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ANALYSIS AND TREATMENT OF MURAL PAINTINGS COVERED WITH PLASTER LAYERS IN YAKAN HOUSE IN HISTORIC CAIRO

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***Abstract**:*
Yakan House is one of the historical houses in Cairo, dating back to the beginning of the nineteenth century. The house was neglected until its elements deteriorated until it was owned by a person interested in heritage who pledged to preserve it to become a cultural center to revive traditional crafts after architectural restoration. During the architectural restoration, blurred and unclear wall paintings dating back to the era of construction were discovered, and they were covered with a thick layer of mortar. Therefore, the research aims to study the discovered wall paintings and remove the plaster layer that covers them by modern mechanical, chemical and scientific detection methods. It was photographed using infrared (FTIR) and ultraviolet rays, and was examined using light microscopy and examination and analysis electron microscopy (SEM-EDAX).It has been identified that the preparation layer consists of calcite ($CaCO_3$), quartz (SiO_2) and gypsum ($CaSO_4.2H_2O$), and that the dark blue color is composed of lapis lazuli, and that the purple color is a result of mixing blue and red together, and that the brown color is a mixture of red with the black. As for the dark yellow color, it consists of iron oxide (goethite). And through the analysis (FTIR) it was found that the adhesive used to bind the coloring material is gum arabic. Then the mural was treated, and this included removing the thick mortar layer with mechanical and chemical cleaning, replacing the damaged layers of preparation, and strengthening and fixing the discovered drawings.

Keywords:
Yakan House
Mural paintings
Lapis lazuli
Purple, infrared
Ultraviolet

1. Introduction

The Yakan house is one of the historical houses in Al-Darb Al-Ahmar district. It is located next to Sabil Hassan Agha, overlooking Souk El-Salalah Street. This area includes a set of historical Islamic buildings dating back to different eras from the 15^{th} century to the twenty-first century, which have preserved their original shape, as the street was planned within Khedive Ismail's plans to modernize Cairo [1,2]. The house dates back to the era of Muhammad Ali, the founder of modern Egypt. Many buildings were established during the reign of Muhammad Ali and his family (1769-1849) [3]. Muhammad Ali gave this house to his nephew, Ahmed Pasha Yakan, who was the governor of Mecca and Hijaz and a member of the Yaqan family that was famous for its wealth and military power during the reign of Muhammad Ali [4]. A plan of Yakan's house and the location of the wall paintings are shown in Fig. (1) [5].

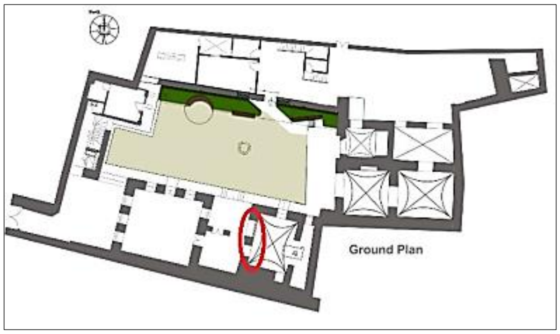


Figure (1) Shows a plan of the ground floor of Yakan's house and the location of the murals paintings.

Ahmed Pasha Yakan restored the house after erasing many elements to show the prevalent Baroque character during that period. The family stayed in this house until the end of the seventies, after which it was subjected to deterioration and lack of maintenance [6]. Then, the house's ownership was transferred to one of those interested in heritage, who pledged to preserve and restore it to become a scientific and cultural center in which training workshops were held to revive traditional crafts and integrate the house and the surrounding community through various cultural activities [7,8]. However, it became a community center for drawing up plans and developments for future neighborhoods [9]. The house was restored in accordance with the principles of restoration and additions following the Venice Charter of 1964 [10, 11]. Executed murals were discovered on one of the house's walls, fig (2-a, b, c), during the architectural restoration process.

Figure (2) Shows **a.** the main entrance of the Yakan house, **b.** the mortar covering murals, and **c.** the mural paintings discovered after removing the mortar layers.

These murals are important because they are not just work of art, but they contain information about the artistic and decorative style used in the house since its construction [12]. They were covered with a thick layer of mortar in some places; in others, the layer was thin and weak, as it helped us discover the murals during the restoration. This research paper illustrates how to remove the old mortar layer covering the surface of the wall paintings by various mechanical methods where viewing windows were used, and a complete survey was made to identify the sites of the implementation of the wall paintings using scientific methods, such as infrared imaging (IR) and ultraviolet (UV) imaging- multispectral imaging under different wavelengths from ultraviolet to near infrared [13]. It is an important non destructive tool for detecting and photographing frescoes [14]. First aid was given to the discovered wall paintings to prevent an environmental shock. Then, a light microscope was used to study the color layers, and a scanning electron microscope (SEM-EDS) with an X-ray scattering unit was used to determine the preparation layer and the coloring layers. Then, the color medium was identified using infrared analysis. The murals were processed, including removing the mortar layer, mechanical and chemical cleaning, replacing damaged preparation layers, removing and reinforcing mural paintings, fixation, and strengthening by modern methods [15, 16].

2. Materials and Methods

2.1. *Samples*

During the architectural restoration of the house, samples were taken from the weak places of the paint layer that covered the walls and the wall paintings that were uncovered, including the preparation layer and the painting layers (blue, purple, brown, and dark yellow).

2.2. *Mechanical and chemical detection methods of mural paintings*

The mural painting covered with a plaster layer was revealed using mechanical tools, scalpels, and various cutting tools—chemical detection using chemical solvents to soften the plaster layer to facilitate the detection process.

2.3. *UV and IR imaging*

The mural paintings were imagined after mechanical detection by removing the thick layer of mortar. There was a very thin layer of lime. Before removing this layer, different electromagnetic wavelengths of visible light (VIS), near-infrared (IR), and ultraviolet (UV) with special filters were used [17]. The imaging was done with 40-watt fluorescent lamps, and the reflected radiation was recorded by cameras sensitive to this spectrum region [18]. UV imaging was done by a Canon® EOS Canon EOS 5D Mark III camera characterized by a 100 mm focal length, f/6.3 exposure T of 25 seconds, and wavelength of 368 nm. Moreover, infrared imaging was done at a wavelength of 830-1000 nm, with a FUJIFILM IS pro camera characterized by a focal length of 60mm, f/16, exposure time of 30 seconds, ISO100, and no flash.

2.4. *Optical microscopy (OM) investigation*

Pigment samples and cross-sections of painting layers were examined by a smart-eye USB digital microscope with different magnifications to determine the morphological and visual features of the colors and identify the stratigraphic sequence of the mural painting layers [19].

2.5. *Scanning electron microscopy (SEM-EDS) investigation and analysis*

Samples of painting were examined and analyzed to identify the components of the color material and prepare layers using SEM (JEOL JSM 5400 LV: EDX Link ISIS – Oxford Detector High Vacuum).

2.6. *Fourier transforms infrared attenuated total reflectance (FTIR-ATR)*

Samples were analyzed with an FTIR spectrometer (Model 6100 Jasco, Japan). Spectra were obtained in the transmission mode with a TGS detector and using ATR crystal representing (2mm/sec) co-added scans at spectral regions ranging from 4000 to 400 cm^{-1} with a 4 cm^{-1} resolution charge.

3. Results

3.1. *Mechanical and chemical detection of mural paintings*

The mortar layer was removed mechanically by shaking the outer layers with blunt tools. Since the lime and gypsum layer was weak and convertible into powder until the borders of the murals appeared, the illustrated spaces were revealed carefully. Windows were used for mechanical detection. Then, the remaining paint layer was softened with a diluted chemical as an aid during detection and removal in some cases, as ethyl alcohol and water were used in a ratio of (1:1) and then in a ratio of (1:2) when approaching the surface of the mural paintings to soften divided into squares and numbered, and the layers were removed one by one, fig (3-a, b, c, d).

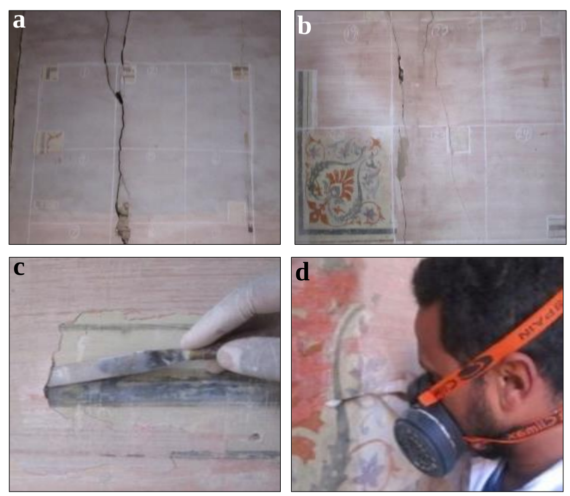


Figure (3) Shows **a.** & **b**. dividing the wall before mechanical detection and the appearance of the borders of mural paintings, **c.** the detection of the lower part of mural paintings, **d.** the detection methods by water and alcohol.

3.2. *UV and IR scientific imaging*

We did not conclude any noticeable results of the wall decorations by UV imaging. However, a light blue color appeared as evidence of using zinc oxide in the mural paintings. Additionally, the color had glare and intensity, possibly resulting from some interventions, such as previous restoration [20]. As for infrared imaging, fig (4-a, b), good results were obtained in identifying the method of implementing murals. They showed that the Shablona method was used, a widespread method in Egypt, especially in printing by emptying the drawing points before implementation, fig (4-c, d).

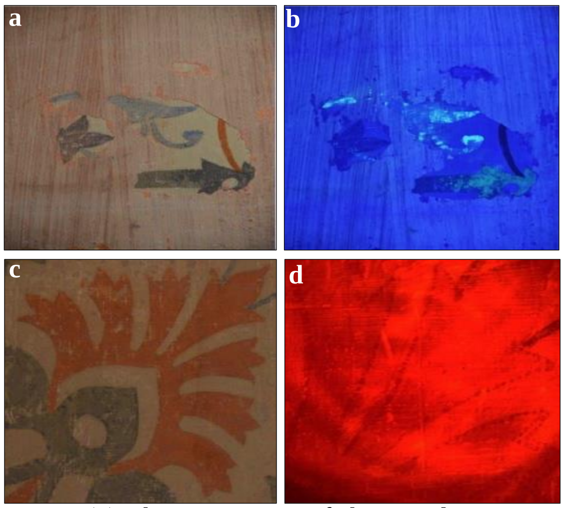
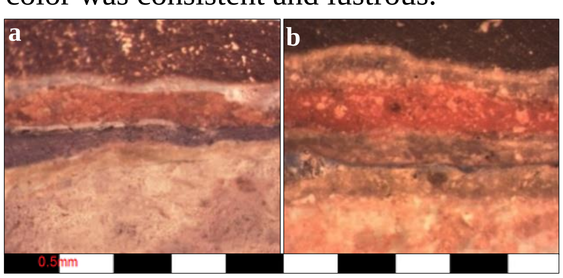


Figure (4) Shows imaging of the mural paintings by **a.** visible light **b.** UV, **c.** visible light, **d.** IR where the The technique of implementation known as the Shablona technique

3.3. *OM investigation*

By examining the layered structure of the mural paintings in the Yakan House using the Smart-Eye USB digital microscope, it was found that the structure was a rough preparation layer, followed by the coloring layer, and then the smooth thin surface layer. The results showed blue, fig (5-a), purple, fig (5-b), brown, fig (5-c), and dark yellow, fig (5-d). In most samples, the color was consistent and lustrous.



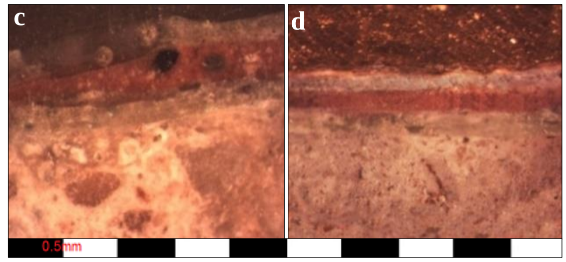


Figure (5) Shows a stratigraphic section of the painting layers in Yakan House, **a.** blue color layer, **b.** purple color layer, **c.** brown color layer, **d.** dark yellow color layer.

3.4. *SEM-EDS investigation and analysis*

3.4.1. Preparation layer

SEM examination of the preparation layer showed that it consisted of weak, non coherent granules of lime and sand grains and a small percentage of gypsum. EDS analysis illustrated that the sample contained calcium by a large percentage of 27%, indicating that the main component of the preparation layer was lime, which resulted from the conversion of Ca $(OH)_2$ to calcite by carbonation [21]. Calcium hydroxide absorbs carbon dioxide and gives calcium carbonate [22]. Additionally, a small percentage of gypsum was found as the sulfur element S appeared at 1.3%, which may indicate the addition of gypsum to the preparation layer, some transformations resulting from moisture, and the transformation of lime into gypsum. Silicon (0.48%) resulted from adding some sand to the preparation layer to improve its mechanical properties. There were some other elements, such as sodium Na (1.56%) and chlorine Cl (0.96%), as a result of the presence of sodium chloride salt, which could be the source of natural impurities in sedimentary rocks [23] and the effect of the groundwater level, affecting many archaeological monuments in Historic Cairo [24], tab. (1) & fig. (6-a,b).

3.4.2. Blue pigment

SEM examination of the blue color showed that the color grains were homogeneous with loss in some areas, with a calcareous layer covering the color before it was detected. EDS analysis illustrated that the blue color layer consisted of some elements, including Zn (33.17%), Al (2.9%), Si (4.04%), Mg (0.75%), Ca (9.44%), S (5.57%), and C (7.72%). These elements suggested the use of blue lapis lazuli $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$) that was used for the first time in the fifteenth and eighteenth centuries with the name ultramarine [25]. The blue color was observed in the tombs of Muhammad Ali in the same era as the wall paintings [26]. The presence of Si and Mg could be impurities [27-29], and the presence of the Cl (1.55%) denoted chloride salts in the preparation layer. Ultramarine blue was identified in an Ottoman Islamic house in Cairo [30,31], tab. (1) & fig. (6-c,d).

3.4.3. Purple pigment

SEM examination of the purple color sample showed that the color granules were fine, coherent, and mixed with dirt residues that covered the surface of the color. EDS analysis illustrated that the color sample contained Zn (10.01%), Ca (28.24%), Na (3.79%), Si (1.69%), Al (0.85), Mg (0.49%), Fe (2.9%), and Cl (4.07%), resulting from the presence of chloride salts and sulfur S (3. 26%) as a result of the presence of gypsum in the preparation layer. The presence of these elements indicated that the sample contained lapis lazuli $(Na,Ca)_8(AlSiO_4)_6(SO_4,SCl)_2$) and red hematite, denoting that the color was a mixture. Additionally, the presence of calcium and quartz in the preparation layer, Al, Cl, S and Zn, as well as the residues of the preparation layer, indicated that the purple color was a mixture of blue and red. Purple was spotted with Islamic murals in Al-Moayyad Bimaristan [31], tab. (1) & fig. (6-e,f).

3.4.4. Brown pigment

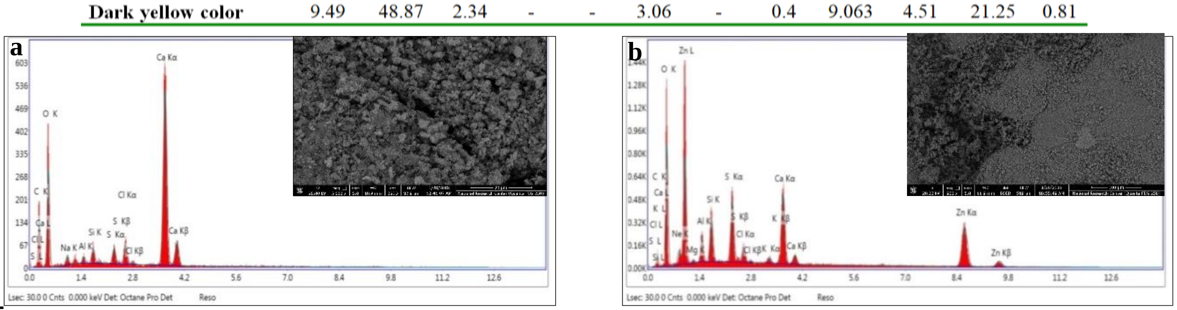
SEM examination showed that the brown layer was homogeneous with small granules. EDS analysis illustrated that the sample contained Ca (18.39%), Na (2.95%), Si (4. 091%), Cl (1.05%), S (9.012%), and Fe (3. 05%)- the characteristic element for the red color- and carbon C (7.98%)- a characteristic for the black color, indicating that the brown color sample was a mixture of red and black. The black color is composed of carbon, one of the oldest known pigments [32], tab. (1) & fig. (6-g,h).

3.4.5. Dark yellow pigment

SEM examination showed that the dark yellow layer appeared clear and distinct, as its crystals appeared in different sizes, and there were internal voids between the crystals. EDS results illustrated that this color contained Ca (21.25%), Si (4. 51%), and Na (2.34%). These elements were the main component of the preparation layer. Other elements were CL (0.81%), S (9.063%) as a result of the presence of gypsum in the preparation layer, C (9.49%) and Fe (3. 06%), the main component of the yellow goethite mineral, indicating the presence of hydrated iron oxide (FeO (OH) (goethite), fig. (6-i,j).

Table (1) EDS results of the investigated color layers

Sample	Elements %											
	C	*O*	*Na*	*Mg*	*Al*	*Fe*	*Zn*	*K*	*S*	*Si*	*Ca*	*Cl*
Preparation Layer	18.11	49.31	1,56	-	0.62	-	-	-	1.3	0.48	27	0.96
Blue color	7.27	35.82	0.79	0.75	2.9	2.03	33.17	0.7	5.57	4.04	9.44	1.55
Purple color	12.09	33.57	3.79	0.49	0.85	_	10.01	0.52	3.26	1.96	28.24	4.07
Brown color	7.98	49.31	2.95	-	2.64	3.05	-	0.6	9.012	4.091	18.39	1.05
Dark yellow color	9.49	48.87	2.34	-	-	3.06	-	0.4	9.063	4.51	21.25	0.81



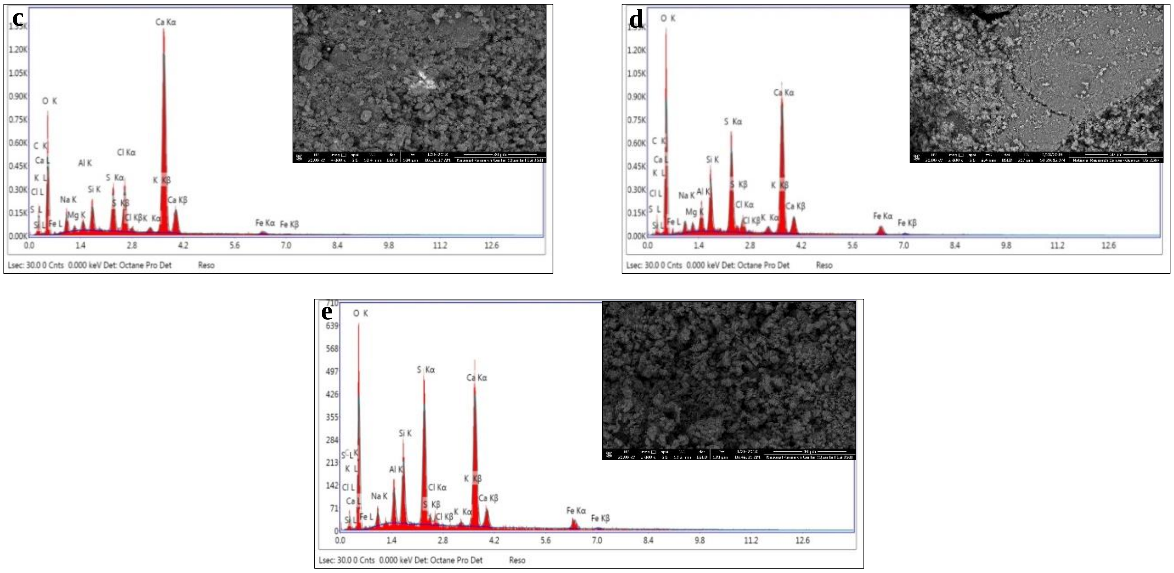


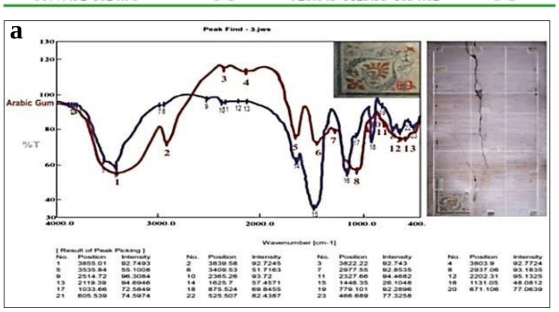
Figure (6) Shows EDS pattern and SEM image of **a.** the preparation layer, **b.** the blue pigment, **c.** the purple pigment, **d.** the brown color, **e.** the dark yellow pigment layer.

3.5. *FTIR-ATR results*

The results of the FTIR analysis of the color samples taken from the wall paintings in the Yakan house demonstrated that gum Arabic was the organic material used to bind the colors blue, purple, brown, and dark yellow to the preparation floor according to the resulting functional groups and compared with the standard sample [33-36], tab. (2) & fig. (7-a,b,c,d). Also, some components of the preparation layer, such as calcium and gypsum, were identified [37,38].

Table (2) Main function groups from the color layer.

Wavelength	Functional groups	Wavelength	Functional groups
Pink		**Blue**	
3535.84-3409.5	O-H	3407-3533.92	O-H
2977.55-2937.6	C-H	2927.41	C-H
1635.7	O-H	1644.73	O-H
1446.35	C-H	1460.81	C-H
1033.66-1131.5	C-O	1126.22	C-O
Dark yellow		**Brown**	
3528.13-3409.53-3691.09	O-H	3411.46	O-H
2931.27	C-H	2964.5-2860.88	C-H
1428.99-1323.89	C-H	1448.28	C-H
8077.452-1024.98	C-O	920.843-1123.33-1034.62	C-O



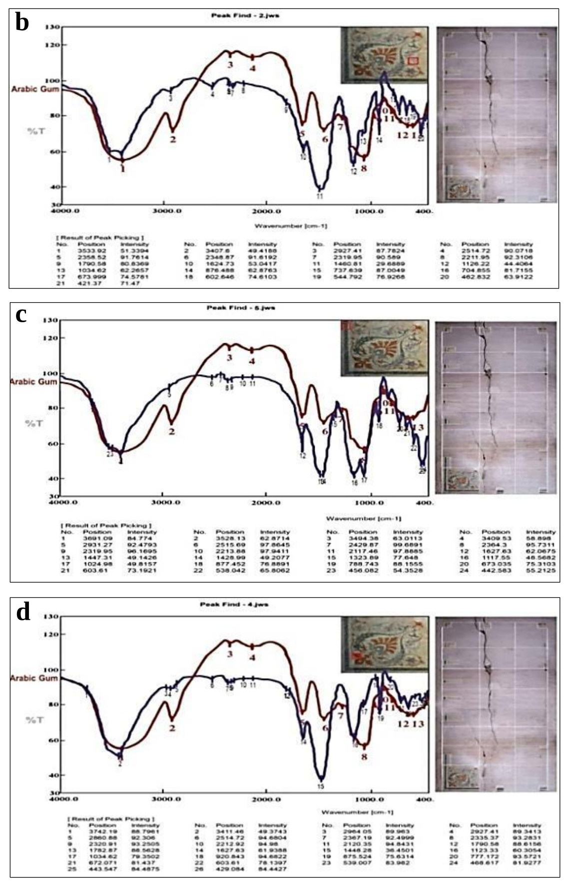


Figure (7) Shows the FTIR pattern of samples from the color layer; a. the purple color, b. the blue color, c. the brown color, d. the dark yellow color

4. Discussion

Some colored murals were discovered in Yakan House by making viewing windows so that the layers of the murals would not be affected. They were examined and analyzed. Examination by the light microscope showed that the stratified structure consisted of a rough preparation layer, followed by another smooth layer, and then the color layer. It was found that this layer was due to some recent renovations and additions by successive residents. SEM and EDS examination and analysis of the preparation layer revealed that the preparation layer contained elements that confirm the use of lime with a small percentage of gypsum and sand. The presence of calcium, sulfur, and silicon was proved. The blue color could be lapis lazuli blue, used for the first time in the 5^{th} and 18^{th} centuries and was called ultramarine [39]. The color purple contained hematite, indicating the color red; therefore, it could be said that the color pink was a mixture of blue and red. The purple color was also found in the Islamic mural in Bimaristan al-Mu'andid [40]. It was proved that the brown color was a mixture of hematite and carbon, as indicated by the presence of iron, the characteristic element for the red color, and carbon, the characteristic of the graphite mineral, to its black color [41]. The dark yellow color contained elements, such as calcium and silicon, which were the main component of the preparation ground. Iron was present in proportion to the basic component of the mineral goethite, giving the yellow color that indicated the presence of hydrated iron oxide (FeO(Oh) (goethite). Sodium and chlorine confirmed the presence of impurities of chloride and sulfate salts, either as a result of gypsum in the preparation ground or as a result of ground moisture that contained salts in most Islamic and historical buildings in Cairo. A set of display windows were implemented on the paint layer in separate areas, with an area for determining the locations of the murals under the mortar layer. They were detected and examined with (UV and IR) lamps to identify the details of the mural [42]. After the discovery, a preliminary restoration was carried out, as it was exposed to different environmental conditions of heat and humidity in order not to subject the discovered color layers to shock, as some separated crusts were fixed by a primer acrylic ac-33 in 15% water [43]. After that, the stage of removing and reinstalling the wall paintings took place, and the removal was resorted to due to the existence of architectural problems in the wall of the murals, as there was a layer of Japanese paper [44]. They were placed with approximate dimensions commensurate with the size of the wall murals to be removed and installed with carboxymethyl cellulose adhesive for all the discovered decorations in preparation for the removal process. After that, the murals and the places for cutting and removing them defined in this way were documented. The colored layer was removed with part of the preparation layers to preserve the decorations. After removal, a slurry consisting of calcium carbonate and fine sand was used to be the same slurry used in the preparation layers. It was reinforced with the raw material to improve its physical and mechanical properties, and then it was reinforced with fiberglass. The murals were stored in special boxes and then treated so that they would not be damaged again due to architectural problems.

5. Restoration Processes

5.1. *Detection of colored murals*

A group of detection windows was implemented with the surface paint layer in separate areas with an approximate area of 40×40 cm, fig. (8) to locate the colored murals. It was found that there was a decorative frame with the appearance of the remains of preliminary indications of the presence of wall decorations in the upper part and the corners, but the lower parts of the wall were devoid of decorations. The surface layer of paint was removed mechanically. Since the main component of the paint was lime, characterized by poor cohesion and ease of removal until the appearance of the mural, great care was given not to lose or distort any details of the murals.

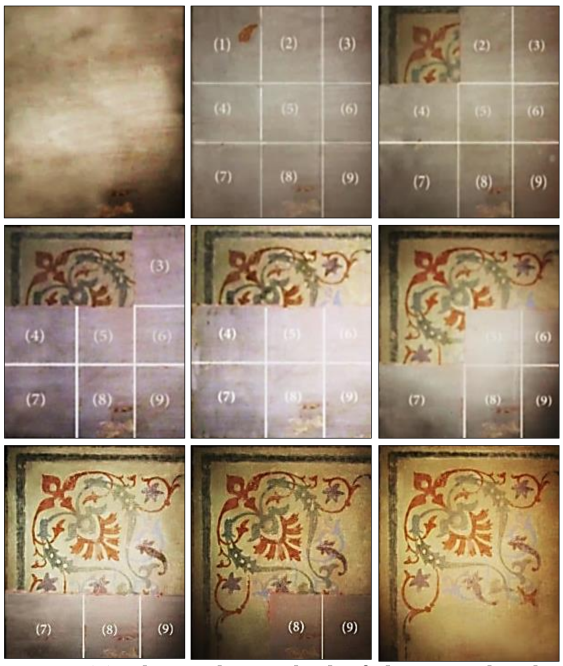


Figure (8) Shows the method of detection by the mechanical method regularly through successive squares and a set of display windows to identify the locations and boundaries of the murals before revealing them.

5.4. *Detection using ultraviolet and infrared imaging*

To identify the details of the mural under the thin layer of lime, multispectral imaging was used under different wavelengths, from ultraviolet to near-infrared [45]. It is one of the non-destructive methods by which the subsurface layers of wall paintings can be detected [46]. The surface was photographed after exposure to ultraviolet lamps and imaging after exposure to infrared lamps. The results illustrated it was possible to identify the details of the murals, fig. (3-g & h).

5.2. *First aid*

After revealing the wall paintings that appeared for the first time after they were covered with a layer of mortar, first aid was carried out to them so that they would not be subjected to environmental shock. They were reinforced with Paraloid B72 at a 1: 2% ratio Sytonx30 (ethyl silicate) was also used to bind fragile parts [48]. The separated scales were fixed by Primal AC-33 in 15% water [49].

5.3. *Mural paintings detachment and re-attachment*

After cementing the surface and colors of the wall paintings, and then treating the fine cracks and the separated layers, injections were made using a diluted calcareous mortar that preliminary supported, then completing the missing parts of the preparation layer with a mortar consisting of calcium carbonate and fine sand to level the mortar at the same level as the surface of the colored layer, and then it was covering the surface with a protective layer of Japanese paper, fig. (9-a,b). Approximate dimensions commensurate with the size of the wall paintings to be removed and fixed with carboxymethyl cellulose adhesive for all the discovered decorations in preparation for the removal process. The cut-outs were located devoid of decoration around the wall panels for ease of separation, fig. (9-c, d, e, f). The cutting was done with a part of the preparation layers with a thickness of 3: 5 cm with great care [50]. The removed pieces were stored in wooden boxes of appropriate dimensions compatible with the size of each piece, lined from the inside with pieces of foam, and numbered according to the work map, fig. (9-g). After completing the architectural restoration of the wall, the wall panels were reinstalled using an alternative carrier of sand and lime reinforced with fiberglass, with dimensions compatible with those of the removed pieces, fig. (9-h). In some cases, it required using stainless steel bars with a length of 35 cm and about 4 cm, fig. (9-i, j, k). The outer framework of the panels was completed with a sand-lime mortar, fig. (9-l), removing the protective layer, cleaning the decorations, and then reinfo-rcing them, fig. (9-m).

Figure (9) Shows **a., b.** a surface protection layer (facing) by Japanese paper and carboxymethyl cellulose, **c.** documenting mural painting, defining edges and places of cutting, the stages of the restoration of the murals, **d.**, **e.**, **f.** removal of the non-decorated parts around the mural for ease of separation; **g.** protection and storage of separate murals in foam-wrapped boxes, **h.** adding a layer of fiberglass to reinforce the mortar, **i.**, **j.**, **k.**, preparation of stainless steel beams and joints, method of jointing and fixing between the wall panel and the wall, **l.** completion of the outer frame of the panels with a mortar consisting of lime and sand, **m.**, **n.** the murals after mechanical installation, filling the edges with mortar, and removing the surface protection layer and cleaning.

6. Conclusion

Through the study of mural paintings executed in historic houses, the utmost importance of mechanical and chemical detection methods and modern methods of homes subjected to renovation or restoration. In most cases, there were murals with recent additions. The detection methods of the windows were the best mechanical ones by using scalable and spatulas through which the mural paintings and their limits were discovered. Chemical detection methods were utilized to remove the remains of lime layers using water and alcohol. Modern methods of detection and examination, such as 1R lambs, helped identify the implementation method of murals, namely the Shablona method. However, the recent detection of UV lamps did not bring anything new rather than identifying the glare of some elements. The digital microscope helped identify the paint layers which consisted of a coarse layer and a soft layer, then the paint layer, then the new layers added above the colors. The electronic microscope and the EDS unit identified the preparation layer, consisting of a large percentage of lime and a small percentage of gypsum and sand. They also determined the colors. The blue color was ultramarine, the pink color was a mixture of red and blue, the brown color was a mixture of red hematite (carbon black) was graphite black, the dark yellow color was goethite, and the binder used was Arabic gum. Moreover, some effective groups that illustrated lime and gypsum were identified. Then, the treatment and restoration processes were carried out. First aid was carried out to make localization of the detected images and color stability and included an injection of the mural paintings, fixing the fragments, making the protection layer(facing) using Japanese paper and carboxymethyl cellulose, removing the paintings by stucco, reducing the preparation layer, consolidating it by adding fiberglass strips, adding mortar to strengthen the preparation layers, reinstalling the paintings in their right place after treating the wall and mechanically fixing using stainless steel joints, filling around the paintings with the appropriate mortar, removing the facing, cleaning the paintings, and consolidating them, respectively.

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