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Rising damp in historical buildings: A Venetian perspective

Laura Falchi[a,*], Debora Slanzi[a], Eleonora Balliana[a], Guido Driussi[b], Elisabetta Zendri[a]

[a] Department of Environmental Sciences Informatics and Statistics, Università Ca' Foscari di Venezia, Via Torino 155 eta, Mestre, Venezia, 30170, Italy
[b] Arcadia Ricerche s.r.l., Via delle Industrie 25/11, 30175, Marghera, Venezia, Italy

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ABSTRACT

Considering several real case studies, moisture distribution due to rising damp in Venetian brick masonries is discussed and empirical models are developed. Moisture content and soluble salt data of 25 historical buildings in Venice are analysed. Data are scrutinized using statistical methods, obtaining contour plots and estimating the validity of linear and non-linear models. The models confirm that masonries are usually soaked with water till 120–150 cm over sea level, while the evaporation zone ranges in height from 200 cm to 350 cm. In the perpendicular section, moisture distribution depends on several contingent factors such as, among them, the proximity and the exposition of the external façades to the water action.

1. Introduction

Fresh or sea water rising damp in historical buildings is a well-known problem. Soaked masonries often show serious conservation issues. The phenomenon and the resulting decay have been extensively studied [1–4], as well as possible remediation methods [5,6], both from the theoretical point of view [7–11], and on several real case studies all over the world [2,12–17].

To determine quantitatively the rising damp phenomena in buildings and the severity of the related decays, several methods - based on samples collected drilling the masonry - have often been used: gravimetric determination of percentage moisture content (MC%) [18]; evaluation of soluble salts via ion chromatography; determination of hygroscopic moisture content (HMC%) [3,19]. Such invasive sampling, even if is still employed with successful results, is quite impacting. For this reason, it should be limited to the most in the case of ancient and historical masonries. Next to these methods, non-destructive moisture analyses are also frequently used: IR thermography, resistive methods, dielectric methods, microwave instruments [4,14,20,21]. Despite their sustainability, the non-destructive techniques present some disadvantages such as: the semi-quantitative qualitative nature of the results; the relative representativeness of the obtained data (often related only to the surface); the need of calibration with data coming from destructive sampling; and the necessity of an adequate data processing [22–24].

In literature, most of the researches focus on single case studies or on mock up masonries. The analysis of the rising damp phenomena in large zones, such as an entire town in a maritime location, is still limited [25]. A large perspective on rising damp in ancient masonries is crucial for the development of local strategic plans and maintenance policies to ensure the preservation of the built heritage in historical coastal/riverine cities.

Venice is the emblematic case of a historical maritime city affected by rising damp [26]. A large percentage of historical Venetian buildings lives in constant contact with lagoon and canals water. This cause-specific and well-known degradation patterns. Quantitative data regarding moisture content in selected Venetian buildings were collected over time, but an overall assessment of the rising damp phenomena and their consequences at a city level is still missing. Rising damp issues in Venice are quite problematic and difficult to synthetize: water affects different structures, heritage building constructed in different times, various building material, several construction methods, and above all masonries are soaked in very large extensions [27,28].

In this paper, we propose empirical models describing the rising damp process in Venice. Our data are based on literature and grey literature data on quantitative moisture content (MC%) and soluble salt contents (SS%).

The study considers 65 masonries built with full fired bricks and hydraulic lime based mortar joints. Buildings distributions cover the whole city centre. The paper considers data related to a timeframe of 30 years of restoration and research, presenting moistures distribution profiles. An empirical model for the estimation of the general extent of rising damp is proposed. Data mining methodologies are applied with the aim of:

i) highlighting the presence of common trends for the moisture

* Corresponding author.
E-mail addresses: laura.falchi@stud.unive.it (L. Falchi), debora.slanzi@unive.it (D. Slanzi), eleonora.balliana@unive.it (E. Balliana), arcadia@vegapark.ve.it (G. Driussi), elizen@unive.it (E. Zendri).

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distribution in Venice.

ii) understanding the rising damp key factors among the data collected.

iii) proposing a model to understand moisture patterns in Venetian buildings.

The results might be extended for similar analysis in other historical coastal cities.

1.1. Rising damp and Venetian buildings: a literature review

Rising damp phenomena in porous materials have been diffusely studied and described from the point of views of the physics laws, as for example the rise of water within single capillary tubes (Jurin Law), or in more complicated structures [1,7,12,29]. In masonries, the maximum height reached by rising damp and the necessary time to reach the steady state vary according to several factors, such as mortar joint types, the presence of renders, the surrounding environment. According to L'Anson et al., 1986 [7] the maximum height of the moisture front - given by the balance point between the water coming from rising damp and the water evaporated from the wall - is reached in different span of times accordingly the relative humidity (RH). The balance point in rendered walls is at 1.3 m and it is reached in around 8 years with a 80% relative humidity (RH), and in 18 years with a 90% RH environment.

The exceptional flooding in November 1966, with tidal water submerging the 80–90% of the city, raised the interest on rising damp phenomena in Venice. Since then, the Superintendence of Venice, the UNESCO committees, the municipality of Venice, Ca' Foscari University, IUAV University, CORILA (Consortium for coordination of research activities concerning the Venice lagoon system) and several private committees have always had an active role in assessing rising damp and in looking for reliable remediation methods [30–38]. Numerous papers, dossiers, and even well-documented University dissertations have been mainly focused on the relation between moisture and soluble salts contents. According to Italian recommendations (Normal 40/93) [18], usually - in these works - the moisture content was gravimetrically determined on samples collected by drilling the masonries at different heights and depths. Limited complete reports discuss also data by considering the building history and its position on the city fabric (e.g. geographical orientation of the masonry, distance from the canals etc.). Only in few cases, also, the composition of bricks and mortar joints and their porosity were evaluated. The results of these studies highlight the severe condition of the Venetian structures. A moisture content of over 5% has been reported at heights of 2–3 m from the floor level (in brick walls with an average porosity around 20%). Numbers report that the moisture front in Venice reaches in average the height of 1.5–3 m [28,34,39].

Available literature focuses commonly on a single Venetian building, however a first attempt to draw a general empirical model for the rising damp in Venice was discussed in Biscontin et al. [39] (Fig. 1). This work considered and discussed together the moisture and soluble salt data distributions from two representative historical structures: the Bucintoro northern wall in the Arsenal and the Narthex wall in the Saint Mark's Basilica. In the model proposed by Biscontin (Fig. 1) [39] (recalled in 20012 by Hall and Hoff [1]), moisture tends to decrease according to the height and three different moisture areas have been identified. At low height, there is a completely *saturated area*, followed by an *evaporation area* characterized by a rapid decrease of moisture (intermediate area), and, finally, at higher heights, an *area in balance with the environmental humidity*. The *evaporation area* is commonly associated with the maximum soluble salts contents.

Further researches focus on the moisture, relating it to the wall depth of the masonry. It has pointed out a profile that shows a diagonal rising damp curve [1]: a higher MC% is registered in the internal part and a lower MC% on the external. These evidences were found since evaporation occurs on the surfaces. Theoretically, salts with different solubility tend to precipitate at different heights according to their solubility. However, in real cases, the salts' precipitation process is strongly influenced by the salts' mixture and by the environmental conditions. The expected theoretical ion distribution is only partially observed (e.g. nitrates are often observed at higher heights in comparison to chlorides or sulphates) [40].

In relation to the rising damp phenomena, the aggressive environmental conditions of the Venetian lagoon have been exacerbated by the subsidence of the city and by the eustatism of the sea level [41]. Subsidence and eustatism worsen in the middle of the 21st century. and nowadays they contribute to the recurring high tide episodes ("acqua alta") and the consequent flooding of larger areas of the city. In relation to these changes, the development of general models - based on several case studies in Venice – is mandatory for future comparisons with changing scenarios. The aim is expanding the current knowledge on the fragility of the historical buildings and promoting a sustainable conservation policy.

2. Experimental part

2.1. Data collection

In this research, 25 case studies have been collected and analysed. The main characteristics of the buildings detected in each case study are summarised in Table 1, and their location in Venice is presented in Fig. 2. The buildings were selected accordingly the available information on rising damp. Available quantitative data of moisture and salt contents were collected from reports, thesis, papers, and books [32,39,40,42–54]. Only masonries where the rising damp has already reached a balance point, and only masonries manufactured with full bricks and traditional hydraulic lime based mortar joints (without cement), were considered. Buildings, in which methods against rising damp were applied, have been discharged from this study.

In all the selected cases a consistent procedure, based on the recommendation Normal 40/93 [18], was followed for the determination of the moisture content. Gravimetric determination of moisture was carried out on powders samples obtained drilling the masonry on a vertical line at different height and depth. The moisture content percentage is given by (eq. (1)).

$$MC\% = ((Wi - Wd)/Wd) * 100 \quad (1)$$

where Wi = initial weight (g); Wd = dried weight (g).

The possible procedure discrepancies are related to the height and depth of the sampling, which is strictly dictated by the specific on-site situations, consequently the researchers had to make specific choices case by case.

The soluble salt contents data were reported only in few studies. Their determination has been done according to different procedures, either by conductivity measurements on the collected powders [55], or by Ion Chromatography of few (chlorides and sodium) or more ion species (chlorides, sulphates, nitrates, sodium, calcium, magnesium). The relative low availability of consistent data obliges us to consider soluble salt distribution only in relation to the single case studies.

In some literature studies the location (e.g. over a canal, internal wall, etc.), the orientation of the wall (e.g. northern, southern, etc.), and the exposition to the atmospheric agents were indicated as discriminating factors. In this paper, two major locations (L in Table .1) are considered in relation to the proximity of adjacent the water body: 1 = *nearby canals* (masonries overlooking canals); 2 = *far from canals* (lack of a direct contact with canal water, few meters away from the embankments).

In the literature sources, the sampling height was referred usually to the walking pavement level. To correctly compare data regarding different buildings, in our study the samplings' height has been referred to the height above sea level using the standard local reference of *Punta*