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Case Studies: Preliminary Investigation on Diagnosis and Repair Measures to Prevent Capillary Water Rise in Historical Buildings

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ABSTRACT

In Portugal, interventions on monuments and historical centers, have been assuming increasing relevance. Most of these buildings have renders based on lime, usually with good cohesion and adhesion to the background, although the gradual use of Portland cement since the beginning of the 20th century leaded to the disuse and consequent loss of knowledge about properties, characteristics and execution of lime renders. In old buildings interventions the most current anomaly is usually due to humidity that penetrates in the walls from external sources such as: rising ground water, sea-salt spray, sea-flooding, etc. In one side, lime renders should be preserved and repaired; when there is a high degree of degradation and their substitution is needed, the application of new compatible renders is required; on the other side, the present requirements of habitability and aesthetic appearance, without de-characterization, in conservation interventions, should guarantee the maintenance of buildings integrity and durability. In order to achieve both goals, it is necessary to implement compatible renders, durable and adequate to the surrounding conditions. In the present work, several case studies with capillary water rise are compiled. The diagnosis methodology to define the probable causes of this anomaly and to evaluate the conservation state is presented, as well as the main measures adopted for the repair, based on control of causes and on the minimization of their effects.

KEYWORDS

Case studies, conservation, lime renders, capillary water rise.

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1 INTRODUCTION

An ineffective rehabilitation and/or conservation intervention using inadequate renders solutions, due to the lack of knowledge about the materials, conservation techniques, maintenance principles and particular surrounding conditions (humidity conditions, presence of soluble salts, ventilation conditions), are factors that can promote the premature degradation.

In conservation action, the priority is to achieve compatibility and optimize the durability and adequate protection to water of the whole building [Magalhães *et al.* [2006]; Veiga *et al.* [2009-1]] and some solutions do not match this goal. For example, an impermeable mortar keeps the water inside masonry or forces its transport through the more permeable old mortar and masonry. Besides, they should not have high contents of salts, to avoid the increase of salt contamination into the walls. Some studies [Charola [2000]; Gonçalves [2007]] refer a synergetic effect of chlorides and sulphates that imply an aggravation of salt attack when both are present, so the contamination with sulphates (present in cement and some kinds of hydraulic limes) may be particularly harmful in buildings close to sea.

In the present work a compilation of twelve Portuguese case studies since the XV century, is made. These case studies have renders and plasters with several types of anomalies due to the exposition to humidity from different sources (rising capillary water, infiltrations due to damaged roof and salt mist). The case studies are located in Portugal: three in the North, in the towns of Porto and Aveiro; six in the centre of Portugal, around Lisbon; and three in the South of Portugal, in Évora, Tavira and Estói.

In this work, the application to those case studies of a methodology to define the possible causes of the anomalies is described, as well as the main anomalies and the measures adopted for their repair are defined, for an adequate intervention, in each case. The diagnosis methodology adopted allowed to identify the distribution and localization of the humidity in the renders and plasters, as well as to evaluate the origin of the humidity and to establish if it is still active or not. The quantification of the effects was also made, leading to an adjusted definition of a set of repair recommendations.

2 METHODOLOGY OF DIAGNOSIS

The adopted methodology of diagnosis was based on visual observation of the main anomalies as well as on non-destructive *in situ* tests (portable humidimeter and strip salt tests). The tests were carried out in several internal and external walls.

2.1 Visual Observation of the Main Anomalies

The description of the main anomalies based on visual observations for each case study is present in Tables 1 to 3. The case studies are divided in three groups depending on the source of humidity and on the time of occurrence: continuous rising damp and/or moisture from damaged roof – anomalies starting before the intervention; continuous rising damp and/or moisture from damaged roof – anomalies starting after intervention; salty mist and sea sparkles.

Table 1. Case studies - rising damp or moisture from damaged roof (anomalies before intervention).

Case studies	*Main anomalies*		
Case 1: National Theatre in Porto (beginning of the XX century).			
	Loss of cohesion of the paint, biological colonization, presence of soluble salts		
Case 2: Old Convent in Aveiro (XVI century).			
	Dark moisture stains, detachments of plasters and paints, salt efflorescences, biological colonization		
Case 3: Old Convent belonging to the Foreign Affairs Portuguese Office in Lisbon (XVII century).			
	Detachments of the plasters, loss of cohesion and adhesion of the plasters and paints, salt efflorescences		
Case 4: Building in Lisbon with “Valmor prize” (beginning of the XX century).			
	Detachments of the renders, biological colonization, dark moisture		

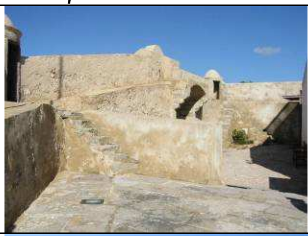
Case studies with cement, lime and cement, and hydraulic lime renders, could present severe anomalies after interventions, when there is continuous rising damp and/or moisture from damaged roof. When the intervention is needed, the choice of compatible renders (lime based renders specially designed for each case) for old buildings becomes crucial for the success of the intervention.

Based on visual observations it could be seen that the main anomalies could be due to humidity problems, because the main observed anomalies were mainly dark moisture, loss of adhesion and cohesion of the renders and plasters, associated with the presence of salts in most of the cases.

Table 2. Case studies - rising damp or moisture from damaged roof (anomalies after intervention).

Case studies	*Main anomalies*
Case 5: Old Monastery converted into a museum in Aveiro (XV century). Intervention in 2008/2009.	   Dark moisture stains along the plasters, efflorescences, detachments of the paint
Case 6: Old Convent converted into a luxurious housing building in Lisbon (XVII century). Intervention 2008/2009.	   Detachments of the plasters, loss of cohesion and adhesion of the plasters and paints, salt efflorescences
Case 7: Old Palace converted into a luxurious housing building in Lisbon (XVIII/XIX centuries). Intervention 2008.	   Dark moisture stains along the renders and plasters, loss of cohesion of the paint
Case 8: Old Palace in Évora used as a public institution office. (XVII century). Intervention on the second half of XX century	   Dark moisture stains along the external mortars, detachments of mortars due to salt efflorescences, loss of cohesion and adhesion and biological colonization
Case 9: Old Convent adapted to a Charming Hotel in Tavira. (XVI/XVII centuries). Intervention 2006.	   Detachments of mortars due to salt eflorescences, loss of cohesion and adhesion of the mortars, detachments of the paint
Case 10: Old Palace adapted to a Charming Hotel in Estói. (XVIII century). Intervention 2009.	   Dark moisture stains along the external mortars

Table 3. Case studies with salty mist and sea sparkles near Lisbon (Fortresses on the coast between Lisbon and Cascais)

Case studies	*Before intervention*	*After intervention*	*Intervention*
Case 11 - Fortress in the coast of Lisbon (XVII century)			Substitution renders composed by mortars with air lime and metakaolin
Case 12 - Fortress in the coast of Lisbon (XVIII century)			Substitution renders composed by mortars with air lime and low content in cement, and silicate paint

2.2 Non-destructive *in situ* tests

2.1.1 Portable humidimeter – evaluation of moisture content

A portable humidimeter was used to evaluate the superficial moisture content in the walls [Veiga *et al*. [2009-1]; Massari & Ippolito [1993]; Henriques [2001]]. This test was performed in several internal and external walls, at different heights - between 0.10 m and 1.80 m from the pavement – and in some case studies at two different periods – dry weather and after a rainy week – in order to determine the possible origin of the water. This equipment presents a range of values from 0 to 6.9, corresponding to a dry and very wet render, respectively. Values between 0 and 2 correspond to dry zones; 2 to 4 correspond to slightly humid zones, 4 to 6 humid zones and from 6 to 6.9 to very humid zones [Veiga *et al.* [2009-2]; Magalhães & Veiga [2009]].

Depending on the values obtained and the distribution of the humidity it was possible to establish the origin of humidity. When wet or very wet zones were concentrated on the lower parts of the walls the probability was that the causes were rising damp or infiltration of superficial water due to the lack or inefficient drainage. When moisture symptoms were localized on the upper parts of the walls, the probable origin of the water could be the damaged roofs or damaged or ineffective roof drainage systems. If there is humidity in the vaults and roofs the moisture was probably inside the walls due to infiltrations by a damaged roof.

2.1.2 Strip tests - salts identification

The strip tests for the semi-quantitative identification of salts give information on the type of salts present as well as on the degree of contamination, based on semi-quantitative determination of ions associated with the type of salts [Veiga *et al.* [2009-1]; Borrelli [1999]].

The presence of sulphates can be associated to the presence of cement or some kinds of hydraulic limes in the mortars as well to the atmospheric pollution, marine environment (sea spray), ground water, contaminated soils or to the presence of old materials (stones, bricks or mortars). The presence of nitrates can be due to contamination with organic products, namely from animals and the presence of chlorides can be due to proximity of sea or to the presence of these salts in other wall materials such as sand. Salts can be transported in a porous material only if dissolved in water, thus their presence indicates water transport through the walls [Lubelli [2006]]. In spite of the lower dissolution rate of sulphates, when compared with the other salts present, the circulation of water in the walls can promote their dissolution and dissemination [Otossen *et al.* [2008]].

3 CAUSES OF THE ANOMALIES

Both visual observations and *in-situ* tests help on the evaluation of the origin, localization and distribution of the moisture in the walls. With the analysis of the results obtained with the adopted *in situ* methodology it was possible to identify the causes of the anomalies. In most of the cases they were mainly a consequence of the high accumulation of water in the walls and ceilings. The evaluation of the distribution and localization of the humidity allowed the identification of the origin of the water (Table 4).

Table 4. Source of humidity in each case study

Case studies	*Source of the water/humidity*
2, 5, 6, 8, 9, 10,	A. Capillary rising water from the underground through foundations and walls
2, 5, 6, 7, 8, 9, 10	B. Capillary rising water from the surface, due to the accumulation of the rain water near the base of external walls and/or due to the absence or disability of rain drainage systems
3, 6, 9	C. Water infiltrations from the exterior with saturation of the walls and ceilings due to the absence or inability of the roof during a long period before the intervention
1, 4, 6, 7, 8, 10	D. Localized infiltrations in some areas of the exterior walls
11, 12	E. Capillary rising ground water associated with sea-salt spray and sea-flooding

4 ADOPTED REPAIR MEASURES

Before an intervention of rehabilitation and/or conservation the repair of anomalies should be preceded, if possible, by the elimination of their causes. If that approach is not possible, it is necessary to minimize the effects of those causes and control the related symptoms [Freitas & Torres [2002]; Veiga *et al.* [2009-3]].

Elimination of the causes (source of water type B, C and D described in table 4):

- Repair of the roof, of the drainage systems and of the rainwater collectors
- Construction of drainage ditches along the exterior walls to prevent the accumulation of rain water
- Construction of ventilation ditches at the base of exterior walls, in order to facilitate the evaporation of water rising from the ground
- Ventilation tunnels under the floor of the ground-floor, with perforated tubes connected to the exterior to avoid capillary rise.

Minimization of the effects (source of water type A described in table 4):

- Removal of impermeable external paints and replace them by permeable renders and plasters.
- Allow the drying of the renders before the application of the final paint.
- Promotion of ventilation during the works by opening the windows.
- Removal of the impermeable plasters from the walls and ceilings and substitute them by traditional plasters to improve the evaporation of the water retained inside the ceilings, vaults and walls.
- Execution of a gap between the floor footers and the floor to allow the ventilation of the interior walls and the continuous drying of masonry over time.

5 SUBSTITUTION RENDERS

Mortars to use in old buildings must be compatible with the background and the pre-existing mortars. The compatibility is a concept dependent on the characteristics of the old masonry and on the specific conditions of the building. In each case, an evaluation must be carried out concerning the strength, deformability and water permeability of masonry and of the old mortars in contact. In parallel, an assessment of the main physical conditions must be performed, considering specifically: the water transport situation (capillary rising water and exposure to rain), the climatic conditions (humidity and temperature ranges, wind and rain intensity) and the environmental issues, such as air pollution and salt environment [Freitas & Torres [2002]; Veiga *et al.* [2009-3]; Veiga *et al.* [2009-4]].

Case studies 1 to 10 present sources of water from type A to D (Table 4). When the anomalies due to water are localized and not severe, (cases 1 and 4) they can be solved by washing and/or substituting the degradated zones by new compatible renders or paintings. When the anomalies are more severe, the choice of the renders solution should be done case by case. In those cases when the presence of water inside the walls is extended in time due to difficulty of evaporation because of the use of less permeable renders than the old ones, they should be removed and substituted by lime based ones (pure or with small contents of hydraulic additions), more porous and permeable [Otossen *et al.* [2008]; Veiga *et al.* [2009-4]]. The impermeable renders and paintings (synthetic finishings, polymeric paints and other polymeric products) should be replaced by materials more compatible with wet walls, such as lime based mortars and silicate based paints [Veiga & Tavares 2002]. In the interior the plasters should be replaced by lime or lime and gypsum plasters and ventilation should be promoted in the interior spaces. The use of sands free of salts is always required, to reduce risks due to salt crystallization [Veiga *et al.* [2009-3]].

Case studies 11 and 12 [Veiga *et al.* [2009-1]; Tavares *et al.* [2008]] present a source of water type E (Table 4). These kind of old buildings (fortresses) placed in coastal areas are subjected to particularly severe actions. They require the use of substitution renders with special properties to assure durability to the referred actions [Veiga *et al.* [2009-4]]. The mortars must have high mechanical strength to resist erosion of sea wind and salt crystallization pressure, moderate elasticity modulus to accommodate deformations due to sudden thermic variations, moderate capillary coefficient and high water vapour permeability to retard the entrance of water and allow for quick drying [Veiga *et al.* [2009-4]]. Samples collected from several constructions located in Lisbon and coastal surroundings show clearly that very resistant and durable materials were used [Santos Silva [2002]], usually based in air lime and additions or aggregates that promoted pozzolanic reactions. The use of mortars composed by air lime and lower content in cement can be adequate, although there are some risks of introducing salts into masonry. Mortars formulated with air lime and pozzolans can be adequate to those buildings depending on the type and proportion of pozzolan and curing conditions of the mortar [Veiga *et al.* [2009-4]]. It is particularly important to check if there is rising capillary water. If this is the case and it is not possible to eliminate the water source, problems with salt crystallization inside the wall are likely to appear and it is usually safer to adopt, for renders and plasters, water permeable mortars, classified as salt transport solutions [Hees & Naldini [2007]].

6 CONCLUSIONS

In interventions in old buildings the mortars and paintings must be carefully studied case by case, considering the state of conservation of the renders, plasters and paintings, the extension of anomalies present and, as most important in this study, the source and quantity of moisture present as well as its distribution and localization.

The elimination of the causes of anomalies whenever possible or the minimization of their effects are the first goal in an intervention.

The capillary rising water from the ground, present in the walls, is the most difficult cause to eliminate. To promote drying of the walls' bases and mitigate the effects of capillary rising, ventilation should be performed as well as removal of the impermeable renders.

The state of conservation and the methodology of diagnosis allowed the definition of the causes of anomalies. The main repair recommendations were defined: increase water drying rate to the exterior, turning it as close as possible to the capillary rising rate, and limiting the water volume that reaches the walls. The choice of repair or substitution solutions for renders, plasters and paintings of old buildings are of the utmost relevance to promote the functionality and durability of the masonry walls, especially when they are affected by high water content due to capillary rising or to previous infiltrations by the roof.

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