Visual assessment of the chimney damages, modification: cut and saturation

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Structural survey and diagnosis of historical constructions the experience of the Construction Institute

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ABSTRACT

The sustainable rehabilitation of an historical construction can only be achieved if there is adequate knowledge about its state of conservation. To obtain such knowledge, reliable structural survey and diagnosis procedures need to be employed. An overall definition of the more important technical procedures that need to be considered is addressed to provide general guidelines for the structural survey and diagnosis of historical constructions. A more detailed description of some of the methods is then also performed. Several case studies are then presented to illustrate these approaches, emphasizing the importance of the technical inspection and survey data in the rehabilitation actions that were developed in each case study.

KEYWORDS
structural survey, structural diagnosis, structural conservation, rehabilitation, historical constructions

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1. INTRODUCTION

It is currently accepted that the heritage or vernacular value of an historical city centre is not defined by the values of its individual constructions (Smith et al., 2010). Instead, this value is the result of the unique features and interactions that characterize the set of constructions as a whole. By acknowledging this fact and integrating it with economic- and sustainability-related issues, it becomes clear that the adequate requalification/rehabilitation of historical constructions needs to involve efforts to maintain their components while rediscovering traditional construction techniques to understand their preservation issues.

By setting that one of the goals of the sustainable rehabilitation of historical constructions should be to preserve their components, namely their structural elements, as much as possible, several factors must then be involved to achieve this goal. Acknowledging the need to have adequate knowledge about the state of conservation of the construction and of its elements is perhaps the most important one. Through this knowledge, which must be obtained using reliable survey operations, the structural capacity of an existing construction can then be established, as well as its level of safety. The importance of these results makes this knowledge instrumental for the decision-making processes that will define which rehabilitation actions need to be undertaken in the construction. Only by having this knowledge will it be possible to determine if and which components of a given construction can be maintained. As such, the economic costs of repair and/or strengthening operations that may be required to rehabilitate a certain construction are also a direct consequence of this knowledge (Forsyth, 2008).

In this context, the current paper addresses some of the more important technical procedures that need to be considered, from the point of view of the structural survey and diagnosis stages, in order to obtain reliable data supporting the sustainable rehabilitation of historical constructions. An overall definition of the procedures involved is first performed to provide a set of general guidelines which is then followed by a more detailed description of some of the methods. Several case studies are then briefly presented to illustrate and complement some of the approaches previously discussed, emphasizing the importance of the technical inspection and survey data in the rehabilitation actions that were developed. The selected case studies reflect some of the work that has been carried out over the past years by the Construction Institute of the Faculty of Engineering of the University of Porto, Portugal, in the fields of structural conservation, rehabilitation and strengthening of historical constructions.

2. STRUCTURAL SURVEY AND DIAGNOSIS PROCEDURES

2.1 GENERAL OVERVIEW

To assess the structural stability and safety of a given construction, adequate knowledge about the construction needs to be obtained. To ensure the soundness of this knowledge, a systematic process must be carried out which involves suitable data and information research procedures that will lead to a reliable diagnosis about the state of the construction. These data and information research procedures involve a series of qualitative and quantitative operations, where the latter are only performed if the former are found to be insufficient to provide the necessary data. These operations are generally termed structural inspection and survey procedures and include site visits to inspect the condition of the construction and its surroundings and to survey the relevant geometric data, mechanical properties of the materials, structural load-transfer mechanisms and damages of the construction. Although a technical inspection involving just a visual assessment is seen to be fundamental to provide a preliminary analysis of the construction, its outcomes are highly dependent on the experience and knowledge of the analyst(s) that carry out the assessment. Therefore, it is always important to involve two or more analysts in a technical inspection to allow for a more in-depth observation of the construction and reduce the existing level of uncertainty. Furthermore, by having more than one analyst doing the assessment, it is possible to discuss the technical validity of what was observed and

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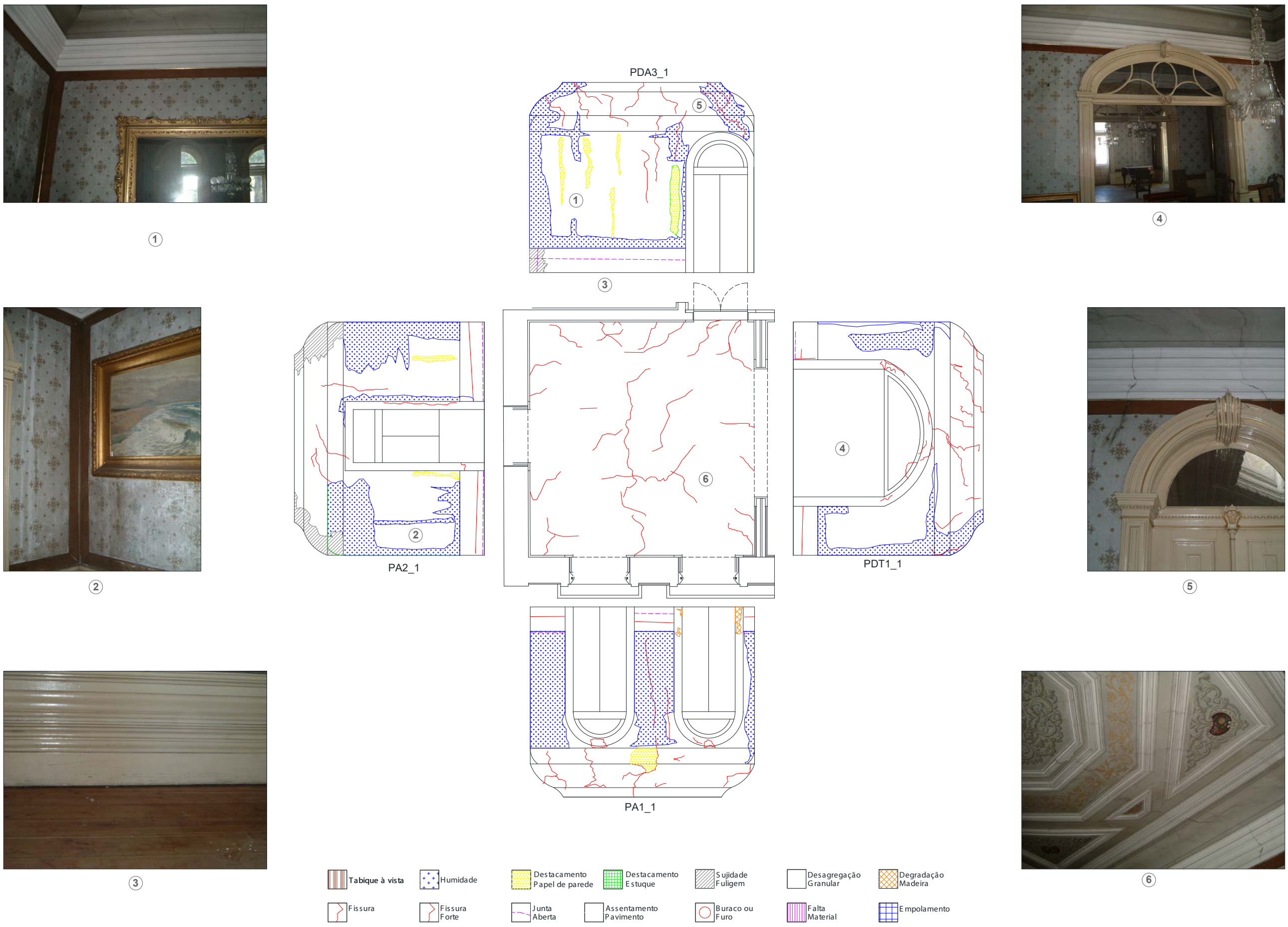
surveyed taking into account different points of view and frames of reference.
After gathering the necessary information about the construction, this information is then compiled and organized within a technical inspection report that will serve as the fundamental information tool for the subsequent definition of the potential need for interventions. With respect to the damages found in the construction, the report usually presents them using damage maps (Fig. 1) and describes their potential sources, as well as possible measures that may be required to repair them or to prevent them from spreading and increasing.

2.2 DESCRIPTION OF THE PROCEDURES

Some of the more relevant procedures that need to be performed in a technical inspection are addressed in the following. Even though not all of the procedures that are described need to be involved in a certain technical inspection, they are mentioned herein to comment on their usefulness and on the type of materials to which they can be applied. The following list of procedures is not exhaustive but represents

Figure 1.

Example of a damage map.



what is believed to be the best practice for structural inspections and surveys in order to achieve a reliable diagnosis about the construction under analysis:

- *Characterization of the overall geometry of the construction* using existing data or using surveyed data obtained from traditional topographic or photogrammetric techniques. In the case of constructions where a highly detailed and rigorous geometric survey may be required, the use of laser scanning techniques can also be envisaged. A rigorous geometrical assessment can often lead to the immediate detection of irregularities such as vertical and/or horizontal misalignments or deviations of the structure that can be associated with structural damage or anomalies (Beckmann and Bowles, 2012).
- *Identification of the current structural load-transfer mechanisms* (and possibly also of previous mechanisms in case the construction has been modified over time).
- *Definition of the more important elements* of the structural load-transfer mechanisms and identification of their material(s).
- *Identification of all the damages (particularly structural damages) and preparation of a detailed photographic record* of the construction adequately referenced in the construction's technical drawings (i.e. a damage map). The survey of the observable cracks found across the structure, along with their shapes and their widths, is particularly important to perform a preliminary qualitative assessment of the construction's stability and structural safety, and to identify possible sources of instability (Beckmann and Bowles, 2012). At this point, the potential for water infiltration should also be analysed since it is one of the main sources of structural degradation. In case of a construction with timber floors or roofs, it is important to observe and analyse the state of conservation of the timber beams, as well as to confirm the existence of noggins and their state of conservation. Analysing the areas where these timber beams are supported by the masonry walls as well as their midspan deflection is also critical. When surveying constructions with old reinforced concrete (RC) slabs it is important to identify the type of slab in order to understand the mechanical behaviour of the whole floor system. Many different types of RC floor systems can be found in older constructions, ranging from grids of RC beams topped with a low thickness solid RC slab to one-way ribbed slabs with clay tile block fillers. Furthermore, analysing the deflection of the slab and the cracks exhibited by the slab and the beams is also essential.
- *Definition of tests that need to be performed* to characterize the mechanical properties of the materials and the behaviour of the structure, including the foundations. The tests carried out for the materials of different parts of the structure and foundations are a fundamental part of the survey procedures and, depending on the test, can provide either quantitative or qualitative information. These tests can be performed on material samples collected throughout the construction (in this case the tests are usually destructive or semi-destructive) or can be performed in situ (in this case the tests are usually non-destructive).

In situ tests usually involve less intrusive actions to the structure and the results obtained are typically qualitative, with the exception of results obtained from dynamic identification or ambient vibration tests. These qualitative results are particularly important since they provide a preliminary assessment of the mechanical characteristics of the materials. This type of test can be used to (Carpinteri and Lacidogna, 2006): (i) identify hidden structural elements such as columns, intermediate floor structures, etc.; (ii) qualify the materials and their heterogeneity across the structure; (iii) assess the extent of mechanical damage in structures with cracked elements; (iv) detect the existence of voids and cavities; (v) evaluate the moisture content and the level of water rise by capillary effects; (vi) identify surface degradation and (vii) evaluate some of the physical and mechanical properties of the materials. Tests such as the sonic test, the ultra-sonic test, the ground penetrating radar test, the dynamic identification test, the ambient vibration test, the Schmidt sclerometer, the phenolphthalein pH indicator, the resistograph test, the rebar detection test, the thermography test and the moisture content test are some examples of in situ non-destructive tests (Hellier, 2001; Schuller, 2003). The results of these non-destructive tests usually do not enable the quantitative characterisation of parameters defining the structural behaviour of materials. Even though some of the tests provide a qualitative description of the structure (e.g. the ground penetrating radar test), a value for the global stiffness (e.g. the dynamic and ambient vibration tests), or even estimates of some structural properties (e.g. the sonic and ultrasonic tests associated with empirical correlations, (Miranda et al., 2012; Miranda et al, 2013)), more reliable and detailed data about the characteristics of the materials need to be obtained using tests that involve more intrusive and destructive actions to the structure. However, the level of intrusiveness and destructiveness of these actions needs to be as small as possible in order not to increase the general level of damage of the structure. Tests such as the compressive test of cored samples, the pull-out test, the pull-off test, the flat-jack test or the dilatometer test are some examples of destructive and semi-destructive tests (Almeida, 2000; Bosiljkov et al., 2010a; Bosiljkov et al., 2010b; Miranda et al., 2012).

In addition to these tests, an additional reference is made to the case where the particular characteristics of the structure under analysis (e.g. its value, difficulties in accessing the structure, difficulties in understanding the structural behaviour, the load transfer mechanisms or the effectiveness of a certain strengthening solution) may require the construction of a reduced scale model. This model will then be tested for a specific loading pattern that will reproduce the scenario that is required, as realistically as possible.

Even though most the referred tests are usually performed to determine the physical and mechanical characteristics of the structural materials, sometimes they are also performed to identify and calibrate constitutive relations that may later be used for the structural modelling stage, when necessary (Almeida et al., 2012). On the other hand, static or dynamic tests involving the entire construction or part of the construction can also be performed to validate its structural behaviour. These tests can be used to determine the structural behaviour under service loads by performing a loading test, but can also be used to compare the experimental response with that of a numerical model to perform its calibration (Costa and Arêde, 2006; Guedes et al., 2007; Atamturktur and Laman, 2012; Bayraktar et al., 2012).

- *Definition of adequate structural models* compatible with the conditions that were observed in the structure and with the results obtained from the experimental tests (if tests were performed). This process must involve the calibration of the structural model (usually a numerical model) and the careful adjustment of its parameters (possibly using sensitivity analyses) to obtain an adequate fit between the model response and the experimental data. The actual purpose of the structural model with respect to the type of results that want to be obtained must also be considered when defining its characteristics, since it may influence the configuration and level of detail of the selected model. For example, models can be developed with the purpose of reproducing and interpreting the structural damage that was observed in the survey or to predict the structural response under loading conditions that did not occurred yet. Alternatively, models can also be developed to simulate the effects of rehabilitation and/or strengthening interventions (Vicente et al, 2010, Silva et al., 2012).
- *Definition of a structural monitoring plan* to analyse how the state of the structure evolves over time. Structural monitoring can be particularly helpful in cases where the information obtained from the structural survey or from other stages of the analysis (e.g. the numerical modelling, etc) is insufficient to establish a final diagnosis (Fu, 2005; Karbhari and Ansari, 2009). Monitoring involves measuring and controlling the temporal evolution of certain parameters such as local and global deformations, joint movements, temperature variations, stress levels, foundation settlements, variations in the underground water level, etc. By analysing these parameters, it is then possible to understand the evolution of damage over time, as well as to identify more clearly the causes of those damages. Subsequently, this analysis provides important information to define the structural diagnosis and the possible measures that may be required to mitigate or eliminate the sources of damage. Common types of monitoring in masonry

structures involve controlling the width of cracks or joints between stones and the structural rotations or vertical tilting, (Costa et al., 2011). This control can be performed using different techniques but, to obtain high precision continuous readings, electrical displacement transducers (commonly known as linear voltage differential transducers – LVDT) are currently used. However, available measuring techniques range from classical plaster labels to the more sophisticated approaches that involve electrical strain gauges connected to a data acquisition and recording system. Even though the plaster label technique is the simplest one, it only indicates if a crack is active or not. This limitation can be overcome by using tell-tale crack monitors or extensometers. Tell-tale crack monitors are made of two transparent plates of acrylic plastic with a millimetre ruler which overlap for part of their length and have the ability to move relative to each other as the crack opens or closes. An extensometer can be a mechanical strain gauge attached to two small metal plates fixed to the structure on each side of the crack that records the evolution of the distance between these two fixed points as the crack opens or closes.

In order to monitor the global deformation of structural elements, equipment such as deflectometers can be used. For most common situations, the use of inexpensive solutions involving mechanical deflectometers are sufficient but digital deflectometers are also currently available. To obtain high precision continuous readings, other equipment can also be used such as LVDTs, vibrating wire transducers which measure the relative displacement between two fixed points that are apart up to a few metres based on the variation of the wire tension, or transducers based on the gradient of the hydrostatic pressure in communicating vessels. With respect to the monitoring of rotations or vertical tilting, this can be performed with unidirectional or bidirectional clinometers which should be combined with temperature sensors for a better interpretation of the results. Furthermore, topographic monitoring is another technique that can be used to measure structural displacements in a structure or even at the element level. The in situ monitoring and measurement of forces or stresses is a less frequent process and also a more expensive one. Possible techniques that can used are the previously referred flat-jack test or load cells (that are based on electrical strain gauges) which are able to provide normal stress values in specific areas where they are placed. The use of load cells is a more expensive technique and requires a data acquisition system for the continuous recording of data. For the monitoring of embankments or foundation soils (which is crucial to understand the behaviour of structures that are founded in those soils), inclinometers are usually used to record the embankment or soil displacements relative to areas or stiff soils that can be used as fixed reference elements.

Regardless of the type of equipment found to be more adequate for a certain measurement campaign, the corresponding monitoring plan must be carefully defined to address all the damages found in the construction and to be compatible with the current situation. This plan should clearly define the measurement locations, the parameters that need to be measured and the most adequate way to perform the measurements, namely by considering redundancy and contingency scenarios to account for possible equipment failures. Finally, it should be noted that inadequate or excessive measurements do not necessarily lead to a more objective and better analysis of the structure since it increases costs and the analysis/processing time.

3. CASE STUDIES

To illustrate the importance of using adequate structural survey techniques to establish an objective diagnosis about the state of conservation of a given historical construction that may then lead to the need to perform a rehabilitation or strengthening intervention, a series of case studies are briefly addressed in the following. The selected case studies cover a wide range of construction types and focus the specifics of the survey techniques that were used in each case to provide the relevant background to understand the decisions that were made in terms of the diagnosis.

The first case study refers to the safety analysis for

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dynamic loading (wind and earthquake) and the strengthening of a solid brick masonry industrial chimney located in the outskirts of Porto, Portugal, (Lopes et al., 2009). The chimney is currently deactivated but remains as an important example of early twentieth century industrial architecture. The analysis that was carried out started by performing a detailed and rigorous survey of the geometry of the chimney using terrestrial laser scanning. By using this technique, the geometric data obtained from the survey was able to represent the exact deformed shape of the chimney. In addition, a

Figure 2.

Visual assessment of the chimney damages

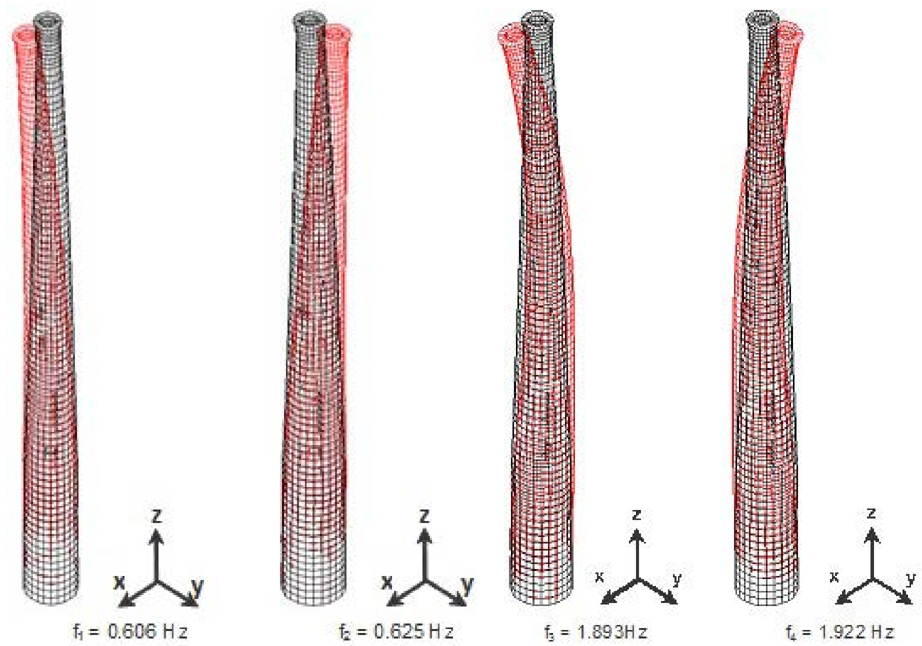

Figure 3.

Modes of vibration of the chimney that were calibrated using the results of the ambient vibration tests.

visual assessment of the damages found across the structure was also performed (Fig. 2). To establish the structural behaviour characteristics of the structure, environmental vibration tests were performed to identify the natural frequencies and vibration modes of the structure. This information was then used to calibrate the numerical model that was developed to simulate the behaviour of the chimney and analyse its structural safety (Fig. 3). Based on this assessment, critical areas of the structure were identified which then led to the design of a strengthening solution. This solution consisted in an interior steel structure which, simultaneously, served as a ladder to access the top of the chimney for maintenance operations.

Even though the use of non-destructive survey and testing techniques has been increasing in the analysis of older and historical masonry structures, evaluating the mechanical properties of their materials using these approaches is still challenging since most of the information that is obtained is qualitative. Therefore, using different techniques and combining the data obtained from all of them for crosschecking is essential to get reliable results. As an example of this type of approach, reference is made to a second case study dealing with the safety assessment of the Clock Tower of Caminha, Portugal, (Silva et al., 2009). The survey of the exterior and interior geometry of the structure was carried out using terrestrial laser scanning, which was then also combined with orthophotography, Figs. 4 a) and b). The mechanical properties of the structure and of the materials were characterized using ambient vibration tests, Figs. 4 c) and d), and sonic tests, Fig. 4 e). Based on the results of the sonic tests, one the walls was found to have structural characteristics that were different than those of the remaining ones. This structural variability was seen to be consistent with the diagnosis made by stone conservators/restorers that, based on the existence of salts on the surface of that wall, concluded there was water in the filling material of the wall (i.e. .between the internal and external stone leaves of the wall) which led to its degradation. Therefore, the combined data of the two assessment techniques was able to detect the degradation of the filling material of the wall, which then led to recommending an intervention involving the injection of a consolidating grout.

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The third case study addressed herein involves the safety assessment analysis of an arch of the Church of Terceiros in Braga, Portugal, (Costa et al., 2005). This church is a granite stone masonry building that started to be built in the XVIIth century but, according to existing records found during the initial survey, suffered several modifications until the XIXth century. At the time of the survey, there were concerns regarding the overall stability of the arch of the high-choir of the church due to the important deformations it exhibited. This situation was particularly serious since the referred arch is a pseudo three-centered arch (i.e. a flattened three-centered arch with an horizontal central span) with an 8.50m span. After shoring the structure for safety, a detailed study was performed to design a strengthening solution for the arch that would ensure its stability without being excessively intrusive. To obtain a more detailed knowledge about the real behaviour of the arch and to test the effectiveness of the strengthening solution that was developed, a 1:2 scale model of the arch was tested at the structural engineering laboratory of the Faculty of Engineering of the University of Porto, Figs 5 a) and b). The several tests that were carried out were able to replicate the real behaviour of the structure and led to the design of a strengthening solution. The solution involved two Ø28 threaded stainless steel tie rods going through the arch longitudinally, across its horizontal components, that would be anchored to the side walls of the church to provide the necessary lateral confinement to the arch. The solution was tested in the scale model and it was found that special care would be needed to ensure the horizontality of the two parallel holes drilled along the 8.50m span. It is noted that, prior to implementing the strengthening solution in the church, the arch was returned to its original (i.e. undeformed) configuration using hydraulic jacks. As previously referred, the tie rods were then anchored to the side walls of the nave of the church from the exterior. Passive anchors were considered for the exterior wall connections while the active anchoring remained inside the church, Fig. 5 c). The level of confinement force that was applied to the ties was around 50kN. The behaviour of the arch and of the ties was monitored during the implementation of the solution (Fig. 5 d)) and this monitoring was kept during an extensive period after the works were completed.

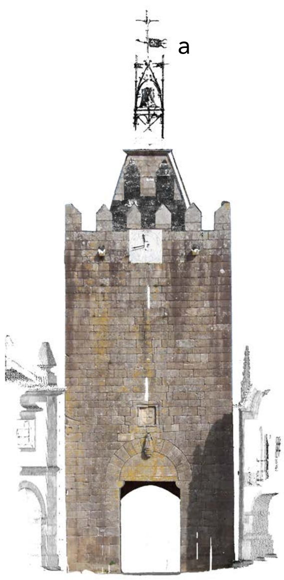

Figure 4.a

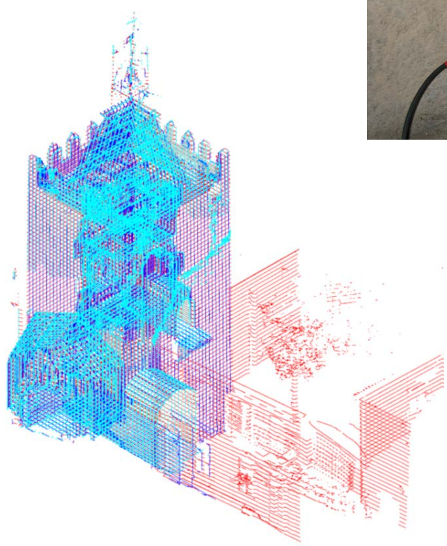

Figure 4.b

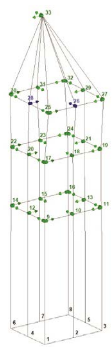

Figure 4.c

Figure 4.d

Figure 4.e

Figures 4.

Combination of the tower façade laser scanning survey with orthophotography (a); laser scanning survey of the structure (b); selected recording positions for the ambient vibration tests (c); accelerometers used in the ambient vibration tests (d); hammer used in the sonic tests (e).

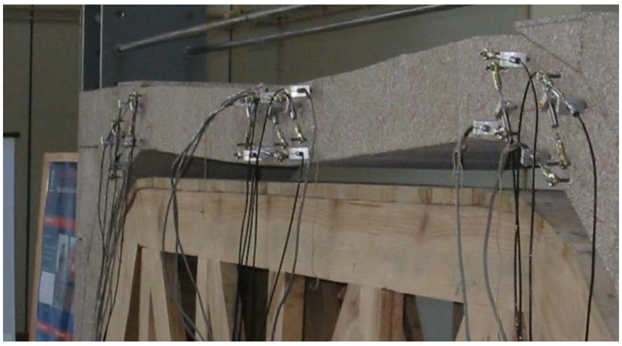

Figure 5.a

Figure 5.c

Figures 5.

Views of the laboratory tests carried out in the 1:2 scale model of the arch (a) and (b); detail of the anchorage of the real arch (c); view of the arch during the implementation of the strengthening solution and plaster labels that were used to monitor the occurrence of possible joint displacements (d).

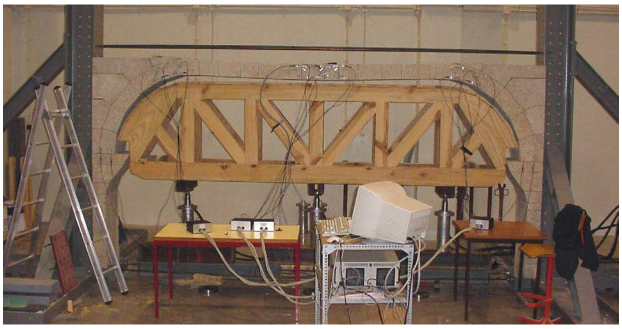

Figure 5.b

Figure 5.d

The fourth case study presented herein involves a retrofitting intervention carried out in the church of Freixo de Espada-a-Cinta, Portugal, (Costa et al., 2009). The construction of this church began in the XVIth century and lasted for almost a century. The church was built according to the Portuguese Manuelino style and has three naves, a chancel, two apsidal chapels and a sacristy. The chancel has a square-shaped plan and is covered by a granite ribbed vault with valuable paintings in the intrados, Figs. 6 a) and b). Over the course of conservation and maintenance operations being performed, joint openings were found between several components of the ribs and panels of the chancel vault. The intensity of the damages indicated that the vault already exhibited a significant level of deformation. The damages were found to be located at about a quarter of the span of the vault and, as a precautionary measure, the structure was temporarily shored until the results of a detailed structural inspection were able to provide a more certain diagnosis, Figs. 6 c) and d). A structural inspection was then performed to analyse the structural safety of the vault which involved a detailed survey of the state of the vault from the intrados and extrados. With the aid of scaffolds and mechanical lifting tools, both sides of the vault were able to be accessed. After removing some of the roof tiles exterior, it was possible to observe that joint openings were also occurring in the extrados of the vault. Furthermore, the survey of extrados of the vault also showed that the roof structure was inadequately designed since part of this structure was vertically supported by the vault, Figs. 6 e) and f).

Based on the conditions and damages that were found during the survey, several actions were defined in order to ensure the safety of the vault. One of the actions involved adding a mass fill on the extrados to increase the stability of the structure. The height of the filling was determined based on a sensitivity analysis performed using a numerical model of the

Figure 6.a Figure 6.b Figure 6.c

Figure 6.d Figure 6.e Figure 6.f Figure 6.d

Figures 6.

View of the triumphal arch and of the chancel vault of the church of Freixo de Espada-a-Cinta (a); detail of the springing area of the vault (b); joint openings in the vault and temporary shoring of the ribs (c); location of the critical deformations of the vault (d); original roof structure supported by the vault (e) and (f); consolidation of the vault stones from the extrados (g).

vault. Moreover, the stone components of the vault were also consolidated, which included repositioning some of the stones and filling the joints with led strips to create additional friction, Fig. 6 g). The vault stones were also tied and clamped from the extrados and a consolidant agent was then applied to enhance the global behaviour of the vault. The actions that were carried out in the structure also included the design of a new timber self-supporting roof structure that provided lateral confinement to the top ends of the walls in order to restrain the displacements of the vault. The last case study that is addressed herein involves the survey and analysis of the remains of the Penas Róias Castle, Portugal (Costa et al., 2008), Fig. 7 a). This castle was built in 1172 on top of a granite outcrop affected by a complex network of faults with many natural cavities which is believed to be an important prehistoric natural site (Groba and Quintas, 2008). Currently, however, only a keep with a diamond-shaped octagonal plan (Fig. 7 b)), a small solid circular tower that was part of the castle wall (Fig. 7 c)) and some ruins of the castle wall with a length of approximately 3.0m (Fig. 7 d)) remain from the original structure. With respect to the damages that were found during the survey, vertical cracks were observed in the top part of the North and East elevations of the keep, as well as near its top openings, Fig. 7 e). Furthermore, in the North elevation, additional cracks were also observed in the bottom and top stones of the entrance door. In the overall, the structure of the keep was found to be in an advanced state of degradation that would irreparably compromise its stability if not ccontained within a short amount of time. With respect to the remaining structure of the castle wall, material degradation and loss of material due to water erosion were observed. Furthermore, aside from these effects related to material disaggregation, inadequate support conditions were also found at the base of the castle wall and at the base of the circular tower due to erosion and failure of the rock. This scenario was

Figure 7.a

Figure 7.b

Figure 7.c

Figure 7.d

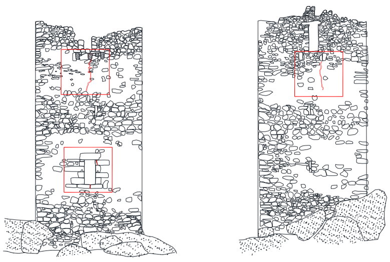

Figure 7.e

Figure 7.f

Figure 7.g

Figure 7.h

Figures 7.

View of the Penas Róias castle (a); keep of the castle (b); circular tower of the castle (c); remaining part of the castle wall with loss of material at the base (d); cracks in the North and East elevations of the keep (e); steel structure confining the keep from the inside (f); consolidation of the supports of the circular tower (g); new stone wall built to fill and smooth unstable rock areas (h).

seen to seriously undermine the stability and safety of these structures. From a geological point of view, the failure and erosion of the referred rock masses that make up the surroundings and support the built structures are the main focus of the analyses that were performed. The continuous erosion of cracked and joint areas of the rock masses supporting the built structures provided inadequate foundations for these structures and led to possible settlements. Given the different nature of the structural elements involved in this case study, the actions that were undertaken involve three different aspects: rehabilitating the built structures, stabilizing rock masses that exhibited unsafe conditions and providing adequate conditions to channel the rain water away from the structures and the supporting rock masses. The referred rock masses are those that supported the medieval castle as well as those that make the prehistoric natural site. Although the safety of these structures was the focus of the intervention that was carried out, the safety of the houses downhill of the castle structures was also accounted for to avoid a potentially disastrous situation resulting from the loss of stability of the rock masses or of the structures.

The rehabilitation actions carried out at the keep included cleaning the vegetation from the elevations and from the top, material consolidation with mortar refilling in the elevation and crowning joints (the latter were moulded to prevent water infiltration), structural consolidation of the cracks at the top and in the North and East elevations by injecting consolidants, and confining the structure from the inside at two levels using a steel structure, Fig. 7 f). This steel structure was designed to provide a temporary consolidation of the keep until an integrated project for the rehabilitation of the whole keep is developed. With respect to the castle wall, the existing materials were consolidated, the joints and the top of the wall were refilled with mortar and the soil at the base was resettled. The same technique was also used for the circular tower, Fig. 7 g). The soil resettlement improves the support conditions of the structures and prevents water infiltration in the degraded areas. In terms of actions for the rain water channelling, the fractured rock areas were filled with stones and mortar. In the access area of the keep, a new stone wall was also built to fill and smooth several unstable rock areas, Fig. 7 h). This new wall was founded in solid rock though excavation and additional vertical anchorages between the foundation stones and the solid rock mass were also performed.

4. FINAL REMARKS

The description of the survey and diagnosis methods addressed herein clearly show that the sustainable rehabilitation of historical constructions requires careful planning in order to preserve their structural characteristics and authenticity. In this context, the use of adequate structural survey, testing and monitoring techniques plays a fundamental role in order to assess the construction's structural behaviour in the most reliable way possible. Furthermore, by having adequate data about the state of conservation of historical constructions, an objective structural diagnosis can be established and effective rehabilitation measures with minimal and reversible effects (if possible) can then be developed for their preservation.

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