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Diagnosis and methods against rising damp in industrial heritage buildings: a case study in Italy

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***Abstract* – The presence of water and rising damp in particular is the most relevant cause of decay in historic buildings. Damage processes such as biodeterioration, frost and salt crystallization arise or are intensified in the presence of rising damp and its relevance is expected to increase in the future, due to climate changes. Treatment against rising damp is therefore generally advised for protection and durable conservation of historic buildings.**

The JPICH Project "Effectiveness of methods against rising damp in buildings: European practice and perspective – EMERISDA" aimed at a scientifically based evaluation of the effectiveness of different methods against rising damp and decision support tool definition for a conscious choice use of these methods in the practice of conservation. During the present contribution, the main results obtained for the case study in Ferrara (Italia) will be discussed. Specifically, the treatments applied and the methodological approach for their effectiveness assessment will be presented.

I. INTRODUCTION

The presence of water in masonry structures is one of the most relevant problems affecting architectural heritage all over the world; it consists in the movement of water through a permeable material whose water content is non-uniform [1]. This presence may be ascribed to different origins, but rising damp is surely the most widespread phenomenon leading to moisture presence in building structures and it severely threatens both performance and conservation of ancient and recent masonries. Furthermore, it can strongly affect the climate indoor with consequences on degradation of building materials (timber, wallpaper and plaster), thermal performance of masonries, frost action, salt crystallization and biological growth, with direct consequences on the health of the inhabitants [2]. Due to climate change and the increased frequency of extreme events (i.e. sea level rise, flooding, episodes of intense rain, etc.), the relevance of the effects due to rising damp will probably increase in the coming decades [3,4,5]. Treatment against rising damp is generally recommended, but despite the great offer of specific products in the market, the methods adopted in the field often fail [2]. Indeed, a scientific approach to identify the origin of the problem based on a proper diagnosis and an evaluation of the effectiveness of treatments over time are still nowadays completely missing. EMERISDA Project (JPICH) aimed purposely at filling this gap by providing a comparative evaluation of existing techniques and by developing guidelines for the user to determine the best solution for each case of damage due to rising damp. This objective has been achieved by sharing the knowledge diffused across Europe and by acquiring new knowledge through the application of selected methods in case studies.

Historic buildings, churches and examples of industrial heritage have been chosen in Netherlands, Belgium and Italy, and among them: St. Bavo's church (Haarlem), Paardenmarkt (Delft), St. Martin's church (Genappe), Antwerp Saint Felix Warehouse, Basilica di San Marco (Venice) and a former sugar factory complex (Ferrara).

During the present contribution, results obtained for the case study in Ferrara (Italy) will be discussed focusing mainly on the methodology approach applied in situ for the diagnosis of the presence of rising damp and for the effectiveness evaluation of treatments based on chemical interruption and plaster application.

II. MATERIALS AND METHODS

A. Case study

As previously indicated, one of the case studies of the EMERISDA Project is the "Zuccherificio Agricolo Ferrarese Eridania" located in the city of Ferrara, Northern Italy. This former sugar factory, built in 1900, covers an area of over 20 hectares with more than 100.000 m^3 of buildings most of which were seriously damaged during the bombing of 1943. Nowadays after a long period of abandonment, the industrial complex consists of several buildings appropriately redesigned, renovated and restored in order to be allocated to the new functions of the University of Ferrara (Fig. 1). For the experimental work the central area of the complex named *Agorà* was selected. The *Agorà* is a large room with a rectangular plan currently without coverage (Fig. 2). The masonries of the original restored buildings are mainly in face view brickwork externally and with surface finish in plaster interiorly (Fig. 3). New buildings have been constructed in concrete.

Fig. 1. Plan of the case study area

The masonry presents elements of degradation clearly attributable to the simultaneously presence of rising damp and salts as efflorescences and sub-efflorescences, cracking, detachments, decohesion and powdering (Fig. 3).

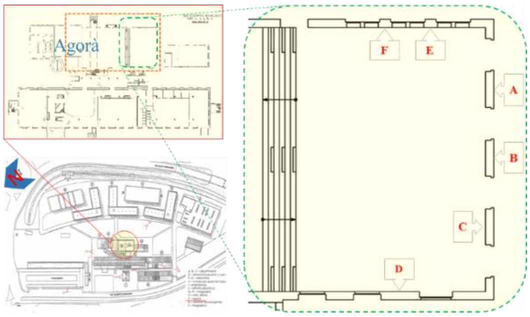

Fig. 2. Plan of Agorà: identification of experimental area and walls for treatments application.

B. Selection and application of treatments

On the basis of the overview of existing solutions against rising damp and definition of the procedures and criteria for the evaluation of their effectiveness defined at the beginning of the EMERIDA Project, the methods to be tested at *Agorà* have been chosen. The present work shows selected results obtained from the experimental activity carried out including the testing of two different methods against rising damp as follows: 1) chemical interruption and 2) application of plasters.

The experimental activity at the case study has been conducted on the basis of the following steps: a) visual assessment; b) selection of masonries and façades for the application of treatments (Fig. 3); c) samples collection of building materials from selected walls, both fragment and powder; d) building material characterization (optical microscopy observation, x-ray diffraction analyses and scanning electron microscope); e) analyses prior/after treatment mainly by gravimetric method to determinate moisture content and hygroscopic moisture content, and ion chromatography to determinate soluble salts content. Treatments have been executed in May 2015 and samples for analysis have been collected immediately prior their application and after 12 months. Chemical injections have been executed on four walls of the *Agorà* masonries named A, B, E and F using a water repellent substance (silane/siloxane) with different means of transport: solvent-based (A and E), water-based (B) and low VOC solvent-based (F) (Fig. 3).

Each application occurred in two steps: a first low pressure injection of liquid in a hole (ø = 1 cm) drilled at depth of 30 cm followed by a second injection at depth of 50 cm, from the internal side of the wall to the external one. The distance among each injection hole was 10 cm. The experimental activity at the case study comprised also the application of plasters on walls C, D and E (Fig. 3). The latter wall was the only one where the chemical injection was applied in combination with the plaster. The application of the plasters has been preceded by the removal of the existing damaged plasters and subsequent cleaning of the walls with pressure washer. Subsequently, in the wall C a first layer of a premixed mortar (natural hydraulic lime and mineral additives) with the function of anti-salts barrier has been applied, followed by the application of a dehumidifying plaster constituted by a macroporous cork based plaster. The average thickness of the first layer was equal to 1,5 cm, whereas the thickness of macroporous plaster was about 3 cm. In the wall D and F only a macroporous plaster has been applied.

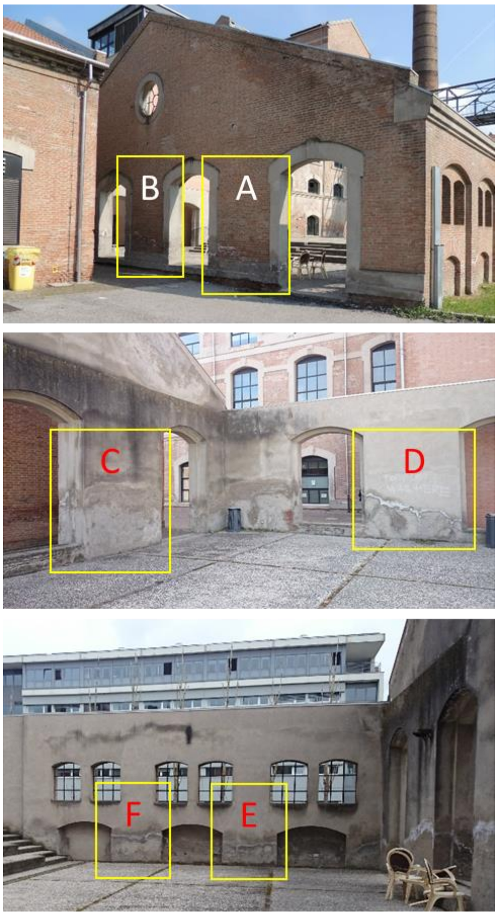

Fig. 3. External and internal walls of Agorà masonries with selected areas for treatments application.

C. Investigation methodology

The effectiveness of the treatments selected and applied on site to stop or mitigate rising damp has been assessed by comparing the moisture content (MC) in the wall before and after one year from the application of the treatments.

The low invasive "gravimetric method" has been considered as the most reliable technique for the determination of the moisture content in the wall.

In fact the no-invasive methods (electrical resistance/capacitance, infrared thermography, etc.) are strongly influenced by the presence of salts and the measurements are representative only of the surface of the wall and no information about the inner part of the wall is available. In order to assess the MC in the selected walls, powder samples have been taken by drilling at different depths and heights along a vertical profile, weighing the wet samples collected (Wwt and determining their moisture content gravimetrically, after drying the specimens in the oven at a temperature of 60°C. The MC is expressed as % of the dry weight (Dwt) of the sample and calculated as follows:

$$MC = 100*(Wwt - Dwt)/Dwt \qquad (1)$$

In addition, in order to have information about the presence of hygroscopic salts in the walls [6], the hygroscopic moisture content (HMC) of the samples has been measured storing the previously dried samples in a climatic chamber under 20 °C of temperature (T) and 96% of relative humidity (RH) for a period of 4 weeks. After the storage in climatic chamber the samples weight, have been determined (Wwt 96%RH). The HMC is expressed as % of the Dwt and calculated as follows:

$$HMC = 100 * (Wwt\ 96\%RH - Dwt)/ Dwt \qquad (2)$$

A MC higher than the HMC indicates that a moisture source, other than the moisture uptake given by the hygroscopicity of the salts, is present. A HMC higher than the MC and with the same distribution pattern through height and depth, suggests that the main moisture source is the hygroscopicity of the salts [7,8].

In order to facilitate the interpretation of MC and HMC, samples should be collected as much as possible in the same material (brick or mortar). Despite this, in the case of the *Agorà* masonries, whose thickness are between 50 and 80 cm, samples are constituted by powder of brick, mortar or a mixture of them. Moreover, the plaster layer, when present, has been sampled separately. Considering the sampling after the treatments application, care has been taken to collect the samples as near as possible to the initial sampling point.

On selected samples, soluble salt concentration (anions and cations) has been quantified by ion chromatography (IC) with an Ion Chromatograph Dionex DIONEX ICS 900 (Anions analysis: Column S23 Pre-column G23; Cations analysis: Column CS12 Pre-column CG12).

III. RESULTS AND DISCUSSION

In this session will be illustrated selected results obtained from the experimentation in situ executed on portions of masonries A and B.

A. Investigation before treatment

The purpose of the investigation before the application of treatments was to characterize the materials constituting the masonries of the case study, evaluate their state of conservation and identify the causes of deterioration currently in place. Particular attention has been given to the correct diagnosis of both rising damp and salt attack that are two separate but interrelated processes. In this paper results of MC, HMC and IC analyses are illustrated.

MC and HMC distribution measured in the walls of the masonry A and B before the application of the chemical barriers is reported in Fig.s 4 and 5.

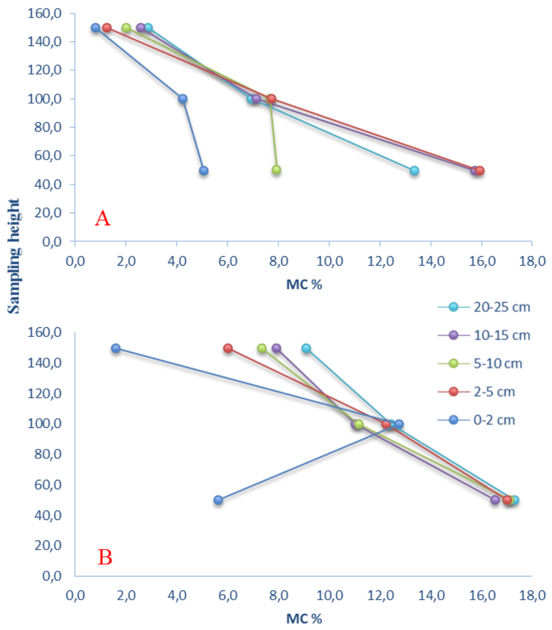

Fig. 4. MC in wall A and B at different height and depth, before treatment.

The graphs in Fig. 4 show that the MC in the lower part of the walls is generally higher and decreases with height. In particular in wall A, the decrease of MC along the vertical profile has been detected at all sampling depths, with maximum values at 50 cm from the ground level varying from 7,9 to 15,9 weight % (wt%) and minimum values at a height of 150 cm raging between 0,8 and 2,6 wt%. The lower values of MC were found at the wall surface (0-2 cm depth), which presents repointing cement mortars and cement plaster in the lower part (Fig. 3). The MC trend in wall B is generally similar to that encountered in wall A, with exception of the value in the external sample (0-2 cm depth) collected at h=100 cm, which is characterized by a MC = 12,8 wt%. Results showed in Fig. 5 evidenced that the HMC in A is higher in the upper part of the wall (h= 150 cm) at sampling depths comprised between 2 and 25 cm in correspondence of the upper fringe of rising damp where evaporation occurs. While the value at the sampling depth 0-2 cm is higher at h=100 cm, where efflorencences were clearly observed by visual assessment.

These data confirm the presence of rising damp from the ground on the investigated walls. Furthermore, the high HMC indicates that hygroscopic salts, which constitutes a possible source of moisture, are also present where the masonries dries. Concerning the high MC value at h=100 cm and 0-2 cm depth in wall B, it may be argued that another source of moisture is present in addition to rising damp and presence of hygroscopic salts.

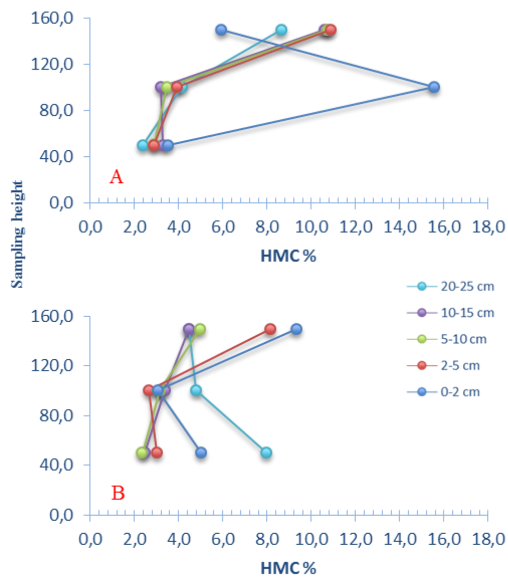

Fig. 5. HMC in wall A and B at different height and depth, before treatment.

Fig. 6 shows Ion Chromatography (IC) results carried out on a selection of samples to assess the type of soluble salts present in wall A before the treatment. The IC analyses show the presence of chlorides (Cl^-), nitrates (NO_3^-) and sulfates (SO_4^{2-}) as main anions whereas sodium (Na^+) and calcium (Ca^{2+}) as main cations. Chlorides and nitrates present the higher concentration in the upper part of the wall (h=150 cm). Both salts are highly hygroscopic and explain the higher HMC measured at the same height of the wall at samplings depths 2-25 cm. Instead sulfates show the highest concentration at the surface (0-2 cm depth) in correspondence of the highest HMC encountered for this depth at h=100 cm (Fig. 5). An additional source of sulfates from the building material (cement mortar) should be considered for this specific case. It is known the sulfates, as sodium sulfate (thenardite) and calcium sulfate (gypsum), that are less soluble than the others concentrate in the middle part of the wall (100 cm high) where most of the mortars, plasters and bricks shows granular disintegration, crumbling and efflorencences appear [8].

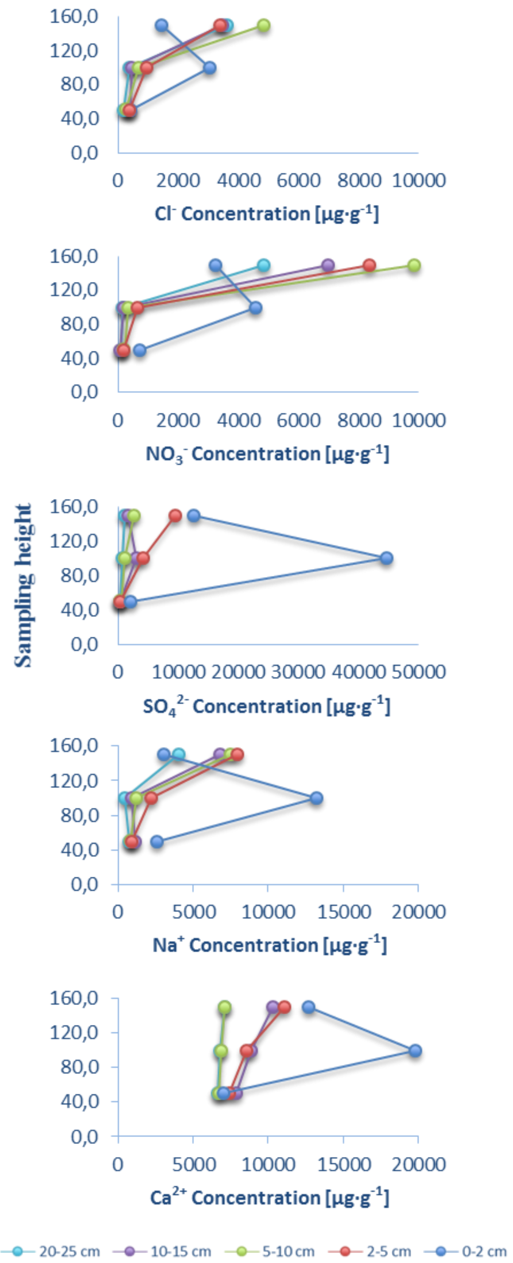

Fig. 6. Trend of main anions and cations in wall A, before treatment.

B. Analyses after treatment

One year after the application of the chemical barriers the MC and HMC of the walls were measured again. In Fig. 7 and Fig. 8 are showed the distribution of MC after one year from the application of the treatments in walls A and B respectively and their comparison with respective initial MC. The graphs show a general decrease of MC in both walls, particularly in the lower and medium part of them. Considering the MC of wall A after treatment (Fig. 7), the values vary between 0,5 and 5,1 wt% with the highest content equal to 7,8 wt% in correspondence of the deepest sample in the medium part of the wall (20-25 cm depth, 100 cm height).

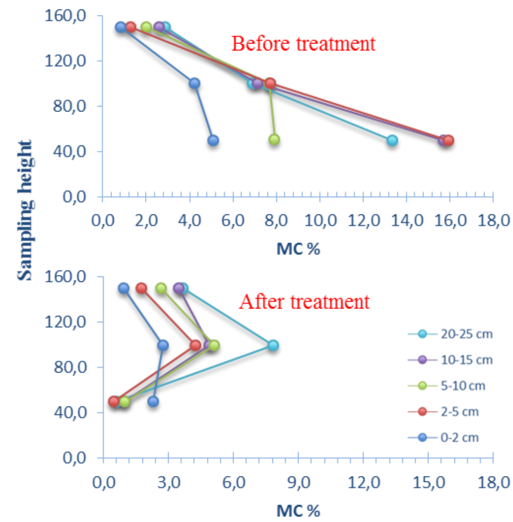

Fig. 7. Trend comparison of MC in wall A, before and after treatment.

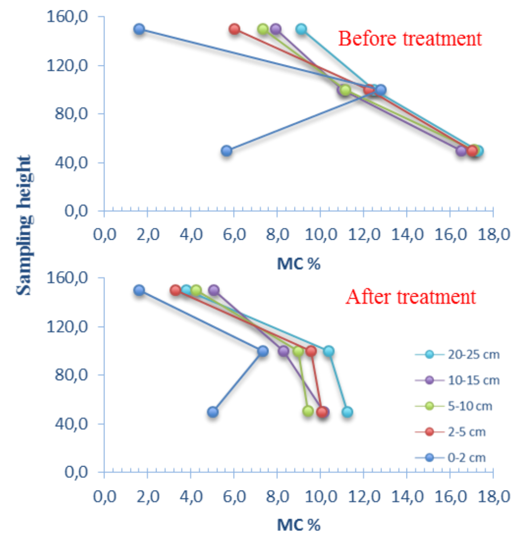

Fig. 8. Trend comparison of MC in wall B, before and after treatment.

Minimum values have been encountered in all lower samples (50 cm height), at 30 cm from the chemical barrier. The lowest values of MC in wall B after treatment (Fig. 8) have been found mostly at the top of the wall whereas in the base and medium part the values range from 7,3 to 11,2 wt%, except for the surface sample at 50 cm high (0-2 cm depth), collected in correspondence of the cement plaster.

C. Decision Support Tool

The results of the experimental work in situ carried out at the case studies, including the *Agorà*, in addition to the experience of the consortium (constituted by research institutes, conservation authorities and SMEs) and the capitalization of the available knowledge at European level on the topic, allowed to elaborate a Decision Support Tool for a conscious choice in conservation practice.

The tool is one of the most important outputs of EMERISDA Project. Implemented by Delft University of Technology (TUD) with the collaboration of the rest of the partnership, is constituted basically by an electronic check list with different forms in support of the determination of the presence of rising damp in masonries on the basis of: i. visual survey, ii. analytical results from a proper diagnosis; iii. masonries characteristics; iv. owner needs.

The tool takes into account the possible methods of treatments and the risks associated with each method. The Decision Support Tool presented at the EMERISDA workshop held in Bologna on January 18, 2016, is currently under implementation for its use outside the consortium and subsequent potential spread in the market.

IV. CONCLUSIONS

A. Effectiveness of methods

The research presented in the present paper aimed at showing the methodological approach followed for assessing in the field the effectiveness of the application in masonries affected by rising damp. Results are mainly related to the application of chemical barriers constituted by the injection of solvent and water based silane-siloxane water repellent. The research has been centred to assess the occurrence of any significant and consistent reduction of the moisture content after one year from the application. For obtaining a trustworthy quantitative evaluation, the moisture content has been assessed gravimetrically, close to the previous sampling points and when possible in the same material. The results of this experimental work show the efficiency of both types of chemical injections in reducing the moisture content in the investigated walls. In particular, wall A, treated with a solvent-based silane/siloxane water repellent, showed better results with a higher reduction of the moisture content.

Anyway it should be considered that results may be obviously affected by several factors, such as: differences in properties and irregularities of materials constituting historic masonries, and diverse exposure conditions of masonries to climate parameters (solar radiation, rain, wind, etc.). Specifically, for our case study in Ferrara, the whole area under investigation is unsheltered making it particularly vulnerable to rain impact. Therefore, for a comprehensive understanding of the effectiveness of methods, long-term monitoring in field on real case studies and scale models in addition to experimental work in laboratory are necessary.

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