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Building pathologies. Analysis of three case studies

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Abstract: Masonry buildings are the main part of the Architectural heritage in the World. The need of preservation for the historical memory, together with the exigence of fruition and use, has evidenced the need of appropriate analysis tools. In general, the stresses in masonry structures are usually considerably lower than those required for their material failure, so that the stability is mainly due to their shape and self weight. These aspects allowed in the past the simple realization of construction models in a reduced scale in order to assess the stability. As the history has pointed out, the behaviour of constructions is strongly linked to the workmanship and the good realization of the construction details. Local or global collapse can occur in fact due to pathologies arising during the construction or to bad realization of construction details. This paper deals with this last aspect, examining three different masonry buildings: the first one is a brick masonry building in Bologna: San Barbaziano Church, the others are two Roman domus in two different archaelogical sites in Campania: Villa Regina (Boscoreale, Napoli) and Villa dei Misteri (Pompeii, Napoli). The defects have been divided into two classes: structural defects and non structural ones. It is shown that structural defects can cause a global damage and could involve significant interventions.

Keywords: ancient masonry building; pathology.

1. Introduction

Knowledge and understanding the damage and failure mechanisms of masonry structures are necessary to prevent catastrophic failures and enhancing effective restoration of historical masonry monuments. The optimum approach includes historical, experimental and numerical studies to achieve a good level of knowledge. There are in fact several aspects that should be examined before developing a restoration design (De Ponti et al., 2017). In particular, experience shows that a broader study of the monument, the history and architecture of the building, its material consistence and actual state are indispensable prerequisites for the successive analyses, in order to account for all initial and consecutive construction phases, previous interventions or additions (Bosiljkov et al., 2010; Asteris, et al., 2017). Furthermore, the results of the experimental investigations regarding geometrical data, the in situ evaluation of the materials mechanical characteristics (Monaco et al., 2021a and 2021b; Guadagnuolo et al., 2020a), the properties of the structural elements like masonry walls, arches, vaults and floors, the complex response of the construction to different possible actions, as well as the results of eventual previous monitoring can be crucial for reliable designing interventions on ancient structures (Monaco et al., 2014; Gesualdo and Monaco, 2015; Guadagnuolo et al., 2020b, 2020c). In the case of San Gimignano towers "...the construction is surprising, the method is based on very thick stone masonries and extraordinary mortars, with just a few later exceptions where bricks were used" (Giorgi and Matracchi, 2017). Sometimes the structural conception of the building or an unsuitable realization of retrofit interventions (Krentowski et al., 2017) is the major cause of collapse. The simple knowledge of the material properties and the actual geometry of the structure cannot be in fact sufficient if not appropriately connected to a rational coordination of the information about the whole past of the monument (Frunzio et al., 2019). As the history has pointed out, the behaviour of constructions is strongly linked to the workmanship and the good realization of the construction details. Differently from the cases in which the strength of the masonry wall is directly involved, like in the in-plane failure (Gesualdo et al, 2019 and 2020; Monaco et al., 2018b), local or global collapse can occur in fact due to pathologies arising during the construction or to bad realization of construction details (Buonocore et al., 2014; Gesualdo et al., 2020). This paper deals with this last aspect, examining three different masonry buildings: the first one is a brick masonry building in Bologna: San Barbaziano Church, the others are two Roman domus in two different archaelogical sites in Campania: Villa Regina, Boscoreale, Napoli and Villa dei Misteri, Pompeii, Napoli.

2. Structural construction pathologies: the San Barbaziano Church in Bologna

The unconsecrated San Barbaziano Church (Figure 1.a) is a brick masonry building at the corner of Via Barberia and Via Cesare Battisti in Bologna. It was built between 1608 and 1612 by Pietro Fiorini in place of the previous late Middle Age Monastery Church, become inappropriate according the new religious statements of the Trento Council. The Church is formed by a late Mannerist single nave with eight side chapels belonging to the original Church, separated by masonry piers and incorporated in the new building at the ground level (Figure 1.b).

The higher part of the Church consists of the central nave only (45 length, 11m wide), with external masonry buttresses corresponding to the separation walls of the lower chapels. The walls are very slender, considering the 85 cm thickness of both façade, apsis walls and lateral walls of the ground level chapels. The longitudinal walls present 40 cm thickness at both the levels. The three-bay nave is longitudinally counterpointed by two barrel vaults with lunettes and a central bay with a cloister vault. A second cloister vault covers the apsis.

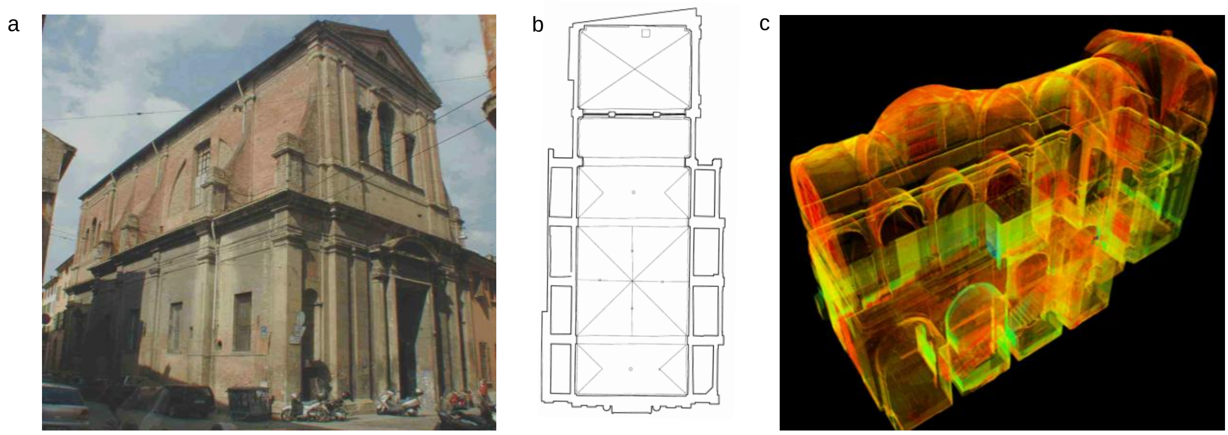
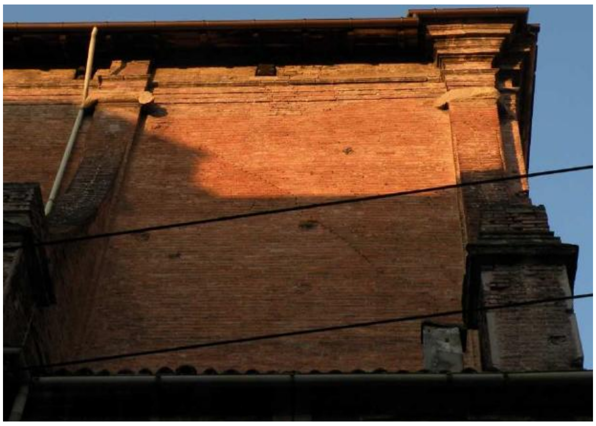


Figure 1. (a) San Barbaziano Church; plan of the building (b); (c) Laser-scanner survey of the Church.

Eleven timber trusses provide support for the roof tiles. At the end of XVIII century the building was dismissed as Church and used as deposit, until the actual property, the Ministry for Cultural Heritage, Activities and Tourism has decided to plan retrofit interventions to change the use of the building. A complete diagnosis plan has been developed and realized to develop a restoration design for the reuse of the building (Bergamasco and Poggioli, 2012), including a laser-scanner survey (Figure 1.c). The considerations below a take in account only a part of the large survey conducted on the Church, in order to highlight the characteristics of the structural system that are cause of the detected damage (Monaco et al., 2018a). The complete map cracking has been simplified putting in evidence only the damage that can be referred to a specific construction issue. In Figure 2. a diagonal crack on the longitudinal wall is representative of the overturning of the facade (Gesualdo et al., 2017; Guadagnuolo and Monaco, 2009). The crack is present only on the side wall along Via Barberia, while in the wall over the adjoining cloister minor cracks have been detected. The corner position of the building shown in Figure 2.b together with the limited stiffness of the longitudinal walls seem to be the main cause of the damage. By a careful reading of the monument history it is deduced that the Municipality allowed "the construction of the façade outside the ancient church in the public land for ounces 18 (57cm)", so that a crack due to settlement is compatible with the construction history (Iannuzzo et al., 2018).

a



b

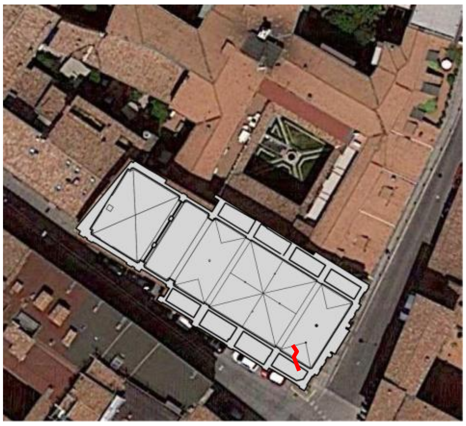


Figure 2. (a) Diagonal crack in the masonry wall at the second level; (b) Position of the Church and its surroundings.

In Figure 3.a the longitudinal crack present at the upper level of the church is highlighted. The crack is undoubtedly due to the extremely vulnerable roofing system.

a

b

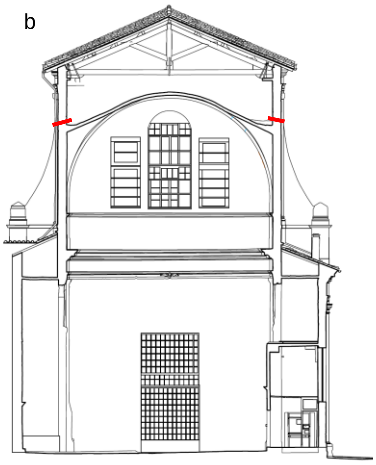
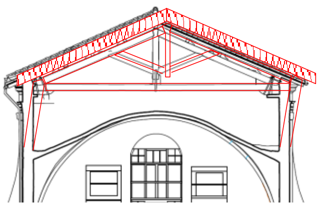
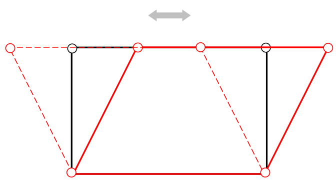


Figure 3. (a) Longitudinal section of San Barbaziano Church; (b) Transversal section of the Church.

As it can be noted in Figure 3.b, the buttresses placed at the second level end at the intersection with the vaults extrados, so that the remaining roofing structure is composed by the slender perimetral walls and the timber trusses. The two longitudinal masonry walls form with the timber elements an extremely vulnerable system, especially for out-of –plane actions, as the longitudinal crack in Figure 3.a testifies (Gesualdo and Monaco, 2010). The nave mechanism is represented in Figure 4, together with the involved structural scheme.



a



b

Figure 4. (a) Possible nave mechanism; (b) structural scheme.

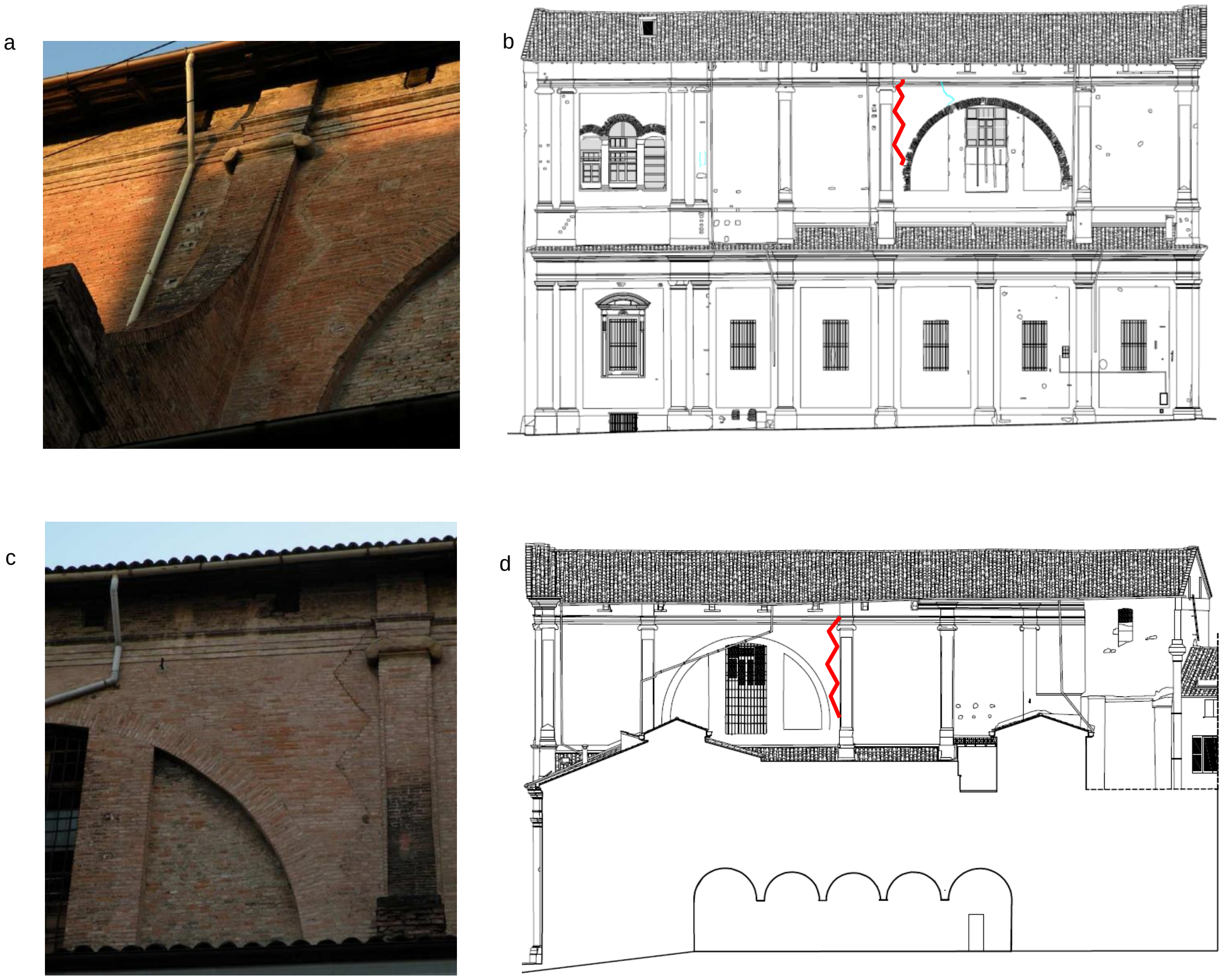


Figure 5. (a, c) Bad masonry toothing; (b, d) Position of the toothing.

Figure 5 reports the detail of two masonry bonding realized during the construction at the same level and in the same longitudinal position in the Church. The incorrect toothing produces as a result a defect in the masonry wall continuity.

3. Pathologies due to details realization: timber roofs

Timber and masonry structures have been the first ones employed in constructions, in fact the realization of timber structures has been in the past the only solution to support roof tiles. Knowledge of the ancient timber structures involves structural, historical, technological and biological aspects. Building materials are decayed by the effects of adverse environmental conditions and the extent of damage depends on both the materials and the environmental conditions (De Matteis et al., 2019).

Differently from inorganic materials like stones and mortars, this is strongly true for timber, where undesirable change in the properties of the material are brought about by the activities of living organisms (Faggiano et al., 2013). The eleven braced king-post timber trusses of San Barbaziano have been realized with two different timber species same age (Picea abies and Abies alba) that present similar mechanical characteristics, partly with rectangular (Figure 6.a) and partly with almost round cross section (Figure 6.b).

Fortunately, the timber principal structure is in good state of conservation, due to the good realization of the truss end supports, allowing a good ventilation of the structure.

a

b

Figure 6. (a) Circular cross sections; (b) rectangular cross sections.

The trusses are placed on a timber cantilever (80-100 cm length), isolated from the masonry load bearing wall (Figure 7.a, b). The truss ends are covered by the roof eaves and free air movement are allowed around timber, so that the presence of fungine attacks is mainly due to poor maintenance of the roof. The principal damage regards the post-rafters connections, as reported in Figure 7.b. Due to the negligent care in fact the purlins and the timber plates shall be substituted (Bergamasco et al., 2009).

a

b

Figure 7. (a) Truss end supports; (b) Post-rafters connection

A different case is that of Pompeian roofs. A large part of them has been realized after the Pompeii discovery, so that the presented exempla regard restoration interventions (Bergamasco et al., 2018). Differently from San Barbaziano trusses, the Pompeii roofs have a long history of bad realization of construction details, poor maintenance and in some cases collapses.

This last case is that of Villa dei Misteri *peristilium* roof, in which a rafter collapsed on 8th September 2012. In this case the main cause of the damage is due to bad realization of the rafter end support. Like in several Pompeian Domus, the timber rafters have not been isolated from damp masonry by air space or damp proof membrane, so to allow free air movement, but are directly placed in the masonry wall. Figure 8.a shows the *peristilium* rafter before the collapse, while in Figure 8.b the rafter end support after the collapse is reported. A neighbour rafter is reported in Figure 8.c.

As it can be seen, the end support conditions are similar to those of the collapsed one. Recently the Pompeii Archeological Park has carried out an in-situ experimental campaign to assess the conservation state of the roofing structures of Villa dei Misteri in order to develop a restoration intervention on the Villa (Bergamasco et al., 2017).

Figure 8. (a) Rafter end support before collapse; (b) End support after collapse; (c) Actual end support conditions of the remaining rafters

The first restoration intervention on the roofing structure of Villa Regina, the only Rural Villa in the Vesuvian area open to the public, significant part of the archaelogical area of Boscoreale, can be an efficient example of incorrect construction detail. The timber roof placed on the Southern rooms of Villa Regina (indicated with a red arrow in Figure 9.a) was designed for archaeological reasons with a limited slope, since in the case of Villa Regina the original roofing structures have been excavated at the end of 1979 (Figure 9.b) and could be surveyed (Bergamasco et al., 2016; Monaco et al., 2020).

Figure 9. (a) General north view of the Villa; (b) The excavation of Villa Regina: detail of the original *porticus* roofing.

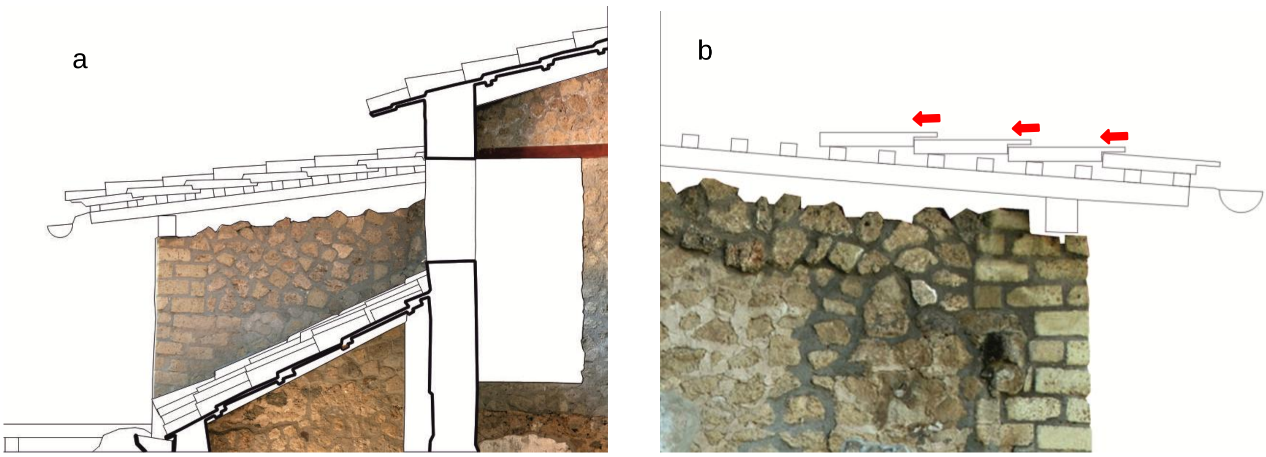


Figure 10. (a, b) Sections of Villa Regina roofing structures

Figure 11. (a) North view of Villa Regina; (b) Detail of the roof; (c) Effects of leaching by rainwater; (d) plan of the villa

Unfortunately, the manufacturing of tiles and their definitive placing was not considered in the first restoration design, so that the rainwater flow turns backward, creating damage to the structures below (Bergamasco et al., 2017). Actually, the restoration works, that include the substitution of the roofing structures, are ongoing (Bergamasco, 2015).

The pictures presented do not need comments, since the effects of the incorrect design and realization are clearly visible in Figure 11.c, where the pavement surface runoff and erosion are reported.

4. Conclusions

This paper presents a discussion on the influence of construction details (structural or technological) on the pathology present in a building. It has been shown that the only maintenance is sufficient in buildings where the construction details are well designed and realized. On the other side, bad structural conception or realization cannot be overcome with a simple maintenance intervention, but a more complex system of interventions is needed to enhance the building conception. Three case studies, San Barbaziano Church (Bologna), Villa Regina (Boscoreale, Napoli) and Villa dei Misteri (Pompeii, Napoli) have been presented to give evidence of the problem. It is shown that structural defects involve damages on the global structure of the building, with consequent significant and expensive interventions, while technological defects can be the cause of local damages, to be repaired with limited interventions.

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measurements and using images respectively of the Pompeii site and the San Barbaziano Church, all rights reserved.

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