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Original article

STUDY OF THE PAINTED DOME OF THE CHURCH OF ARCHANGEL GABRIEL, CAIRO

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Abstract
This study was carried out in preparation for the conservation of the oil painted dome of Archangel Gabriel church located at Haret El Saqqayeen in Abdeen (Cairo). Stratigraphic, chemical and environmental studies were conducted to examine the painting technique and to assess the conservation state of the dome. The dome was imaged using Multi-spectral imaging and samples were collected from representative areas. Cross-sections were investigated by the means of scanning electron microscopy coupled with dispersive energy of X-ray spectrometer (SEM-EDS) and stereo microscopy. Fourier transformed infrared spectroscopy (FTIR) and gas chromatography-mass spectroscopy (GC/MS) was employed for the identification of the paint medium. X-ray diffraction (XRD) and the colorimetric measurements were conducted for characterization the differences of hues between the original and non-original pigments. As a part of the study, the environment within the dome was measured with data loggers and gas sampling. The results showed that the painted dome dates back to two different periods. The older paintings were applied before 1907 and were covered by ground layers to be repainted in 1907. Non-professional over-painting and the uncontrolled indoor climate have a significant role in the deterioration phenomena of the dome.

Keywords: *Dome, Data loggers, Gas sampling, Multi-spectral imaging, Over paintings*

1. Introduction

The starting point for the restoration plan of any historically painted surfaces is to understand the original painting materials, technique and to assess their deterioration problems. This is not standard practice in most of the conservation process carried out in Egyptian historical churches. Authenticity is not taken into consideration due to the required research and employment of non-professional conservators: repainting is common which compromising appreciation of the physical history and original aesthetics. Furthermore, the wall paintings in churches pose many challenges due to a lack of environmental control and the absence of documentation of previous restoration interventions. This raises the need for intensive technical studies for the wall paintings and decorations in the Egyptian churches to document the techniques and conditions of wall paintings, with the goal of maintaining their authenticity and integrity. The Church of Archangel Gabriel is located at Haret El Saqqayeen in Abdeen district (Cairo). The story of the church building began when IV Pope Cyril of Alexandria (Ava Kyrillos IV) received permission from the Khedive Mohamed Saied pasha to build a church with Archangel Gabriel name. The building construction started on 15th November 1855. For this purpose, an appropriate place of El Kesway house was selected to be used as a temporary chapel for performing the liturgies for approximately 25 years. In 1881, three other houses were bought for the church expansion and construction works were carried out until the church was opened in 1884 [1]. The ceiling of Archangel Gabriel church is painted in a European style [2,3] brought to the Ottoman Empire and the Middle East since the second half of the 18th century [4]. While wall paintings at the beginning of the Ottoman Empire were commonly executed in either tempera or fresco techniques [5], these techniques started to be modified with European analogs to satisfy the needs of Mohamed Ali's renaissance era. The oil wall painting technique was executed using oil paints either directly on dried plaster layers or on other primed supports attached to the walls and ceilings [3]. The unique examples of oil wall paintings characterize few of royal historical palaces, mosques and churches in Egypt as El Gawhra palace [6], El Sakakini palace [3], Krabia School [7] and the Greek Orthodox church of Saint George [8]. The ceiling of Archangel Gabriel consists of twelve domes. The main oval dome is considered to be one of the rare domes due to its unusual depiction of the joyful annunciation. It shows the Archangel Gabriel joyfully heralds the Holy Virgin St. Mary by Christ birth while the pendentives are decorated with the four evangelists; Matthew, Mark, Lucca, and John. The other domes are depicted by colored geometric trappings, in which both facing domes are alike in their geometric colored trappings, fig. (1). The painted domes of Archangel Gabriel church were painted directly on dry plasters. One of the painted domes in the decorated ceiling (next to the main Apse) showed heavier deterioration than the others (such as darkening, losses, flaking, accumulation of dust and staining). Many different factors may influence the stability of the dome. These may be due to extrinsic factors as material interactions with uncontrolled environmental conditions of relative humidity, temperature [9], pollutants [10] infiltration of rainwater, salt weathering and bad ventilation. Being a worship place, the usage of incense and candles during praying [11] in combination with the presence of accumulated soot and dust from air pollutants also may lead to several physical, chemical and mechanical deterioration processes [12,13]. The church also suffered from serious structural problems due to the effects of the 1992 earthquake in Egypt. The church was also subjected to several restoration interventions before and after the 1992 earthquake including the interventions carried out by Michael Bakhoum in the 1960$_s$ for the architectural elements by building built process [1]. Non-systematic restoration interventions of walls, floors and ceiling insulation and over-painting of the paintings of the ceiling were recorded since 1994, fig. (2). The aim of this work is to study the painting materials, technique and condition assessment of the oil painted dome in the ceiling of Archangel Gabriel church, Haret El Saqqayeen in Cairo. Investigations included the relationship between uncontrolled environmental conditions, non -professional restoration interventions and the deterioration phenomena for the purpose of determining preventive procedures.

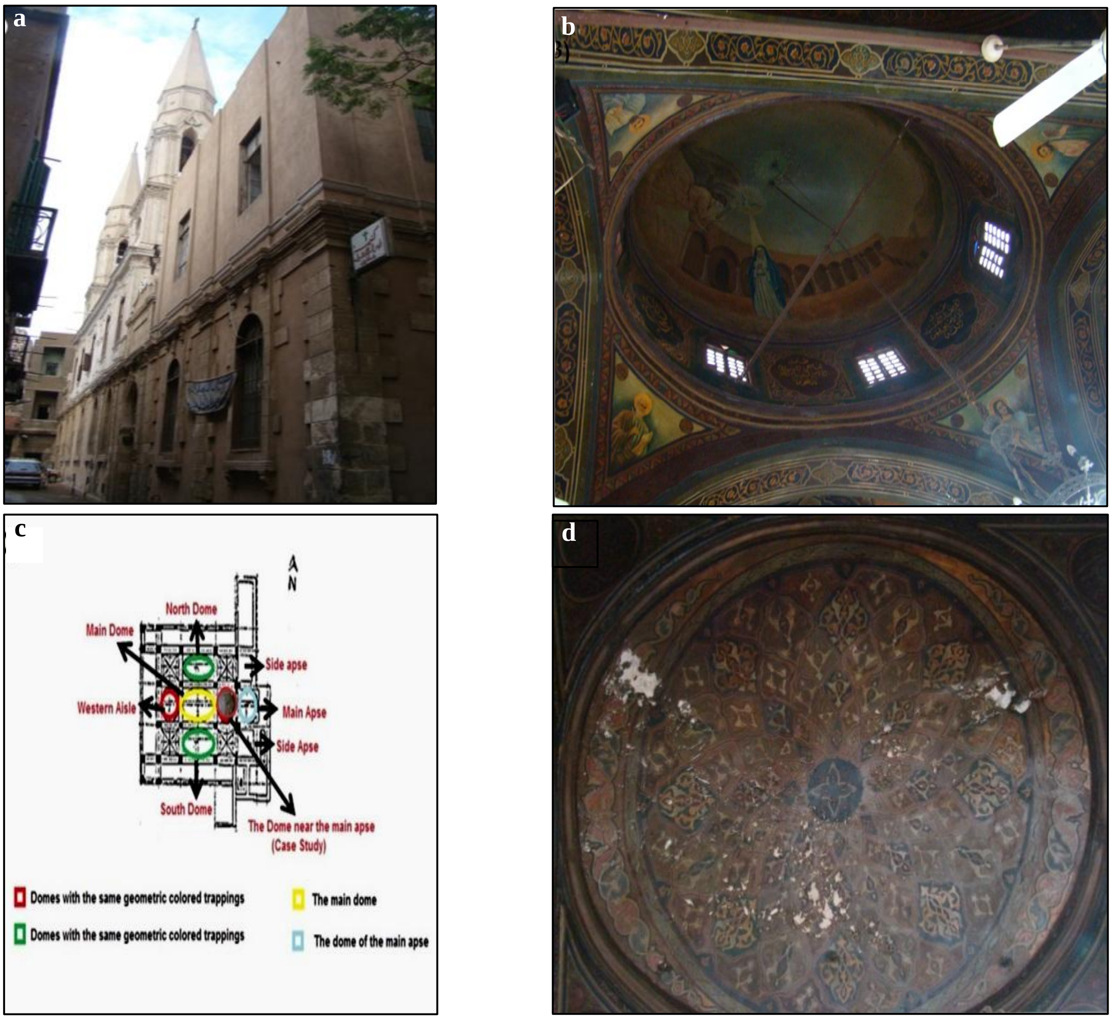

Figure (1) Shows **a.** out view of Archangel Gabriel church, Haret El Saqqayeen in Cairo, **b.** the central dome with the unusual depiction of the joyful annunciation in which the Archangel Gabriel joyfully heralds the Holy Virgin St. Mary by the Christ birth, **c.** & **d** the selected painted dome

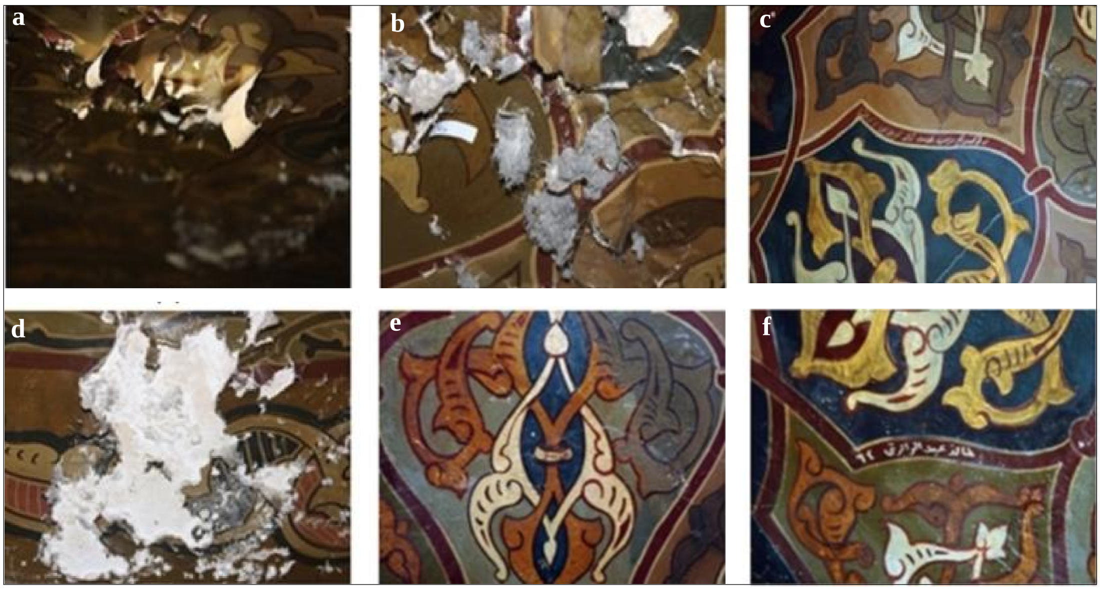

Figure (2) Shows examples of deterioration phenomena of the painted dome **a.** flaking, detachments, **b.** salt weathering, **c.** Conservator's signature, **d.** missing areas, **e.** & **f.** darkening and over-painting

2. Materials and Methods

2.1. *Condition assessment in situ*

2.1.1. Multi-spectral Imaging

To investigate the condition of the surface and the distribution of paints, a multispectral imaging system [14] has been used which operates in the range between 380-1100 nm in the visible (VIS), near-ultraviolet (UVA) and near-infrared (NIR) using a modified Fuji Film S5 DSLR camera and monochromatic area camera Artray ArtCam-150PIII with a Nikon AF-NIKKOR 35 mm f/2D. The multispectral images were collected and processed in the following modes: Visible (VIS), Infrared CCD. Reflected (IR), Infrared False Colors (IRFC), Ultraviolet Reflected (UVR), Ultraviolet Fluorescence (UVF), Ultraviolet False Colors (UVFC).

2.1.2. Colorimetric measurements

Colorimetric measurements were performed to study the differences between the hues of original paints and overpaints added since 1994 restoration interventions. The measurements were employed in accordance with the Commission Internationale de l'Eclaraige (CIE) Lab color system (1976) using a spectro-densitometer (Exact X-Rite, Switzerland) to measure color changes on the L***** scale (Luminosity), b***** scale (yellow/blue color) and a***** scale (red/green color. Five measurements were averaged to obtain one data point.

2.1.3. Environmental monitoring

Environmental conditions and pollution gas concentrations were analyzed using the data logger and diffusion tubes [15]. Temperature (T) and relative humidity (RH) were monitored in 30-min intervals with Onset (Cape Cod, MA) HOBO U12 data loggers for one year (Jan-Dec 2015). These devices have the ability to measure the changes of both relative humidity and temperatures daily with high accuracy. The concentrations of pollutants, i.e. NO_2, SO_2, and O_3, were also monitored using Gradko passive samplers DIF 500 RTU for NO_2 and SO_2, and DIF 300 RTU for O_3 (Winchester, UK). The tubes were exposed indoor and outdoor for four weeks from during summer 2015.

2.2. *Sampling*

13 samples were collected from the flaking edges of the dome, with the aim of identifying the components of plaster layers, pigments, binding medium and deterioration products. The visual investigation, multi-spectral imaging, and flaking of the painted dome proved that the dome painting was carried out at two different times. The older paintings applied before 1907 with the same decorated motifs of 1907 paintings. These paintings do not seem to cover all of the dome area under 1907 painting and are only found along the outer edges of the dome so further two samples were collected from them to be studied. Cross-sections were prepared for some paint layers samples which embedded in a transparent epoxy resin. The surfaces of the cross-section were polished using different grades of silicon carbide grinding papers.

2.3. *Analytical techniques*

2.3.1. Microscopic investigation

Microscopic and chemical examinations of samples taken from the painted dome were performed using Carl Zeiss c-2000 stereomicroscope (Germany) and Scanning Electron Microscope coupled with Energy Dispersive X-ray Spectrometer (SEM-EDS) model (Quanta-200 FEI, Netherlands).

2.3.2. Fourier Transform Infrared (FTIR)

For investigating and identifying of the paint medium, FTIR spectra were performed with a portable Bruker Optics ALPHA FT-IR Spectrometer equipped with SiC Globar source and a DTGS detector. Non-destructive analyses of samples were carried out with a Platinum single reflection diamond ATR module, collecting 16 scans, with a resolution of 4 cm^{-1} in the 4000-400 cm^{-1} range. The collected IR spectra were processed using OPUS 7.2 software.

2.3.3. Gas Chromatography-Mass Spectroscopy (GC/MS)

To determine the type of drying oil medium used in the painting, GC/MS analysis was carried out using Perkin Elmer Auto System XL equipped with a Flame ionization detector (FID).

2.3.4. X-Ray Diffraction analysis (XRD)

X-ray diffraction analysis was carried out using X'Pert PRO X pert PRO system with a monochromator, Cu radiation (λ= 1.542 A) at 50 Kv, 40 mA and scanning speed 0.02 /sec were used. The reflection peaks between $2\theta=2^o$ and 60^o, correspo-nding spacing (d, a) and relative intensities (I /I^o) were obtained. The diffractograms and relative intensities are obtained and compared with ICDD files.

3. Results

3.1. *Condition assessment*

3.1.1. Previous overpainting

The Ultraviolet fluorescence (UVF) image characterized the signatures of Ismail Mahmoud and Mahmoud Bahgat who are the original painters of the dome with a date of 1907. Infrared reflected (IRR) and UVF images showed that the dome was heavily overpainted during the restoration interventions carried out in 1994. This is evidently detected in darker areas. Since the dome was restored in 1994 after the earthquake of 1992, some of the conservators signed their names with the date of restoration interventions, fig. (3). Colorimetric measurements of the brown over-painted on the original yellow showed a reduction of the luminosity and yellowness (L= 33.78; a = 14.5; b= 41.8) than the original yellow paint (L= 40.3; a= 9.44; b= 25.29). EDS and XRD analysis showed that Burnt sienna brown pigment was painted over the original yellow ochre. EDS analysis of the dark green pigments (original and overpainting) sho-wed the presence of elements Ba, Na, Fe, Cu, Si, Mg, Al, and Zn. This suggests that the original green earth (Fe, Na, Si, Al, Mg) overpainted by Copper-based pigment (Cu). Furthermore, analysis by XRD indicated that the presence of Malachite [$CuCO_3.2Cu(OH)_2$] was painted over the original green earth of Glauconite $(Na, K)(Fe, Al, Mg)_2(Si_4O_{10})(OH)_2$.

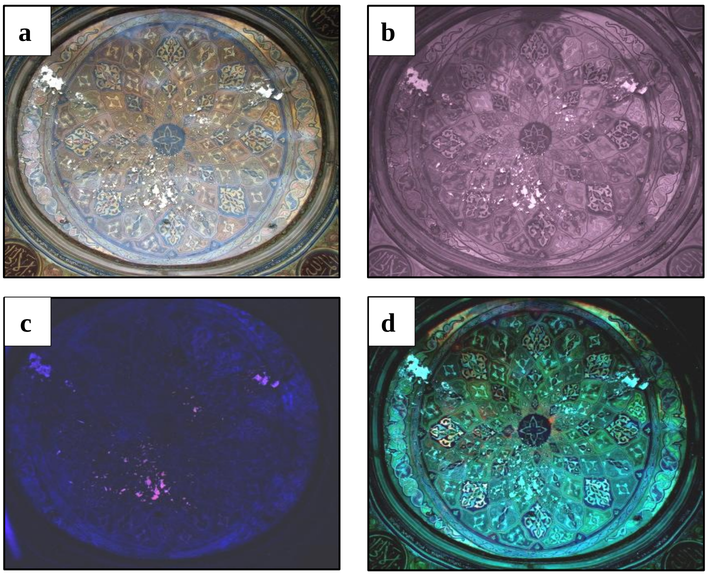

Figure (3) Shows Multi-spectral images (VIS, IRR, UV, IRFC) of the overpainted areas applied to the original paints

3.1.2. Monitoring of the environmental conditions

By comparison of the pollutant concentrations inside and outside the church, fig. (4) the results demonstrated that SO_2 concentrations inside the church were low (2.67ppb) compared to outdoor (12.27 ppb). Whereas the NO_2 concentrations were high in both outdoor (27.005 ppb) and indoor (21.75 ppb) environments demonstrating the existence of internal source inside the church may be candle burning [16]. The concentration of O_3 inside the church was 2.97 ppb. The results of gas pollutant concentrations showed that the concentrations of both NO_2 and O_3 are high. It is noted that a max. of 4 ppb for both SO_2 and NO_2 and 1 ppb for O_3 have been published in the recommended guidelines criteria [17]. The results of temperature and relative humidity variations showed that the outdoor climate has an effective factor on indoor climate. This has been noticed in convergent fluctuations between maximum and minimum temperature values per season which may have accumulatively destructed effect in long-term years. The maximum value of RH was 68 % and T values were ranging from 16 to 34°C in indoor climate throughout the year, tab_s. (1-a,b).

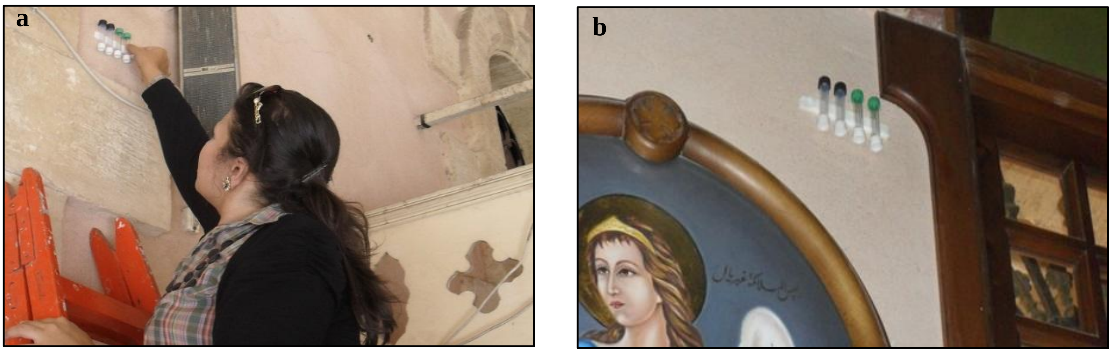

Figure (4) Shows the locations of diffusion tubes **a.** outdoor the church (left), **b.** indoor the church (right)

Table (1-a) Temperature variations in Archangel Gabriel Church through the year (2015)

Temp(°C)	**Seasonal Variations**	**Mean Value**		
		Min	***Max***	***Average***
Spring	Outdoor	18.5	36.8	**27.1**
	Indoor	21.3	34.0	**27.3**
Summer	Outdoor	27.5	36.7	**31.7**
	Indoor	28.4	33.4	**31.3**
Autumn	Outdoor	17.0	33.7	**23.7**
	Indoor	20.3	32.0	**25.5**
Winter	Outdoor	10.9	24.5	**17.9**
	Indoor	16.0	24.4	**19.9**

Table (1-b) RH variations in Archangel Gabriel Church through the year (2015)

RH (%)	**Seasonal Variations**	**Mean Value**		
		Min	***Max***	***Average***
Spring	Outdoor	17.1	68.1	**41.9**
	Indoor	23.2	58.4	**43.2**
Summer	Outdoor	29.3	67.5	**49.6**
	Indoor	35.7	62.8	**49.9**
Autumn	Outdoor	31.3	77.5	**56.6**
	Indoor	34.9	66.3	**51.8**
Winter	Outdoor	22.6	74.9	**52.0**
	Indoor	25.7	65.6	**48.7**

3.1.3. Soiling (dust/salt)

While the roof was isolated since the restoration interventions of 1994, the insulating materials show some deterioration now. This is increasing the likelihood of water infiltration from the roof to the painted surfaces causing salts dissolving from the construction materials. Then the dissolved salts migrate within the multilayered structure of the ceiling and crystallize between the layers creating mechanical pressure which leads to paint flaking, cracking and loss of cohesion of the support and the paint layers to completed loss in paints. SEM-EDS and XRD analysis of soiling revealed the presence of dust elements (Sodium Aluminum silicates) which may promote the oxidation of pigments [17]. Furthermore, the leakage of rainwater from the roof with fluctuations of the temperature values between day and night and throughout the year could promote salt recrystallization in the ground (plaster) layers that were clearly detected in the form of fluffy and needle forms, fig. (5). Salt crystallization exerts mechanical pressure leading to loss of cohesion, cracks, flacking and complete loss of paint layers. SEM-EDS showed Sodium chloride salt ($NaCl$) which is associated with deliquescence at 75 % RH [18].

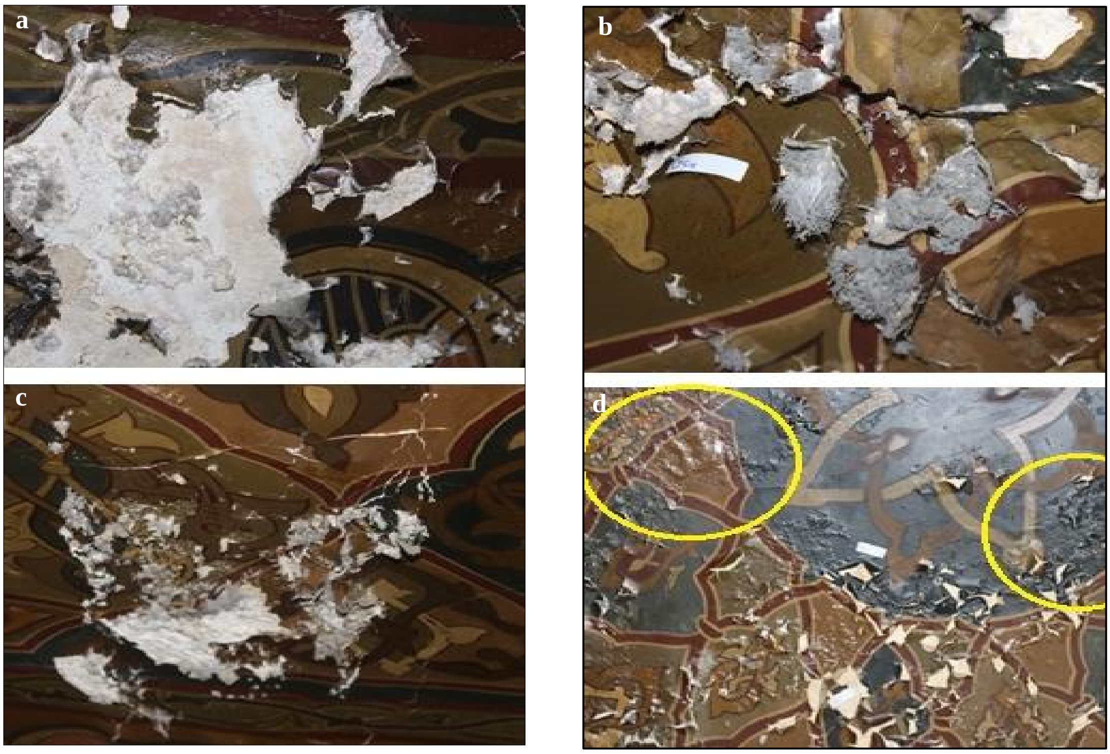

Figure (5) Shows **a.** paint loss and salt crystallization, **b.** & **c.** needle form of salt and paint flaking, **d.** brittleness of paint layer due to salt crystallization below the paint layer

3.2. *Technical analysis*

3.2.1. Ground layers

Microscopic investigations of various cross-sections showed that the stratigraphy of the ground layers was formed by four consequent layers that differ in their thickness, fig. (6). EDS analysis indicated that the ground layers are containing Ca, Ba and Zn with different concentrations of each layer. XRD analysis proved that they mainly consist of Calcite ($CaCO_3$), Barite ($BaSO_4$) and Zinc Oxide (ZnO). Finally, FTIR analysis of the ground layers demonstrated the presence both of organic and inorganic materials. Sulfates and Carbonates were easy to be characterized which might have been applied in a drying oil to create a less absorbent surface for painting.

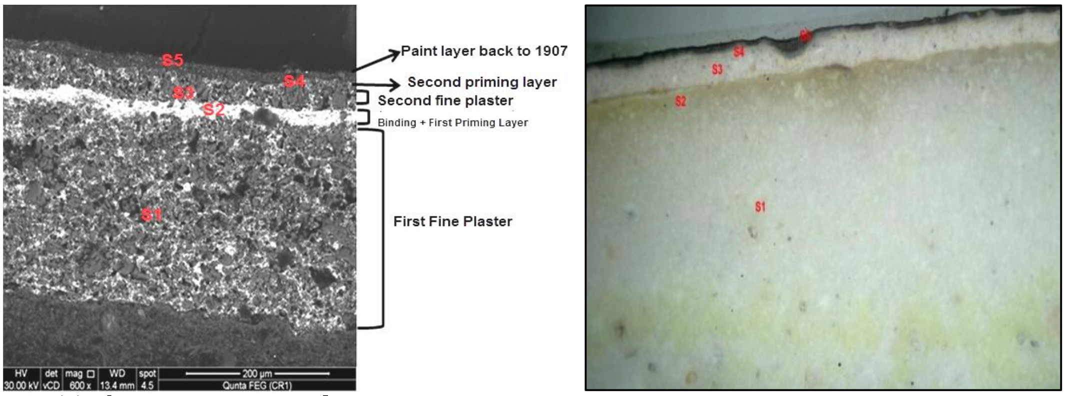

Figure (6) Shows **a.** SEM image, **b.** microscopic investigation of the stratigraphy of 1907 painting

3.2.2. Oil painting medium

Walnut, poppy seed and linseed oils are common drying oils used in paintings since the medieval and modern times. FTIR spectrum collected from the black pigment sample indicated the presence of drying oil where the peaks of carbonyl groups recorded of C=O stretching band of ester at 1720cm^{-1}, C-H absorption of fatty acids at 2928 cm^{-1} and 2853 cm^{-1}, fig. (7). Due to the similarity of the drying oils spectra and the overlapping of calcium carbonate and sulfate peaks, further, GC/MS was carried out to determine the drying oil type based on the Palmitic (P) and Stearic (S) acids ratios. GC/MS of black pigment sample confirmed the presence of P/S (40.72/ 20.05) ratio of 2.03, close to that of linseed oil is (1.9 +/- 0.5) [19].

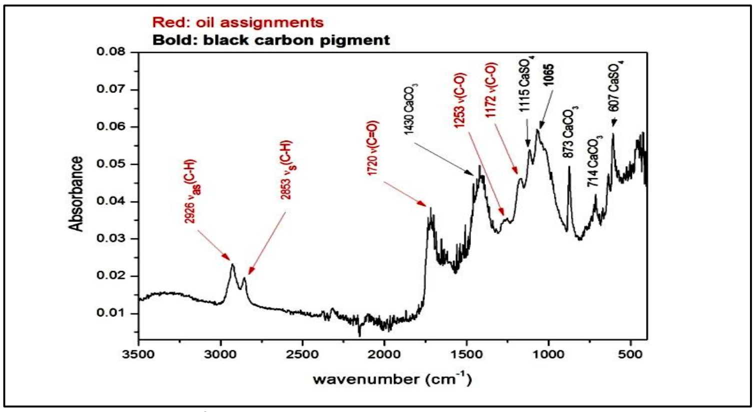

Figure (7) Shows FTIR spectrum of the drying oil medium

3.2.3. Pigments

3.2.3.1. *The pictorial palette of 1907*

* **Black:** EDS showed that the dominant elements of the black pigment contain predominantly Ca, Ba, Zn while XRD analysis showed that the main compounds are those from the plaster: Calcite, Barite and Zinc Oxide. A band in FTIR spectra at 1065 cm^{-1} is ascribed to carbon black. The results of black pigment suggest that the Black pigment is Carbon-based pigment. * **Red:** EDS confirmed that the dominant elements of the red pigment are Fe while the mineralogical composition of the red pigment sample by XRD showed that it mainly composes of Hematite (Fe_2O_3) together with minerals identified in the plaster. * **Olive green:** EDS showed that the dominant elements of olive green pigment are Fe, Ba, Na, Si, Al, Mg, CL while the mineralogical composition of the olive green by XRD indicated the presence of green earth, Glauconite type (Na, K)(Fe, Al, Mg)$_2$(Si_4O_{10})(OH)$_2$, Sodium chloride NaCl and the compounds

of the plaster . The presence of NaCl is referring to a deterioration phenomenon. * **Beige:** EDS analysis of the beige pigment confirmed that the dominant elements are Ba, Fe, Na, K, Si, Al and Mg which suggests that the beige pigment might be a mixture of Barite and green earth. * **Dark green:** EDS analysis of the dark green pigment showed the presence of Fe, Na, Si, Al, Mg. The elemental composition of dark green suggests that it might be green earth from Glauconite type. The elements of Ca, Ba, Zn are ascribed to the ground layers. * **Yellow:** EDS analysis indicated that the dominant elements of the yellow pigment are Fe, K, Al, and Si. XRD pattern of the yellow pigment indicated the presence of Orthoclase ($KAlSi_3O_8$), Hydrous Iron oxide FeO(OH) and the compounds of the ground layers which suggest that the yellow pigment is Yellow Ochre. * **Blue:** EDS analysis of the blue pigment confirmed that the dominant elements are Na, S, Si, Al. The mineralogical composition of the blue pigment indicated the presence of ultramarine $3Na_2O. Al_2O_3.6SiO_2.2Na_2S$ and the components of the plaster layers. * **Pink:** EDS analysis of the pink pigment confirmed that the dominant elements are Ba and Fe. The mineralogical analysis of the pink pigment by XRD showed it mainly composes of Barite $BaSO_4$ and Hematite Fe_2O_3 together with the components of the plaster which suggest that the pink pigment is a mixture of Barite added to Hematite to get the pink tonality. * **Dark brown:** EDS analysis of the dark brown pigment showed that the dominant element is Fe. The mineralogical composition of the dark brown pigment by XRD analysis showed that the pigment mainly composes of Hematite (Fe_2O_3) and components originated from the ground layers which suggest that the brown pigment is Burnt Sienna. * **Gilded pigment:** EDS analysis of the gilded pigment showed that the dominant elements are Cu and Zn which suggests that the pigment might be of a brass alloy.

3.2.3.2. *Pictorial palette of older paintings*

EDS analysis of the gilded pigment from the older paintings, fig. (8) showed that the dominant elements are Cu and Zn with the absence of (Au) suggesting that the gilded pigment might be from a brass alloy. EDS analysis of the red pigment showed that the dominant element is Fe suggesting that the pigment might be Hematite.

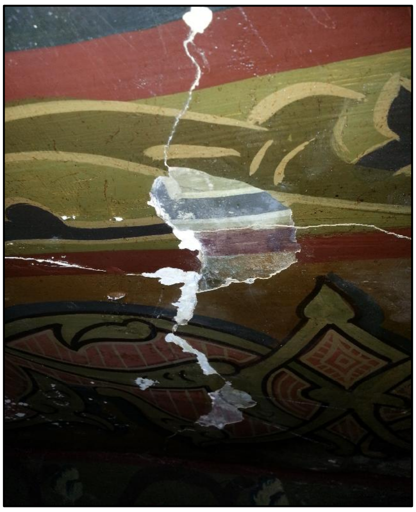

Figure (8) Shows the older paintings

4. Discussion

Multispectral images of the dome near the main apse in the church of Archangel Gabriel, Haret El saqqayeen in Cairo showed that the dome was heavily overpainted with darker paints during the restoration interventions of

1994, which demonstrated how do the stakeholders rely on their own funding to hire non-professional conservators to carry out in Egyptian historical churches [20]. Monitoring the climatic conditions of Archangel Gabriel church showed the air exchange between outdoor and indoor climate. This is apparently noticed in max. and min. values of temperatures and relative humidity with RH below 70 % and T ranging from 16 to 34˚ C. These fluctuations of relative humidity and temperatures could have severe damage to the oil wall paintings. The rate of deterioration does not stop at the condensation on the surface by temperature fluctuations and moving water within the wall bringing dissolved salts [17] to the oil painted surface but also mechanical, durable and dimensional properties of oil paints cause further deterioration responding to these fluctuations of the environmental conditions. The oil paints based on earth pigments form weak paints as they get fairly responsive dimensionally when the relative humidity exceeds 60 % This is a result of the swelling of natural clays found in these pigments so the acceptable recommended values of RH and T to preserve the earth oil paints bounded between 37 % RH to 53 % RH and (18.5 ºC to 23.5 ºC [21]. In this respect, the indoor climate of the church does not appropriate the oil based earth paints applied on the dome. However the concentrations of NO_2 and O_3 are exceeding the recommended guidelines criteria, SO_2 concentrations indoor climate were convenient to the recommended criteria [17] which interpret the existence of internal source of NO_2 inside the church; maybe candle and incense burning [16]. These pollutants could be transported by air into contact with paintings increasing the oxidation rate of the oil medium and forming subsequent low molecular breakdown products [9]. As RH results did not reach to the deliquescence of sodium chloride salt, water infiltration from the roof seems to play a significant role in Sodium chloride dissolving and crystallization in different layers of the painted surface causing mechanical stress that finally leads to completed losses of the paints [17,18]. The depiction of the dome was carried out in two different periods. The first period is back to a date before 1907 in which the painting was only found along the outer edges of the dome. This suggests the incompleteness of the dome painting in this period to be continued in 1907 by applying four ground layers over the remnant of the earlier paintings to receive the final oil painted layer. The dome is painted with the same European oil painting technique brought to the Ottoman Empire [5] in Egypt. The technical studies of the Egyptian oil based wall paintings showed the similarity of the painting materials used in the dome [3,6-8]. The ground layers of 1907 paintings mainly consist of Calcium Carbonates, Barite and Zinc Oxide with different concentrations in each layer. Ismail Mahmoud and Mahmoud Bahgat are the original painters of 1907 paintings. EDS and XRD analysis confirmed that the original painters painted the dome with earth pigments as Carbon black, Hematite, Yellow Ochre, Green earth, Burnt Sienna besides using stabilizer in the pigment mixtures as Barite.

5. CONCLUSION

The dome of Archangel Gabriel church has been studied in preparation for restoration intervention. The study proved that the dome is painted with the same European oil wall painting technique. The conservation state showed that the dome exposed to uncontrolled environmental conditions and non-professional restoration interventions. In this respect, it is necessary to raise awareness of the importance of authentication and historical value of paintings in Egyptian historical churches. Continuous monitoring of the environment is a critical issue. The technical equipment for light and climate measurements and mobile advanced equipment for climate control (humidifier and dehumidifier) should be provided. To avoid the excessive level of NO_2 concentrations, ventilation is equally important and the *church should be aired regularly by opening windows and doors during and after liturgies to allow pollutant air to escape. Consolidation of the roof with an appropriate insulating material is a significant step to protect the ceiling from water infiltration.*

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