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DOCUMENTATION, ASSESSMENT AND PROPOSED INTERVENTIONS FOR THE HISTORAL BUILDING OF VILLA KLONARIDI

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Abstract. *The paper presents the methodology which was followed in order to assess the current state of a late 19th century building, and to propose compatible and adequate interventions for its conservation. Villa Klonaridi, Athens, Greece has been listed as a cultural heritage building because of its significant historical and architectural value. Three separate construction phases are identified. The load bearing system of the building is made of rubble stone masonry and brickwork masonry (depending on the construction phase), whereas the floors and roof structures consist of timber and steel members. The first step in assessing the building's bearing capacity and overall response is to document its present condition. The non-destructive technique of the radar was applied in representative areas so as to identify the construction type of the stone masonry. This was supplemented by an explicit survey of the building's pathology (damages due to seismic actions, material deterioration etc.). Masonry mechanical characterization was achieved through material sampling and subsequent in-laboratory material testing. In addition, finite element analysis was performed. The results were in accordance with the observed damages, thereby proving the validity of the computational model. The analysis confirmed that the initial bearing capacity of the Villa has been reduced as a result of the aforementioned pathology, as well as due to the wrongful application of inconsistent structural interventions (e.g., non-monolithic connection between the masonry walls of separate construction phases). The vulnerabilities of the structure were studied, and an appropriate intervention strategy was designed. Subsequently, the interventions were implemented in the computational model, and their adequacy and efficacy were verified by the analysis results. Among others, the proposed intervention techniques include the application of grout injections, the enhancement of the diaphragm action (at floor and roof levels), and the (partial) reconstruction of the poor quality brickwork masonry.*

1 INTRODUCTION

The work described in this paper forms part of a research project [1] aiming at documenting/ evaluating the state of a late 19th century building, and accordingly designing an intervention strategy for its conservation and overall behavior improvement. Because of its significant historical and architectural value Villa Klonaridi (Athens, Greece) has been listed as a cultural heritage building by the Hellenic Ministry of Culture.

As can be seen in Figure 1, the building consists of three main floors (i.e., basement, ground floor, first floor) while an intermediate floor can be found at its northwest corner. Three separate construction phases are identified. The vertical load bearing system met upon construction phases A and B comprises of rubble stone masonry, with the exception of the areas below the window sills which are made of brickwork masonry instead. The walls of construction phase C consist solely of brickwork masonry (both solid and hollow). Masonry wall thickness ranges between 50cm and 80cm. It should be noted that the adjacent walls of separate construction phases are not monolithically connected to each other (i.e., there is no interlocking between them).

In general, the floors and roof structures comprise of timber and steel members. However, the adopted construction method varies between construction phases. In case of phase A, floors are formed by timber beams and timber planking. Whereas, in the case of the two subsequent construction phases the floors consist either by timber joists and planking supported by steel beams, or by floor boards supported by steel beams. As far as the roof system is concerned, there are three discrete assemblies. Specifically, a long gable roof covers construction phase A, a non-accessible flat roof covers construction phase B, and a small pyramid roof covers construction phase C. Finally, the door and window lintels are made of timber elements in construction phase A, and steel elements in phases B and C respectively.

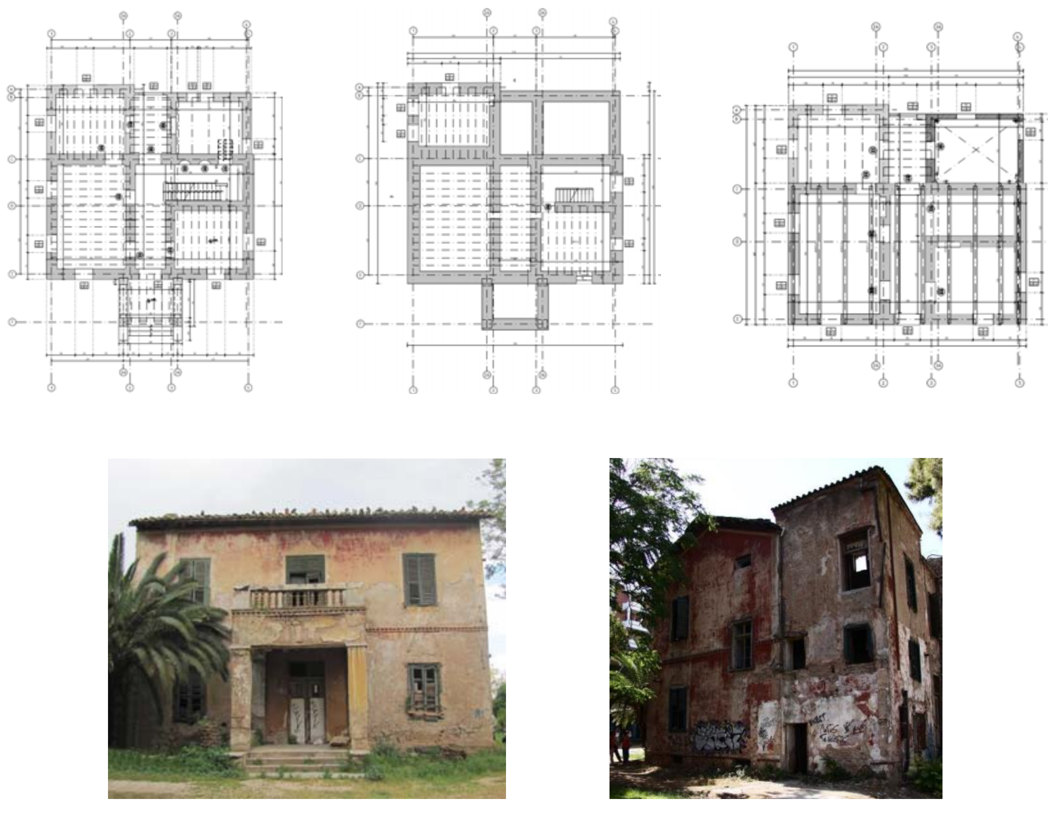

Figure 1: Floor plans and representative aspects of Villa Klonaridi.

2 ASSESSMENT OF THE VILLA'S CURRENT STATE

2.1 Stone masonry construction type

Documenting the masonry's construction type is a prerequisite in order to: (i) assess its current mechanical characteristics, (ii) select appropriate intervention techniques, and (iii) evaluate its expected mechanical properties after rehabilitation. In the case of Villa Klonaridi, the stone masonry geometry was only discernible in the areas where the plaster had fallen off. Thus, in order to determine the in-depth method of construction the non-destructive technique of the radar was applied in representative regions of the building's ground floor.

Radar settings were calibrated by performing preliminary measurements on areas where the masonry geometry was known (i.e., all three sides of the stones were visible). It should be mentioned that throughout the building the stones dielectric constant was assessed at an approximate value of 6.5. Three characteristic piers, the faces of which were completely covered by plaster with a mean thickness of 3-4cm, were thoroughly investigated. Horizontal and vertical scans were performed on each side of the piers. The obtained results indicate the use of the well-known three-leaf stone masonry construction type. As illustrated in the typical horizontal sections of Figure 2, the masonry comprises of two parallel external layers and a loose inner core. It was shown that the specific technique was used in both construction phase A and construction phase B.

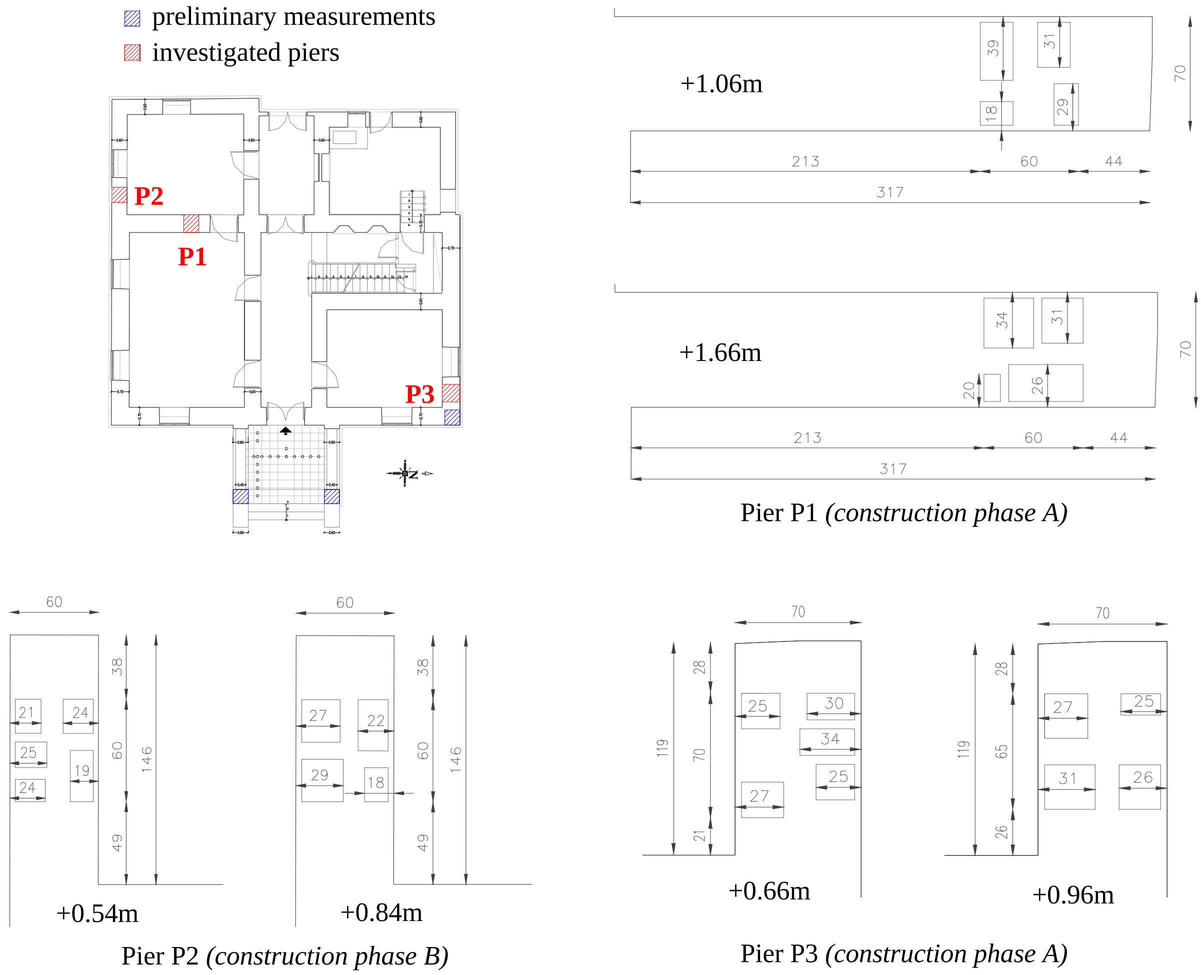

Figure 2: Regions where radar measurements were performed, and typical horizontal sections of piers P1, P2 and P3 at various heights above the ground level.

2.2 Building pathology

Over the years the building has suffered extensive damages and is considered to be in a rather poor condition due to the complete lack of conservation/maintenance. Seismic actions have caused a variety of cracks, as well as the detachment of the non-monolithically connected adjacent walls belonging to separate construction phases (see Figure 3). Extensive material decay is observed due to water penetration and fire outbreaks. Mortar has been washed out of the joints at significant depths, leading to masonry disintegration in several regions of the building. The brickwork masonry met upon construction phase C is of extremely poor quality. Several timber and steel members of the floor and roof structures are damaged or worn out. The timber roof of construction phase C is poorly constructed and badly preserved. Most of the door and window lintels are damaged beyond repair. The building's floors and roofs do not represent a rigid diaphragm, thus resulting in increased vulnerability against out-of-plane actions. Finally, the diversity of applied building materials and construction methods has resulted in strength and stiffness disparities along the structure's load bearing system.

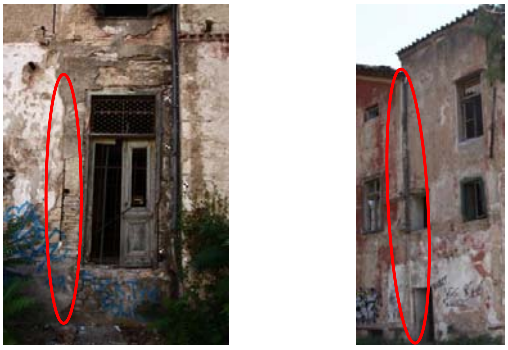

Figure 3: Evident detachment cracks due to the lack of interconnection between adjacent masonry walls belonging to different construction phases.

2.3 Material testing and masonry mechanical properties

With the aim of evaluating their mechanical properties, samples of mortar, stones and bricks were taken from representative regions of all three construction phases. Subsequently, the masonry mechanical properties (per region) were estimated by taking into account: (i) the method of construction, and (ii) the strength values of the constituent materials. The measured tensile and compressive strength values, as well as the estimated masonry compressive strength and long term modulus of elasticity are summarized in Table 1.

Table 1: Mechanical properties per construction phase.

Mechanical property	Phase A	Phase B	Phase C
Mortar tensile strength [MPa]	0.06	0.15	0.03
Stone compressive strength [MPa]	28	28	–
Brick compressive strength [MPa]	7.40	4.90	4.90
Stone masonry compressive strength [MPa]	1.20	1.53	–
Stone masonry modulus of elasticity [MPa]	1620	2065	–
Brickwork masonry compressive strength [MPa]	1.93	2.11	1.28
Brickwork masonry modulus of elasticity [MPa]	2316	2110	1536

3 NUMERICAL ANALYSIS

A numerical analysis was carried out with the help of the finite element modelling software SAP2000 [2]. Thick shell elements were employed to model the masonry walls, while frame elements were used to model the timber and steel members of the floor and roof structures, as well as the sections of the lintels. The structure was assumed to be fixed on the ground. The material properties adopted for the numerical analysis were derived by the data presented in section 2.3. The equivalent seismic load method of analysis was employed (i.e., equivalent seismic actions were distributed along the height of the building), so as to be able to extract the quantitative data (action-effects) required to perform capacity checks. Nine load combinations were investigated (1 for vertical loads and 8 for seismic actions) according to the Greek Seismic Codes of 1959 and 2000 ([3], [4]). It should be mentioned that the obtained principal tensile stress diagrams were well in accordance with the observed pathology (see Figure 4), thus verifying the validity of the computational model.

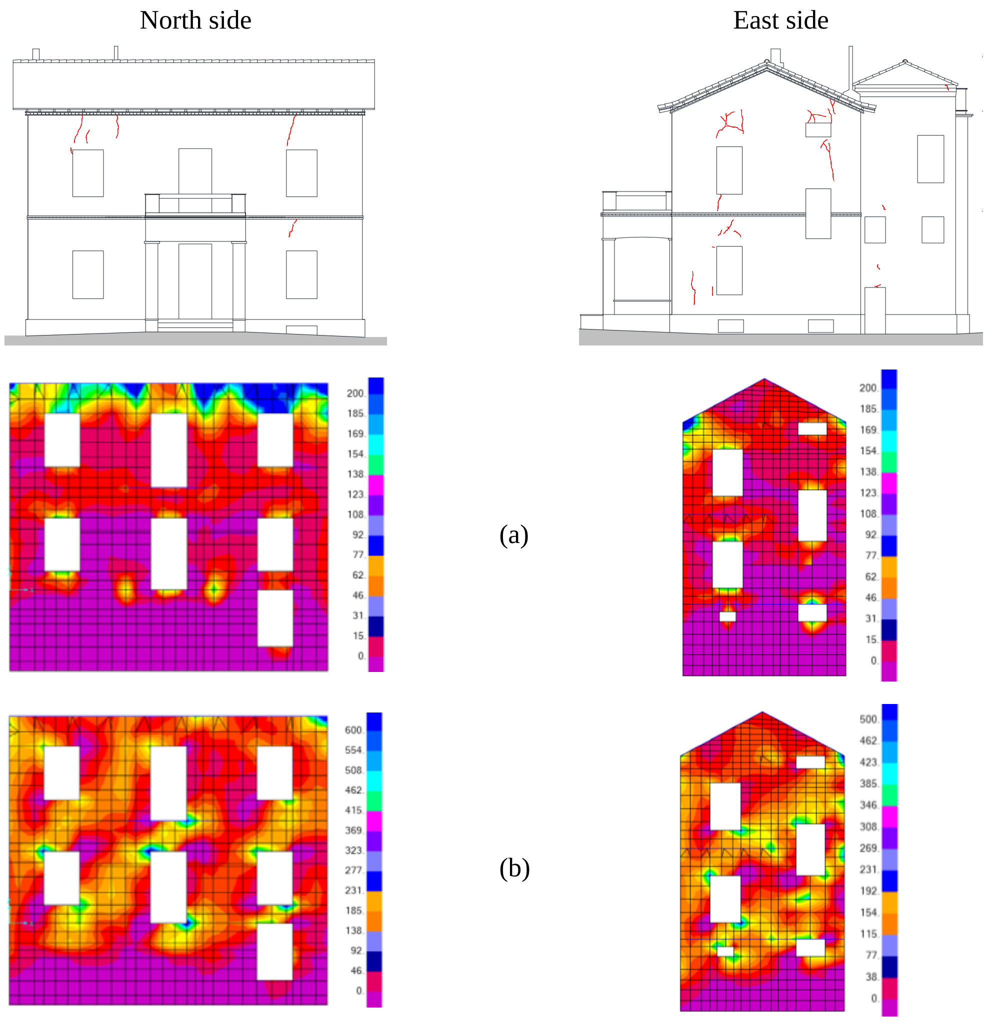

Figure 4: Verification of the building's pathology through typical principal tension stress diagrams obtained by the analysis for the cases of: (a) vertical loads combination, and (b) seismic actions combination.

Safety checks against in-plane and out-of-plane loading were performed in every critical section of the structure. This allowed for the bearing capacity margins to be estimated, and also for the areas of deficiency to be identified. More specifically, 12% of the masonry piers, in addition to the majority of the lintels, proved to be unable to safely withstand the applied loading. The timber roof trusses analysis was performed with the help of the structural timber design program WOODexpress [5]. In the case of the gable roof structure of construction phase A, safety checks were not satisfied only for the cross-section of the collar beams.

What's more, qualitative data regarding the overall seismic response of the structure was obtained through the finite element analysis. The deformed shape of the model (see Figure 5) demonstrated the enhanced vulnerability of the building against out-of-plane actions, due to the lack of diaphragm action at floor and roof levels. The analysis also recorded large relative displacements between the separate construction phases of the model (non-monolithic connection).

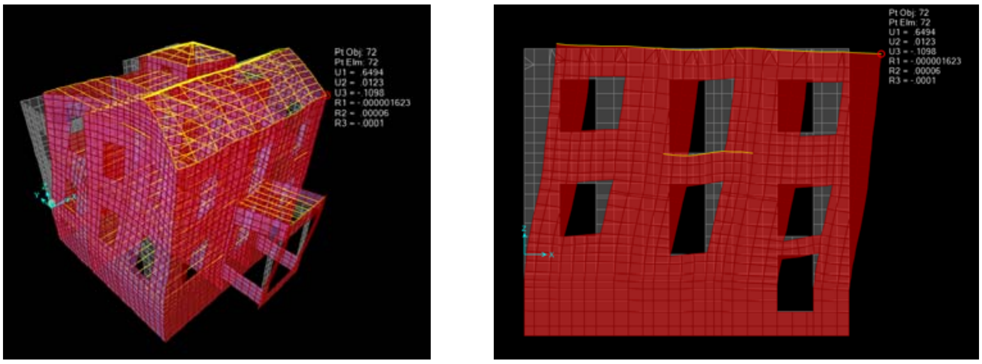

Figure 5: Deformed shape of the model and large relative displacements between separate construction phases.

4 PROPOSED INTERVENTIONS

An appropriate and compatible intervention strategy was designed taking account of the revealed structure vulnerabilities, along with the results of the performed bearing capacity checks. The interventions were implemented in the computational model, and their adequacy and efficacy were confirmed by the analysis.

More specifically, the application of compatible grout injections in conjunction with deep repointing is proposed for the homogenization of the three-leaf stone masonry walls met upon construction phases A and B. The designed natural hydraulic lime grout mixture has a compressive strength of 8MPa. After grouting the masonry will possess enhanced mechanical characteristics, and will be able to safely withstand the prescribed loads and seismic actions. The mechanical characteristics of the grouted masonry are summarized in Table 2 below.

As far as the poor quality brickwork masonry of construction phase C is concerned, (partial) reconstruction with the use of vertically perforated bricks is recommended. In order to eliminate the vulnerability against out-of-plane actions and minimize the relative displacements between separate construction phases, the restoration of the masonry continuity is proposed. Specifically, a monolithic connection by means of interlocking should be achieved not only between adjacent stone masonry walls, but also between the reconstructed brickwork masonry walls and the adjacent stone masonry ones (see Figure 6).

Table 2: Stone masonry mechanical properties after rehabilitation.

Mechanical property	Phase A	Phase B
Grout compression strength [MPa]	8	8
Grouted masonry compression strength [MPa]	1.91	3.30
Grouted masonry modulus of elasticity [MPa]	1910	2310

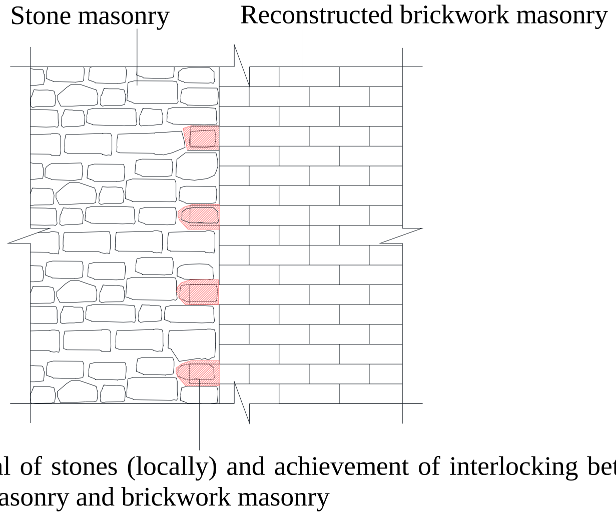

Figure 6: Proposal for the achievement of monolithic connection between separate construction phases.

The damaged lintel sections should be replaced by HEA100 steel beams. Accordingly, all damaged and worn out timber and/or steel members of the floor and roof structures must be replaced by new healthy members. In regards with the poorly constructed timber roof of construction phase C, complete reconstruction is in order. Furthermore, with the aim of enhancing the diaphragm action at floor and roof levels, the placement of double timber planking is suggested (achievement of floor and roof in-plane stiffening). Proper connection (anchoring) between the diaphragms and the masonry walls should be ensured through perimeter steel beams and anchor bolts. To that end, the construction of reinforced concrete beams at the masonry wall crests (at roof level) is also recommended.

5 CONCLUSIONS

- The current condition of a late 19th century building was successfully evaluated by combining in-situ and in-laboratory investigations with numerical analysis.
- The construction type of the building was assessed via the non-destructive technique of the radar.
- Mechanical characterization of the masonry was achieved through material sampling and testing.
- The building's pathology was surveyed and qualitatively interpreted.
- The finite element analysis results were in accordance with the observed damages, thereby proving the validity of the model. In addition, useful observations were made regarding the overall performance of the structure.
- Bearing capacity checks were performed in critical sections, and the areas of deficiency were identified.
- A compatible intervention strategy was designed according to the structure vulnerabilities, observed damages and analysis results. Proposed interventions include masonry homogenization via grout injections, diaphragm action enhancement, and reconstruction of the poor quality brickwork masonry.

ACKNOWLEDGEMENTS

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