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Insight into the traditional timber frame walls: Herculaneum evidence versus braced frame structures in Portugal and in Italy

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Abstract

In recent years there has been an increasing interest in the traditional timber frame constructions in earthquake prone areas, due to their good earthquake resistance and the remarkable architectural features.
The purpose of this paper is to provide an insight into the historic timber frame walls and the reasons underpinning their use and dissemination within three different contexts, i.e. Herculaneum (until 79AD), Portugal and South of Italy (18th century).
During the Roman Age, the large use of timber frame walls corresponds to a proactive approach to working within a project's external constrains. Population growth and the need for fast and low-priced structures spurred an upgrade of construction techniques, especially in Herculaneum.
After the macro-earthquakes in Portugal and in Italy, instead, a similar construction system, based on three-dimensional timber frames, is expressly employed for its seismic resistance.
This diachronic comparison based on literature review and on-site analysis aims to clarify the influence of the timber frame walls on the architectural layout and on the building behaviour in these three case studies.

1 INTRODUCTION

The timber-framed structure can be interpreted as a constructive archetype that correlates *genius loci* with *genius artis* and *genius materialis*. Nardi introduces these concepts to define the technical acts a generator of archetypes where the construction and cultural instances merged and became the essential points of building system [1].

The persistence of the half-timbered system spans centuries and civilizations with various local declinations according to each environment. However, the archaeological evidence is scarce, especially within very strongly inhabited areas. The majority of the walls made of timber framework were lost after the structures had fallen into disuse.

Exceptions are those rare examples in which special conditions have fostered their conservation: in the European temperate climate, in cases where the wooden elements were baked (e.g. remnants of a fire), or in specific conditions of water saturation; or in the dry climates of North and East Africa [2]. In addition to the perishability of the components, there was previously little interest in analysing and preserving these structures, as demonstrated in the destructive early excavation campaigns in the Vesuvian area [2, 3].

Leaving aside the debate on its provenience, the timber-framed structure represents the most common type among the mixed construction practices employed by Romans. The Romans spread this mixed construction system throughout Gaul to the provinces of their jurisdiction, implementing the non-indigenous construction experience with their distinctively pragmatic, shrewd, and standardized work in order to increase the rapidity of construction.

Accordingly, the analysis of the Roman timber framed walls can be a starting point for discussing the genesis of this construction system in the Mediterranean basin.

Within the considerable literature on the Roman building techniques, an essential overview was addressed by Lugli in 1957 and by Adam in 1984 [4,5]. More recently, Giuliani re-examines these materials in order to overcome the risk of historical-archaeological simplifications through an accurate investigation in terms of metrological, material, and structural features, as appreciated by Bacchetta [2,6]. In addition, Ulrich provides a clear overview of the ancient sources and of the main questions surrounding the woodworking tools, examining recent discoveries within the Roman Empire in the Italian provinces (e.g. Lavinium) and in Britain (e.g. Verulamium)[7].

In this paper, a brief analysis of the timber frame walls at Herculaneum is carried out based on literature review and on-site analysis. Firstly, the reasons for the relevant presence of wooden components and the difficulties in gathering evidence are underlined. A remarkable case study, *Casa a Graticcio*, is described as precious yet controversial physical evidence. Its speculative reconstruction, often overlooked in the literature, is discussed to raise issues related to its value, conservation, and public appreciation (Figure 1).

Figure 1: Reconstruction works of *Casa a Graticcio* (1929) [8]

Secondly, the authors compare a few archaeological findings at Herculaneum with the internal structural skeleton of the buildings in Lisbon downtown and in the quake-damaged towns of South of Italy (XVIII-XIX century).

A considerable literature on these construction systems respectively aftermath of the macro-earthquakes in Lisbon (1755), and in less than thirty years in the South of Italy can be found [9,10,11]. However, further studies are still required in order to devise proper safe-guarding strategy.

2 PHYSICAL EVIDENCE OF TIMBER FRAME WALLS AT HERCULANEUM

2.1 Unlocking the reasons for the relevant presence of wooden findings at Herculaneum

Regardless of several adverse factors that prevent the comprehensive acquaintance of its historical backdrop, the ancient Herculaneum includes unparalleled cases study for a deeply understanding of the traditional half-timbered system.

The wider diffusion of this technique in this mid-sized town compared to other Roman settlements (e.g. Pompeii, Stabiae, Oplontis, Boscoreale) depends on: (i) a contingent cause, due to the intervention works along the Roman expansions and after the 62 AD earthquake; and (ii) the historical event, i.e. the eruption of Mount Vesuvius (79 AD) that allows the well preservation of the timber components. These two key points are briefly analysed.

Firstly, the strong demand of new constructions and the need of heavy repairs aftermath of the 62 AD earthquake may have influenced the diffusion of thin and cheap half-timbered walls [12,13]. The traditional timber frame system made use of available materials and did not require specific preparation of the materials or highly skilled labour. The pioneering and systematic use of mixed technique stemmed from the Romans' ability to structure their spaces according to the paradigms of their contemporary life, with a consequence of redefying the boundaries of the intimacy [14].

After seventeen years of the post-earthquake reconstruction, Herculaneum was overwhelmed and submerged by volcanic material flows at very high temperature (400ºC), which carbonized the organic components, encapsulating them in an anoxic environment, and determined its unique conservations conditions [3,12].

Unfortunately, many of the carbonized wooden artefacts have not been maintained. The fragility of the charred woods and the difficulty to extrapolate its among a solidified volcanic ash, as well as the low interest in these components in the early archaeological campaign, explain the absence of references in the excavations reports and also the heavy on-site destructions in 1780s [15,16].

2.2 Overlapping historical layers: *Casa a Graticcio* (*Insula III*, 13-15)

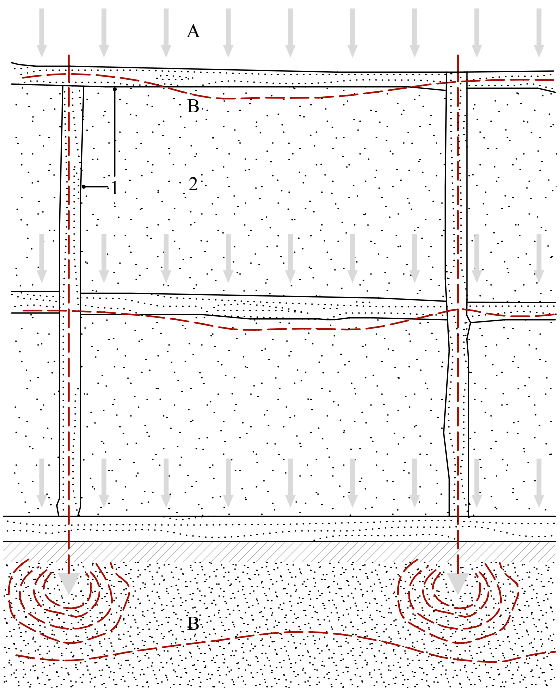
Among many dwellings discovered and restored at Herculaneum, *Casa a Graticcio* (*Insula III*, 13-15) is a remarkable evidence of the socio-economic organisation of the last building phase of the city.

In terms of typological features, it represents the transition from the single-family atrium houses to multi-family houses with courtyard. It is also representative of humble Roman houses in the narrow hybrid *insulae* (grid of rectangular blocks) that included commercial trading on the ground floor and rental apartments in upper floors.

From the early findings it was clear that the building layout is a result of a post-earthquake reconstruction. Monteix underlines the changes to the original layout through evidence of an early Samnite settlement of pre-Roman Age [8,16]. However, the construction solutions were likely selected for the cost-effectiveness, the thinness (possibility to split efficiently the interior space), rather than for the seismic resistance of the timber frame system. The internal construction system of the ground floor was probably chosen for the speed of execution and low thickness. In fact, the timber frame walls would have implied the possibility of easy dismantling. In its original conception, the construction system was characterized by a timber skeleton filled with heterogeneous components including straw, clay, and fragments of roof tiles. Divided into regular frames of 0.60cmX0.80cm of carbonised wooden components, the framework walls were locked within pillars in brickwork or tuff rocks and brick.

When *Casa a Graticcio* was discovered in 1927, only the structure on the ground floor still was integrally remaining, not including two thirds of the height of the three brick pillars that were later reconstructed by Maiuri. Occupying the public sidewalk, these pillars were executed with the specific aim to support the timber floor and the upper wall. Maiuri declares that the original timber framed structure was conserved only on the south side of the ground floor [16].

By being fully supported by the brick pillars, the external facade in (restored) timber framework acts as a non-loading system. The structural behaviour depends also on the boundary conditions, i.e. the adjacent houses which form a compact urban agglomeration. Due to their high flexural strength, the internal frame structures are presumed to collaborate with the external to support the weight of the roof structure. As underlined by Giuliani, this follows a structural model consisting of a load-bearing skeleton of linear elements appropriately spaced, which take and transfer all the stresses of the imposed loads vertically downwards [6] (Figure 2).



1. structural skeleton A. compression
2. filling B. combined compressive and bending stress.

Figure 2: Distribution of loads in a structure frame from Giuliani [6] (reprocessed by the author)

The 1930s interventions on the architectural vestiges of *Casa a Graticcio* implied heavy reconstructions of the internal structures and of the volume overhanging the main street (Figure 1). Even in the absence of a dataset from the daybook record, Monteix discovers several incongruities in terms of the external configuration as well as regarding items of furniture (e.g. bronze statuettes, positions of the wooden beds). Archive photographs allow interpretation of the recent works, especially the one related to the reconstruction of the external wall structure and the balcony; the different phases may be identified in time through the date of the snapshot incised on the negative [16].

As occurs in other buildings at Herculaneum, the type and the regularity of the replaced elements expose the modernity of this intervention that aimed at a semantic unity. In addition, the high degradation of the materials induced by these improper and incompatible restoration works is clear evidence of the low authenticity of this building following its reconstruction. On the external facade, the detachment of the coating layer shows two L-shaped steel beams distanced by hollow bricks that support the balcony and bear on the aforementioned pillars (Figure 3). The square frames of the external upper walls, whose timber components were replaced by new elements of the same size, were filled by blocks of yellow tuff stone [16], which is a foreign material to the local construction culture.

Figure 3: *Casa a Graticcio* (*Insula III*, 13-15, Herculaneum): main elevation after the 1930s restoration [16] and detail of L-shaped steel beams (2016, photo by the author).

Leaving aside the controversial aspects the structure inherited in the 1930s, this case exemplifies the persistence of human experimentalism in the ex-post earthquake intervention.

Casa a Graticcio may be the most relevant historical example of the proactive approach to working within a project's external constrains, an attitude that has since become the basis of modern engineering.

3 DIACHRONIC COMPARISON OF TIMBER FRAME WALLS

3.1 Localization in the building

Craticii parietes (i.e. timber frame wall) at Herculaneum can be divided into two groups depending on their localization: (i) the external walls on upper level, whereas the ground floor is in masonry or brick works; and (ii) the internal partitions on the ground floor and upper floors, directly supported by the floor structure, often coated with *opus sectile* (i.e. type of mosaic work).

When the external facade is made of timber framework (i), the lightness of this construction system allows an increase in the height of the upper-floor housing by ensuring a proper distribution of additional loads. It demands an alteration of the formal composition of the building, by squeezing the proportion of the facade through an inversion of the ratio between the height of the ground floor and the upper floor (e.g. *Casa di Nettuno e di Anfitrite*), or by lowering the overall elevation (e.g. *Casa a Graticcio*).

In cases of internal half-timbered walls (ii), the thinness of the partitions allows the limited floor space to be more easily organized while still providing some insulation. These partitions divide either secondary or principal spaces (e.g. *Casa del Larario di Achille*): the wall structure was completely hidden by figurative and coloured frescos in a such way that this construction solution was not distinguishable from a brick or masonry wall.

Regardless of their internal or external localization, the original load-bearing capacity of the frame walls at Herculaneum is completely lost due to the on-site burial, the damage caused by the excavations since the 1780s, and the works of the 1930s. In the latter phase, metallic structures, new infill, modern timber frame with some original casting pieces, and consolidation with paraffin were widely employed [15].

In the literature, Papaccio pointes out the Roman system's structural effectiveness under seismic forces [13]. On the other hand, Laumain underlines its structural fragility when compared to the medieval French timber frame buildings. Even in the presence of a regular structural grid that allows good load distribution, the slenderness of the timber framework and the limited cross-section of the components leads us to suppose that the Romans were not aware of the potential strength of this system [17].

Focusing now on the timber framework walls in Portugal (so-called *frontal* walls), this technique is a structural permanence before and after the 1755 earthquake, as can be seen in the overhanging dwellings in Lisbon [19]. The timber frame walls, whose seismic resistance has been fully documented on the basis of experimental tests, are the key components of a three-dimensional system above the first floor (Figure 4). Its use was systematised and largely employed during the reconstruction of Lisbon downtown after the 1755 earthquake, with a remarkable improvement of the earthquake-resistance performance of the so-called *Pombalino* multi-storey buildings [9, 10].

In contrast to the uniformity and standardization of the *Pombalino* system, several construction layouts and geometrical can be found in the braced frame heritage of the South of Italy. In these buildings, the timbered walls are filled in rubble masonry (external walls) or with horizontally arranged reeds between regularly spaced vertical posts (internal walls), as shown in Figure 5 [10]. As proven by recent experimental campaign, the timber framework would provide to the masonry wall an additional tensile strength under dynamic action [18].

Figure 4: Internal timber frame wall: *Pombalino* building in Lisbon versus Bishop's Palace in Mileto (Calabria region) (2015, photo by author).

2.2 Connections and materials characterization

This analysis focuses on the main construction features (i.e. connections, diagonal members, frames) and the materials characterization of the timber frame walls in the three mentioned case studies.

- *Connections:* Physical evidence shows how this type of internal wall at Herculaneum was executed after the construction of the floor and roof, as simple partitions in order to subdivide the interior space. As an example, in *Collegio degli Augustali* (VI, 21), the absence of technical devices (e.g. metallic fasteners and interlockings) to connect the half-timbered wall to the orthogonal structure (the external masonry wall) demonstrates that this was a later alteration of the original layout. The timber frame wall was executed in a second phase for a subsidiary function, detracting from the decorative scheme and compromising the inner spatial layout based on blind arches (Figure 5). In other cases, vertical posts were executed next to the orthogonal wall without any transversal connections, whose anchor devices remain unclear due to the surface finish applied in the 1930s.

In *Pombalino* buildings, a vast number of timber elements are lumped together by iron or metal ties [9,10]. The most common carpentry joints are half-lap joints (cogged half-lap joint or dovetailed or wedged dovetail) and mortise-tenon joints. These joints together to the *Trait de Jupiter* can be found also in the Herculaneum findings.

Figure 5: *Collegio degli Augustali,* Herculaneum (2016, photo by author).

This latter joint is commonly employed when the wooden beams are not available in the required length. It can be found also in a Bishop's Palace built in 1784 at Mileto (Calabria region). In this building, the internal timber frame walls are connected to the floor beams by half-lap joints (Figure 6).

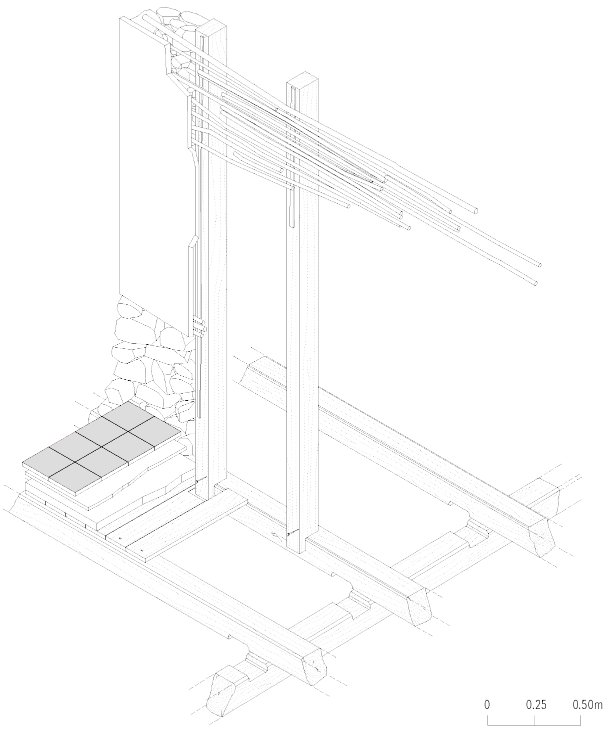


Figure 6: Internal half-timbered wall: Bishop's Palace in Mileto (Calabria region)(by author).

- *Diagonal members*: While stating the incompleteness of the archaeological excavations in Vesuvian towns, Adam argues that the use of bracing components (so-called "*tra-*

versa sbieca” or “*saetta*”) is rare within the Roman vestiges [5]. As shown by the low percentage of findings, Romans did not commonly execute diagonal components. The execution of bracing diagonals increases the time of construction and the degree of its difficulty. However, in terms of structural performance, the frames assume the behaviour of non-deformable triangles and they are then able to withstand the seismic effects related to 45° cracking. In the only exception so far discovered, timber diagonal elements can be found in the internal wall on the upper floor of *Villa di M. Arrius Diomedes* at Pompeii, although the wooden components were later replaced by plaster (Figure 7).

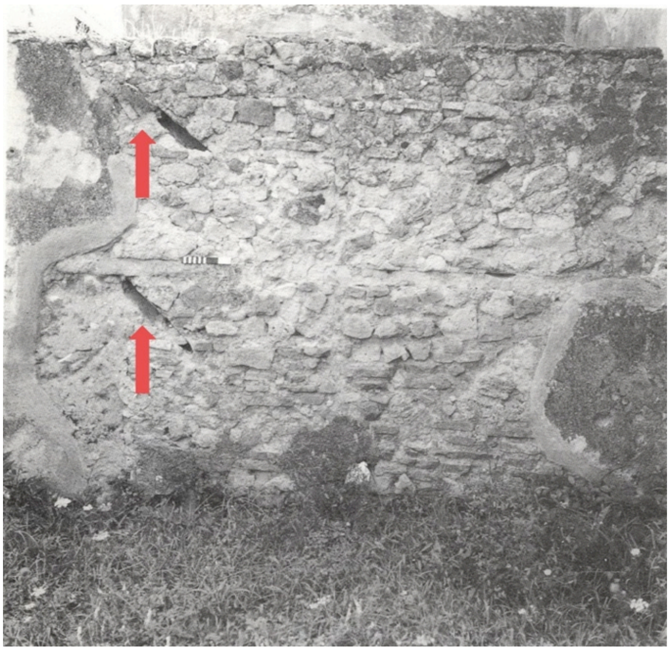


Figure 7: *Villa di M. Arrius Diomedes* at Pompeii by Adam [5]

Regardless of a less accuracy during the latest construction process, the *Pombalino* system until 1880 (when this type of construction was abandoned) always included most of timber frame wall reinforced by cross bracing components. In the Italian cases, instead, the diagonal components were not always employed, e.g. a building in Filadelfia described by Tobriner [11] versus Bishop’s Palace in Mileto [20].

- *Frames:* The timber frame walls are subdivided into squared frames. There is a dimensional correspondence between the width of the timber frame and the width of the doors (e.g. *Casa del Bel Cortile*). The same principle can be found in the other systems in analysis.

The regular geometry, implying an increase of the structural reliability under dynamic loads, was lost in the Portuguese timber frame walls during the Middle Ages, where unequally-sized squares prevailed [19]. Instead, after the 1755 earthquake, the regularity and the standardization of the construction process was respected [9,10].

- *Materials characterization*: The most commonly employed wooden species in Herculaneum was the same recommended by Vitruvius, the *Abies alba* (*De Architectura* 2, 8-9, 11-12), used both for building construction and for interior furniture, as confirmed by ancient sources and recent laboratory testing [21, 22].

Various types of wooden species and genus may be found in a single *Pombalino* building, i.e. *Pinus pinaster*, *Castanea sativa*, *Quercus ilex*, *Pinus silvestris*, *Pinus palustris, Quercus robur*, and *Quercus suber* [8,9]. *Calabrian Chestnut* is the most frequently used in the buildings of Calabria region.

The timber frameworks were commonly filled with heterogeneous materials, whose differences of the thermal capacity and hygroscopicity with the wood would cause the crumbling of the surface finish. In addition to the rising damp and the high ignitability, this is one of the most important drawbacks relating to this traditional technique.

4 CONCLUSION

The authors provide a comparison between Herculaneum's findings and the buildings executed aftermath of the late XVIII century earthquakes in Lisbon and in the South of Italy. It is shown that, regardless of their relevant construction differences, these systems involve similar structural principles and techniques that influence the buildings behaviour under static and cyclic loadings. The structural reliability of these constructions is based on the reduction in the weight from the lower to the upper floors, the ductile behaviour of the carpentry joints, and the high strength-to-density ratio of timber.

However, the building stock of the late XVIII century embodies an awareness of the seismic resistance of the timber frame system that it cannot be identified in the houses at Herculaneum.

This field of research should be further deepened (e.g. detailed survey of timber frames in the Vesuvian dwellings) in order to underlook the main features of this traditional technique.

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