities with responsibilities for managing such areas, a number of methodologies (see table) and terms of reference were developed to ensure technical and scientific rigour and a methodological and formal unity in interventions.

As well as creating good practice rules to be applied to all intervention areas, it was necessary to develop specific intervention projects. The first projects/interventions were implemented in 2008 on an experimental basis. Proposals were put forward and solutions tested in an attempt to opt for reversible and low-impact interventions to be later validated by a joint debate.

From the early stages of the project, it was concluded that it would not be possible or advisable to apply a single solution. Therefore, two intervention approaches were developed for the military earthworks integrating the Route.

Table 1. Methodology—Basic procedures.

1. Diagnosis:
   a) Historical and documentary background;
   b) Structural features and state of conservation;
   c) Vegetation survey of the study area and surroundings;
   d) Past interventions;
   e) Archaeological excavations.
2. Planning:
   a) Vegetation cleaning and maintenance;
   b) Safeguarding and enhancing plan;
   c) Monitoring and maintenance plan;
3. Intervention.

Table 2. Cleaning and conservation actions—Basic procedures.

1. Continuous archaeological monitoring including recording of resources used.
2. Minimizing staying and trampling impacts by all those involved in the operation;
3. Delimitating work sites preferably outside the military earthwork;
4. Cleaning and scrub clearing operations should be made in such a way as to avoid earth movements, caused namely by machinery impact.

Figure 4. Ramparts: volume repositioning sediment compaction, Forte do Zambujal, Mafra, 2009 (Ana Catarina Sousa).

Table 3. Consolidation of earthen structures—*Basic guidlines.*

1. Structural consolidation of military earthworks should be made according to the minimal intervention principle;
2. In exceptional cases where structure size has been reduced to such an extent that it can lead to a wrong interpretation of the structure, the possibility of a volume recomposition should be considered, if duly justified and recorded in a technical report; in such case, the earth to be used should be collected and reused within the required area without jeopardizing the integrity of the remaining structures or altering the territory's morphology;
3. The consolidation of earth structures by resorting to soil compaction and other consolidation methods should only be considered in case of unequivocal ruin threat;

Table 4. Different stages in consolidating and restoring earthworks in Forte do Zambujal.

1. Manual cleaning of vegetation and loose humus from ramparts;
2. Archaeological intervention for determining the original structure;
3. Laying rock outcrops in terraces after thorough clearing of vegetation and humus—a technique that was originally used for building some ramparts;
4. Applying herbicide/biocide spray for eliminating vegetation;
5. Applying fiberglass matting as a separator for reconstitution;
6. Laying stone and clay material in layers for restoring ramparts.

The conservative one, restricted to treating the vegetation cover, delimitating the structure and visit circuits, signposting and implementing a minimalist conservation and restoration program.

The evaluative/interpretative approach involves a direct action enabling a deeper interpretation and reading of the site, archaeological excavations and the implementation of a conservation and restoration program adjusted to the morphological, functional and building features of the study area. The impact of visitors on earthworks was also taken into account.

Pilot interventions led to a number of indicators that became fundamental in subsequent interventions: the frequency of control action on the vegetation cover, the reliability and durability of supportive information, the resistance capacity of structures to visitors' impact, and the efficiency of applying contemporary solutions to a space that has been converted to a new use. For example, the Zambujal Fort project (coordinates 38.94933; –9.385983), completed in September 2009, led to a more comprehensive intervention thanks to the specificity of this fort and the value of its landscape setting.

The Zambujal Fort has a composite plan comprising a central redoubt and an advanced battery

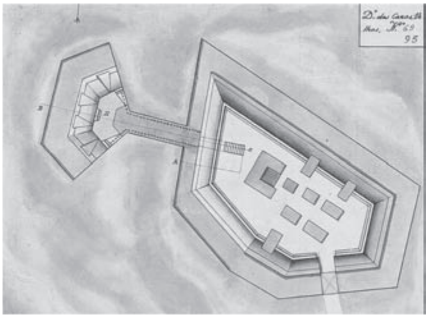

Figure 5. Military and topographical map of Forte do Zambujal; Gabinete de estudos arqueologicos de engenharia militar/direção de infra-estruturas do exercito, Lisboa.

Figure 6. Access to the battery before and after enhancement works, Forte do Zambujal, Mafra, 2008 (Ana Catarina Sousa).

Figure 7. Access to the battery after enhancement works, Forte do Zambujal, Mafra, 2009 (archive DPO/IGESPAR).

Figure 8. Earthwork cross section (traverse); Forte do Zambujal, Mafra, 2009 (Ana Catarina Sousa).

Figure 9. Archaeological works; Forte do Zambujal, Mafra, 2009 (Ana Catarina Sousa).

Figure 10. Aspects of the magazine before and during the intervention; Forte da Feira, Mafra, 2008/2011 (Ana Catarina Sousa).

Figure 11. Aspects of the magazine before and during the intervention; Forte da Feira, Mafra, 2008/2011 (Ana Catarina Sousa).

that is accessed by a tunnel. This is one of the most complex structures of the 2nd Line. A scrub vegetation cover extended to 90% of the whole structure thereby affecting its integrity.

Archaeological excavations were carried out in an area covering nearly 15% of the total structure, thereby leading to the definition of the monument's plan and to information about building techniques used. Works carried out on earth traverses led to information about stratigraphic profiles for understanding the building techniques used. Registration was made of the first earthworks identified in Linhas de Torres and later in other redoubts such as Forte da Carvalha (Arruda), Feira (Mafra) and Ajuda Grande (Loures).

Restoration works and archaeological interventions took place simultaneously, as original techniques used in soil compaction were reproduced in rehabilitating ramparts and traverses. This earthwork is mostly made of stone masonry, as it is lined with ramparts. Overthrow of stone structures were removed, detail cleaning was carried out and in some places walls were consolidated by using original building techniques.

The intervention in Forte da Feira (38°56'08.50'' N 9°15'17.49'' W), located in the town of Malveira, posed new challenges to intervention approaches.

Archaeological works (2010–2011) brought major changes to the interpretation of this fort. Sedimentary features and the type of construction in these earthworks caused extensive overthrow of earth that hid the original structures.

Following extensive excavation works, a complex construction was identified comprising masonry and timber structures in the fort's magazine, entrance and embrasures. Data obtained raised doubts about the model proposed for intervention in the second line, as it was traditionally associated to earthen construction.

Restoration works had to be adjusted to an essentially earthen building technique. Only compacted soil and soil additives were used for stabilization purposes and for the final presentation. Unlike any other structure in the Lines of Torres Historic Route, the Forte da Feira's magazine had to undergo a complete repositioning of soil, as the whole structure had to be rebuilt, including its wooden elements.

This option was taken bearing in mind the existing of vast and safe information to be used for rebuilding and, particularly, the need to preserve earth ramparts that had undergone repairs during archaeological excavations.

4 CONCLUSIONS

The "Linhas de Torres Historic Route" project was developed between 2007 and 2011. It played a major role in contributing to the evolution of historic, constructive and archaeological knowledge as a result of interventions on around 30 military earthworks.

Works are currently nearing completion, as technical and scientific reports are being prepared, and maintenance and monitoring actions are underway.

This project is a major step forward in Portugal in terms of interventions in "fragile and ephemeral" military earthworks. It has been proved that managing the vegetation cover is always a critical issue, both at the initial stage of intervention and after completion of the conservation and enhancing works. Minimum intervention on the vegetation cover (pest control) or non-intervention is recommended for military earthworks not included in the project (heritage reserve for future generations).

Another conclusion to be drawn is that archaeological research on Contemporary Age, particularly military archaeology, has not been sufficiently developed in Portugal. This type of research has been conducted mainly by military researchers with a scarce involvement from archaeologists.

Regarding the project's contribution to information about architecture and building techniques, it may be concluded that, drawing from data collected from 11 excavations in the Route Project earthworks, preliminary studies based only on old maps and readings of the terrain will have to be complemented by topographic surveys and excavations.

We may effectively review the image of second line forts that were exclusively made of earth, since their main elements (magazine, embrasures, entrance) seem to have a much more complex building technique, such as the stone component hidden by earth overthrow.

Similarly, archaeological interventions led to the identification of one of the most important elements in military works: timber constructions. Even though they were visible in old plans and were referred to in historical documentation, their timber component was not visible.

Archaeological excavations were also crucial for better understanding earthen construction techniques. Erosion phenomena in these earthen structures raised important interpretation difficulties, as sediments are deposited in reverse order. Drawing from the experience in the Linhas de Torres Historic Route, there is an absolute need for an integrated action including areas such as Landscape, Archaeology and Restoration, avoiding at all costs separation into different stages.

Noteworthy in this study are the methodologies used in consolidating ramparts and traverses. An attempt was made to reproduce the original building technique by using clay and different grain size stone material compacted with water and hand press (roller and hammer).

Preserving and rescuing "fragile" earthworks from the old Lines and exposing them in public is no easy task, nor is it risk free.

Constant information gathering (monitoring) and a critical analysis of all the technical and scientific data produced or underway will be crucial for the future of this unique heritage.

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The rammed earth technique, in all its variants, is widespread all over the world. This enormously prevalent building technique harbours an important richness of varieties both in application and in materials used. Interventions on historical rammed earth buildings have also been carried out in all the geographical areas where these structures are found. This historical heritage has undergone diverse forms of reconstruction, conservation, repair, substitution and/or structural consolidation. The different criteria applied require different techniques, materials or forms of intervention. The results of the interventions have also been manifold, both in terms of the impact on the building and the technical and material durability. With a view to these issues, this book deals with rammed earth architecture and its restoration, and, in a more general sense, with the construction techniques and restoration of all earthen structures.

Rammed Earth Conservation will be a valuable source of information for academics and professionals in the fields of Civil Engineering, Construction and Building Engineering and Architecture.

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