Characterisation of Masonry Walls from the National Palace of Sintra (Portugal)

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Abstract – National Palace of Sintra is a medieval palace used in numerous reigns of Portuguese history. This palace has been a royal residence since the 14th century until the establishment of the Republic at the beginning of the 20th century. It has been the target of regular expansion or renovation interventions, from its construction up until modern times, to maintain the infrastructure's functionality.

The main motivation for the development of this dissertation was the qualitative characterization of the palace's masonries and its constitutive materials. In this context, besides the description and characterization of some masonries of the palace, selected to be representative of a certain construction period, one of the main goals of this dissertation was to contribute for the definition of methodologies that allowed the attribution of a quality index to the rubble stone masonries. These methodologies were based on the qualitative visual assessment of masonries and its materials, using two distinct methods: the analysis of masonry cores and masonry panels. It is intended that the quality indexes reflect constructive features and the mechanical resistance of the walls. In this way, they were confronted with the constructive and mechanical properties of the walls, assessed using flat-jack tests and ground penetrating radar (GPR), to validate the proposed methodologies.

The quality indexes defined by the two methodologies obtained different levels of success regarding their relationship with the mechanical properties of the masonries: the methodology based on the masonry cores analysis revealed the highest correlation between the quality indexes of the masonry and mechanical properties of the wall, while the methodology based on masonry panels analysis revealed that it is still in need of further calibration.

Another objective of the dissertation was the survey and analysis of the state of conservation of the Bonet Building, the oldest and worst-preserved body in the entire Palácio Nacional de Sintra. This site has numerous anomalies in virtually all walls, floors, ceilings or stonework, with cracking of structural origin having the highest presence and severity.

Keywords – Nacional Palace of Sintra; Masonry Quality Index; Flat-jack; Ground Penetrating Radar; Anomalies

1 – Introduction

National Palace of Sintra is located in the historic centre of the village of Sintra in Portugal. The building, originally an Arab castle, became a royal residence during the reign of King Dinis. The Palace has been listed as a National Monument since 1910 and is part of the focal point of Sintra's cultural landscape, listed by UNESCO as a World Heritage Site in 1995. Over the centuries, the Palace has undergone several remodelling and enlargement campaigns, most notably those of the reigns of King Dinis, King João I and King Manuel I. As a consequence of the numerous interventions that took place, the Palace's bodies have a varied set of geometries, reflecting its organic growth.

The subject of this dissertation is part of the research project "Masonry characterisation of the National Palace of Sintra" developed following the protocol established between Instituto Superior Técnico and Parques de Sintra – Monte da Lua (PSML) to evaluate the seismic vulnerability of the monument.

The dissertation aims to contribute to the characterization of the masonries, and its constituent materials, taking into account the constructive evolution and eventual interventions suffered over time. The study was supported by an *in-situ* inspection and characterization campaign, complemented by laboratory characterization. This campaign included the analysis of several representative walls of different constructive periods and was carried out by visual observation of masonry cores and masonry panels with an area of approximately 1m^2, complemented by *in situ* flat-jack and GPR tests.

It was also an objective of this work to contribute for the definition of methodologies that allow the attribution of a quality index to the Palace's masonries. It is intended that this parameter can be correlated with the mechanical and constructive properties of the walls, so the use of this index will allow predicting the behaviour of the masonries in terms of its load-bearing ability. These methodologies were based exclusively on data collected through the visual assessment of the cores and masonry panels. In this way, it is possible to define quality indexes readily and inexpensively without the need for laboratory or *in situ* tests. Validation of the proposed methodologies was carried out using the mechanical characterization results obtained by flat-jack tests.

An additional objective of this work was the survey of the state of conservation of the top floor of the Bonet building, which corresponds to one of the oldest areas of the Palace and has very evident and numerous anomalies.

2 – Methodologies

In this study, some masonries, representative of the different main constructive periods, were selected to carry out the core extraction, panel observation, flat-jack and GPR tests. The location of the selected masonries is depicted in Figure 1. The different masonries are identified by a letter – representing the constructive period of the various reigns (D – Dinis, J – João; A - Afonso and M – Manuel) followed by a number code indicative of their location the Palace.

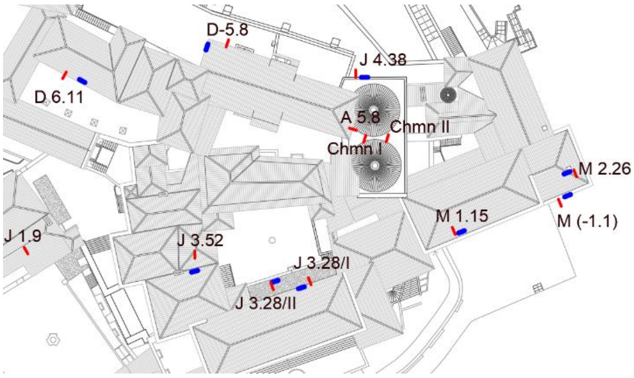

Figure 1 - Location of the studied masonries: red - core extraction; blue - masonry panels flat-jack and GPR tests

The core extraction process was performed by dry drilling and allowed to obtain cores, in most cases not intact, with approximately 10 cm in diameter and variable length, between 20 cm and 30 cm. All cores were extracted at approximately 1 m above the pavement level. The core extraction operation was performed by the company IntempArt.

Most of the areas selected for core extraction were also subjected to mechanical characterization by flat-jack testing and GPR. As flat-jack tests require the masonry to be exposed, there was the need to remove the plaster exposing a masonry panel of approximately 1m^2.

- *Quality index (QI) of the masonries based on core analysis– proposed methodology*

The definition of a QI based on core analysis followed a proposed methodology that involves the definition of five main parameters (C1 to C5), selected according to their influence on the mechanical strength of the walls. Depending on this influence, a weight was assigned to each parameter. These parameters were then classified with a level ranging from 1 to 3 (1 being the best quality level). QI's ratings were obtained by the weighted average of these classification levels. It should be noted that, according to the author's best knowledge, this methodology based on core analysis is innovative since no similar approach could be found in the literature. The various parameters used and their weighs are described below:

C1. Core cohesion (weight: 30%) - This parameter evaluates the cohesion level of the material in the core. It takes into account the core integrity and the size of the fragments resulting from the core extraction process. Level 1 corresponds to an intact (or mostly intact) core, with a cylindrical configuration and reduced presence of small fragments. Level 3 represents a fragmented core presenting small-sized fragments.

C2. Mortar - stone/brick interface (weight: 15%) - This parameter evaluates the adhesion between the mortar and the resistant units (stone or ceramic). A level 1 interface has no discontinuities, with the mortar completely adherent to the stone/ceramic, while a level 3 interface represents the cases where the mortar tends to be detached from the resistant units.

C3. Characteristics of stone/brick (weighting: 5%) - This parameter evaluates the state of degradation of the stone or ceramic material in the masonry. Since most materials are in good conditions, and no significant differences were found between the stone varieties and their strengths in the different cores, this parameter was given a small weight.

C4. Mortar cohesion (weight: 20%) - Level 1 is representative of a sound, cohesive-looking mortar while level 3 is a mortar in which the core extraction process has produced small fragments and shows a tendency to disintegrate when handled.

C5. Interior of the cored area (weight: 30%) - This parameter evaluates the state of the interior of the wall observable after core extraction. Level 1 represents masonries without any voids whereas level 3 represents masonries with a significant presence of voids of considerable size.

- *Quality index (QI) of the masonries based on masonry panels analysis– proposed methodology*

The establishment of a QI based on the visual assessment of masonry panels was based on the work of Borri et al (2015) and Borri et al (2018), who explored and calibrated a procedure for classifying historical masonry. The methodology adopted in this work adapts some of the parameters established by these authors and proposes new ones as described below (P1 to P5):

P1. Size of constituent units (weight 20%) - This parameter takes into account the size of the units that make up the masonry (stone/ceramic). Larger units give the wall a more monolithic nature. On the other hand, the higher weight of the constituent units causes a mutual confinement effect between adjacent stones, which facilitates the distribution of stresses over a larger portion of masonry, contributing to a higher mechanical strength. In this way, level 1 represents walls with a higher percentage of stones with a size between 20 and >30 cm while level 3 corresponds to walls with a large percentage of stones smaller than 15 cm.

P2. Shape of the constituent units (weight 15%) - The shape of the units reflects the mechanical characteristics of the wall and, consequently, the quality of the masonry. Units cut into more regular shapes increase the surface area of contact, ensuring higher friction with each other. Level 1 represents walls with units that tend to be more rectangular and regular in shape, while level 3 features walls with a prevalence of irregular, rounded elements. Note that this parameter is adjusted to the studied set of walls since none of the masonries presented perfectly cut stones.

P3. Mortar bed joint alignment (weight 20%) - Alignment of mortar bed joints is important for the compressive strength of the wall, as they ensure a uniform load distribution across the wall, avoiding stress concentration zones. Level 1 represents continuous mortar bed joints (horizontally and vertically) while level 3 represents small non-continuous mortar bed joints.

P4. Mortar quality (weight 25%) - This parameter is important as it ensures uniform transmission and distribution of loads between resistant units. The mortar, besides smoothing the contact between the stones, provides higher cohesion of the masonry, increasing its monolithic nature. Level 1 represents very cohesive mortars, with good adhesion to the resistant units, while level 3 is indicative of non-cohesive mortars which easily desegregate.

P5. Presence of voids (weight 20%) - The presence of voids in masonry has obvious consequences on its strength and monolithic nature, so this parameter is suggested for the definition of the masonry quality index. Level 1 represents a wall without any voids. Level 2 represents walls with one or two unimportant voids while level 3 represents walls with large numbers of voids.

- *Flat-jack test*

Flat-jack testing is a versatile and reliable technique that allows the in situ determination of some mechanical properties of masonry. In the present work, two evaluation techniques were used: the simple flat-jack test, which allows evaluating the in situ stress level of the masonry, and the double flat-jack test, through which is possible to obtain information regarding the resistance and deformability characteristics. A detailed description of both tests is given below:

The simple flat-jack test is based on the change in the stress level at a given point in the structure resulting from a cut (or notch) that is made in the surface. This leads to a partial relief of stress causing a deformation. A hydraulic flat-jack is then inserted into the notch and pressurized using a hydraulic system until the deformation is eliminated. The pressure that needs to be imposed to the jack to restore the initial deformation state reflects the value of the vertical stress level to which the masonry was subjected prior to the notch (Binda L., 1999). The stress level (σ) can be determined by equation 1:

$$\sigma = p \times Km \times Ka \qquad (1)$$

where Km is a dimensionless factor accounting for the flat-jack rigidity and Ka is the ratio between the areas of the jack and of the notch (Domingues, J. 2019).

The double flat-jack test uses two flat-jacks inserted into horizontal notches parallel to each other. In this way, the masonry between both notches will be insulated from the surrounding wall and can be thus tested under uniaxial compression. From the obtained stress-strain curves it is possible to determine Young's modulus (E), the yield stress (σy) and the ultimate tensile strength (UTS).

The tests were carried out by Oz - Diagnóstico, Levantamento e Controlo de Qualidade em Estruturas e Fundações, Lda. using a semi-circular jack with an area of 750 cm^2. Three vertical reference alignments arranged perpendicular to the notch and equidistant from it were used for the measurement of the deformation (Figure 2). Although the procedure described in the RILEM TC 177-MDT (2004) standard suggests the use of four reference alignments in the present case only three were used.

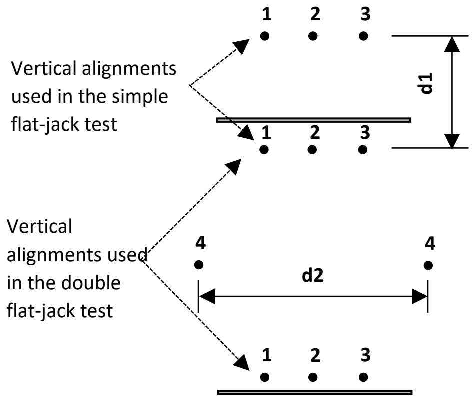

Figure 2 - Schematics of flat-jack tests

- *Ground penetrating radar (GPR)*

Ground penetrating radar is a non-destructive method that allows remote detection of inaccessible objects or structures inside of the studied surface. It is based on the emission, reflection and reception of a high-frequency electromagnetic wave. When the emitted electromagnetic wave crosses through different materials, with different electrical properties, part of the wave's energy is reflected at their interface, returning to the surface, while the rest is used to cross the second material. The time elapsed between the wave emission and its reflection correlates with the depth at which the interface is located (Bergamo, O. 2015).

Typically, a GPR apparatus contains an emitting antenna that emits an electromagnetic pulse which is subsequently received on another receiving antenna, after being partially reflected within the tested structure. The antennas are connected to a control unit that manages wave emission and acquisition parameters. GRP testing was carried out by an external company Morph Lda.

- *Physical properties of the masonry's constitutive materials*

Stone, mortar and ceramics were characterized regarding the determination of porosity accessible to water, water absorption by capillarity and ultrasonic testing.

Porosity was determined by gravimetric tests according to equation (2)

$$P = \frac{m_3 - m_1}{m_3 - m_2} \times 100\ [\%] \qquad (2)$$

where m_1 represents the dry mass of the sample, m_2 the hydrostatic weight and m_3 the saturated mass.

Capillarity water absorption test was performed according to RILEM Test No. II.6. (1980). The representation of water absorption/unit of area as a function of the square root of time gives the water absorption curve. This curve presents two regions: an initial linear section, corresponding to the rapid water absorption phase, and a second region associated with slow water absorption. The value of the capillarity coefficient (CC) is obtained by the slope of the linear zone.

Ultrasound tests were carried out using Proceq Pundit ultrasonic equipment with two pairs of transducers (frequencies of 150 Hz and 54 Hz). The tests were performed on air-dried stone blocks. Vaseline was used in the contact between the transducers and the stone to minimize the presence of air at the interface. Three measurements were made for each set of collinear points, marked on parallel surfaces obtained by cutting the stone blocks. The test was performed by direct transmission, in which the emitting and receiving transducers are placed on the same plane and opposite parallel faces of the material.

3 – Results and discussion

From core and masonry panels analysis two types of masonries were identified in the Palace: ceramic brick masonry, found in the cores taken from the two chimneys, and rubble stone masonry in all other cases. The materials from the masonries consisted of mortars, several varieties of stone and two varieties of ceramic material, one used as the main resistant unit in the chimneys, and another as filler material (found in both stone masonry and brick masonry). The mortars were found to be visually very similar in all the masonries, which was not expected since the studied walls are representative of constructive periods temporally distant from each other. These mortars are lime-based with stone aggregates and the presence of ceramic particles. However, their level of cohesion and the interface with the stone/ceramic is quite different, although not correlated with the correspondent constructive period. Regarding the stone, masonry analysis revealed the main variety of stone was a dark grey limestone, widely used in all the walls, irrespective of the constructive periods. Two main types of ceramic material were also found: one with a stronger orange colour and numerous voids, mostly used as a chimney-resistant unit, and a paler orange one with a smaller number of voids, used as a filler.

3.1 – Ground penetrating radar (GPR)

The main goals for the GPR tests were the following:

- Wall thickness assessment;
- Characterisation of the constructive features;
- Identification of compartments or voids inside the walls.

Regarding the first objective defined, GPR allowed, in most cases, the determination of the wall thickness with relative success. Moreover, in certain cases, it was also possible to detect interior masonry leaf and/or different constructive environments inside the same wall (Figure 3 and 4). However, GPR tests did not meet all the previously defined objectives as the technique did not detect voids of considerable dimensions that were easily detected from the visual analysis of some masonry panels. Also, this technique has not been able to conclusively characterize the constructive features of the walls and it was not possible to collect reliable data through this method.

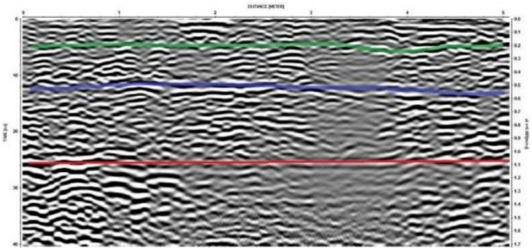

Figure 3 - Radargram showing interior leaf interface (J4.38)

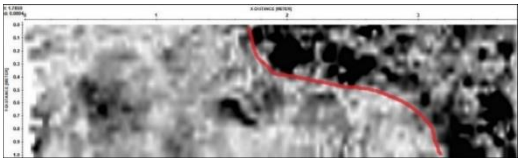

Figure 4 - Time-slice with two different constructive environments (J3.28/II)

3.2 – Masonry characterisation

- *Quality index – Cores and masonry panels*

In Tables 1 and 2, the values of the QI's determined through core and masonry panel analysis are presented respectively.

Table 1 – QI based on core analysis

Masonry	C1 (30%)	C2 (15%)	C3 (5%)	C4 (20%)	C5 (30%)	QI
D 6.11	3	3	2	3	2	**2,65**
D 5.8	3	3	2	3	3	**2,95**
J 4.38	3	3	1	3	2	**2,60**
J 3.52	3	3	2	3	2	**2,65**
J 3.28/I	1	2	2	2	3	**2,00**
J 3.28/II	2	2	1	1	1	**1,45**
J 1.9	1	1	1	1	2	**1,30**
Chmn I	1	1	1	1	1	**1,00**
Chmn II	2	2	1	1	1	**1,45**
A 5.8	2	2	1	1	2	**1,75**
M (-1.1)	2	1	1	1	1	**1,30**
M 1.15	3	3	1	2	1	**2,10**
M 2.26	2	3	1	3	3	**2,60**

Table 2 – QI based on masonry panel analysis

Masonry	P1 (20%)	P2 (15%)	P3 (20%)	P4 (25%)	P5 (20%)	QI
D 6.11	2	2	2	1	1	**1,55**
D 5.8	1	2	3	3	3	**2,45**
J 4.38	1	1	1	3	1	**1,50**
J 3.52	1	1	3	2	1	**1,65**
J 3.28/I	1	2	2	2	3	**2,00**
J 3.28/II	3	3	2	1	1	**1,90**
M (-1.1)	1	2	2	1	2	**1,55**
M 1.15	2	1	1	2	2	**1,65**
M 2.26	1	2	3	3	3	**2,45**

The QI values obtained using the two methodologies points to the lower quality of D 5.8 and M 2.26 masonries. On the contrary, the highest quality was obtained for M (-1.1) masonry. The fact that masonries from the same constructive period (M – Manuel) present the highest and lower quality indexes indicates that these indexes cannot be correlated with the constructive periods. The same is valid when examining the other QI's values, which are not similar in the same constructive periods.

In an attempt to compare the two methodologies, Figure 5 presents the QI values obtained from core and panel analysis.

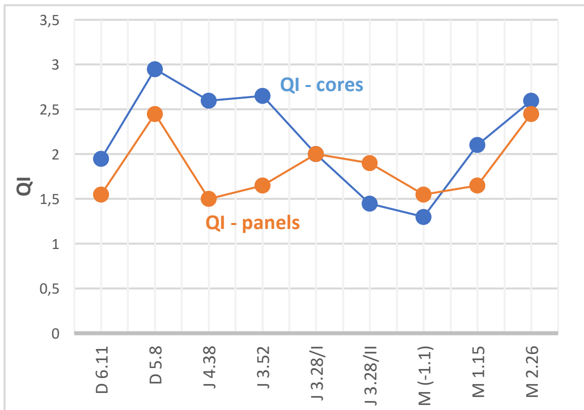

Figure 5- Comparison between QI obtained from both methodologies

As can be seen, both curves show a similar profile. However, some differences can be detected, the most significant corresponding to J 3.52 and J 4.38 masonries. In the case of J 3.52, it is important to note that the tests were performed on opposite sides of a thick wall (2.7 m) which means that the qualitative assessment was not performed for the same masonry leaf and thus are not comparable. On the other hand, in J 4.38, despite the short distance between the location of the tests, the difference between QI was also significant. This can be explained by the criteria adopted in each methodology. In fact, the parameters adopted in the evaluation of the cores focuses more on the quality of the materials while the parameters used in the evaluation of the panels fall mainly on the constructive characteristics of the wall. Looking at Table 2, J 4.38 masonry was classified with level 1 in the parameters regarding constructive characteristics (shape and size of the units and alignment of the mortar bed joints) and with the lowest quality level for the parameter associated with the material quality (mortar quality).

- *Simple flat-jack testing*

In situ stress levels of the selected masonries were determined via simple flat-jack tests (Figure 6). As it can be seen the stress levels are in all cases quite low, and can be related to the height of the wall existing over the tested location.

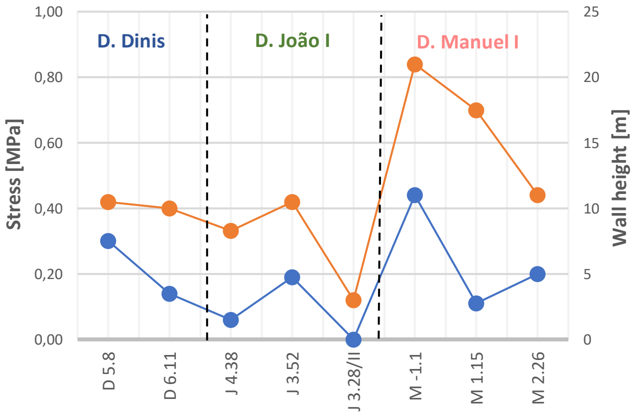

Figure 6 - Relation between in situ stress levels and wall height over the testing location

The stress levels are therefore dependent on the structure's weight and are not related to the construction period.

- *Double flat-jack testing*

Young´s modulus, yield stress and UTS, determined by double flat-jack testing, are presented in Table 3.

Table 3 – Mechanical properties of the masonries (Oz, 2018)

Masonry	E (GPa)	σ_y (MPa)	UTS (MPa)
D 5.8	1,9	0,9	1,8
D 6.11	8,9	1,7	2,94
J 4.38	1,2	0,4	1,3
J 3.52	2,4	1,1	1,7
J 3.28/II	2,2	2,2	2,94
M -1.1	3,4	1,1	2,4
M 1.15	0,5	0,4	1,1
M 2.26	0,1	0,2	0,7

The elastic modulus values reported by Oz (Oz, 2018) obtained in this work for most masonries (1.2 to 3.6 GPa) are of the same order of magnitude as those found in the literature. It can be mentioned the work of Simões, A et al (2014), who obtained values of E = 2.0 GPa for stone masonry of the exterior facade of a Pombaline building, or Vicente, R. (2008) who obtained an average rigidity of 2.08 GPa in the case of stone masonries from downtown Coimbra.

Regarding the values of UTS and yield stress reported by Oz (Oz, 2018) it can be seen, that UTS varies between 0.7 and 2.9 MPa and that, in most cases, is more than 50% higher than the respective yield stresses. These values are similar to those obtained in the literature for masonries with irregular/semi-regular stones and partially/non-aligned mortar bed joints, similar to those found in Palácio Nacional de Sintra (IMIT 2009).

Finally, it should be noted that in the vast majority of cases the yield strength and UTS values are significantly higher than the *in-situ* stress levels pointing to a high safety coefficient to vertical loads.

- *QI vs Mechanical properties*

In order to validate the methodologies used for quality index definition in Figures 7 and 8 the quality levels determined by each methodology are compared with the values of UTS respectively.

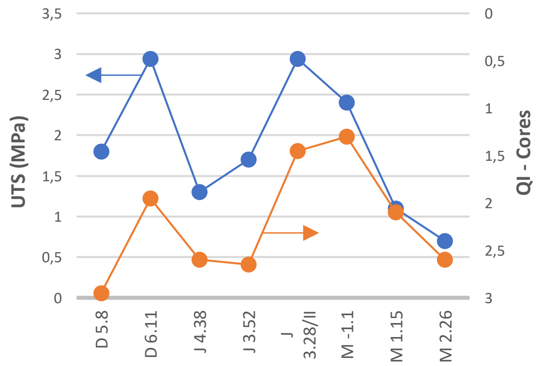

Figure 7 - Comparison between core QI's and UTS

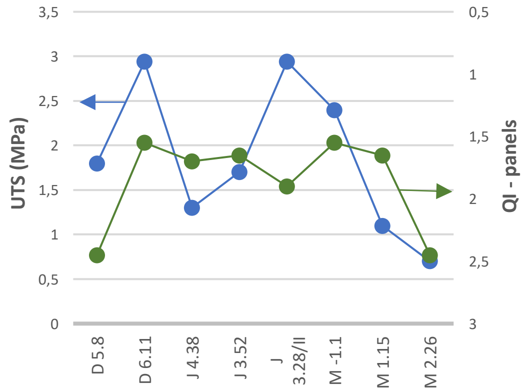

Figure 8 - Comparison between panels QI's and UTS

Regarding the core QI (Figure 7), both curves display similar profiles, resulting in higher UTS values occurring for masonries presenting a high-quality degree (low QI value), and masonry with lower strength presenting lower quality grades (high QI value). This relationship is easily seen in Figure 9 where core QI values are plotted against UTS.

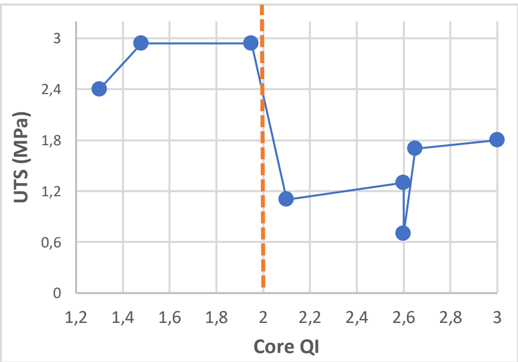

Figure 9 - Relation between UTS and core QI

Two regions can be considered in the plot: one for QI values <2 (the value that corresponds to an average quality), for which UTS is high (≥2.4 MPa) and another, for QI>2, where lower UTS values are obtained. It seems therefore possible to conclude that the methodology adopted for defining core QI's was adequate both in terms of its parameters and their weights, and shows that QI cores can be correlated with the mechanical strength of masonry.

In the case of QI's obtained by analysing the masonry panels (Figure 8), although it is possible to observe some similarities in the curves, they are not so evident. Using this methodology, the QI value seems less sensitive to differences in the mechanical strength of the masonries, with some discrepancies being found, namely for J 4.38, J 3.52 and M 1.15.

This lower correlation between the QI of the panels and the mechanical resistance may originate from the weight of the various parameters since, as referred, previously, this methodology puts more emphasis on the constructive characteristics rather than on the quality of the constitutive materials. On the other hand, it should be noted that the methodologies found in the literature also take into consideration the analysis of the cross-section of the walls, being the degree of connection between the wall leaves considered to be a key parameter for the overall behaviour of the structure. In the present study, this parameter could not be evaluated as it was not possible to have access to the cross-section of the walls. Therefore, due to these limitations, the selected parameters and their weights should be better calibrated.

- *Physical characterization*

The physical characterization of the constitutive materials of the various masonry studied in this work included the determination of the porosity accessible to water, capillarity coefficients and the velocity of propagation of ultrasounds. The results obtained allowed to reach some conclusions:

For the stone samples, a clear correlation was found between the different properties and the type of stone. It was found that the dark-grey limestone, present in all the masonry studied, showed low porosity and high compacity (Figure 10).

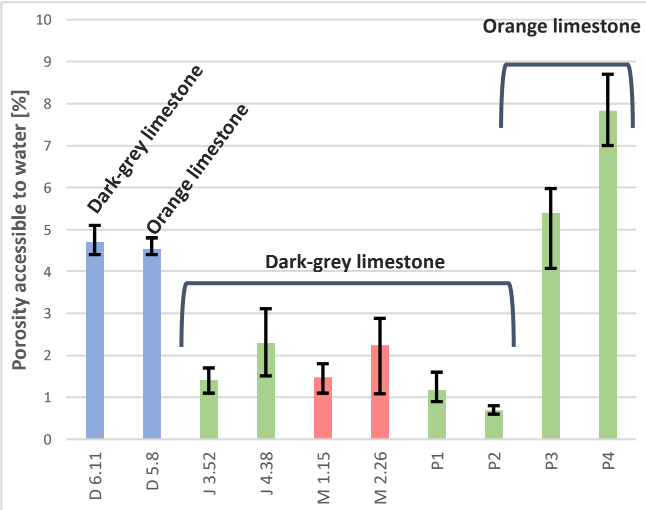

Figure 10 - Stone – porosity accessible to water

On the contrary, no significant differences were obtained in the results of the different lime-based mortar samples, which presented porosity values ranging between 34% and 40% (Figure 11). Substantially lower values of porosities and CC's were however found in repair mortars, collected in mended zones, indicating that these materials are somewhat different (presence of hydraulic component).

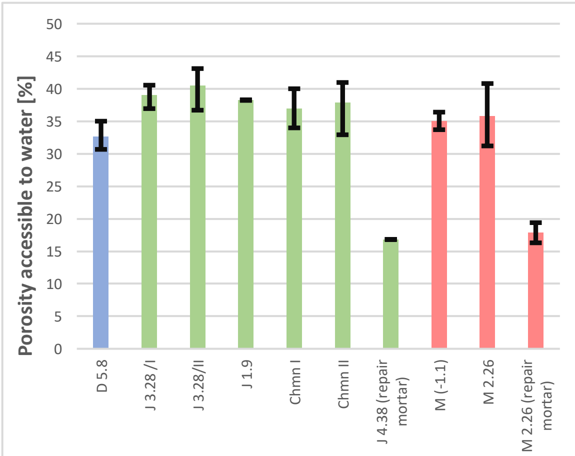

Figure 11 - Mortar – porosity accessible to water

Finally, regarding the two varieties of the ceramic material, it was possible to detect differences in the porosity values between them, which is in accordance with the visual analysis performed

3.3 – Survey of the conservation state of the Bonet Building

The conservation state of the top floor of the Bonet Building was surveyed and the main anomalies were identified and located. This area is not included in the visiting route of the Palace.

In the stone masonry walls, the main anomalies detected correspond to cracking (Figure 12), present in almost all of the walls, and moisture stains. Wall cracking is by far the most common type of anomaly present in the studied area and crack opening ranges from <1mm to 20mm. Cracking is possibly the result of horizontal impulses – caused by the action of perpendicular walls or tie rods - wall movements or stress concentration zones (spans). Some of these cracks reveal recent activity visible by the cracking of plaster casts applied over the wall crack.

Figure 12 - Two examples of wall cracking in the Bonet Building

All the masonry walls were surveyed, and their anomalies were mapped. The cracks were grouped according to their opening into five groups: [0 to 1 [mm (blue), [1 to 2 [mm (green), [2 to 5 [mm (orange), [5 to 9 [mm (red); ≥9 mm (black). Figure 13 presents an example of such work.

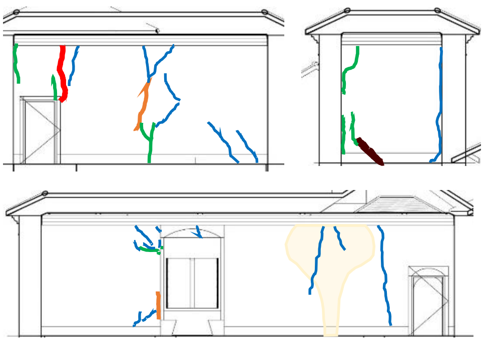

Figure 13 – Examples of the mapping of masonry wall anomalies (pale orange represents humidity stains

In stonework, the main anomalies detected were the occurrence of cracks and fractures of stone elements, possibly resulting from excessive loads, and non-functional joints between stone elements due to disintegration of the mortar (Figure 14). These anomalies are also fairly important because they contribute to the infiltration of water from window framings, allowing for rainwater to come in and causing humidity related anomalies such as stains and degradation of wooden elements.

Lastly, the anomalies identified in pavements are related to the creep effect of the wood, which combined with its deterioration due to the effect of excess humidity and xylophagous insects, led to the deformation of the pavements. In the wood coatings of the ceilings, longitudinal cracking was detected associated with dimensional variations.

Figure 14 - Non-functional joints of a window framing

4 – Conclusions

Visual analysis of both masonry cores and panels, revealed, in most cases, similar information in terms of characterization of the studied masonry. This analysis revealed that most of the Palace’s walls are of rubble stone masonry, except for the two chimneys that were built with red-ceramic brick. Moreover, the visual characterization of their constitutive materials showed many similarities and it was not possible to assign a constructive period to the studied materials just by this visual analysis.

Another goal of this work was to contribute for the definition of a masonry quality index, intended to be related with the constructive and mechanical properties of the walls. To this end, two methodologies were used, based on the analysis of the cores and panels, in which several parameters were defined. Although the information obtained through these two methods gave generically the same information, some differences were also detected. These can be associated with the parameters selected for each methodology: parameters used in the core-based methodology relate more with the quality of the constituent materials, while the analysis of the masonry panels is based mainly on information regarding the constructive characteristics.

GPR study did not allow to achieve all the proposed objectives. In fact, it was not possible to successfully distinguish the construction features or to detect void spaces. However, the technique proved more efficient in determining wall thickness and, in some cases, allowed the detection and of interior masonry leaf

Mechanical characterization by flat-jack testing showed that the stress levels of the walls are generally relatively low and, being directly related to the wall height above the test site and are not correlated with the constructive period. Moreover, it was possible to verify that the studied walls have yield and UTS values significantly higher than the in situ stress levels.

The results of the mechanical characterization were also used to validate the quality indexes. A good correlation was found between the QI's based on core analysis and UTS values: the masonries that presented the best mortar cohesion, good mortar/stone interface quality and no voids were the ones which presented the highest values of E, σy and UTS. It is, therefore, possible to conclude that the parameters selected for QI definition through the core analysis reflect characteristics that influence the mechanical properties of the wall. On the other hand, panel QI did not show such a clear correlation, which may be explained by the parameters used in their definition. Thus, it is concluded that the methodology used for panel evaluation should be recalibrated.

Similarly to the visual analysis of the materials, the physical characterization showed once again that the materials show similar properties irrespectively the constructive periods.

The last goal of this work was the survey of the conservation state of the top floor of the Bonet building. The main structural anomalies identified in the stone masonry walls of this body were cracking, possibly promoted by horizontal impulses and differential settlements, and humidity stains. Cracks were detected in the stonework, resulting from excessive loads, and non-functional joints between the stone elements due to the disintegration of the mortar. Deformation of the wooden floor structures was also observed due to creep in conjunction with the presence of moisture and deteriorating agents.

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