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DYNAMIC ANALYSIS OF A POMPEIAN DOMUS

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Abstract. *The archaeological site of Pompeii has been subjected to restoration interventions since the beginning of its excavation. After the second World War concrete structures replaced the old wooden roofs erected in the late XIX. A systematic study of these structures is lacking, despite the number and the significant role they play in the stress state of the ancient masonry. In particular, the structural role of atriums roofing structures in the Pompeii buildings is examined. The impact of the restoration interventions actually present in the archaeological area of Pompeii is analyzed. A dynamic analysis has been performed to assess the seismic vulnerability of the ancient buildings in their actual state. The paper shows that maintenance of the existing interventions is a fundamental topic and substitution of r.c. roofs with timber structures cannot be justified by structural reasons. As a case study the entire Domus of the Tragic Poet is analyzed. A simulation involving a wooden roof is compared with the actual structure of concrete roof building.*

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1 INTRODUCTION

Pompeii, since its first excavation campaign, has been profoundly altered by successive mutilations, additions and transformations. In some cases strong interventions have been made in order to rebuild the original construction. This makes archaeological remains the object of complex, interdisciplinary studies involving archaeologists and applied scientists [1]. The balance between the respect of the ancient construction and the exigence of safety is a great challenge for the structural engineer [2, 3, 4]. Several different approaches for the interventions on Cultural heritage have been developed in these last decades [5, 6]. Different restoration materials have been in fact used during the decades, according the scientific approach to the structural technology of the time.



Fig. 1. Concrete Atrium roofs: Villa dei Misteri (left), Fabius Rufus (center) and Tragic Poet (right).

The first structural interventions in many Pompeian *Domus* involved the replacement of old wooden roofs with concrete structures similar to the old ones, especially in the two decades among 1960 and 1980, as the photo archives testify. Several of these roofs realized in particular on the atriums are nowadays visible (Figure 1) and the scientific debate is mainly about opportunity and durability of these interventions [7]. Reinforced concrete and wood are in fact the most diffused materials for the roofing structures of the atriums actually present in the archaeological area of Pompeii (Figure 2). A systematic study of these structures is lacking, despite the number and the significant role they play in the stress state of the ancient masonry.



Fig. 2. Wooden atrium roofs: Vettii Domus (left) and Domus on *Cardo V inferiore*

The use of steel structures in the atriums is limited, being extensively employed for quasi-provisional structures, therefore perhaps a more detailed analysis about the structural performance of both wood and r.c. in the seismic case could be a starting point in the scientific debate about the necessity of substitution of last with the first one [7]. It must be noted that all the upper part of the *Domus* atriums have been rebuilt and the ancient Pompeian masonry represents only the lower part of the walls [8], so that the seismic vulnerability should be regarded only from the point of view of the human safety and protection of original mosaics and paintings

[9]. An eventual collapse without damage to artworks could only bring back the walls to the original ruins state [10].

A Pompeian atrium is only a limited part of the complex structure of the *Domus*, so that the cultural discussion about the quality and scheme of the roof cannot be set apart from the structural analysis of the whole structure of the building and its history [11, 12]. The analysis of part of the structure, as successfully done in some cases [13, 14] cannot be applied to the Roman Domus, that is a complex arrangement of different materials and structures.

This paper deals with this last aspect, analyzing the whole *Tragic Poet Domus* by means of a finite element code. The influence of two distinct materials (wood and reinforced concrete) for the roof of the Tuscanic atrium. The structural behaviour is not significantly affected by the structural material chosen for restoration, so that the actual concrete roof (at present in perfect conditions) do not need an urgent replacement. The structural dynamic analysis of the whole Domus has shown that the atrium is the core structural element of the entire construction and the roofing technique do not significantly influence the vulnerability of the construction**.**

2 STRUCTURAL ANALYSIS

The Tragic Poet Domus in Pompeii, also known as the Domus of the "*Cave canem*" for its splendid black-white mosaic with a dog has been analyzed [15]. The case study is a corner building (Figure 13) with a Tuscanic atrium. The actual roofing structure is composed of r.c. beams, wooden rafters and clay shingles (Figure 1). The Domus has been chosen because it is a typical example of the Pompeian House [16] in which a key structural role is played by the large atrium, with a r.c. roofing structure in good conditions [7].

A finite element analysis has been performed in order to evaluate the role of the roofing structures' technologies in the structural behavior of the Domus (Figure 4).



Fig. 3. The "Cave canem" mosaic (left) and the Tragic Poet Domus (right) [7].

The linear analysis has been considered sufficient [17, 18] and has been carried out by means of a commercial finite element code [19], the whole structure has been modelled with solid tetrahedral elements C3D10 with medium dimensions 0.4 m. Different constitutive parameters have been taken into account, as reported in Table 1.

Mechanical properties	Masonry	R.C.	Wood	Wooden deck
Density, ρ [kg/m^3]	1937	2500	550	400
Elastic modulus, E [N/mm^2]	1140	30000	9800	6000
Poisson's ratio ν	0.2	0.16	0.2	0.2

Table 1. Mechanical properties.

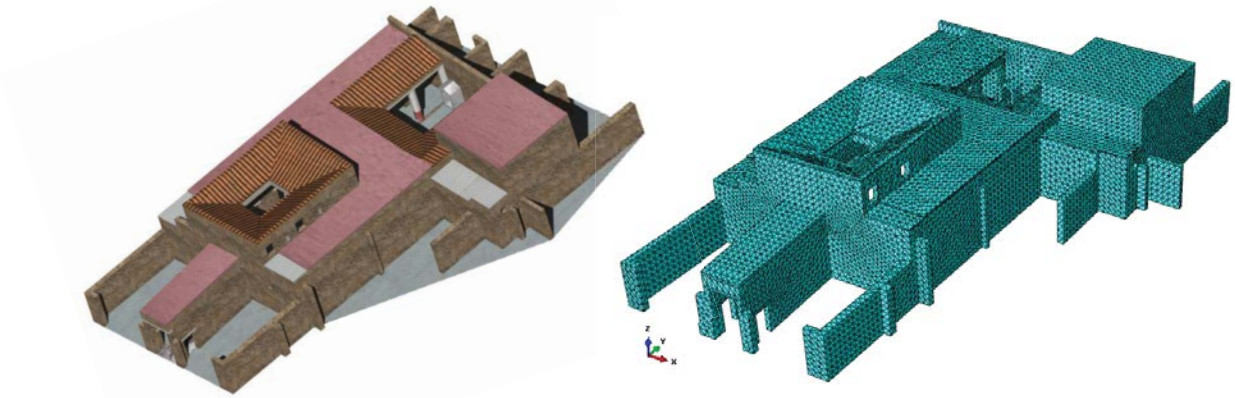


Fig. 4. Picture (left) and 3D mesh for the case study (right)

Two different roofing structures have been considered for the analysis: an ideal wooden structure and the actual r.c. one, leaving unaltered every other element of the Domus (geometry, material characteristics and self weight). The analysis results are reported in the following pictures, so to allow comparison in the two considered structural cases.

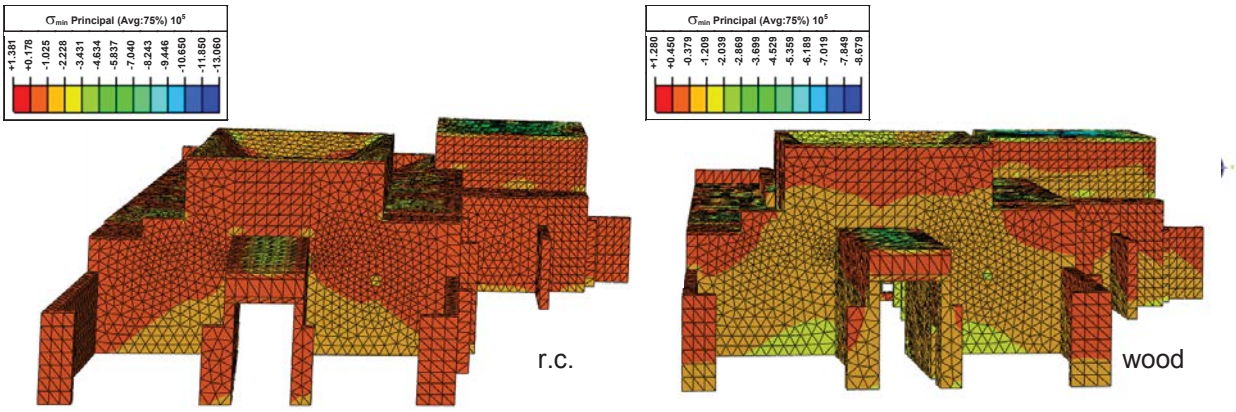


Fig. 5. Principal compressive stresses due to self weight. Detail of the front view

In Figure 5 a detail of the front view with a map of the principal compressive stresses due to the self weight is reported. Considering that the Roman masonry is only the lower part of the walls, its stress state in the two examined cases is similar, and this is true for all the ancient Domus masonry.

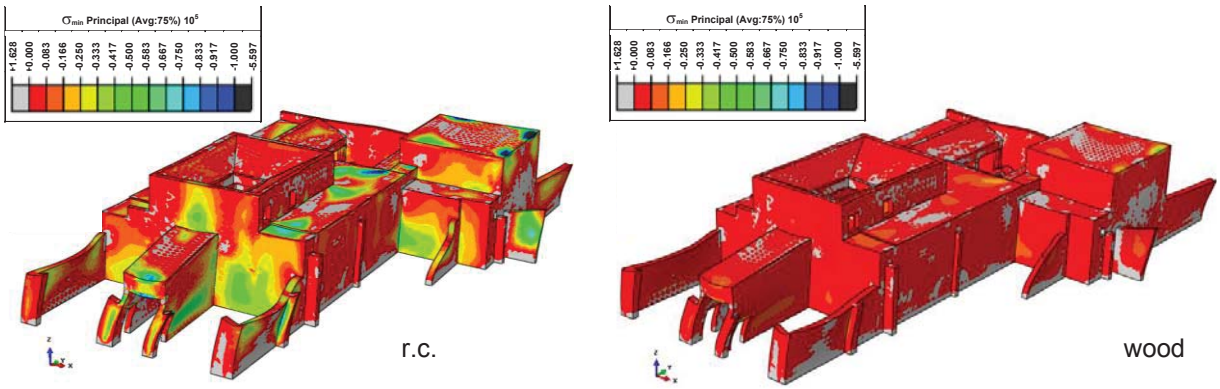


Fig. 6. Distribution of stresses in the case of selfweight and seismic action along x-axis.

Dynamic analyses have been performed considering the seismic action along the two principal axes of the Domus, involving a PGA 0.244 g and masonry tensile and compressive strength equal to 0.1 MPa and 3 MPa respectively [20, 21].

A similar condition can be evaluated in Figure 6 reporting the principal stress maps in the case of the combined actions of selfweight and seismic load along x-axis.

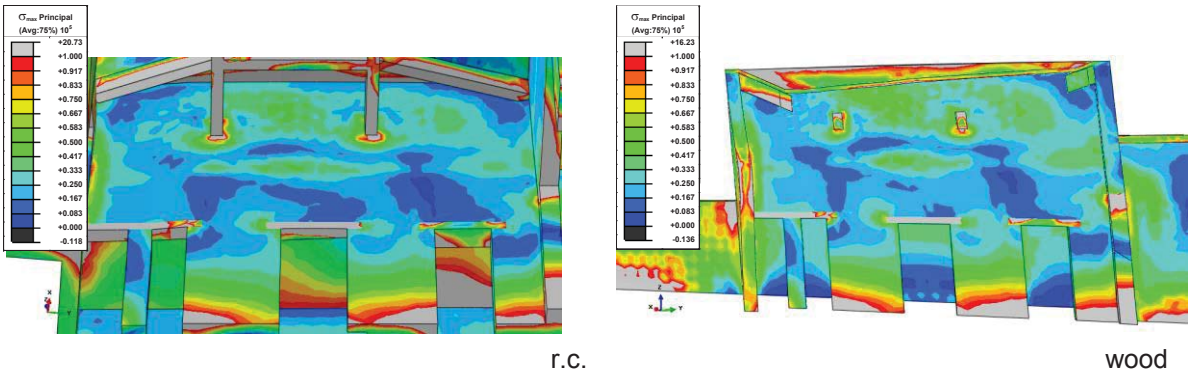


Fig. 7. Atrium distribution of stresses in the case of selfweight and seismic action along x-axis

In Figure 7 the stress state of the atrium is picted. As it can be note, the stress values are of the same order. The seismic analysis according the y-axis, reported in Figure 8, does not give more information, due to the larger inertia of the Domus in this direction.

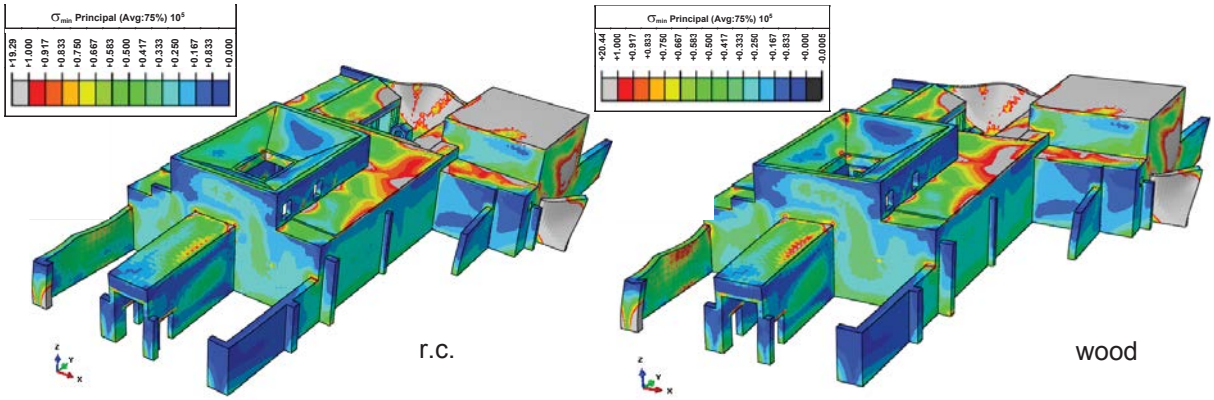


Fig. 8. Distribution of stresses in the case of selfweight and seismic action along y-axis

A dynamic modal analysis has been performed to assess the quality of response to seismic actions. The first 8 modes of vibration involve only limited structural elements: in general, all the masonry walls departing from the central block of rooms and the vestibulum. A representation of the first mode of vibration, where the vestibulum is involved, is reported in Figure 9.

The eventual collapse of the peripheral masonry elements makes the Domus become a more compact structure around the central atrium, since only the ninth mode of vibration involves almost all the domus structure, atrium and peristilium, as it can be seen in Figure 9.

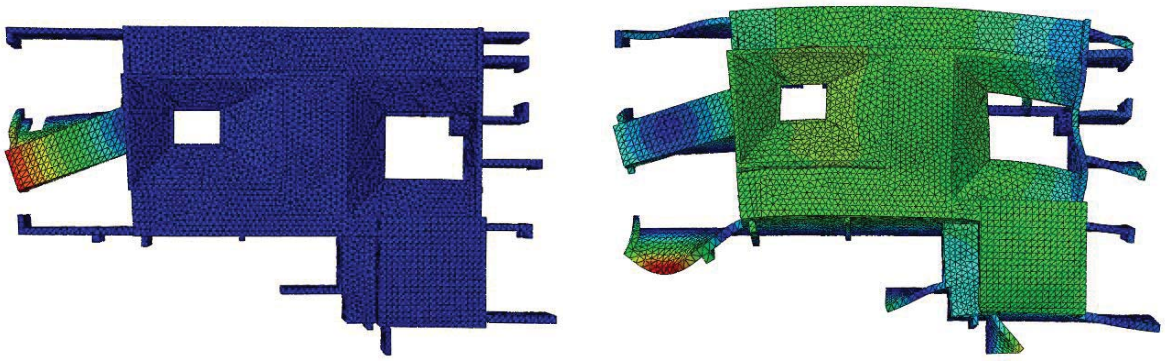


Fig. 9. First (left) and ninth (right) mode of vibration according the x-direction

These last considerations about the modes of vibration underline again the central role of the atrium in the overall behaviour of the Domus.

3 FINAL REMARKS

A Pompeian Domus is a complex arrangement of various structural elements, subjected in their previous life to heavy restoration interventions, in general respecting the original structural geometry only. Different restoration materials have been in fact used during the decades, according the scientific approach to the structural technology of the time. This paper analyzes the roofing interventions actually present in the atriums of the Pompeii archaeological area.

The entire structure of the Tragic Poet Domus (masonry walls and r.c. roof) is analyzed by means of a finite element code to evaluate the influence of structural material. Two cases have been examined: the actual r.c. roof structures, due to a post War intervention, and a geometrically similar timber structure. With regard to stress and strain maps, the two structures affect similarly the lower Roman masonry structures, so that substitution of r.c. roofs with timber structures cannot be justified with structural reasons.

Archaeological, aesthetical and durability considerations together with the restoration yard management, excluded in this approach, are the main aspects to take into account in a restoration program, since the stability and vulnerability questions depending on the roofing material assume limited importance as it has been shown in this paper.

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