Egyptian Journal of Archaeological and Restoration Studies (EJARS)
An international peer-reviewed journal published bi-annually
www.ejars.sohag-univ.edu.eg

Original article

COMPARATIVE MATERIAL AND DETERIORATION STUDY OF STUCCO DECORATIVE CONSOLES ON MOHAMED ALI PASHA–ERA FACADES IN EGYPT

Mahmoud, S.[1], Abdelrahim, Sh.[1(*)], Khallaf, M.[1], & Afifi, H.[2]

[1] *Conservation dept., Faculty of Archaeology, Fayoum Univ., Fayoum, Egypt*
[2] *Conservation dept., Faculty of Archaeology, Cairo Univ., Giza, Egypt*
**E-mail address: saa00@fayoum.edu.eg*

Article info.
EJARS – Vol. 16 (1) – June 2026: 23-30

Article history:
Received: 20-2-2025
Accepted: 18-10-2025
Doi: 10.21608/ejars.2026.511043

Keywords:
Stucco decorations
Console
SEM
XRD
Fungal biodeterioration
Gypsum.

Abstract:
This research paper focuses on studying the materials used in stucco consoles of historical building facades in the period of Muhammad Ali Pasha and their deterioration, specifically in the stucco consoles of Al-Shanawi palace in Mansoura and the building No. 17 in Mohamed Mahmoud St. in Cairo. Both structures are from the same period but differ in their surrounding environmental conditions, such as humidity levels, pollution exposure, and maintenance practices, which may contribute to the differences in their deterioration rates. Various examination and analysis techniques were employed to confirm the deterioration and changes between them. It was confirmed by the analytical and investigation methods that were performed, such as light microscopy, scanning electron microscopy (SEM-EDX, X-ray diffraction (XRD) and microbiological deterioration assessment. Gypsum, calcite, and quartz were detected as main components of stucco with halite and anhydrite that increased in the stucco console in a Cairo residential building, while the percentage of halite increased in samples of the Al-Shennawi palace in Al Mansoura. Aspergillus and Penicillium species were identified, which illustrates the vulnerability of the stucco porous material to biodeterioration. The findings aim to define and develop effective conservation and restoration strategies that maintain the architectural and historical integrity of stucco-decorated facades.

1. Introduction

Architectural stucco and transported museum exhibits are two types of stucco [1-4]. An essential component of the cultural legacy is the stucco ornamentation that adorns the exteriors of archaeological buildings. For several hundred years, stucco has been utilized all over the world. Each region has a different composition [5]. reflecting the availability of its constituent parts as well as the materials and practices that are available locally. "Stucco" is defined in art as mortar and is used for both exterior and interior construction decorative elements [6]. The primary ingredients of stucco are aggregates and a binding substance (gypsum or slaked lime), which are added to enhance specific qualities. It gained qualities like decreasing shrinking and boosting strength, cohesiveness, and water repellence from organic ingredients like animal hair, linseed, eggs, beer, urine, and blood. Inorganic additives like brick dust or natural cement improved cohesiveness. Rapid Hydraulic [7, 8]. The family of Mohamed Ali's ruler period is rich with stucco works influenced by European Renaissance arts [9]. Khedive Ismail brought them to Egypt's many governorates. Stucco decorations including consoles, scagliola, cast stones, balustrades, mounted wall columns, crowns and column bases, and colored and gilded cornices. During the European Renaissance, stucco was employed to produce a wide range of decorative features by casting molds or forms into various shapes. They introduced decorative styles. The Italians introduced stucco to England first because they were the most competent at stucco design techniques. It affected Cairo's architecture throughout the nineteenth century, especially those influenced by the Renaissance and Baroque styles [7]. Renaissance architecture was known for its magnificent façade. Italy was the origin of that cultural renaissance and its colors since it still had a significant Roman cultural history. Its important location on the Mediterranean basin has made it easier for people to communicate and convey their cultures to other countries throughout the world [9]. The facades are particularly significant because they depict the building's broad thickness from the exterior. These are the most significant units in Egypt where Merz, the painter, the engineer, and the late artist excelled in path and decorative formation. The facades are described as unique work. They are crucial in allocating the street's worth of architectural waste, both internal and external. Stucco is a multi-component porous material composed of more than one substance, each of which has its own physical, chemical, and mechanical properties and reacts differently to the various deterioration factors. The composition of stucco and its transformation into other materials are important factors to consider. Additionally, increased humidity creates a conducive environment for the growth of various microorganisms. Colored and gilded stucco is significantly impacted by various damage factors. The particles disintegrate, resulting in the loss of certain parts due to the varying composition of the stucco components [6,8]. These decorations are subjected to fluctuations in temperature and humidity, leading to phase changes; water is lost, and salt crystallizes. Therefore, the main component of the stucco decoration material transforms from the dehydrated phase to the bassanite and anhydrite phases, losing the water chemically bound to it. When the gypsum transforms into anhydrite, it becomes soluble and very brittle, which weakens its structure. Calcium carbonate, the second component of stucco, also undergoes thermal decomposition when directly exposed to fire. It turns into calcium oxide, and in the presence of humidity, it turns into calcium hydroxide, which falls in the form of a powder, and Salts represent a major factor in the damage of stucco decorations, the most important of which are sulfate salts, as their danger lies in their continuous transformation from the aqueous phase to the anhydrous phase. Because they don't dissolve as quickly as other salts, sulfate salts move around inside the artifact in the water phase. When the salts take in water, they become hydrated [10-12]. Environmental pollution and the presence of solid particles in urban environments play a major role in the increased rate of damage and rapid deterioration of stucco decorations adorning the archaeological and historical sites. The presence of these suspensions and dirt provides an effective medium for biological damage on these decorative elements due to the growth of bacteria, fungi, algae, plants, and animals, [13]. This depends on the humid surface, the chemical composition, and the structure and porosity of the stucco surface [11,12]. The Al-Shanawi palace was built between 1339 and 1344 between the Nile and El-Gomhoria St. Its facades are designed in the Baroque and Rococo styles. *Al-Shanawi palace* was built between 1339 and 1344 between the Nile and El-Gomhoria St. Its facades are designed in the Baroque and Rococo styles, and they are in good condition. It was built in the Italian style. The building with the garden is about 4164 m^2, and the built area is 441 m^2 (20.5 m×22 m); the skeleton of the building is made of stones covered with bricks [14,15].

Figure (1) geographical location of the Al-Shanawi palace [21] a historical residential building 17 Mohamed Mahmoud St.

2. Materials and Methods

2.1. *Sampling*

Analytical and investigative research considering most documentation processes [16]. It offers a long-term framework for defining conservation, maintenance, treatment, and management methods [11]. Four samples were taken from the fallen and detached parts of the stucco decorations of consoles adorning the facades of two historic architectural buildings: Al-Shennawi palace in Al Mansoura, Dakahlia governorate, and a historic residential building at 17 Mohamed Mahmoud Street in Khedive Cairo. In order to ensure successful repair operations, the goal is to determine the mineral composition, surface texture, and deterioration products of the stucco samples. fig$_s$. (2 & 3).

Figure (2) the various facades of the Al-Shennawi palace in Mansoura and their damage; **a.** the complete loss of the stucco consoles on the front facade sample (S1), **b.** partial loss of the stucco consoles in the side façade, sample (S2), **c.** the stucco consoles close to the ground in relatively good condition, not exposed to rain and air pollution as in the upper parts of the building, **d.** the presence of dense layers of surface calcification accumulated on the surface of the pilasters.

Figure (3) the various facades of the building 17 Mohamed Mahmoud St.; **a.** the shape of the stucco consoles and the black calcification layers on them resulting from the accumulation of aerosols from transport vehicles sample (S3), **b.** the loss of some parts of the stucco consoles under the balcony sample (S4), **c.** the different types of consoles in the same building, **d.** damage aspects in the form of blacking calcification on the stucco decorations.

2.2. *Methods*

The digital light microscope was used to describe the surface properties and texture of the stucco samples. Details are seen more clearly than with the naked eye. It is connected to the computer via USB cables. A ZEISS-type optical light microscope was used. The scanning electron microscope was used to obtain accurate information about the crystal structure and the mineral composition of samples with changes that occurred on the mineral crystals because of damage factors. The samples were imaged in the scientific laboratories of the Grand Egyptian Museum in Al-Ramiyah using a FEL Quante 3D200i model device. The operating conditions of the device. The microanalysis was carried out using energy-dispersive X-ray analysis, Pegasus (XMY). The accelerating voltage was between 15 and 20 kV—highly polished cross-section. Coating - AU, Vaccoat - DSR1, Thickness 70Å. X-ray diffraction (XRD) analysis provides insight into the geochemical composition, apart from the properties of the main crystalline phase. It identifies the major, minor, and trace inorganic chemical compounds, and through it, the structural, compositional, and chemical properties are recognized. It also identifies the types of materials that make up archaeological samples. This type of analysis is performed on materials with a solid, crystalline mineral composition. The samples are flat, and the types of compounds are determined through fixed, low inclination angles. Analysis requires taking necessary samples of archaeological decorations and grinding the extracted samples, which is a destructive and damaging analysis method. An X-ray diffraction (XRD) analysis was carried out using a PANalytical computer-certified program with the aid of the Int. Centre of Diffraction Database (ICCD), PDF-2 Database-CD-Release 2005-Type No. 943050001611. X-Pert HighScore Software 2006 - Licensed modules: PW 3209 tube anode; cupper (Cu). The 2ϴ (theta) scan range varied from 5-50̊. Microbiological examination: a total of 12 swabs were collected from the two historical facade buildings. Samples were transported as soon as possible in an icebox under complete aseptic conditions to the dept., of Zoonoses, Faculty of Veterinary Medicine, Damanhur Univ., for processing, isolation, and identification of species. Media for the isolation and identification of fungi were the following: **a)** *Solid Media*: Sabouraud Dextrose Agar (SDA). **b)** *Liquid Media*: Sabouraud Dextrose Broth (SDB). **c)** *Reagents and Stains*: Lactophenol Cotton Blue Stain, Giemsa Stain, Gram Stain. Fifteen grams of Sabouraud Dextrose Agar (SDA) were dissolved in one liter of distilled water in accordance with the manufacturer's instructions. Tightly closed graduated flasks were placed in an autoclave at 121°C for a quarter of an hour. Figure (4) explained the steps of media preparation, and placing it on a surface previously sterilized with alcohol and the flame-burning method. Then, leave the media until it cools to 45-50 °C and then pour it into Petri dishes and leave the media until solidification. To ensure proper solidification for easy culturing, we place it in the refrigerator at 4° C for two hours. Finally, we take it out, culture the samples on the media, and incubate them at 45°C. The identification techniques that were used include the morphology alone may be insufficient for species identification due to phenotypic variability. The identification techniques employed include assays for enzyme activity, such as urease and amylase, as well as assessments of temperature tolerance, with growth at 45 °C being characteristic of A. fumigatus. Additionally, species differentiation can occur based on enzymatic profiles (for example, urease activity), growth at elevated temperatures (such as 45 °C for A. fumigatus), or the production of secondary metabolites like aflatoxins.

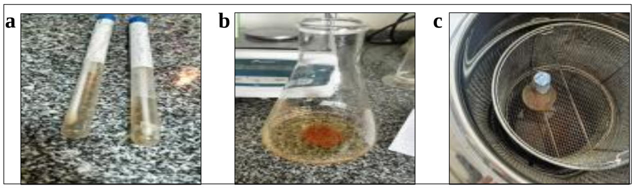

Figure (4) media preparation steps; **a.** preparing the swabs, **b.** dissolving the media, **c.** placing the media in the mold

3. Results

3.1. *LM*

Digital light microscope (LM) images of the Al-Shennawi Palace console sample are presented in fig. (5-a & b), while the sample of consoles under the balconies on the front and side facades of building 17, Mohamed Mahmoud Street, are shown in fig. (5-c & d). The description of the surface shape provides details about the composition of the samples and the configuration of the surface grains that constitute the archaeological technique [17,18]. This is observed in the internal sections of the samples, including the layers beneath the soiled surface. Some cracks or simple fissures and blisters appear, indicating the presence of pores due to the heterogeneity of the sample components. Dense layers of dust and dirt appear on the outer surface layer exposed to environmental factors, which are distorting and obscuring the surface decorations of the artifact.

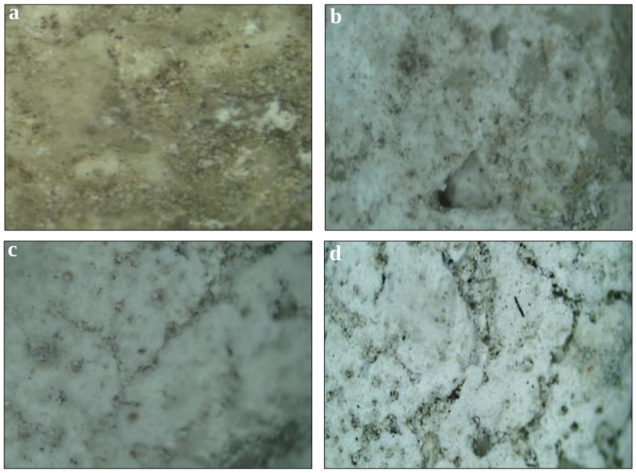

Figure (5) light microscope images at 1200-X; **a.** appearance of the sample surface, the dust and local calcifications, and the sample distortion of the, **b.** gaps due to manufacturing defects during casting process and fine cracks due to surface heterogeneity, **c.** deep cracks and separations in the internal components, **d.** presence of layers of calcification.

3.2. *EDX*

The result of SEM photomicrographs of Al-Shennawi palace is presented in fig. (6) the images of consoles under the balconies on the front and side facades of building 17, Mohamed Mahmoud St. These images showed clear pores between the mineral crystals, indicating disintegration and weakness besides some simple gaps and cracks.

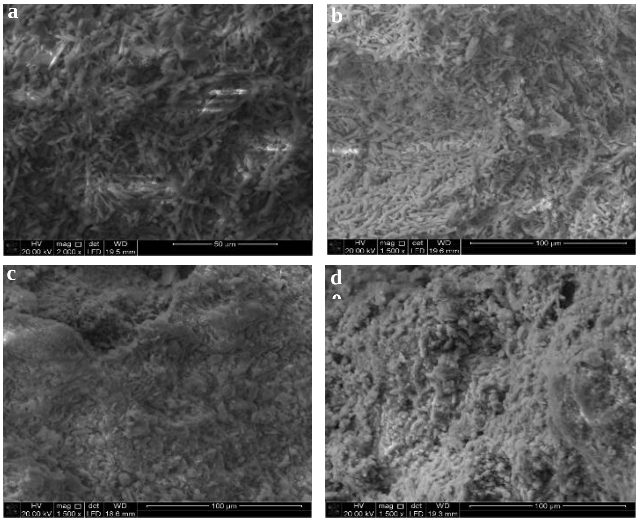

Figure (6) SEM photomicrographs at 2000-X; **a.** the shape of the internal texture, small voids, and the needle shape of the gypsum crystals, **b.** the gypsum crystals and the small pores, **c.** the surface texture, the blurring of its features, and the calcification of the black layers, **d.** the blurring of the surface, forces, and the voids.

Energy dispersive x ray analysis of the sample (sample 1), fig. (7-a) from one of the consoles on the main facade of Al-Shennawi palace revealed the presence of calcium, carbon, and oxygen, confirming the presence of the mineral calcite, which is calcium carbonate ($CaCO_3$). The presence of Ca with S and O indicates the presence of gypsum in its various forms, such as gypsum ($CaSO_4.2H_2O$) or anhydrite, which is composed of anhydrous calcium sulfate ($CaSO_4$). The appearance of silica and oxygen indicates the presence of quartz, which is composed of silicon oxide (SiO_2). From the analysis of the components of the samples, it was found that the gypsum consoles of Al-Shennawi palace consists of basic compounds, namely gypsum in a large proportion due to the presence of a large proportion of sulfur, while lime as an auxiliary component due to the presence of C at a lower rate than sulfur. Quartz was also present at a small rate due to the low rate of silica in the sample. Anhydrite may also be present due to the presence of sulfur, calcium, and oxygen. This indicates the damage that occurred to the components of the gypsum component due to its exposure to the surrounding weather conditions. The transformation of gypsum into anhydrite, which demonstrates the antiquity of this artifact. The result of (sample 2), fig. (7-b) from one of the consoles on the side facade of Al-Shennawi palace revealed the presence of C, O, and Ca, which are the components of calcite ($CaCO_3$), while the presence of Ca, S, and O indicates the presence of gypsum phases. There are also Si and O as quartz (SiO_2). Al, Fe, and Si, indicates the presence of mixed earth impurities as main raw materials. Given the possibility of the presence of the compounds, the sample contains gypsum as a primary component and lime as an auxiliary component. Silica also appears as a secondary material in a very small proportion, and there are clay minerals of aluminum silicate and iron oxides as impurities or in the calcified surface layers on the surface of the gypsum cable. The analysis result of the (sample 3), fig. (7-c) from the console under the balconies on the front facade of building revealed the presence of sulfur, calcium, and oxygen, which form the main compound gypsum due to the presence of a large percentage of Ca, C, and O indicating the presence of gypsum and anhydrite. which indicates the antiquity of the stucco, and the extent of damage has been exposed to. The presence of Si and O indicates the presence of quartz, as secondary compound. Al, Si, and Fe are also present in small percentages, indicating the presence of silicates of earth minerals, which may be impurities or from layers of dirt adhering to the archaeological stucco surface. (Sample 4), fig. (7-d) from the side facade console of building. The previous analysis yielded many elements that confirmed the presence of some compounds, such as calcite, which is composed of C, Ca, and O, and gypsum or anhydrite that composed of S, Ca, and O, as calcium sulfate. Quartz is composed of Si with O. There are also some components of clay minerals as: Al, Mg, Fe, and Zn, as listed in tab.(1).

Table (1) results of elemental analysis of EDX

Elements of samples	Ca	O	S	C	Si	Fe
S1	24.2	34.7	28.5	8.2	2.5	0
S2	29.9	37.3	19.5	10.1	1.2	0.6
S3	28.7	36.5	17.5	14.0	0.9	0.3
S4	20.1	41.4	17.6	9.5	2.6	-

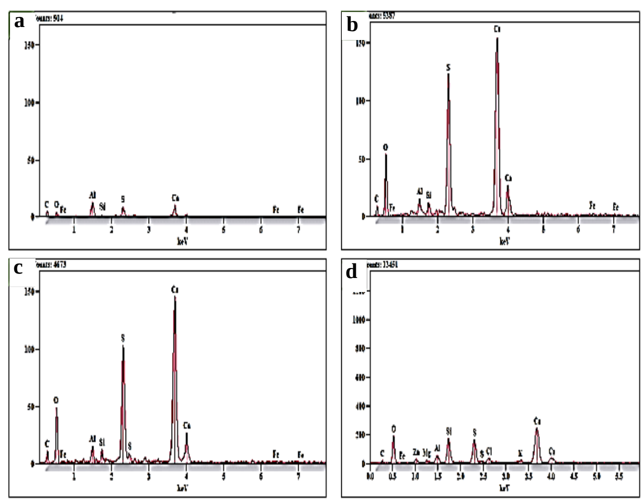

Figure (7) EDX patterns of the stucco samples S1, S2, S3, S4

3.3. *XRD*

Two samples from the Shennawi palace (SP1 & SP2) and two sample from the various facades of the building on 17 Mohamed Mahmoud St. (SP3 & SP4). The XRD result of the sample (SP1) from the same place as the Shennawi palace, fig. (8-a), revealed the presence of many minerals as follows: gypsum ($CaSO_4.2H_2O$) 44.7% with card number 036-000432 as a basic material; calcite ($CaCO_3$) 22.5% with card number 3262-078-01 with moderate percentage; quartz (SiO_2) 19.9% with card number 8320-075-101; anhydrite ($CaSO_4$) was also found 10.2% with card number 123-05-01 which indicates the damage that occurred to the components of the stucco console due to its exposure to the surrounding weather conditions, which played the largest role in damaging its basic materials; and halite (NaCl) with card number 3458-076-01 a hegemonic salt, also appeared, which could destroy the stucco and clump on the surface or within the pores with ease. The phase transformations of halite from solid to liquid and back create pressure that causes differentiation and crystallization stress within the porous, where, heterogeneous stucco material leading to the crystals disintegrate, cracking and formation of fissures and gaps, as revealed by microscopic investigation. The result of the sample (SP2) of the Shennawi palace the same place of S2, fig. (8-b) revealed the presence of gypsum at 65.4%, calcite at 16.8%, anhydrite at 5.4%, and quartz at 12.4%. Gypsum, calcite, and quartz were the main components of the gypsum console mixture, with gypsum present in a high percentage, calcite at a lower percentage, and quartz at a lower percentage. Traces of anhydrite, the non-hydrophobic phase of gypsum, were also found. The results of the sample (SP3) the same place, fig. (8-c) showed the pre-sence of gypsum as moderate percentage 42.9%, and calcite 26.2% as well as the traces of anhydrite 5.6%; quartz 9.8%; halite 9.5%, and hematite oxide 0.6%. It was found that it is a gypsum-stucco mixture constituted of the basic components of gypsum, calcite, and quartz. The presence of the anhydrite compound, resulting from high temperatures and climate changes, converts gypsum, the principal component, into its dry phase. This dry phase is less solid, more brittle, and prone to loss and dissolution. Consequently, it transforms into a powder that is easily removed, leading to a loss of effectiveness. It is probable that it was caused by the transition of hydrated calcium sulfate due to environmental interactions. Halite, a salt found in abundance in the soil, is a hegemon salt that readily absorbs and loses water from its surroundings. When this salt crystallizes or dissolves, it exerts significant pressure on the components of stucco decorations via crystallization processes. The salt accumulates in pores, cavities, or cracks. As a result, the salt crystals increase the pressure on the pores, eroding and destroying the structural composition, causing parts of the decorations to fall off, become completely lost, or appear as deformities on the outside surface. Iron oxide (Fe_2O_3) is also found, which is a common contaminant in the raw materials used in the production of gypsum decorations. The result of the sample (SP4) from the same location as sample S4, fig. (8-d) demonstrated the presence of gypsum as the main component at 59.3% and anhydrite at 22.8%, resulting from varying climate changes and high temperatures that transformed the gypsum to anhydrite stucco consoles. Calcite accounted for 12.6% of the sample, with traces of quartz at 2.1% and halite at 3.2%, all of these results are listed in tab. (2).

Table (2) XRD analytical results of samples SP1, SP2 SP3, SP4

Components of samples	$CaSO_4.2H_2O$	$CaCO_3$	$CaSO_4$	SiO_2	NaCl	Fe_2O_3
SP1	44.7	22.5	10.2	19.9	2.7	-
SP2	65.4	16.8	5.4	12.4	-	-
SP3	42.9	26.2	5.6	9.8	9.5	6.0
SP4	59.3	12.6	22. 8	2.1	3.2	-

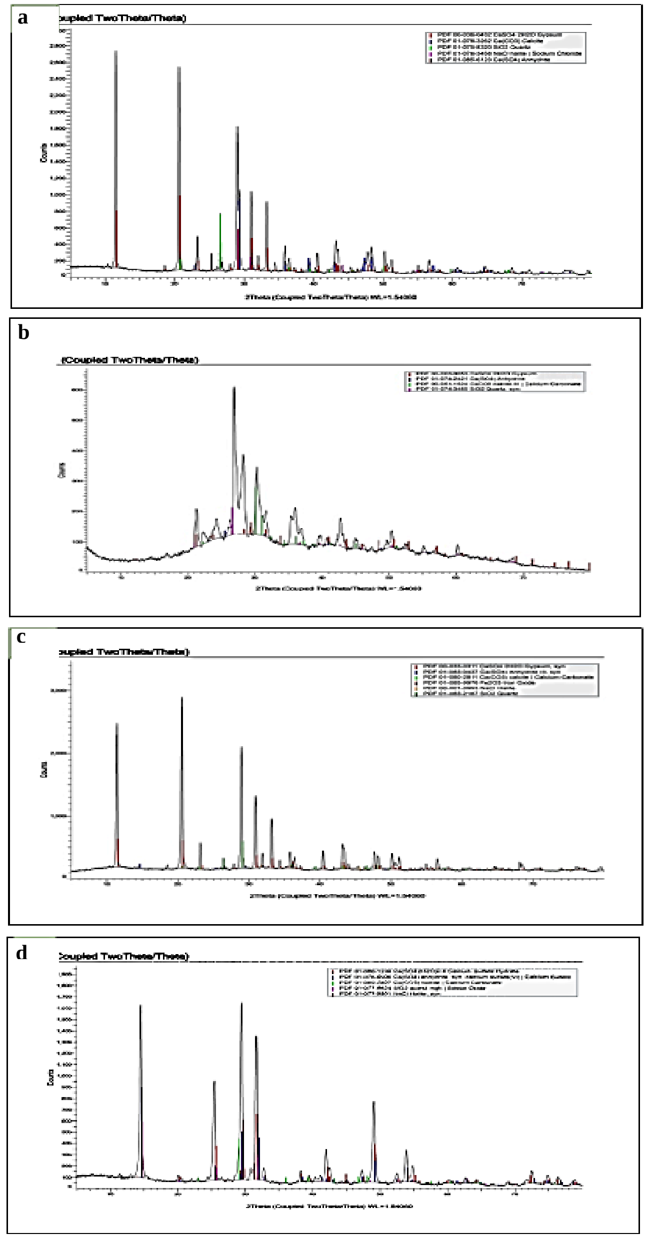

Figure (8) The XRD analysis patterns of for samples SP1, SP2 SP3, SP4

3.4. Microbiological study

Aspergillus species account for 83.3% of the total isolates (10 out of 12 samples), indicating a dominant fungal genus in the biodeterioration of stucco surfaces while *A. flavus* was the most prevalent, representing 25% of all isolates, suggesting its strong adaptability to the environmental conditions present on the facades. Other *Aspergillus sp*. (*subflavus*, *bertholletius*, *alliaceous*, and *niger*) were also identified, each contributing between 8-16.7%. reinforcing the genus' prevalence in stucco colonization these results were agreed with the resulted data mentioned by some authors, fig. (9-a: l). Presence of *Penicillium spp*. *Penicillium rubens/chrysogenum* accounted for 16.7% of the isolates. This species is known for its saprophytic nature and ability to colonize building materials, esp-ecially in damp environments. Several species (*A. flavus*, *A. niger* and *Penicillium*) are capable of producing mycotoxins and organic acids, which can degrade calcium-based materials through acidification, pose health risks to occupants and conservators through airborne spores and accelerate surface erosion, discoloration, and mechanical weakening of stucco. The presence of these fungi correlates with environmental influence, particularly, High relative humidity (suitable for mold growth). Porous materials like stucco, which retain moisture. Airborne contaminants and dust, which serve as nutrient sources. The facade's exposure to atmospheric pollution and rainwater infiltration likely created microenvironments conducive to fungal colonization.

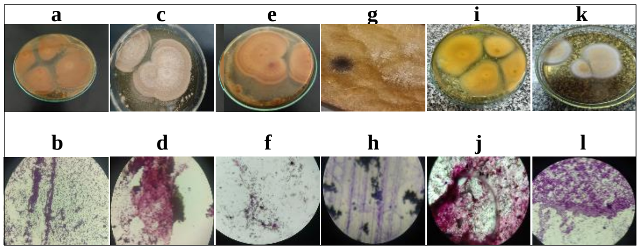

Figure (9) Petri dishes with isolated fungi and their shapes under the light microscope lens; **a.** & **b.** *Aspergillus flavus*, **c.** & **d.** *Aspergillus Subflavus*, **e.** & **f.** *Aspergillus bertholletius*, **g.** & **h.** *Aspergillus niger*, **i.** & **j.** *Aspergillus alliaceus*, **k.** & **l.** *Penicillium rubens Penicillium chrysogenum*

4. Discussion

The microstructural heterogeneity observed via stereo and optical microscopy provides critical evidence of the long-term degradation mechanisms affecting the stucco matrix. The prevalence of fine cracks and surface gaps is not merely a morphological feature but a direct consequence of the dehydration/rehydration cycles characteristic of Cairo's arid environment. Specifically, the internal separations observed in the samples from Mohamed Mahmoud St. are diagnostic of the gypsum-to-anhydrite phase transformation. This chemical transition results in a significant volumetric contraction of the binder, leading to the formation of a brittle, friable matrix that lacks mechanical cohesion. Furthermore, the 'calcification layers' and salt crusts identified in the Shennawi palace samples indicate advanced surface sulfation, where atmospheric pollutants react with the calcium-bearing phases to obscure original decorative details. These findings are consistent with the deterioration profiles reported for Mohamed Ali pasha-era facades, where high porosity (facilitated by the loss of original binders) acts as a primary catalyst for salt ingress and sub-sequent physical weathering. By comparing these disparate sites, it becomes evident that while the 'recipe' of the stucco may vary, the susceptibility to atmospheric SO_2 and moisture cycling remains a dominant factor in the loss of Egyptian architectural heritage. SEM investigation, coupled with EDX elemental mapping, provides a high-resolution diagnostic view of the structural decay affecting the stucco samples [19]. The observed weakness in bonding and granular disintegration are direct physical manifestations of the gypsum-to-anhydrite phase transformation. This transition from the dihydrate ($CaSO_4$ $2H_2O$) to the anhydrous phase ($CaSO_4$) involves a significant loss of crystalline water, resulting in volumetric shrinkage and the formation of the observed internal void networks. A comparative analysis of the microstructures reveals a clear divergence dictated by regional micro-climates. Samples from Shennawi palace (Mansoura) exhibit a dense 'material mask' or surface crust, which is attributed to hygroscopic salt cycling. The high relative humidity and rainfall in the Delta region promote the dissolution and reprecipitation of gypsum, leading to surface distortion and the entrapment of soot and dust. In contrast, the samples from Mohamed Mahmoud St., Cairo show more pronounced internal pulverization. The aggressive urban environment of Cairo, characterized by high thermal loads and SO_x pollution, accelerates the dehydration of gypsum and the subsequent formation of brittle anhydrite. The EDX results further illuminate the functional 'recipe' of the stucco, identifying a specialized gypsum-lime-silica system. In this matrix, the lime serves as a carbonated binder to enhance workability, while the silica (quartz) acts as a structural reinforcement to mitigate shrinkage [20]. However, the presence of aluminosilicates (clay minerals) and carbonaceous particles points to the detrimental impact of urban aerosol loading. These external particles, combined with the higher solubility of the formed anhydrite, create a highly vulnerable surface. If these harsh environmental conditions persist, the progressive loss of the binding matrix will lead to the irreversible detachment of the decorative stucco layers [21,22]. XRD analysis confirms that gypsum ($CaSO_4$. $2H_2O$) remains the predominant mineral phase in the stucco matrix [23]. However, its presence on the outer surfaces is likely influenced by recrystallization processes driven by the unique architectural positioning of the consoles. Located at the upper extremities of the facades, these elements are topped by flat areas that lack proper drainage outlets, creating "water traps" for rainfall. This architectural vulnerability simulates the effects of capillary rise from groundwater, even at elevated heights, maintaining a state of constant humidity within the stucco fabric. The detection of halite (NaCl) within the samples is diagnostic of the geochemical context of the Egyptian soil and the aggressive urban environment [24]. The high solubility of sodium chloride allows it to migrate through the masonry, reaching the upper decorative consoles where it undergoes repeated crystallization-dissolution cycles. These cycles, coupled with thermal fluctuations, generate internal expansive pressures that lead to the observed grain disintegration and loss of aesthetic features [25,26]. Furthermore, the XRD data provides evidence for the gypsum-to-anhydrite phase transition, a critical degradation pathway in industrial urban environments. As atmospheric pollution and SO_x particulates react with the moisture-laden surface, they accelerate the dehydration of gypsum into the anhydrous phase ($CaSO_4$) [27]. Unlike the original binder, this secondary anhydrite is highly friable and tends to shed as a fine powder, leading to the gradual "obliteration" of the intricate Mamluk and Mohamed Ali-era carvings. The synergistic effect of high porosity (52.83%) and air pollution facilitates deep penetration of these pollutants, significantly compromising the mechanical integrity of the ornaments and threatening the structural stability of the entire facade if left untreated. Identification of fungal isolates from the stucco consoles reveals a significant biological dimension to the degradation process. The presence of *Aspergillus* in both Cairo and Man-soura samples indicate its high adaptability to diverse Egyptian microclimates [28]. However, the exclusive appearance of *Penicillium* in the Shennawi palace (Mansoura) samples is a diagnostic indicator of the higher relative humidity and lower seasonal temperatures characteristic of the Delta region, which favour the growth of this specific genus. The colonization by these microorganisms is not merely a surface aesthetic issue; it represents a serious biodeterioration mechanism. Fungi contribute to the mechanical breakdown of the stucco through hyphal penetration into the high-porosity matrix (52.83%), leading to internal micro-cracking and grain detachment [29,30]. Chemically, these species excrete organic acids (such as oxalic and citric acids) as metabolic by products, which react with the calcium-bearing phases of the gypsum-lime binder. This bio-chemical reaction facilitates the dissolution of the binder and the formation of secondary minerals, further compromising the structural integrity of the decorative consoles. While global studies, such as those conducted in temperate climates like Poland, highlight the health risks of mycotoxins in residential buildings. The synergy between high moisture levels trapped by the architectural "water traps" discussed previously and the metabolic activity of *Aspergillus* and *Penicillium* creates a biofilm that retains pollutants and accelerates chemical weathering. Therefore, the mycological findings underscore the urgent need for biocidal treatments as an integral part of any future conservation strategy for these historical facades.

5. Conclusion

The analytical investigation confirms that the stucco decorations primarily consist of a composite gypsum-lime binder system. The degradation of this matrix is driven by complex phase transformations, specifically the dehydration of gypsum to brittle anhydrite and the moisture-triggered formation of expansive ettringite and thaumasite application of micro-destructive techniques (SEM-EDX and XRD) revealed that high porosity and architectural 'water traps' (flat tops of consoles) facilitate these destructive reactions. To ensure sustainable preservation, the following stucco conservation recommendations are proposed: Water management: Installing lead or zinc flashings on flat console tops to prevent rainwater stagnation. Desalination: using deionized water poultices to extract soluble halite salts. Consolidation: applying nano-lime dispersions to re-establish the carbonated network, ensuring mineralogical compatibility with the original lime-gypsum matrix. Biological control: targeted application of biocides to mitigate Aspergillus and Penicillium colonization. This integrated diagnostic approach provides a scientific foundation for compatible restoration interventions, moving from descriptive analysis to evidence-based preservation.

Reference

[1] Afifi, H. & Geweely, N., Galal, H., et al. (2016). Antimicrobial activity of gold nanoparticles (AuNPs) on deterioration of archaeological gilded painted cartonnage, late period, Saqqara, Egypt. *Geomicrobiology. J*. 33 (7), doi: 10.1080/01490451.2015.1062064.

[2] Afifi, H., Galal, H. & Ali Hassan, R. (2020) Characterization of pharaonic cartonnage from a late period, Saqqara excavations, *Pigment & Resin Technology*. 49 (4): 255-264

[3] Kamel, A., Marie, H., Ali, M., et al., (2014). Chemical and physical characterization of the stucco mihrab of the mausoleum of Muhammad Al-Hasawati, Fatimid period, Cairo, Egypt. *Periodico di Mineralogia*. 83 (3): 313-327.

[4] Durga B. (2020). Stucco as a building material - A study of its composition, use and scientific analysis. *J. of Multidisciplinary Studies in Archaeology*. 8 (2): 662-679.

[5] Nyein, W. (2018). Significant features of stucco art from ancient monuments in Bagan. *Dagon Univ. Research J*. 9 (1): 339-345.

[6] Eunice S., Said J., Luís M., et al. (2013). Historical stuccowork techniques inspire new formulations. *Construction & Building Materials*. 48: 858-867.

[7] Abdelrahim, Sh., Mohammed, A., Afifi, H., et al., (2026). Characterization of the architectural stucco rococo style of El-Sakakini palace facades, Cairo, Egypt (Analytical and investigation study). *Shedet*. 15 (1): 310-324.

[8] Qasim, A. & Abd Alghani F. (2022). Human ornaments. An inherited architectural element. *J. of Tourism Hotels & Heritage*. Vol. 5 (2): 285- 306

[9] Ahmed, M. & Ali, M. (2022). The architectural and decorative units and elements in the façades of some residential buildings in the city of Mit Ghamr during the era of Muhammad Ali dynasty: "An artistic archaeological study". *J. of Archaeological Research & Studies*, 11, doi: 10. 21608/Archmu.2022.263990 (In Arabic).

[10] Abdelrahim, S., Elnagar, K. & Mohamed, A., (2020). Analytical study and conservation processes of late period limestone canopic jar: Case study, Scientific *Culture*, 6 (1): 25-38

[11] Honeyborne, D. (1990). Weathering and decay of masonry. In: Dimes, F. & Ashurst, J. (eds.) *Conservation of Building & Decorative Stone*, Vol. 1, Butterworth-Heinemann Pub., Oxford, pp. 153-178.

[12] Geweely, N. & Afifi, H., (2011). Bioremediation of some deterioration products from sandstone of archaeological Karnak temple using stimulated irradiated alkalothermophilic purified microbial enzymes. *Geomicrobiology J*. 28 (1): 56-67

[13] Kamel, A., Marie, H., Mahmoud, H., et al., (2014). Technical examination and restoration of the stucco decorations of Al Hasawaty mihrab, Fatimid period, Cairo, Egypt. *IJCS*. 5 (4): 469-478

[14] Khalil, M. & El-Eashy, A. (2011). Analysis of the Architectural heritage of El-Mansoura city. Egypt towards urban conservation approach. In: Macchia, A., Greco, E., Chiarand, B., et al. (eds.) *Youth in Conservation of Cultural Heritage (YOCOCU)*, Italian Association of Conservation Scientist, Rome, 437-444.

[15] Elsebaei, S. & Hamaiel, S. (2025). Weathering and Its Geomorphologic impact on heritage buildings at Mansoura city, Nile delta, Egypt: A Geomorpho archaeologic Study, *J. of Sustainable Development in Social & Environmental Sciences*. 4 (1): 29-59.

[16] Motawea, A-G, El-Hossary, F. & El-Gohary, M. (2023). condition assessment of the Osiris chapel wall paintings in Seti-i temple, Abydos - Egypt. *EJARS*. 13 (1): 75-90.

[17] Abdel Moneim, E.; Mansour, M.; Ali, M. (2024). An evaluation study on the reassembly of inscribed stone pieces in the grand Egyptian museum. *EJARS*. 14 (2): 191-197.

[18] Duran, A., Herrera, L., Jimenez de Haro, M., et al., (2008). Non -destructive analysis of cultural heritage artefacts from Andalusia, Spain, by X-ray diffraction with Gobel mirrors. *Talanta*. 76 (1): 183-188
[19] Mantler, M. & Schreiner, M. (2000). X-Ray fluorescence spectrometry in art and archaeology, *X-Ray Spectrometry*, 29 (1): 3-17.
[20] Marocchi, M., Dellisanti, F., Maria, G., et al., (2010). SEM-XRD Investigation of deterioration morphologies consolidation prior to restoration: The case of Port a Nuovain Ravenna (Italy). *Periodico di Mineralogia*. 79 (1): 81-93.
[21] Marcos, L., Oliveira, S., Dario, C., et al., (2019). Historic building materials from Alhambra: Nanoparticles and global climate change effects. *J. of Cleaner Production*. 232: 751-758.
[22] Elsen, J. (2006). Microscopy of historical mortars. *Cement & Concrete Research*. 36 (8): 1416-1424.
[23] Fassina, V., Benchiarin, S. & Molin, G. (2019). The decay of Nanto stone in an outdoor-sheltered environment in the cloister of saint Anthony basilica in Padova. *EJARS*. 9 (2): 115-127
[24] Addis, A., Secco, M., Preto, N., et al., (2016). New strategies for radiocarbon dating of mortars: Multistep purification of the lime binder. In: Papayianni, I., Stefanidou, M. & Pachta, V. (eds.) *Proc. of 4th Historic Mortars Conf. (HMC 2016)*, Aristotle Univ. of Thessaloniki, Greece, 665-672.
[25] Steiger, M., Charola, A. & Sterflinger, K., (2014). Weathering and deterioration. In: Siegesmund, S. & Snethlage. R. (eds.) *Stone in Architecture*. Springer. Berlin, 227-316.
[26] Abdel-Ghani, M., Afifi, H., Mahmoud, R.., et al. (2020). Graeco-Roman Egyptian cartonnage from the Egyptian museum in Cairo, Egypt: Technical and analytical investigation, *J. of Archaeological Science: Reports*. 31, doi: 10.1016/j.jasrep.2020.102360.
[27] Salavessa E., Jalali, S., Luís, M., et al., (2013). Historical stuccowork techniques inspire new formulations. *Construction & Building Materials*. 48: 858-867.
[28] Piontek, M., Łuszczyńska, K., & Lechów, H., (2016). Occurrence of the toxin-producing Aspergillus versicolor Tiraboschi in residential buildings. *Int. J. of Environ. Res. & Public Health*. 13 (9) doi: 10.3390/ijerph1309 0862.
[29] Bloom, E., Bal, K., Nyman E., et al., (2007) Mass spectrometry-based strategy for direct detection and quantification of some mycotoxins produced by Stachybotrys and Aspergillus spp. in indoor environments. *Appl & Environ Microbiol*. 73 (13): 4211-4217
[30] Hunter, C. Grant, C., Flannigan, B., et al. (1988). Mould in buildings: The air spore of domestic dwellings. *Int. Biodeterioration*. 24 (2): 81-101