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THE IMPACT OF PLASTERING ON THE HYGROTHERMAL BEHAVIOUR OF HISTORICAL SANDSTONE LOCATED IN THE COASTAL REGION OF LEBANON

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THE IMPACT OF PLASTERING ON THE HYGROTHERMAL BEHAVIOUR OF HISTORICAL SANDSTONE LOCATED IN THE COASTAL REGION OF LEBANON

Abstract

In an unusual trend in the conservation practice of built heritage in Lebanon, the external plaster layer, which protects the sandstone from weathering factors, is being removed for aesthetic reasons. These buildings are in a coastal region, hot humid climate in the summer and moderate cold weather in the winter. This paper discusses the importance of external and internal plastering of the historical sandstone bearing wall, by the mean of a computational tool that underlines the role of the plastering in the hygrothermal behaviour of the historical stone, in the aim to validate the practice of the ancestors in covering the envelope of their buildings to avoid the degradation of these natural stones. The methodology adopted in this paper is a comparative quantitative study, using a hygrothermal simulation modelling tool, named Wufi Pro, which is a standard program for evaluating moisture conditions in building envelopes developed by the Fraunhofer Institute for Building Physics (IBP) Stuttgart, Germany. The results are in the form of values for the heat and moisture fluxes through the high porosity sandstone assembly that composes the building envelope. These values represent the hygrothermal behaviour of the stone, and they are compared between two cases, one without plastering while the second has the inner and outer layers of traditional plaster. The analysis of the results is guiding to a conclusion that favours one of the two cases, taking into consideration the interstitial condensation threat avoided by the means of plastering.

Keywords

Conservation, Hygrothermal Behaviour, Historical Sandstone, Traditional Lime Plaster

1. INTRODUCTION

Lebanon has a large coastal built heritage that has significant characteristics and properties, which makes the preservation of such asset, with its inherited significance values, an essential issue in the protection of the national cultural identity. The practice of conservation in this region has no clear guidelines that forbid or permit many interventions. One of these practices is the elimination of the plastering layer in the aim to expose the sandstone layer which gives the building a special pleasant look, as stated by the practitioners of such intervention. Souk Byblos and Tyre were renovated by exposing the sandstone, even though they are adjacent to the sea, and they are threatened by the saturated wind with moisture and salt all over the year. The reason behind these decisions is the conservation strategy adopted by the government authorities, which endorses the cultural tourism approach as manifested in Cultural Heritage and Sustainable Development (CHUD) projects implemented in several Lebanese historical cores of four coastal cities (Zeayter & Mansour, 2016).

This paper is a part of a more detailed PhD thesis that examines the hygrothermal properties of the sandstones used in the coastal built heritage with respect to the indoor climate control and preventive conservation assigned to the built heritage in this region; however, it studies an important aspect of conservation decision which is external plastering and its importance to protect the envelope of the historical building.

Nowadays, transient models of Heat, Air, and Moisture (HAM) transfer are common tools used by building practitioners to better understand moisture movement within building elements and construction systems (Künzel & Fitz, 2019; Santos & Mendes, 2009). Furthermore, many international standards validated the hygrothermal simulations and used them for condensation risk analysis and to estimate the likelihood of mould growth and fabric decay (Leijonhufvud & Broström, 2016), for example, by the DIN EN 15026 standard (BSI, 2007).

2. METHODOLOGY

In the aim to conduct a quantitative research to discuss the impact of plastering of the historical sandstone, there are two possible approaches, the first is to test it in real cases, where samples of these sandstones are studied in controlled conditions in the laboratory, to isolate the variables that affect the accumulation of water content, and the appearance of the internal moisture condensation phenomena, in a long period of time, more than a year. The second approach is to conduct simulations for the case study in several scenarios, one with plastering and the other without it, taking into consideration that all the scenarios have the same boundary conditions presented by weather condition and same physical properties of the sandstone used in the case study .

With respect to these two options, the second one is more convenient from a preventive conservation point of view since it avoids irreversible interventions and saves valuable time in the decision-making process.

The tool used to compare the hygrothermal behaviour of the assembly of sandstone in all the scenarios, is WUFI Pro, which is a software that performs one-dimensional hygrothermal calculations on building component cross-sections, considering built-in moisture, driving rain, solar radiation, long-wave radiation, capillary transport, and summer condensation, under real climate conditions. This software, unlike the other programs and traditional methods, like the Glaser-Method, is not limited to only evaluating winter condensation effects (João M. P. Q. Delgado, Barreira, Ramos, & Freitas, 2013). Furthermore, to run these simulations, it is required to define the physical properties of the structural materials which are considered a main factor in the hygrothermal behaviour of the historical buildings' envelope (Ankersmit & Stappers, 2017). The Heat- Air- Moisture transfer through the stones of the building is proportional to the porosity of the stones (Hens, 2013; Santos & Mendes, 2009).

2.1 Salt Weathering Threat

The studied natural historical stone in this paper is the sandstone located in the coastal region of Lebanon, particularly in the old city of Tyre where the original research project is taking place.

The most noticeable threat to these stones is the erosion caused by the salt weathering, where formation of cavities is shown and keeps growing and reaching bigger dimensions with time. The literature defines this phenomenon as the crystallisation of soluble salts that contaminate the stone through air pollution, rising damp, sea wind, incompatible building material or unsuitable cleaning materials (Princi, 2014). In a porous material, as the case of the sandstone, the accumulation of the salt crystals within the stones' pores generates stresses that leads to crumbling and disintegration. If the salt deposit is formed on the exterior surface of the stone it is called "efflorescence", while the growth of crystals inside stone pores is termed "sub-efflorescence", which is the most damaging process (Steiger, 2003; Stück, 2013).

To protect the historic building envelop of high porosity from the salt weathering, it is required to improve its assembly through buffer layers internally and externally, which guard the breathability of the sandstone, at the same time they avoid condensation risk prior to the addition of the plaster layers (Campbell, AIA, BD+C, & DeRosa, 2014; Pickles, Brocklebank, & Wood, 2010).

Fig.1: Pictures of the damaged historical sandstones in Tyre old city, where on the left the efflorescence case is presented, while on the right the cavities are formed due to the sub-efflorescence phenomenon, taken in January 2022.
Reference: (Zeayter, 2022)

2.2 Lime-Based Traditional Plastering

Apart from rendering the wall, the plastering affects the envelope component in regard to water and air infiltration. Prior to the discovery of Portland cement and gypsum, lime was the only cementitious material available for plaster, which makes the use of the traditional lime plaster as the available choice in the old time. During the late 1970s and the 1980s, the practice of repairing with cement mortar became known to be of potential threat on any delicate fabric (Young, 2008). The considerably lower porosity and higher density of the Portland cement plaster impedes the breathability of the historical stone and causes internal condensation which generates internal stresses in the stone which leads to its degradation (João M.P.Q. Delgado, Guimarães, & Freitas, 2015).

The factors that govern the performance of historic fabric are *porosity, flexibility, and strength*. Which means, the focus on the assessment of adequate lime plastering to cover historic building, should be on the impact of the mixture used on these three factors.

2.3 Input Parameters

There are two types of required input parameters to run the hygrothermal simulation of the sandstone assembly, as follow: (1) material data of the layers composing the envelope component, and (2) the climate data of the indoor and outdoor side.

2.3.1 The material data used in the hygrothermal simulations conducted in this paper depends on the numerical results of testing the samples of historical sandstone of Tyre city in the laboratory. These results are summarized in the following table 1, published in the PhD thesis previously mentioned.

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Table 1: Material Properties for the layers composing the sandstone assembly used in the simulations.
Reference: after (Zeayter, 2022) for the sandstone, and Wufi Pro Material Data Library for the lime plaster(1)

Material	Property	Unit	Value
Sandstone	Bulk density	[kg/m³]	1816
	Porosity	[m³/m³]	0.32
	Specific Heat Capacity	[J/(kg K)]	1155
	Thermal conductivity	[W/(m K)]	0.74
	Water Vapour Diffusion Resistance Factor	[-]	40
Lime plaster (1)	Bulk density	[kg/m³]	1600
	Porosity	[m³/m³]	0.3
	Specific Heat Capacity	[J/(kg K)]	850
	Thermal conductivity	[W/(m K)]	0.7
	Water Vapour Diffusion Resistance Factor	[-]	7

2.3.2 The climate weather file used in the simulation is the same climate weather file used in the original research project, which is a weather data of the typical coastal Lebanese city, from Beirut Airport forecast station, as shown in the figure 2.

Fig.2: temperature and relative humidity data recorded for the year 2018, used in the simulation
Reference: Wufi pro capture based on data file from Beirut Airport forecast station

3. SIMULATION SCENARIOS

The simulation cases are run for a period of ten years, from 2022 to 2032, to investigate the amount of water content / moisture accumulation in the assembly, which reflects the hygrothermal behaviour and the moisture condensation risk due to the vapour diffusion and capillary conduction through the envelope component .

The boundary conditions of all conducted simulations in this paper are the same, where in the outdoor side the weather defined by the real climate zone of Lebanese coastal region, and on the indoor side the indoor climate is defined according to EN 15026 High Moisture Load (EN/DIN/WTA).

In case #1 the simulation is run for the envelop assembly composed of a layer of sandstone with 30cm thick without internal or external plastering, as shown in the fig. 3. While in the case #2 the simulation is conducted to test the moisture accumulation risk in the assembly if external and internal layers of lime plaster were added, the outer layer is of 3cm thick and the internal one is of 2cm; the lime plaster used in the case #2 as shown in the fig. 4 is inserted from the Wufi Pro material library.

3.1 Case #1: Sandstone without Internal and External Plaster

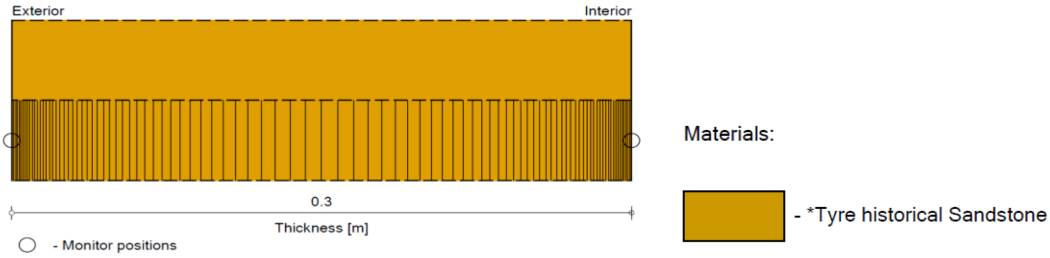

Fig.3: Cross-section in the sandstone assembly for the case #1

Based on the input data for the scenario case #1, the assembly has these following properties:
Total Thickness: 0.3 m
The thermal resistance R-Value: **0.35** (m² K)/W
The heat transfer coefficient U-Value: 1.888 W/(m² K)

3.2 Case #2: Sandstone with Internal and External Plaster

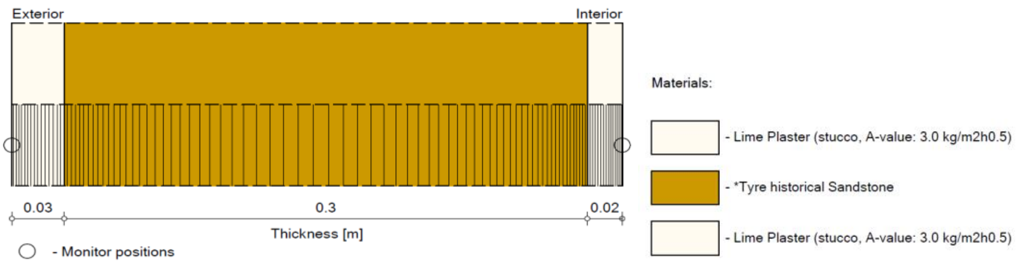

Fig.4: Cross-section in the sandstone assembly for the case #2

Based on the input data for the scenario case #2, the assembly has these following properties:
Total Thickness: 0.35 m
The thermal resistance R-Value: **0.41** (m² K)/W
The heat transfer coefficient U-Value: 1.69 W/(m² K)

4. RESULTS ANALYSIS AND DISCUSSION

Fig. 5 represents the evaluation of the water content in the exposed sandstone without plastering, the graph does not show any accumulation of moisture content, which reflects the breathability of such sandstone of high porosity. The risk of salt weathering is the main threat in this condition, for this reason the case #2 is trying to investigate the use of internal and external layers of lime plaster. The parameter of the trial one of plaster is from the Wufi Pro material data library, where a common type of lime plaster is used.

Fig. 6 represents the result of the water content for the assembly of sandstone plastered by the conventional lime plaster, it shows a real threat of accumulation of moisture with time, that causes internal condensation. For this reason, a third case is conducted to optimize the results.

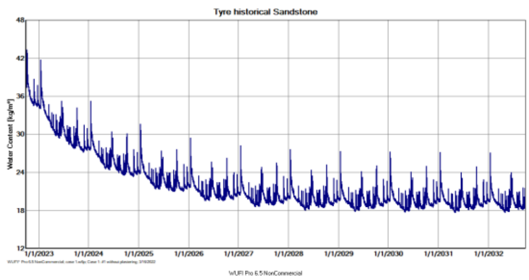

Fig.5: water content evaluation in the sandstone assembly for the case #1, for the ten-year of the simulation period

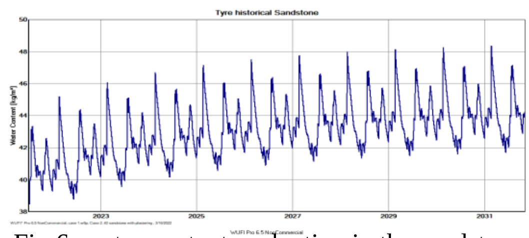

Fig.6: water content evaluation in the sandstone assembly for the case #2, for the ten-year of the simulation period

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4.1 Optimization Case

As discussed in the previous part, there is a need to make change in the material properties of the used lime plaster to optimize the results. The proposed modifications aim to make the physical parameters of the covering layer compatible with the parameters of the studied sandstone.

4.1.1 Case #3: Sandstone with optimized internal and external lime plastering

Originally, the traditional lime plaster used in the historic buildings is composed of lime, sand, fine aggregate, ash and some organic fibres from plants or animals (Levant, 2004).

The modifications in the properties of lime plaster, which are made to approach the original traditional mixture, are as follow: increasing the porosity factor and the water vapour diffusion resistance factor, which are controlling the hygrothermal behaviour of the plaster layer, as shown in the table 2. Practically, these parameters are obtained by changing the proportions of the mixture components used in the composition.

Table 2: Material Properties for the layer of optimized lime plaster used in the simulations.

Material	Property	Unit	Value
Optimized Lime plaster (2)	Bulk density	[kg/m³]	1600
	Porosity	[m³/m³]	**0.5**
	Specific Heat Capacity	[J/(kg K)]	1000
	Thermal conductivity	[W/(m K)]	0.75
	Water Vapour Diffusion Resistance Factor	[-]	**40**

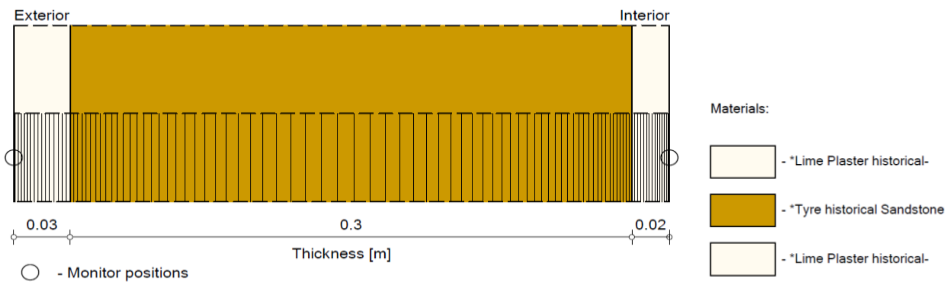

Fig.7: Cross-section in the sandstone assembly for the case #3

Based on the input data for the scenario case #3, the assembly has these following properties:
Total Thickness: 0.35 m
The thermal resistance R-Value: **0.4** (m² K)/W
The heat transfer coefficient U-Value: 1.701 W/(m² K)

The result presented in fig. 8 is for the simulation of case #3, it shows an obvious improvement, where there is no threat of moisture accumulation. This means that the scenario has achieved the required optimization, where the induced plaster layers with the proposed physical properties can protect the historic sandstone from salt weathering while avoiding moisture accumulation leading to internal condensation.

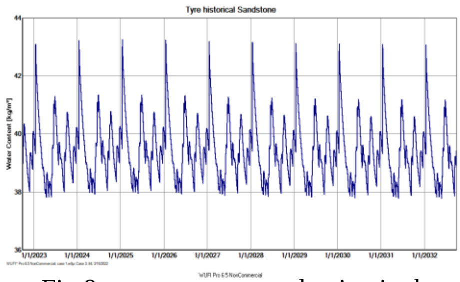

Fig.8: water content evaluation in the sandstone assembly for the case #3, for the ten-year of the simulation

5. CONCLUSIONS

This paper has two main objectives, the first one is to clarify the weathering threats menacing the exposed porous sandstone in the historic building near the sea, and the second objective is to establish a method to evaluate the plastering used to protect the sandstone by the mean of hygrothermal simulation that model the accumulation of internal moisture risk in the assembly by the time.

The conservation of the historic sandstone threatened by salt weathering, is performed mainly by cleaning it as primary phase prior to covering it by a traditional lime plaster. The recommendations here are as follow:

- Conducting computational hygrothermal simulations for historic envelope assemblies prior to any intervention in order to obtain the optimum physical parameters of the proposed plastering.
- Performing a thorough mix-design process for the lime plaster to be used in preserving historic stone envelopes, in order to match the required physical properties obtained from computational hygrothermal simulation. It is desirable to repair considerately by using materials very similar to or at least compatible with those used in the original structure.
- The successful preservation action plan elaborated for protecting historic structures, adopts minimum intervention to its original fabric, which are reversible and do not harm the important fabric if they must be removed. The lime plaster, contrarily to the plaster made from Portland cement, has the capacity to disintegrate and fall away without causing damage to important fabric during any subsequent actions of weathering on, and settlement within, a historic structure (Young, 2008).

The practice of exposing the historic sandstone is evidently a harmful decision from a preventive conservation approach, and the debate of recovering it for protection, or removing the plaster layers for “aesthetic” approach is still ongoing. It depends on the location and context of the built heritage structure, the covering choice should be a priority in the case of sea wind, air pollution, and rising damp threat from the soil.

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