REHAB 2014

Proceedings of the International Conference on
Preservation, Maintenance and Rehabilitation
of Historical Buildings and Structures

Edited by

Rogério Amoêda
Sérgio Lira
Cristina Pinheiro

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on Preservation, Maintenance and Rehabilitation
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Foreword

REHAB 2014 – International Conference on Preservation, Maintenance and Rehabilitation of Historic Buildings and Structure aimed at pushing further the discussion on built heritage and the preservation of its legacy, establishing a settle of knowledge and experience from several parts of the world. The importance of conservation of historical constructions (built landscape, urban fabrics, buildings, and engineering works) are of utmost importance to preserve the cultural references of a community.

Under the main topics of discussion, subjects of preservation and rehabilitation methodologies and technologies, as well the importance of the economic and social impacts of preservation practices were covered by several papers as the main leading guidelines of this the conference. Furthermore, different communities' scales (local, regional national or even worldwide) raise different questions and approaches, and therefore different solutions that are worthily studying, in order to compare experiences and practices. The sustainability approach was also covered, highlighting the importance of the commitment between heritage preservation and technical requirements related to its occupancy and use, such as energy efficiency or materials recovery. Inclusivity was an important topic of discussion too during the conference, as public historical sites and buildings need to be adapted to receive different kind of visitors (children, elderly or handicapped persons) and to establish an adequacy with the perceiving of the physical environment and information contents.

As for the Special Chapter of this event Archaeological sites were brought in because they demand a particular approach specially on what concerns the preservation of historical elements that are to be maintained and visited long after the diggings and the field work is over and done. This kind of structures raises unique problems of preservation and promotion and therefore is the focus of special and specific solutions.

This conference also gave stage to early stage researchers and students willing to share the results of their research projects, namely post-graduation projects and doctoral projects. REHAB received a significant number of such proposals the quality of which was confirmed during double-blind review.

We would like to express our gratefulness to all the partners and sponsors of REHAB 2014 who joined efforts to make it a significant Conference.

Our special word of recognition to the Secretário de Estado da Cultura, Direcção-Geral do Património Cultural, Convento de Cristo, Câmara Municipal de Tomar, to the IPT – Instituto Politécnico de Tomar.

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Deterioration of the granitic stone at Misericórdia chapel in Murça (northern Portugal)

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ABSTRACT: In this work are considered the main deterioration processes of the granitic stone at the Misericórdia chapel of Murça (Vila Real). In the main façade and indoors there are erosive features (that can endanger decorative elements) and salt efflorescences with distributions that suggested the influence of capillary rising solutions, hypothesis supported by studies with ground penetrating radar and thermography. The extension of the weakening effect was assessed by measurements with a Drilling Resistance Measurement System. In the main façade, there are also erosive features at the upper portions, as well as black crust, salt efflorescences, biological colonization and other coatings. In the interior of the building several salt efflorescence are observed both in the stone and in the plaster. In general, the salt efflorescence found in the stone are not associated to erosion. However, in a door of the north façade some erosion is observed, which is associated to granular disaggregation. The salt efflorescence's that develop on the plaster promotes the erosion of the painting in the walls and in the vaults of the ceiling of the chapel. Based on the analysis made, it is supposed that salt contamination should be the most important agent associated with the deterioration processes found in the stones and in the plaster with paintings. The contribution of a past existing channel with animal effluents in the neighborhood of the north façade should be considered. Therefore, besides the identification of the salts the definition of the causes, it is made an inspection of the most deteriorated zones in the stone based o non-destructive methods (ultrasonic pulse velocity and drilling resistance) aiming at understanding in more detail the extension of the damage in the stones. A detailed discussion of the results is provided in the paper.

1 INTRODUCTION

This work concerns alteration features of granitic stones at the Misericórdia chapel in Murça (Vila Real district), a XVII century building of baroque style with a main façade turned towards east (architectural and historical information is available at the Information System for Architectural Heritage, http://www monumentos.pt/Site/APP_PagesUser/SIPA.aspx?id=5268). The chapel presents remarkable carvings in granitic stones at the main façade and indoors (namely at the wall of the surrounding the altar and at another one in the sacristy). The deterioration state of the stone on the main façade was already the subject of a study by Castro et al. (1987) that, among other things, referred extensive erosion of stone elements, namely at portions nearer the ground, presence of darkish coatings and interventions with cement mortars that could contribute to the deterioration of the stone.

The main objective of the present study is the diagnosis of the deterioration processes that affect the stones in a perspective of contributing to the discussion that will support the intervention strategy to be implemented.

2 MATERIALS AND METHODS

Observational field studies were developed to identify the alteration features that affect the stone elements and scanning electron microscopy studies were performed in samples of neoformations. Measurements with a Drilling Resistance Measurement System (DRMS) were made to evaluate the depth of physical weakening related to the alteration processes. The DRMS has been developed as an attempt to design a portable system capable of carrying out minor-destructive tests in laboratory and *in situ* based on microdrilling. The original objective was to measure, continuously and reliably, the superficial resistance and in depth cohesional properties of natural stones (Exadaktylos et al., 2000). It allowed to show the depth of the deterioration of the stone and the depth where the strength is lower and higher.

The definition of the humidity patterns and assessment of the humidity sources can be useful to explain the salt efflorescence and stone degradation, which should be associated to the transport of dissolved salts in water through the thickness of the walls and stone elements. Therefore, aiming at evaluating the possible sources of humidity in the walls, it was decided to make non-destructive testing based on ground penetrating radar (GPR) and thermography (IR) in the stone slabs of the chapel and in the walls in the zone of the main entrance.

GPR is one of the most versatile nondestructive techniques available currently, which include several applications in civil engineering structures, namely the presence of moisture (Maierhofer et al., 1998) and assessment of water content in fresh content and degree of hydration of cement (Rzepecka, 1972). GPR working principle is based on the emission of radiowaves of a particular frequency and in the regain of reflected echoes. These waves travel through all non-metallic materials and travel in air at the speed of light. Differences in dielectric properties between adjacent materials cause the waves to be partially reflected and registered in the system. Moisture presence decreases the signal's amplitude (causing an increase of the signal's attenuation) as well as a decrease of the radiowave's speed. These affect, cumulatively, the penetration depth of the signal. A typical radar system consists of a transmitting and receiving antenna, a control unit and a visualization/storage unit. Radar antennas are characterized by their central frequency, typically ranging from 10 to 2000MHz and more. The choice of a particular frequency is dependent on the type of application, depth and dimensions of potential targets and field environment.

Infrared thermography is a useful non-destructive investigation technique that can be widely used in numerous applications where surface temperature variations might denote problems such as the presence of structural elements that would otherwise remain hidden, voids, detached areas, and to identify moisture in masonry walls (Moropoulou et al., 2000, Avdelidis & Moropoulou, 2004). Thermography is considered as a qualitative method which is used primarily to indicate variations in thermal resistance on a wall or roof. Infrared thermography is used in building conservation to determine the presence of moisture in masonry walls. The readings of an infrared thermography camera produce an image in color, mapping the differential in temperatures (even small differences) of the surface of the walls. Infrared images measure surface temperature, not water content. Moisture can be detected due to the absorption of energy during evaporation. The moist areas are colder than dry ones, assuming the same atmospheric boundary conditions exist across the surface (Akevren, 2010). The temperature difference created by the presence of moisture on the inside surface of a wall will appear differently in relation to the surrounding area.

The profiles measured with the GPR in the pavement of the chapel (main nave and sacristy) are shown in Figure 1 as well as the locations of the measurements carried out with infrared camera. The GPR measurements were made in two distinct moments, namely in mid-September and end of November, so that possible changes of the moisture patterns could be identified after the first raining.

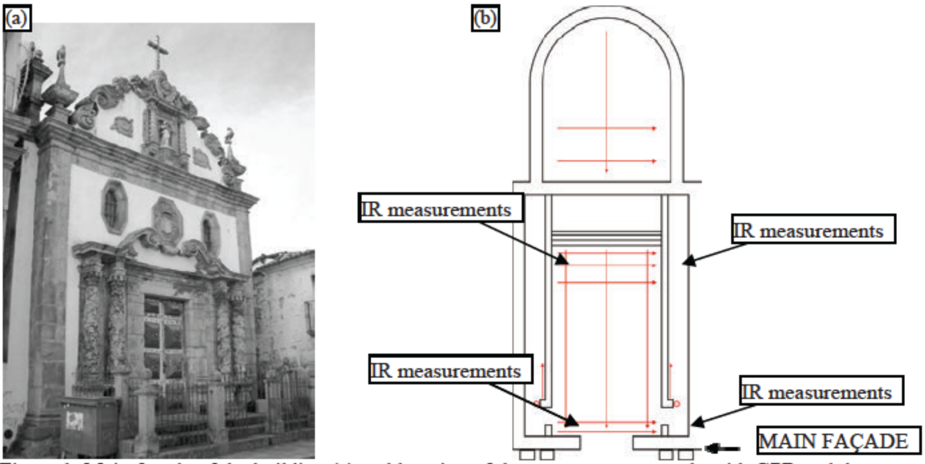


Figure 1. Main façade of the building (a) and location of the measurements made with GPR and thermography (b).

The walls inside the Misericórdia chapel in Murça were photographed using a FLIR T400 infrared camera. Walls that showed most deterioration and evidence of plaster and stone delamination were selected to be the objects of this study. A strip of each wall was selected and analyzed from bottom to top and the strip was photographed. The thermography measurements were made only on November and after the heating of the internal environment of the chapel so that thermal gradients could be obtained, making the recording of the thermography images possible. The heating of the internal space was carried out through industrial heaters (mushroom heaters).

3 RESULTS AND DISCUSSION

Several deterioration aspects were observed. Erosive processes (Fig. 2) deserve more attention since they imply loss of material. Features involving detachment of grains or portions of variable size along nearly planar surfaces or cracks were observed. These erosive processes are more intense and widespread in the main façade, especially in the areas of the columns and the jambs of the portal nearer the soil, but may also occur at the upper portions of the façade. The erosion has caused the disappearance of ornamental details and thinning of stone elements, including the base of columns and portal jambs. Some erosive features are also observed indoors, affecting granitic stones mainly in jambs of a lateral door of the nave and decorative carvings of the wall surrounding the altar (pilasters and the south side of arch above the altar). The extension of the physical weakening processes (and hence of erosive hazard) was assessed by measurements with DRMS. In one of the jambs of the portal, that exhibit a marked thinning (Fig. 2), the DRMS measurements showed that the stone weakening can extends to depths around 5 cm.

Erosive features are also observed in other materials such as paintings and mortars, namely indoors, which could help to discuss solutions sources and pathways. The erosion of these materials affects the portions nearer the ground but also the materials in the ceiling of the nave. Diverse salt efflorescences were found at the main façade and indoors mostly in the portions nearer the ground.

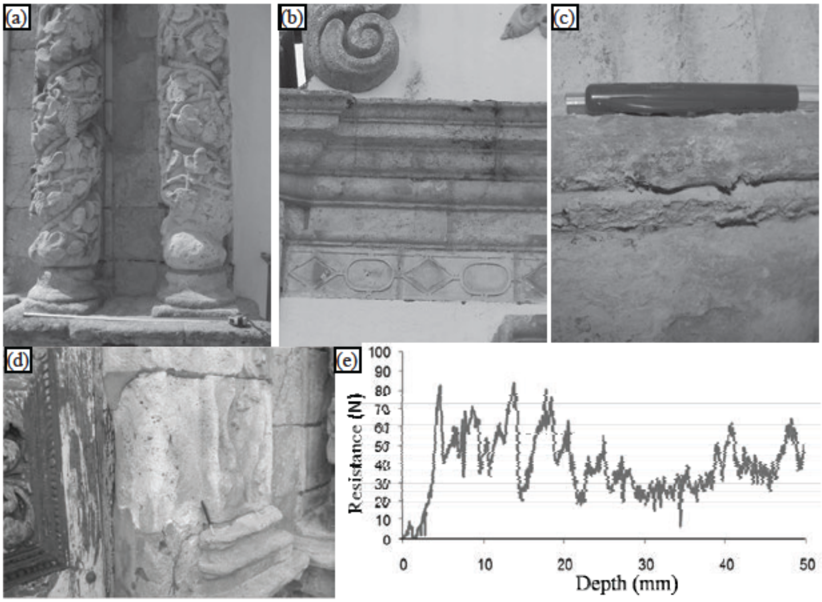


Figure 2. Erosive effects on the main façade nearer the ground (a) and in the upper portions (b) as well as indoors (c). Erosive depth in a stone of the portal of the main façade (d) was assessed by a DRMS profile (e).

It was possible to observe the disappearance in winter of outdoor efflorescences and also some indoor ones.Analytical studies indicated the presence of alkaline nitrates, chlorides and sulfates and calcium sulfate. Some of the identified salts (alkaline chlorides and nitrates) suggest organic contributions similar to what is observed in buildings of historical centers of mainland Portugal such as Amarante (Begonha, 2009), Braga (Matias & Alves, 2002), Caminha (Begonha, 2011), Évora (Antunes & Alves, 2003), Salzedas (Alves & Pamplona, 2007) and Torre de Moncorvo (Moreno et al., 2006). Salt pollution on this monument could have been accentuated by animal sewage that circulated in older times on a channel that is found just north of the chapel. Alkaline sulfates are often found in modern buildings (Alves, 2013) and might reflect the influence of recent interventions in particular the application of cement mortars (Arnold & Zehnder, 1991). Note that the report of Castro et al. (1987) referred that the interventions with cement mortar in the main façade could be a future source of soluble salts.

There are other alteration features that are observed in the stone elements and that can be considered depreciating. In several sheltered places on the main façade, particularly in the capitals of columns, were detected darkish coatings with textural features that suggested black crusts. This hypothesis has been confirmed by SEM studies that showed the presence of aggregates of calcium sulfate crystals. Throughout cuttings showed the occurrence of areas with calcium sulfate and areas with calcium but without sulfur. In the main façade were also detected the presence of higher plants and other biological colonization in places favoring moisture conditions as well as dark brownish or reddish coatings whose origin is uncertain.

3.1 *Assessment of the source and moisture patterns with non-destructive techniques*

As above-mentioned, GPR and IR were used to evaluate the possible moisture sources present in the walls and to define the major moisture patterns in the walls. The results of the longitudinal profiles in the right and left part of the nave of the chapel are presented in Figure 3. It is observed that any significant differences were found in the events recorded in September and November. This seems to indicate that the humidity level in the soil under the stone pavement kept reasonable similar between September and November.

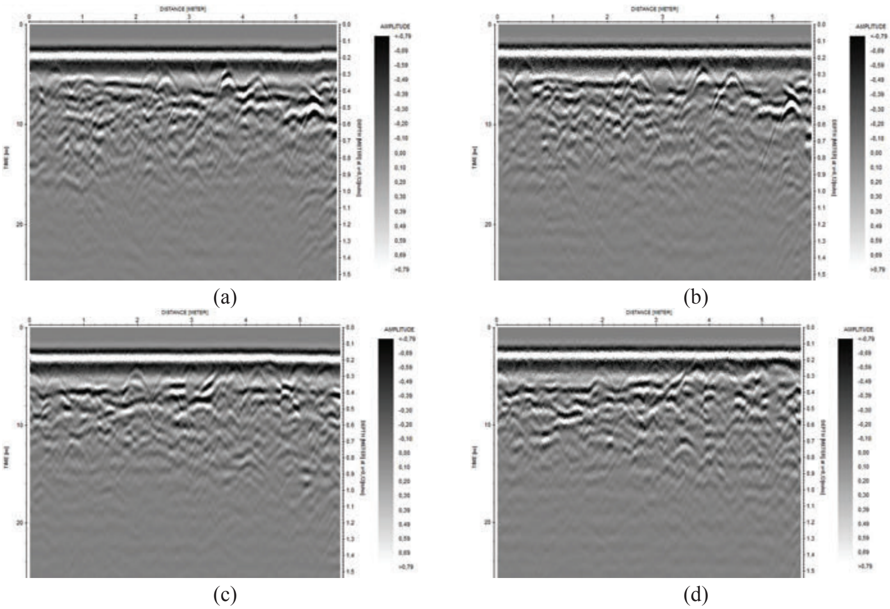


Figure 3. Radargrams in the longitudinal direction of the nave measured in the right and left sides; (a) September; (b) November.

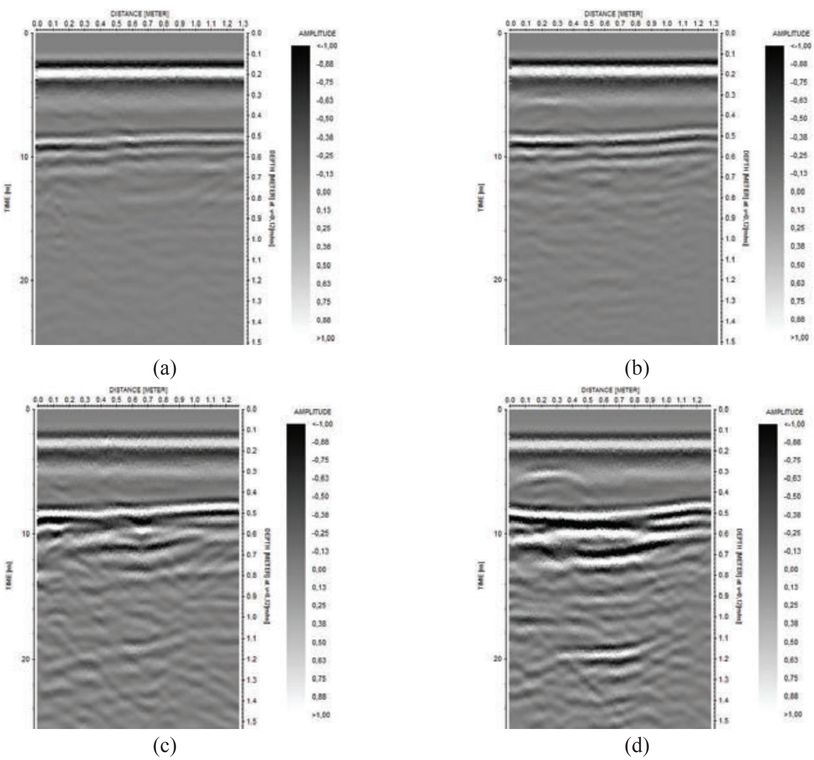


Figure 4. Vertical radargrams carried out on the lateral walls in the proximity of the openings (doors): (a) (b) profiles at left and right walls in September; (c) (d) profiles at left and right walls in November.

With regard to the level of the maximum frequencies, these are also very similar, which appears to confirm the low differences in terms of humidity in the period of time considered. However, it should be noticed that the GPR signal appears to reach higher depth in the proximity of the main entrance of the chapel. The comparison of the GPR profiles in the transversal direction of the nave in the proximity of the main entrance carried out at 95cm and 30cm reveals that the level of information given by the latter transversal profile and the GPR signal are stronger, This feature should be associated to the presence of stones belonging to the foundation of the entrance wall, which should also justifies the higher depth of the signal in the longitudinal profiles in the proximity of the wall. The transversal profiles obtained with GPR in the sacristy revealed that there is homogeneity of data but it is possible to see that the GPR signal is deeper in the right side, which seems to indicate lower percentage of humidity under the stone pavement. The salts detected in the right side of the sacristy can be associated to the presence of water before the relation of the tests. In any case, the profiles are similar in the measurements made in September and November. The presence of a higher concentration of salts in the right side can be associated also to the water migration from outside through the wall resulting from the direct precipitation as the right walls is not so protected as the left wall.

The radargrams shown in Figure 4 concerns the measurements made along the internal walls in the proximity of the lateral doors just after the main entrance wall. It is observed that the wall and the pillar in the wall located in the right side has higher humidity comparatively to the same elements of the left side. It is seen also that the humidity decrease in height, being practically constant at the same height.

The higher degree of humidity in the right lateral walls is also evident from the images taken through thermography. From the analysis of Figures 5 and 6 it is possible to confirm the presence of humidity at the base of the wall at the right side of the nave and at the base of the main entrance wall. It appears that the humidity progresses in height and it is possible to observe the limit of the moisture pockets at the level of the portal frame of the main entrance, see Figure 6. It is also possible to observe the presence of humidity in the intersection of the main façade and the right lateral wall at the level of the cornice of the barrel vault of the nave, see Figura 7a.

In the opposite wall (left side) and intersection of this with the main façade, it is seen that much lower levels of humidity are detected, even at the base of the walls. In left lateral load a moisture area was detected between the main façade and the vault, see Figure 7b.

The observation of the humidity patterns seems to show that the humidity existing in the walls is associated to distinct sources, namely from migration of water by capillary from the foundation, being detected a variation with height of the walls. The humidity detected in the intersections of the main façade and the lateral walls of the nave should be associated to water infiltration from outside, mainly due to the proximity of windows (inefficient barriers) through the thickness of the walls and also due to infiltration from the roof. It was noticed that same tiles were broken and other ones were not appropriately positioned, which can promote the entrance of water. The observation of the lateral wall located in the right side allow to see that superficial damage of the finishing is evident and black stains are concentrated at the base of the wall, with results from the continuous humidity from the rain and from the inexistence of gutters. It should be noticed that the granite with yellow color, associated to a certain degree of alteration is a porous media that enables the migration of water from zones with more concentration to zones with lower concentration.

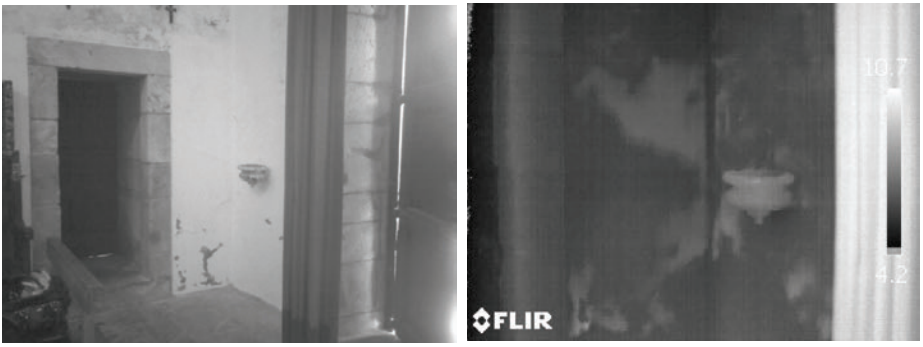


Figure 5. Moisture stain revealed by thermography: intersection of the main entrance walls and lateral right wall.

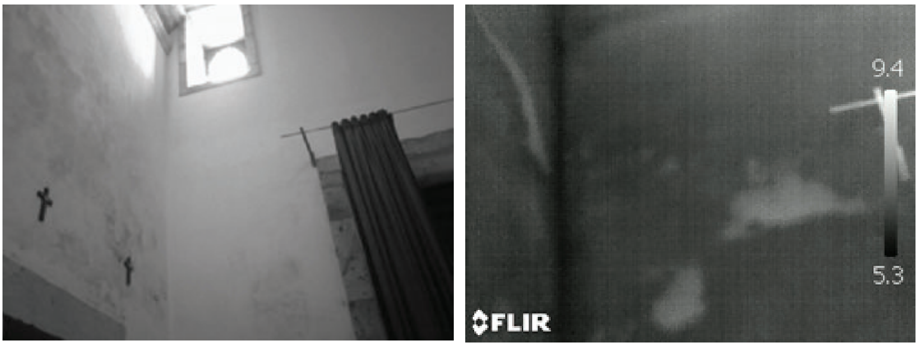
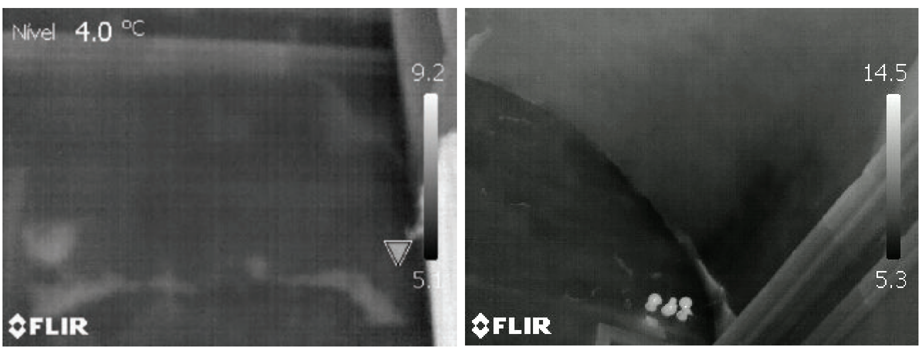


Figure 6: Limits of the moisture stains in the intersection of the main entrance walls and lateral right wall).



(a) (b)

Figure 7: Thermographic images: (a) intersection of the main façade with the right walls (moisture stain ate the level of the cornice of the vault); (b) moisture area at the intersection of the main façade with the vault in the left side.

3.2 *Discussion of deterioration processes*

Based on these data, erosive aspects can be explained by salt weathering and models related to water balance in porous media (as presented in Hammecker, 1995). Similarly to what is observed in other buildings with granitic stones, for example Salzedas (Alves & Pamplona, 2007) and Torre de Moncorvo (Moreno et al., 2006), the erosive effects are more pronounced in outdoors zones exposed to more intense weather conditions. Sun exposure of the main façade promotes more extreme drying conditions and consequently crystallization of salts in the interior of the porous stone. The erosion observed in the upper portions of the main façade may be related to pollutants that might result from mortar joints or dry deposition (this possible source is further supported by the occurrence of black crusts on the façade). In relation to façades of monuments in the town of Braga, Alves et al. (2002) and Matias & Alves (2002) also refer the concentration of erosive aspects in areas nearer horizontal elements that favor the accumulation and concentration of pollutants. Moreno et al. (2003) found higher levels of soluble salts in such places on the main façade of the church of Tibães (Braga). Castro et al. (1987) mentioned the deterioration effects associated with the infiltration of water from the horizontal elements of the façade.

Some cracks that can constitute an erosive hazard to ornamental details might not result from the action of soluble salts but represent the result of features inherited from the quarry (see Alves, 2011) and from the cutting/carving processes to which the stone where subjected.

In accordance with the models usually referred for explaining the origin of black crusts (see e.g. Sanjurjo-Sanchez & Alves, 2012), their presence could be related to contributions of air pollution as was already suggested by Castro et al. (1987). Traces of coatings presumably of lime found in the façade and in another nearby building suggest that the formation of these black crusts could have been also promoted by the existence of coatings applied on the stones, as has been referred, e.g. for monuments of Galicia (Sanjurjo-Sanchez et al., 2009). Biological colonization distribution shows typical patterns related to moisture presence. In relation to the other brownish coatings, it is unclear whether these coatings are derived solely from the interaction of the stones with external agents or whether they represent remains of coatings purposely applied, for example to protect the stone, as is referred by Pan et al. (2010) for monuments of Galicia. The hypothesis of previous coatings contributing to the development of dark crusts on the main façade of the monument was already mentioned by Castro et al. (1987). Indoors there are occurrences of clearly artificial coatings and dark stains that might be traces also of artificial applications.

4 CONCLUSIONS

The survey performed showed that the stone elements of the chapel of Misericórdia at Murça are affected by erosive processes that can be a hazard for decorative details mainly at the main façade but also indoors. The erosive processes can also affect other materials such as mortars and paintings. Distribution of erosive features and salt neoformations as well as GPR and thermography studies suggest that erosive decay processes are mostly related to capillary rising salt solutions. However, there are also erosive features in the upper portions of the main façade, namely in horizontal elements and in the zones near them (which would be associated with pollutants accumulation). Studies by DRMS showed that the weakening processes associated with the deterioration processes after emplacement can attain several mm in depth. There are also cracks that might not be related to the salt weathering processes but to the weakness features inherited from the quarry and that can also contribute to erosive hazards for the stone elements.

There are other alteration features that imply visual changes on the stone surface such as black crusts, biological colonization and other coatings but their impact in the physical state and conservation of the stone is of lesser importance.

This diagnostic is relevant for the definition of the conservation strategy for the stone elements of this monument that, consequently, must consider:

- The promotion of lower drying conditions trying to mitigate salt crystallisation inside the pore space of the materials;
- The elimination of sources of further pollutants (moisture and salts) in the lower portions of the main façade and indoors as well as in the upper portions of the main façade;
- Desalination measures in order to remove salts from the pore space and avoid furthering salt weathering processes due to climatic conditions;

- The stabilization of weakened surfaces given that physical decay processes could progress even in the absence of further development of salt weathering.

In relation to the other alteration features the balance between the risk posed by the alteration features and the consequences of the interventions must be carefully assessed.

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