A METHODOLOGY FOR THE SAFETY ASSESSMENT OF PROTECTIVE ROOFS COVERING ARCHAEOLOGICAL SITES: THE CASE OF THE “VILLA DEI MISTERI” AT POMPEII

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Abstract. Pompeii is the largest archaeological site in the world and one of the most visited as well. Villa dei Misteri is a great suburban villa just outside the ancient city. Every year, thousands of visitors are attracted by the superb frescoes from which the domus takes its name. In the course of excavations, the most significant rooms were roofed with the dual purpose of providing weather protection and returning the monument to its ancient state. The results of the restoring interventions display a wide range of roof structure typologies: reinforced concrete frame, reinforced concrete-tiles mixed floor, timber and steel frame. The evaluation of their health status requires a detailed study by means of a multidisciplinary approach, which should include historical research, geometrical and structural surveys, damage assessment based on both in situ and laboratory diagnostic tests, UAV (Unmanned Aerial Vehicles) remote sensing to inspect area and coverings not easy to reach in safe, and, as basis for seismic safety assessment, ambient vibration measurement (discussed in a separate paper). In this paper the preliminary results of the survey are presented. In particular, the main causes of decaying have been identified and preventive measures to reduce risk of damage have been suggested. Furthermore, considering that the described methodology has been developed also with the aim to qualify a standard procedure in view of further applications to similar roofing typologies, very common in the archaeological site of Pompeii, a more detailed diagnostic campaign has been planned in order to gather adequate data for a comprehensive safety assessment including seismic vulnerability analysis.
1 INTRODUCTION

The need to protect archaeological sites and remains from weathering is a major problem, especially in sites like Pompeii, where the ruins cover a very large area. Since the early days of archaeological research, the fragile nature of structures and objects just brought to light was a matter of concern which has been addressed in very different ways. To some extent, the history of archaeology is also the history of the methods and systems to preserve the archaeological remains during or after excavations. This issue was brought to attention for the first time at the beginning of the last century, especially after the reconstructions carried out by Arthur Evans at Knossos. In order to protect the most impressive discoveries, like the so-called Throne Room, Evans did not hesitate to restore parts of the palace according to the architectural fashion of the day, and to make extensive use of reinforced concrete frames, so transforming “poorly preserved ruins into a multistoried concrete vision of the past” [1]. This example of intervention, which can be defined as paradigmatic for the time, had its supporter among the experts, but soon became highly controversial. During the first international conference on restoration of historical monuments held in Athens in 1931, Evans’s bold reconstructions were generally deplored, while a “judicious” use of modern techniques, especially reinforced concrete, were approved. It is interesting to note that the Athens Charter recommended, not unwisely indeed, to rebury the ruins when it is not possible to assure proper preservation measures. It also important to stress that the Charter underlined the importance of what should have become the cornerstone of conservation management policy, the planning of regular and permanent maintenance.

In recent times, the matter has come again to the fore after which, in September 2005, the project to protect the important Minoan settlement of Akrotiri at Thera (Santorini) by means of an advanced steel covering ended in failure just before its completion, as the roof structure partially collapsed, killing one visitor and seriously injuring several others.

Such a disaster raises a critical question. Archaeological sites have become important economic resources in many parts of the world, and their economic potential is almost always realized through tourism. The necessity to preserve archaeological remains, as well as the need to make visitors' experiences more appealing and meaningful, has focused attention on the ways in which historical sites are interpreted and presented to the visiting public. For decades, reconstruction of ruins was thought to be a good method for protecting physical remains and making sites understandable to visitors. In many cases, however, modern structures weight on ancient masonry that could have lost the structural integrity required to provide safety to visitors, especially in case of earthquakes. In such instances, both monument and public are endangered.

Pompeii is the largest and maybe most visited archaeological site of the world. During past excavations several domus have been restored rebuilding the roofs with the dual purpose of providing weather protection and bringing them to their ancient shape. In the light of above, it is therefore important for these structures to be constantly monitored, and regularly subjected to a close examination to check their state of preservation [2].

With regards to the Villa dei Misteri, the present day state of roof structures displays a wide range of typologies (RC frame, RC floor, timber and steel frame) that has required the development of an analysis procedure with which both integrity and structural stability can be assessed. With this aim a multidisciplinary approach has been used, which includes historical analysis, geometrical and structural surveys, damage assessment based on both in situ and laboratory diagnostic tests, and UAV (Unmanned Aerial Vehicles) remote sensing to inspect area and coverings not easy to reach in safe. As basis for seismic safety assessment, vibration
analysis to characterize the dynamic behaviour of the soil and some heavy coverings structures have also been performed; the results are presented in a separate paper [3].

Finally, it is worth to stress that the described methodology has been devised also with the aim to qualify a standard procedure in view of further applications to similar roofing typologies, which are very common in the archaeological site of Pompeii.

2 THE VILLA DEI MISTERI IN POMPEII

Villa dei Misteri is one of the most famous domus in the ancient Roman city of Pompeii. It is located just outside the archaeological area of Pompeii and is so called for its superb frescoes depicting mystery rites (Figure 1). The early structures of the villa date to the 2th c. B.C., while significant building phases are attested around 90-70 B.C. and after the A.D. 62 earthquake. Discovered in 1909, the early excavations were led, in 1909-10, by Giulio De Petra, the archaeologist director then in office. After him, in 1924 came the renowned archaeologist Amedeo Maiuri, who held the direction of the Pompeii site until his retirement in 1961. Maiuri not only completed the excavation but also undertook an intense activity of reconstruction, to which is largely due the present-day conformation of the monument. On the basis of the resulting evidences from excavations, during the period 1928-1931 several rooms were roofed, and to reach the height of the original roof-beams’ impost plane, large parts of masonry walls were also rebuilt (four metres high on some ancient walls of the Atrium tuscanicum, Figure 2). In these first restoring works, horizontal beams and architraves were mainly supported by L-shaped cross-section steel elements, on which timber rafters rested on. In the course of the period between the 1960s and the 1970s, many roof structures, including the Peristilium and the Atrium tuscanicum, were replaced with heavy reinforced concrete frames (Figure 3). Over the same period, many rooms were covered with flat roofs supported by reinforced concrete and hollow brick elements mixed floors. In recent restoring interventions, timber and steel elements has been preferred, aiming to reduce the loads on ancient masonry.

Figure 1: Frescoes depicting the sequence of mysteries rite
Figure 2. Early restoration of the *Atrium tuscanicum*, on the left, and the *Peristilium*, on the right (source: Archive of the Soprintendenza Beni Archeologici di Pompei Ercolano Stabia)

Figure 3. *Atrium tuscanicum*: reconstruction of the roof structure in reinforced concrete in 1969 (source: Archive of the Soprintendenza Beni Archeologici di Pompei Ercolano Stabia)
3 SURVEY CAMPAIGN

3.1 Visual inspection

The visual inspection has been the first step of the vast in situ survey carried out aiming at the evaluation of the preservation state and the structural identification of the whole roofing structures, with reference to each room of the villa (Figure 4). During the survey common tools have been used in addition to more sophisticated ones, useful for the identification of hidden structures. In particular a thermal-camera has been employed to individuate the structural element covered by plaster.

All data have been collected on IPad tablet using a specifically developed digital survey form, which has allowed the collection and the “real time” sharing of various kinds of data (text, photos, movies, thermal images, audio recordings, historical sources etc. [4].

![Figure 4. Villa dei Misteri: a) Roofing layout; b) Rooms numbering](image)

3.2 High resolution images acquisition of the roofs by UAV

The remote methodology description

LARS (Low Altitude Remote Sensing) or UAV (Unmanned Aerial Vehicles) remote sensing is a set of techniques for collecting data through the use of sensors mounted on carriers operating at low altitude. The proximity sensing is used in all those cases where it is not possible or convenient to use the traditional platforms to collect data from high altitudes or in those contexts in which it can be useful to integrate data from different altitudes of observation. The platform allows to acquire, at low altitude and with high resolution, structural and architectural details of buildings, and to determine the conservation status, structural damage and collapse danger [5].

In “Villa dei Misteri” the technology has allowed us to have an overview of the complex roofs system and the preliminary assessment of its conservation status. The technology, associated with traditional and innovative survey techniques, allows the vulnerability assessment of historic-architectural and archaeological heritage [6][7].

Drone and sensor technology

The instrumentation used in the study area is constituted by an electric propulsion quadricopter (Figure 5) with a high resolution camera installed. The drone was equipped with a tool for
automatic control of positioning and stabilization of the camera, so as to have the entire sys-
tem perfectly orthogonal to the scene to be captured.

The high resolution camera is installed in a slide whose movement according to the axes x, y, z is made possible by a RC servo; the camera, a GoPro video with 960 x 540 px resolution, captures high-definition images and video in the visible range (0.45-0.69μm).

**Flight planning and image processing**

Identify a point at which the pilot had a synoptic view of the entire structure in total safety wasn’t possible therefore the video capture of the building was acquired in sub-zones. In Figure 6 the positions of the drone take-off / landing are shown.

Video recordings were processed using video-editing software that allowed the single frame extraction. The images captured by the video have been developed with image processing applications and the RGB components in the visible range have been extracted. The polygons on the plan (Figures 7 and 8) show two captured flight areas and shown in the next pictures.
Then, the colour images are displayed into three spectral bands (blue, green and red) in order to highlight possible problems in the roofs. An example of this procedure is shown in Figure 9 in which dark areas are observed on a roof pitch of the Peristilium. This particular is very evident in the blue component of the image (the blue spectral band is defined on the water reflection peak), photo on the right, and suggests the presence of a surface layer that retains moisture.
3.3 Preliminary “in situ” tests

In some position it has been necessary to realize local tests, where visual inspection was not adequate to obtain the necessary information about the structure features [8]; a pachometer (covermeter) has been employed for the localisation of reinforcement in concrete elements; a sclerometer for timber has been useful for the evaluation of the superficial preservation state of some timber elements; finally, local tests have been necessary when the protective coating hid the actual structural typology (Figure 10).

The location of the tests has been selected taking into account the preservation of structures, precious plaster, and decoration elements. As a consequence they are realized in areas free from frescos and precious plasters.

4 RESULTS

4.1 Definition of roof typologies

Many covering structures of the Villa dei Misteri are clearly visible, therefore the typology and their preservation state has been already evident during the visual inspection (Figure 11): timber structures are in the Tablinium (room n. 2), in the rooms from 11 to 18, in the Torcolarium (48 and 49), Vestibulum (62), Peristilium (63), Arcades (67, 71 and 78) and in Corridor 79 and 81; concrete-tiles mixed structures are in the rooms n. 5, namely Mysteries Room (5), and Serviceability room (36); vaulted masonry structures are in the rooms 4 and 8 (Cubiculum), in Corridors 7 and 19, in the Exedra (42) and in Corridor 68. Otherwise, thermal camera and local tests have been useful to the structural identification (Figure 12). In particular, the thermal camera has foreseen the direction and the spacing of concrete-tiles covering floors. In both latter cases concrete-tiles floors are evidenced in the all other rooms.
Figure 11. Naked roofing structures: a) Timber structure (2); b) Concrete-tiles (5); c) Masonry vault (4)

Figure 12. Covered structures: a) Visual and termographical survey; b) Local test for structural identification

Two mixed structures have been surveyed. The first one (rooms 31 and 32) is composed by a timber rafter supported by a RC beam, which in the middle span is supported by a pillar, bearing on an inferior horizontal floor (Figure 13a). The second, (room 64), is realized with timber inclined rafter completely covered by cementer mortar, supported by RC beams (Figure 13b). The covering layer of inclined structures is composed by tiles or metal sheets while, for the horizontal structures, a bituminous waterproof layer has been assessed (Figure 14).
4.2 Evaluation of the conservation state

The visual inspection has evidenced some significant degradation phenomena. In particular, widespread water seepage (Fig. 15a) due to the degradation of the waterproof membrane, which is separated from the inferior supporting layers in many points of the perimeter (Figure 15b). In addition, the ineffective maintenance of the completion layer is demonstrated by the growth of vegetation that infests the tiles layer on vast areas (Figure 15c).

The horizontal structure of room 36 is hardly damaged at both the two levels (Fig. 16a), therefore they are out of reach and propped up (Fig. 16b).

Finally, the timber elements of Peristilium (63) are affected by general degradation state due to the elevated humidity content caused by the water seepage (Figure 17a): also the results of sclerometric tests have revealed poor mechanical properties. As a consequence, the collapse of an element has been occurred (Figure 17b). Moreover, the reinforcing bars of the supporting RC beams are excessively rusted (Figure 17c).

Figure 15. Water seepage: a) Internal view; b) Damaged waterproof membrane; c) Vegetation on tile layer

Figure 16. Room 36: a) Horizontal structure; b) Propped up system

Figure 17. Room 63: a) Water seepage; b) Collapsed element; c) Rusted rebars
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5 EMERGENCY ACTIONS

Together with the definition of roofs typologies and the assessment of the conservation state of roofing structures, the aim of the survey was to suggest a series of activities that are believed to be undertaken in the short term to preserve both the roofs and the precious decorations present inside the rooms.

Among the suggested interventions, particularly urgent is the substitution of the degraded bituminous waterproof membranes with new ones for the horizontal structures and the realization of protections on the top of the perimeter walls to avoid the water seepage inside the masonries.

Regarding the timber elements roofs covered by a layer of tiles, it seems to be necessary the substitution of the most degraded timber elements and the simultaneous replacement of the tiles layer together with a waterproof layer, actually not existent.

Moreover, the presence in many areas of the Villa of heavy RC beams directly laying on the ancient masonries is a vulnerability point that should be necessary taken into account to avoid possible damages to both original structures and visitors, especially in case of seismic shocks [3][9].

6 CONCLUSIONS

An analysis procedure based on a multidisciplinary approach, to assess both integrity and structural stability of the roof structures of Villa dei Misteri has been presented. The main causes of decaying and damage have been identified and preventive measures to reduce risk of damage have been suggested. In particular, some heavy reinforced concrete roof frames built during the 1960s and 1970s, give serious cause for concern. These structures rest on ancient masonry that could have lost the structural integrity required to provide safety of both archaeological heritage and visitors, and are vulnerable to seismic forces due to the lack of effective roof-to-wall connections. Moreover, ambient vibration analysis shows frequency content that could affect the seismic response of the structure [3]. Finally, it should be noted that reinforced concrete frames were built without any earthquake-resistant design.

Considering that the described methodology has been developed also with the aim to qualify a standard procedure in view of further applications to similar roofing typologies, very common in the archaeological site of Pompeii, a more detailed diagnostic campaign in order to obtain a better identification and a deeper knowledge of the roofing structures has been developed. To this aim, two specific sets of in situ tests have been planned. The first one, regarding the RC structures, includes sonic-rebound test (SONREB), core drilling and measurement of the carbonation depth, compression tests on RC specimens. The second set, focused on timber elements, includes the identification of the wood essence, definition of the class of resistance according to the Italian technical standards (UNI codes), measurement of the moist content, drill resistance tests by means of a Resistograph type device, and endoscopic observation of the timber elements supports.

The data so collected will be elaborated for carrying out a comprehensive safety assessment that should include both static and dynamic analysis.

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