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THE CONTRIVANCE OF NEW MUD BRICKS FOR RESTORING AND PRESERVING THE EDFA ANCIENT GRANARY - SOHAG, EGYPT

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Abstract

A mud brick functions as an element of masonry structures. Being an integral part of a wall mass, it must be understood structurally and chemically. The susceptibility of a mud brick to be affected by decay agents depends on the type of raw materials used, the methods of construction, location, the microclimatic conditions, the mechanical and microstructural characteristics of the mud brick itself. In this research, mineralogical composition and granulometric distribution of ancient mud bricks were studied by using some scientific techniques such as XRD, SEM and electrical mechanical sieves, to determine the main components and characteristics, which will serve as reference for the contrivance of new mud bricks. In addition, special knowledge of the physical properties of historic mud bricks were defined by some scientific techniques to get some information about their properties, such as density, porosity, water absorption and shrinkage. Furthermore, all of those characteristics were studied in two groups of new mud bricks, to determine their properties. Finally, our results proved that the 6th category in the 1st group and the 10th category in the 2nd group are the most appropriate types for restoring and preserving the studied monument, due to their good physical properties, morphological appearances and their suitable characteristics.

Keywords: *Contrivance; Mud brick; Restoration; Preservation; Mineralogical composition; Granulometric distribution.*

Introduction

Bricks, or clay blocks, were used as masonry units by the earliest civilizations, especially in ancient Egypt and Babylonia [1]. An ancient granary (Fig. 1a and b), located in Edfa, is a monumental store, considered one of the most important ancient buildings in the Sohag governorate. That monument is entirely made of *mud bricks*, which were one of the local building materials in Egypt a long time ago [2]. *Mud bricks* are composed of clay, gritting red brick, oven ash and straw. Each of those materials has its special characteristics, deterioration problems and resulting patterns [3]. In fact, the site around that monument is subject to many aggressive destruction and alteration processes and the building itself suffered serious damage, due to various factors, which lead to a great number of deterioration and degradation effects. Symptoms, such as *crumbing and granular disintegration* of brick units, were the result of wind erosion [4, 5]. Moreover**,** *wash away***,** either in the soil or in the components of brick, resulted from the action of both ground-water and domestic wastewater [6 - 10]. *The Degradation by*

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decomposition and alteration of the building's main structure resulted from the effect of different destructive human actions, such as vandalism, by the use of some inappropriate restoration materials, by inadequate preservation techniques [11] and the disregard for the weaknesses of the materials [12 - 14].

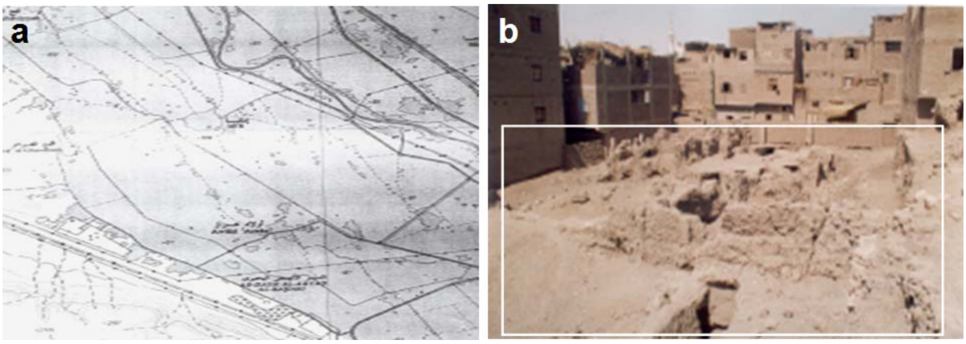

Fig. 1. Edfa town on the map of Egypt (a) and the monument under study (b)

Moreover, the *disintegration and collapse* of brick units occurred due to aggressive variations in air temperature and humidity and to wind erosion [15]. Those variations that affected the monumental site may lead to many irreversible deterioration and degradation effects [16 - 19]. *Desegregation, corrosion and holes* resulted from the actions of biological agents, such as some species of animals (mice, rats etc.), and of aggressive climatic factors. *Pitting effects* also resulted from the action of some biological factors (insects and microorganisms) [20, 21]. Moreover, the *collapse and fall* of the main structure of the monument occurred due to some severe mechanical and physical actions [22, 23]. Some of those forms of deterioration are shown in figure 2a and b. All of the previously mentioned factors can play an important role in the progressive deterioration of the monumental site. Thus, we will try to contrive new types of mud bricks to be used for the restoration and preservation of the site.

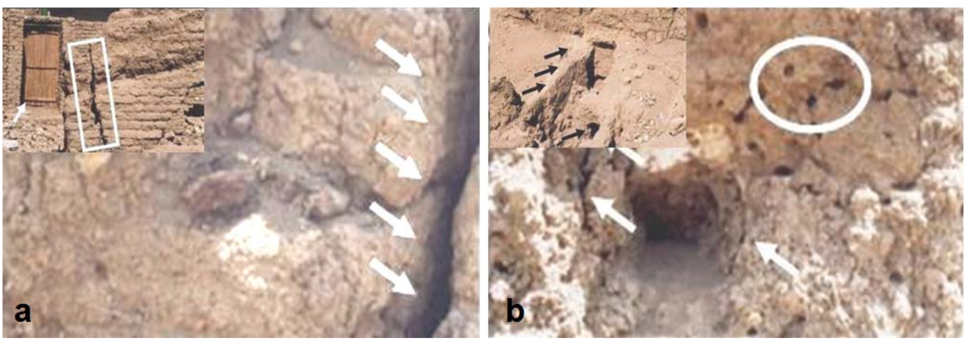

Fig. 2. Deterioration and degradation features such as embrittlement, decomposition, dissolution and alteration of the main building structure, in addition to disintegration and the collapse of mud brick units (a) and granular desegregation and pitting caused by white termites, as well as the collapse and fall of the main structure, as a result of other actions of destruction and of alteration processes, especially due to human factors and physical weathering (b)

Experimental study

In our experimental part, random samples of *ancient mud brick* were investigated, in order to identify their chemical, physical and mechanical characteristics. The investigations were done so as to determine the best type to be used in contriving *new mud bricks,* to be used for preservation and restoration interventions of the studied monument.

a. Ancient mud brick

In this part, some blocks of ancient *mud bricks*, measuring 37.5 × 19.5 ×13, were cut in cubic samples (2.5 × 2.5 × 2.5) and were studied and measured by many scientific techniques as follows:

Mineralogical characteristics by XRD

For the chemicals and mineralogical analysis, six samples were collected from the archeological site. These samples were investigated and analyzed using a Philips (PW1840) diffractometer with Ni-filtered Cu-Kα radiation, to define their mineralogical composition [24, 25]. The results indicated that all the samples consisted mainly of *Quartz* [SiO_2 *(Alpha quartz)*], *Albite* [$NaAlSi_3O_8$] and *Anorthoclease* [$(Na,K)AlSi_3O_8$], as major minerals. *Diaspore* [$AlO(OH)$] *Orthorhombic* [$KAlSi_3O_8$], *Kaolinite* [$Al_2Si_2O_5(OH)_4$], *Calcite* [$CaCO_3$] and *K-feldspars* [$KAlSi_3O_8$] were also detected. Furthermore, *Montmorillonite* [$(Na,Ca)_{0.33}\ (Al,Mg)_2SiO_4 \cdot nH_2O$], *Illite* [$(K,H_3O)(Al,Mg,Fe)_2(Al,Si)_4O_{10}\ \{(OH)_2,H_2O\}$] were present in small amounts. Moreover, there were traces of *Spinel magnesian* [$MgAl_2O_4$] and *Tridymite* [SiO_2 *(pseudo hexagonal)*] in sample 6. The results are shown in figure 3.

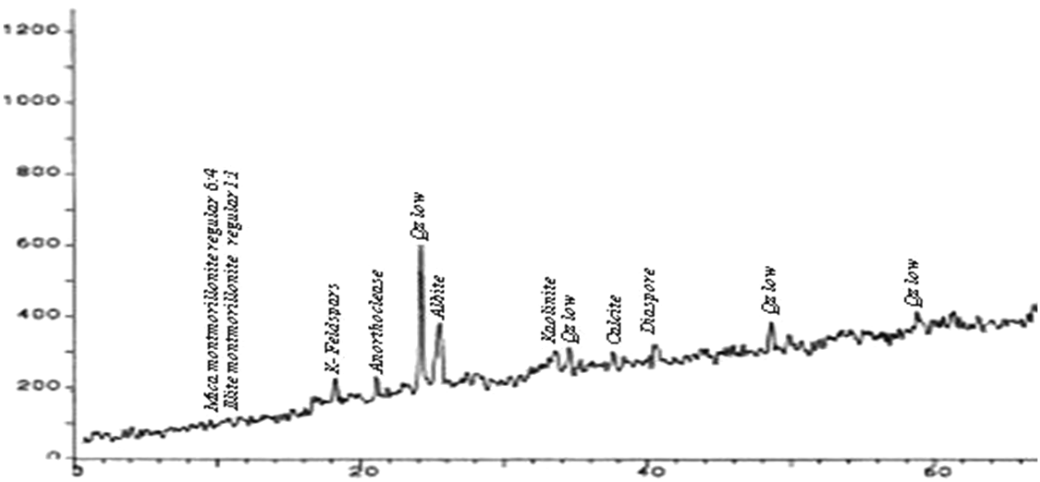

Fig. 3. XRD Spectra of ancient mud brick.

Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) is widely considered a fundamental instrument in the study and characterization of archaeological materials. It was proved to be an invaluable aid for the development of conservation procedures that involve ancient objects, works of art and buildings [26, 27]. *Ancient mud brick* samples were examined by SEM. The results indicated the presence of an eroded surface of mud brick and some micro pores resulting from several deterioration and degradation effects, especially from biological agents, air temperature and humidity factors and wind erosion. SEM photomicrographs show some cracks in the core of the mud brick and a desegregation of quartz grains, resulting from an aggressive matrix of deterioration effects, especially due to mechanical factors and some minor causes, such as salt crystallization (Fig. 4).

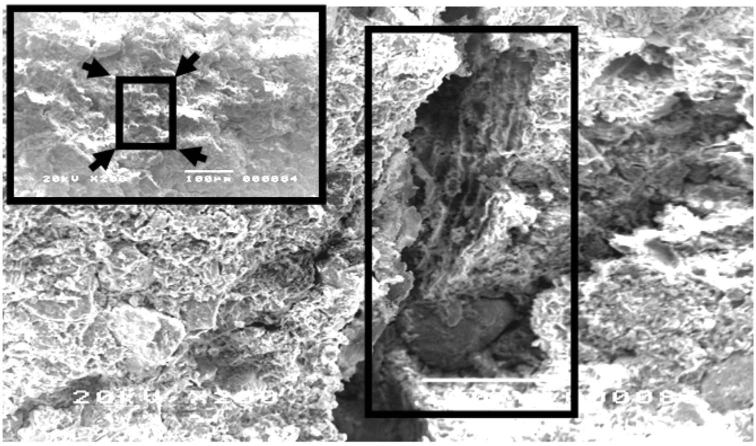

Fig. 4. SEM photomicrographs of ancient mud brick showing an eroded surface, some micro pores and cracks in the core of mud brick resulted from biological agents, air temperature and humidity factors in addition to wind erosion.

Granulometric distributions

It is an important characteristic affecting the properties of bricks. The grain distribution of mineral aggregates affects the mud brick, especially its different chemical, physical and mechanical properties, such as density, porosity and water absorption. For example, water resistance can be enhanced by changing the silt grain distribution. Nevertheless, a high volume of silt may result extreme erosion and the increase of sand exhibited very little erosion [28]. An *ancient mud brick* sample (volume = 73.83 cm^3 and weight = 117.242 g) was crushed and evaluated, in order to identify its grain size and granulometric distribution [29, 30], by using the mechanical graded sieve (2.5, 1.0, 0.5 mm). The results proved that there are some differences between the components of the sample; where the sample is classifiable as irregular grains, gravels, silty gravels and fine silt. The results also clarified that the samples contain 4.005 % irregular grains, 18.542 % gravels, 13.994 % silty gravels and 63.456 % fine silt.

Physical and mechanical properties

In the field of monumental restoration, particularly for monumental building materials, physical and mechanical properties play an important role, both in destruction and alteration processes and in choosing the suitable raw materials to be used in restoration works. Some of those effective properties (*density* [31, 32], *porosity* [33], *water absorption* [34], and *shrinkage* [35, 36]) were investigated in some *ancient mud brick* samples. The investigation results are summarized in table 1. According to the data of the previous experiments the main components, special properties and real measurements of the ancient mud brick were determined, to be used as reference for the contrivance and making of new mud bricks.

Table 1. Physical properties of ancient mud brick samples

Properties	Samples					
	1	2	3	4	5	Average
Weight (g)	25.077	25.337	25.409	25.052	25.043	**25.164**
Volume (cm^3)	15.00	15.63	14.40	14.40	15.00	**14.766**
Density (g/cm^3)	1.718	1.623	1.765	1.739	1.669	**1.703**
Porosity (%)	34.72	34.57	34.13	34.64	34.53	**34.52**
Water absor. (%)	20.76	21.40	19.34	19.91	20.68	**20.42**

b. New mud brick

New types of mud bricks are considered some of the most important materials to be used for the conservation of ancient brick buildings in general and in the restoration of the studied monument in particular. Thus, the scope of our research is to contrive and compose new categories of mud brick with the same components as those established for the ancient bricks and to submit them for chemical, mineralogical and physical investigations in order to detect their properties. Our aim is to find the best solution in conservation works for the studied monument. For this part, 12 categories of *mud bricks* were contrived and composed, according to the standard visual appearance [37], the main chemical, mineralogical composition and granulometric distributions of the *ancient bricks*. They were divided into 2 groups: *group A* **(*Sandy clay*)** and *group B* (***Alumina clay***). From a specialized point of view, some natural materials (gritting red brick, flay ash grains, straw and ingredients "animal fertilizers") as fillers and additive materials (lime powder) were used to modify and improve the final composition of the *new brick* units. After finishing the fermentation period, the samples of *new bricks* were prepared first in a column shape (measuring 18.5cm x 3cm x 3cm), then cutting them into cubic samples (measuring 2.5cm x 2.5cm x 2.5cm) which were dried in open air (30^{o}C) for 48 hours and in electric oven (105^{o}C) for 24 hours and, finally, they were subjected to the same experiments as the ancient bricks.

Physical properties determination

The same physical properties, apart from the shrinkage index of *new mud bricks,* were measured in order to determine the suitable group or groups of new mud brick units that will be used in the restoration interventions, both in the lower and in the upper parts of the building under study. The results are listed in table 2.

Table 2. Average of physical properties of the categories of *new mud brick* samples

Groups	Average of the physical properties of the samples					
	Weight (g)	Volume (cm^3)	Density (g/cm^3)	Porosity (%)	Water Absorption (%)	Shrinkage (%)
1	16.129	14.38	1.12	40.257	35.879	1.70
2	15.130	14.40	1.05	39.819	37.898	1.78
3	13.852	12.23	1.14	45.217	43.170	1.32
4	15.605	13.80	1.20	45.485	40.224	0.86
5	12.983	12.70	1.02	49.833	48.347	2.62
6	13.114	13.23	0.99	36.196	35.502	2.12
7	22.780	17.901	1.27	54.14	42.66	3.20
8	23.951	16.250	1.47	50.44	34.22	2.58
9	25.828	17.556	1.47	52.00	35.84	2.61
10	19.847	15.624	1.20	46.45	40.82	1.25
11	16.253	16.562	1.04	65.52	66.76	1.62
12	19.419	15.687	1.23	44.66	38.34	3.94

SEM examination of the 1st and 2nd groups of new brick samples indicated that there are some differences between the 12 categories belonging to the 2 groups, according to their chemical and mineralogical composition. There were also some differences in the morphological appearances of each group, due to compacting and to the interferences between their grains, porosity degree and percentage of additive materials. Some of these features are shown in figures 5 and 6.

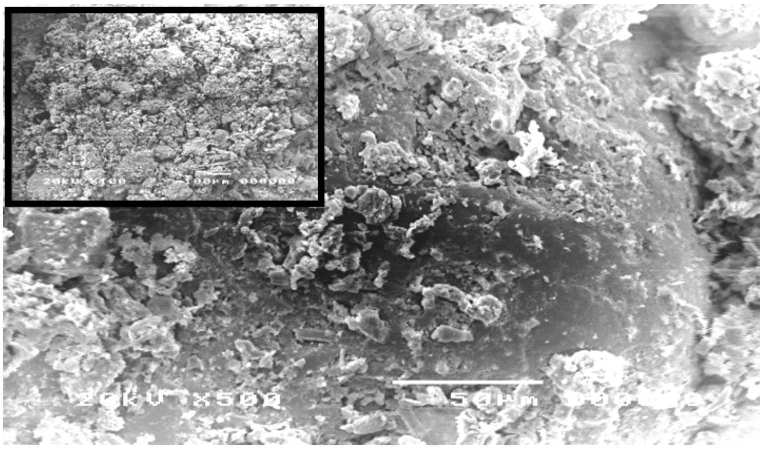

Fig. 5. SEM photomicrographs of new mud brick showing good compacting of the samples belonging to category no. 6.

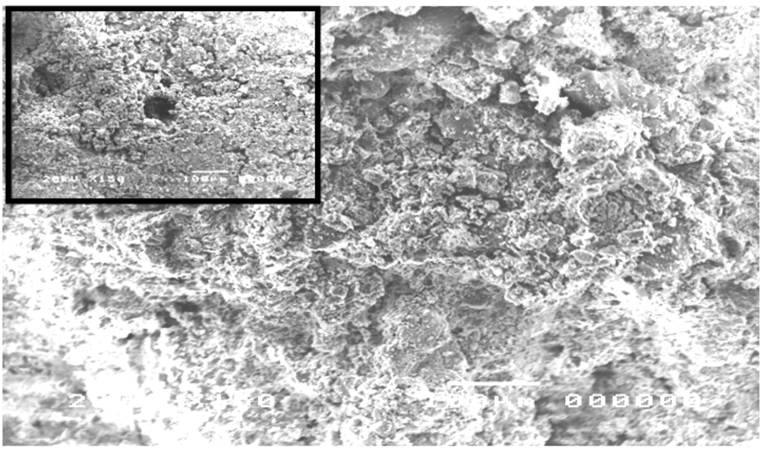

Fig. 6. SEM photomicrographs of new mud brick showing homogeneity and low porosity of the samples especially in category no 10.

Discussions

The previously mentioned studies can be divided into two main lines: the 1st one consists of the results from the analysis of ancient mud bricks (bricks taken from the Edfa granary) and the 2nd one consists of the results that refer to new mud brick units (Contrived samples).

a. Ancient mud brick

The visual appearance of the ancient mud bricks indicated that all the deterioration symptoms were due to the synergetic effects of various deterioration factors [38], especially air temperature and humidity factors. They also resulted from wind erosion, ground and domestic wastewater, human activities and also some biological agents. XRD analysis results indicated the presence of *Quartz grains* [SiO_2], *Albite* [$NaAlSi_3O_8$] and *Anorthoclease* [$(Na,K)AlSi_3O_8$] as major minerals. Those minerals originated in the raw materials of mud bricks. The presence of other minerals in the samples was essentially linked to the aggressive effects of some deterioration factors, particularly the chemical weathering agents. *Kaolinite* [$Al_2Si_2O_5(OH)_4$] is a mixture of different minerals. Its main component is kaolinite. It may also contain Q*uartz, Mica, Feldspar, Illite* and *Montmorillonite*. It is made up of tiny sheets of triclinic crystals with a pseudo-hexagonal morphology [39]. It is the result of a kaolinization process [40] caused by the effect of chemical weathering, hydration and hydrolysis mechanisms. Those mechanisms that that involve absorption and chemical reactions affected silicate clays, such as *Albite,* or other species of clay minerals, such as Illite*, Montmorillonite* and *K-Feldspars*, according to the following formula:

$$\underset{\textit{Albite}}{2NaAlSi_3O_8} + 2H^+ + H_2O \longrightarrow \underset{\textit{Kaolinite}}{Al_2Si_2O_5(OH)_4} + 4SiO_2 + 2Na^+$$

Calcite [$CaCO_3$] is one of the most abundant mineral species on the surface of this planet. It is found in biogenic and inorganically precipitated sediments and sedimentary rocks. It is the principal mineral constituent in metamorphic rocks. Thus, it is found in igneous *carbonatites* and *kimberlites* derived from deep mantle sources [41]. It was found as a binder material, in the decomposition of some feldspars minerals in the original components of mud bricks, or in contamination factors in the study area, resulted from some human actions, such domestic and industrial activities [42]. *Spinel magnesian* [$MgAl_2O_4$] is found in basic igneous rocks and in contact metamorphic rocks [43]. In our case it was found as a minor component in local materials used in brick manufacture. *Tridymite* [SiO_2] exists as monoclinic or psudoorthorhombic structures. It is also present as the other forms of crystalline silica. Its occurrence in workplaces may be restricted to some materials such as the silica bricks that have been used for many years at high temperature [44]. They were found in the samples as traces of minerals resulting from the interferences, exchange and reaction between the original minerals and some contamination and deterioration factors in the area under study [45]. *SEM investigation* results confirmed the results of XRD. It revealed some degradation and decomposition effects in all samples, especially in *Quartz grains*. We also found some cracks on the surface of ancient mud bricks. Moreover, we found some salt crystals resulted from the chemical reaction and ion exchange between water sources (groundwater and domestic waste water) and the main components of bricks. *Granulometric distribution* results proved that there is some heterogeneity among the main components, as a result of some defaults during the brick manufacture process**.** *Physical properties* results indicated that the samples were affected by some agents of chemical, mechanical and physical nature, especially weathering effects of wind erosion and groundwater, in the case of low granulometric distribution values.

b. New mud brick

The visual appearance of the new mud bricks indicate that there are some noticeable differences among the different categories, which meant that the unsuitable categories must be naturally avoided. Those categories were 1, 2, 3, 4, 5 in the 1st group and 7, 8, 9, 11, 12 in the 2nd group. The suitable categories, which were submitted for further examinations were (6 in 1st group and 10 in 2nd group). *Physical properties* results proved that density, porosity, water absorption and shrinkage indexes taken from the samples of categories belonging to the 1st group, were lower than the same values recorded for the samples of categories belonging to the 2nd one. Based on the density index, the 1st group was suitable for restoration works of the lower parts and foundations of the studied monument and the 2nd group was suitable for restoration works in the upper parts. The groups of new mud bricks could be divided into two categories in the conservation works, according to their properties. *SEM investigations* indicated that there were great differences between all new types of contrived bricks, according to their main composition and properties. Some variations in their morphological features, such as the semi-compacting and intermediate porosity, were found in categories 1, 8, 11 and 12. High compacting values and low porosity was detected in categories 2, 3 and 9. Friable grains and surface micro-fissures, in addition to highly loose grains, were detected in categories 4, 5 and 7. Moreover, good compacting, surface homogeneity and low porosity were found for categories 6 and 10. Finally, we could conclude that "*category No. 6 in the 1st group*" was considered ideal for restoring and preserving the upper parts of the studied monument, because of its good characteristics: "low density, low porosity, low water absorption and very good surface morphological appearance. Similarly, "*category No. 10 in the 2nd group*" was considered an ideal group for the same purpose in the lower parts of the monument. That was due to its suitable characteristics: intermediate density, porosity, water absorption and very good surface morphological appearances, under SEM, as listed in table 3. Finally, we should mention that all of those properties and characteristics of the contrived new mud bricks can be modified and improved by using some methods and materials, such as consolidants, water repellents and anti-microorganism materials.

Table 3. Final results of investigated samples of *new mud brick*

Sample	**Properties**					
	Density	**Porosity**	**Water ab.**	**Shrinkage**	**SEM**	**Total**
1	*	**	***	**	*	*9*
2	**	***	**	*	**	*10*
3	*	*	*	***	***	*9*
4	*	*	*	****	*	*8*
5	***	*	*	*	*	*7*
6	****	****	****	*	****	*17*
7	*	*	*	*	*	*5*
8	*	**	****	**	*	*10*
9	*	*	***	*	**	*8*
10	***	***	***	****	****	*17*
11	****	*	*	***	***	*12*
12	**	****	**	*	*	*10*

* = 1 point   ** = 2 points   *** = 3 points   **** = 4 points

Conclusions

The present study was an attempt to find out the suitable and appropriate material to be used for restoring one of the oldest mud brick buildings in Upper Egypt. That building suffers from severe deterioration and degradation forms, caused by the interaction between several correlated environmental factors, apart from the low quality of brick materials, which finally led to the creation of complex weathering cycles. We needed to contrive new materials for preservation and restoration interventions. The study essentially focused on detecting or contriving a new material for achieving this goal, through the evaluation of different chemical, physical and morphological characteristics. It also, shed light on the suitable materials and additives that should be added to improve the different characteristics of new bricks and fundamentally on the essential properties of the original material used in the study area.

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