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# Recycling of bricks in rammed earth walls

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ABSTRACT: As Vitruvius' reflections shows, bricks are recyclable and can often be sold as aged raw material or ground up to make mortar additives. The first solution, concerning the reuse of ancient bricks, is interestingly associated with traditional rammed earth walls on the east Mediterranean coast of Spain. This successful combination of these two materials probably dates back to the end of the 14th century related to the medieval impoverishment context. The variety of rammed earth walls with bricks can be grouped into different categories, according to the different proportion of clay, lime and gravel or ceramic. In this frame, through the research project "Analysis of rammed earth walls with bricks: documentation and performance", several masonries have been studied to understand the role of the bricks and their function in association with rammed earth walls. This paper adresses the use methodology in preliminary results of the project.

## 1 INTRODUCTION

Valencian rammed earth construction is a hybrid masonry, where mortar plays a leading role alongside recycled brick reinforcement, which actually comprises a mixture of lime, gravel and rammed earth (Cristini & Ruiz Checa 2009ab).

The on-going study manages to throw some light on its origin, development and the disappearance of the technique in the province of the city of Valencia (Figure 1). In a nutshell, its moment of greatest use in construction was throughout the 15th and 16th centuries. But, furthermore, this technique is linked, on the one hand, with the tradition of "poor" masonries.

Valencian rammed earth walls form part of the "family" of constructive techniques using earth with reinforcements comprising pieces of brick protected by a crust of lime.

This combination of a mortar nucleus, bricks and a protective coat (Figure 2) responds to a secular constructive technique and a balanced system based on a singular hierarchy of materials, as the studies have proven (Cristini 2012).

In recent researches (Cristini & Ruiz Checa 2009c) the presence of bricks, from a mechanical point of view, has been found to perform the function of a connector, making it possible to absorb the shear stresses present in the nucleus.

These stresses may be due to possible seismic movements or subsidence in land with deficient geotechnical conditions.

Another possible cause of these horizontal stresses could have been something that took place while the wall was being built. The horizontal stress produced in compacting the layers would cause pressure that would be partly counteracted by the presence of the bricks (Figure 3).

Figure 1. Xátiva: Details of masonries of the Old Hospital and Ruiz de Alarcón Palace (Credits: Cristini/Ruiz).

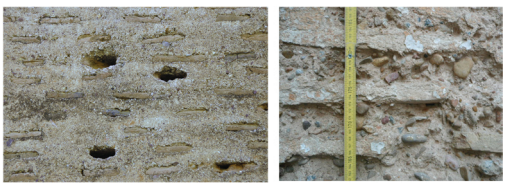

Figure 2. Detail of the presence of recycled bricks in the masonries and the protective crust (Credits: Cristini/Ruiz).

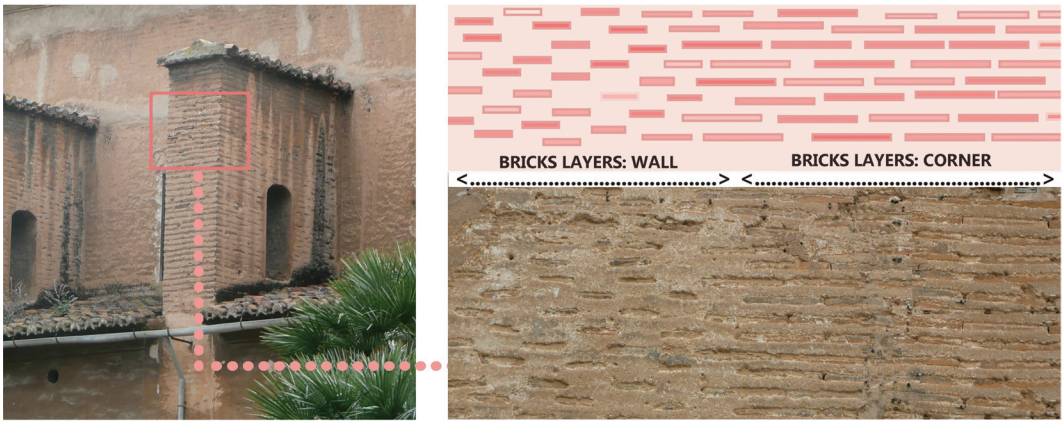


Figure 3. Analysis of brick layers differentiated at the corners (Credits: Cristini/Ruiz).

Knowledge of this historic technique, its masonries and execution is a necessary factor that can help establish possible criteria for interventions on historic Valencian rammed earth walls.

It can also be used to design protocols for quality control to be used for sustainable construction.

In this sphere, the background of the study covers a series of research projects connected with both national and international studies of rammed earth construction (AA.VV. 2007–2011).

## 2 THE ORIGIN OF THE TECHNIQUE

What is the origin of the technique and how was rammed earth first filled with bricks?

The presence of the oldest rammed earth technique in Spain dates back to Pliny's time (López Martínez 2003), which he refers to in his *Natural History* as *formatium*, that is a constructive module made with a last or a plank, a basic tool for making a wall.

It was in the Christian Reconquista of the city of Valencia that the technique came into its own, principally because of the combination of bricks in its composition.

At the present time, several theories about its origin are being debated, but the most convincing hypothesis seems to signal the old *Fàbrica de Mur y Valls* as the cause of the technological transformation (Serra Desfilis 2007), specifically as regards the process of building the Christian wall around the city (Figure 4).

But this institution did not promote the use of these techniques as a novelty, but rather based on a solid preexisting urban tradition (Braudel 1949).

There is an important gap in the history of the city in the 4th, 5th and 6th centuries, linked with

Figure 4. Valencia: city wall beside the Torres de Quart and a copy of Josep Lop's manuscript [1675] about the institution *Fàbrica de Murs i Valls* (Credits: Cristini/Ruiz).

the socio-cultural transition and the change that took place between Roman and Muslim political power.

Not only *Valentia* and *Balansiya* existed, but a little-known and little-documented hybrid entity between the two that spanned three centuries of history. Goths and Byzantines (Vizcaíno Sánchez & Ramallo Asensio, 2002) had controlled the Province of Hispania from the fall of the empire until 625 AD, the year the Byzantines were expelled, an event about which few documents have been published.

The presence of masonries with well-marked layers exists all over the Mediterranean countries (Mango 1978), related with the post-Roman constructive tradition, characterised by masonries with joints the same thickness as the bricks or even thicker (70–90 cm).

In fact, there are several techniques from the Orient made with this kind of brick. Some of them

Figure 5. From ground brick to the making of improved mortar (Credits: Cristini/Ruiz).

combine mixed techniques, using stone or timber, while others just use ceramic elements (Ward Perkins1954).

It is worth defining in more detail one of these techniques, whose constructive historic potential is undoubtedly of great importance, although not directly related to Valencia.

For example one solution is mentioned as "recessed-brick technique", built with a row of bricks set back from the vertical line of the wall in alternate rows (Ousterhout1999).

At the same time, the use of recycled bricks can be found in the Mediterranean area in the case of *opus signimun* or *cocciopesto*. In this case, the reused bricks act as a waterproof material and raw material to be used for making especially resistant mortars and coatings for pavements, cisterns and ponds (Figure 5).

## 3 GEOGRAPHIC LOCATION

This technique, a mixture between the application of raw clay (rammed earth) and fired clay (bricks), is not found in archaeological sites until the second half of the 13th century (Galarza Tortajada 1996).

Even the name does not appear explicitly until the 16th century (Galarza Tortajada 2012).

The adjective "Valencian" used for these walls is significant, although they were also used outside the city of Valencia (in Alcira, Xàtiva, Alaquàs, Castellón, Mascarell, Masamagrell, Sagunto, among other towns), and also outside what is today the Valencian Community (Murcia, Aragón, even in Guadix, in Granada).

There are even references to these Valencia rammed earth walls in the north of Africa (Algeria), maybe as a result of the arrival there of the Moors expelled from Valencia in the first half of the 17th century.

The study carried out has made it possible to distinguish between the use of the constructive technique according to the typological destination and its use in the different buildings where it can be found (Project UPV/PAID-06–12/SP20120466).

Very few cases are private buildings (10%); in fact, the technique, reflecting constructive logic according to a planned and systemic management of cycles of demolition and construction, is usually related to public buildings (45%), such as city walls and fortified spaces (Taberner 2012), warehouses or hospices/hospitals.

At the same time, this same proportion is reflected in religious buildings (45%), where the technique can be found in small chapels, seminaries (Lerma, Mas & Gil 2012), convents, the backs of churches or fences (Figure 6).

## 4 CONSTRUCTIVE CHARACTERISATION

Rammed earth walls actually look like a simple brick masonry, but if we look closely we will see that the mortar layers can be up to 10 cm thick.

An analysis of their metric characteristics shows total heterogeneity in the characteristics of the bricks used.

In spite of the half-bat layout of ceramic pieces, they are actually acting as connectors between the different layers of mortar (Cristini & Ruiz Checa 2012).

Another peculiarity of these masonries is the presence of a large variety of sizes and types of clay in the different walls. This leads us to consider the ceramic material as though it were a recycled material (Figure 7).

The presence of these irregular pieces of brick is not random, since they are little structural reinforcements acting as a frame or connector.

Therefore, they are not a mere bonding method. Their real function is more as a connection between layers than as a bonding agent. For that reason, three different clearly defined parts can be identified as forming a Valencian rammed earth wall: the mortar nucleus, the ceramic connectors and the lime crust.

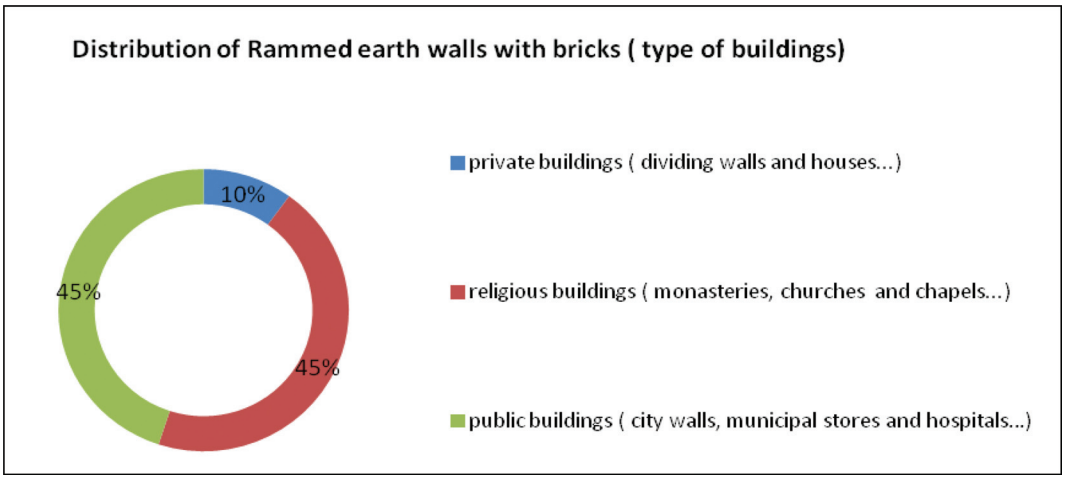


Figure 6. Graph showing the statistical distribution of the technique in different sorts of buildings (Credits:Cristini/Ruiz).

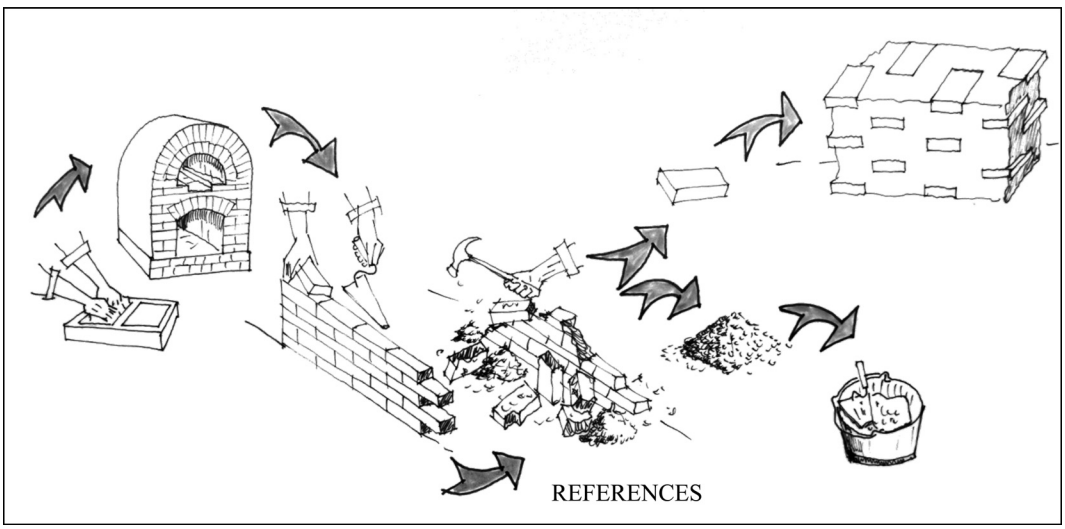


Figure 7. Life cycle of a brick and possible recycling phases (Credits: Cristini/Ruiz).

## 5 A CONSTRUCTIVE TRADITION THAT LEADS TO SUSTAINABILITY?

Valencian rammed earth walls are a clear example of sustainability in architecture, possibly a paradigmatic example of reuse of construction material in the past.

This hybrid character makes it extremely complex to focus in any study (they are made with formwork, yet with brick at the same time).

On the other hand, from a constructive point of view, the contemporary potential of the technique has been ignored completely, and it has only been considered as a method of the past.

Constructive experiments concerning Valencian rammed earth walls have been few and far between, and are limited to particular interventions on heritage buildings (Tormo, Garcia Martinez, Cortes & Palaia 2012; Font & Hidalgo 2009). So far, none of them has highlighted the hypothesis that the material used in making these masonries is reused.

For that reason, the recycling of the ceramic connectors, their characterisation, dosage and application are all aspects that have not been contemplated in the most important interventions carried out with this technique.

And it is precisely these aspects that are being addressed and promoted in the present study.

Thence the special interest involved in delving into different aspects of their being the way they are: the raw material, the possibility of recycling it, sifting, the ideal dosage for these masonries, their mechanical behaviour in earthquakes, their physical (acoustic and thermal) behaviour. The viability of the technique today completely lacks any systematic studies in new buildings (Bestraten & Hormías 2011; Iborra 2012), thence its experimental contemporary potential.

The ideal proportion of brick in each module of historic rammed earth wall analysed (length, width, thickness 2 mx1 mx1 m approximately) has currently been found to be between 100 and 150 bricks per m3 constructed. Besides, there is a series of interesting variations such as: different types of brick "pattern" (with stretcher, header or mixed bond on the outside), a different concentration of bricks and a variable level of conservation of the ceramic elements. The bricks are nearly always (in 80% of the cases analysed) in stretcher bond and their position is closer in the crust than in the filling. This is due to their role as connectors between the finish and the nucleus, apart from the fact that they provide reinforcement for the footing of all the modules.

The size and the chromatic and visual characteristics are always very variable, a token of the fact that they are being reused and come from very different sources. Furthermore, many pieces (approximately 70% of the cases analysed) are broken to begin with.

These are broken pieces (1/2 or 2/3 of a brick) that are placed in the parts of the fabric where they cannot be seen, just at the nucleus, which is an area that is not exposed to weathering. On the other hand, the visible side of the bricks is in a good state of conservation, with a uniform texture and a complete geometry, despite the differences in colour and in the raw materials used. With these data we can confirm that in the structure of Valencian rammed earth construction, comprising a nucleus, connectors and a crust, the connectors possess a large number of variables and peculiar features as transition elements and are largely responsible for the possible typological variants to be found.

## ACKNOWLEDGEMENTS

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