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ARCHAEOMETRIC STUDY OF THE HISTORIC TERRAZZO PAVEMENT OF PRINCE MOHAMED ALI MUSEUM, CAIRO, EGYPT

[1] Mohammed S. A. KHEDR ,[2] Mona F. ALI,[3] Abdullah M. A. KAMEL*, [4] Manal A. A. EL-GHANAM

[1] El Manial Palace, Ministry of Antiquities, Cairo, Egypt
e-mail: m.soliman10112013@gmail.com
[2,3] Conservation Department, Faculty of Archaeology, Cairo University
12613 Giza, Egypt, e- mail: [2]monalyeg@yahoo.com, [3]dandarawy_241@cu.edu.eg
[4] National Museum of Egyptian Civilization, Ministry of Antiquities,
Cairo, Egypt, e-mail: mmanal12@yahoo.com

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Abstract: This research will shed light on studying a terrazzo pavement in Prince Mohamed Ali Museum (the case study). The authors used visual inspection, stereo microscope, USB microscope, XRPD analysis, and SEM.EDX to identify its components, deterioration aspects and execution techniques. The XRPD and SEM.EDX results revealed that Portland cement was used in the three layers of terrazzo because of the detection of Hatrurite, Alite, Anorthite, Albite, Aragonite, etc. Many pigments were used in the topping terrazzo layer as; Goethite, Greenalite, Hematite, Azurite and Magnetite. The divider strips were made of brass alloy and the topping layer chips were prepared from basalt, marble and sea shells.

Keywords: Terrazzo, Portland cement, Pigments, Divider strips, Deterioration, Prince Mohamed Ali Museum

1. Introduction

Terrazzo art was used in the decoration of floors and many architectural elements in the historic buildings. Although it had played an important role in the art history, its technology of execution and conservation not sufficiently studied yet.

Historically terrazzo had been used widely either as decorative treatments for walls or as artificial pavements. That may relate to its durability which is increased by time and to the easiness of application [1], [2].

* Corresponding Author

Terrazzo is an Italian term derived from the word ‘Terrace’ or ‘Terrass’ or ‘terrazza’. It had been known as a form of mosaic floors for many centuries, which were prepared by mixing small gravels of marble or colored stone with mortar containing pigments and binders. This composite will give a distinctive aesthetic shape after grinding and surface polishing [3], [4], [5], [2], [6], [7].

The beginning of terrazzo art in the execution of floors was done by using a mixture of lime and burnt clays [8], [9], [10]. In Egypt, the first use of terrazzo technique had been executed in Alexandria [2]. Then the Romans refined this technique especially in the Golden Age of Rome [5]. In Italy, the Venetian marble workers had used terrazzo pavements in Venice (15^{th} century) as they had placed marble chips inside cementing material (either air or hydraulic lime) then the surface was polished with special stones [4].

After that century, Italy was practically the monopoly of craftsmen from the Fruili region for the terrazzo and mosaic industry. In 1890, terrazzo had been executed by Italian manufacturers in USA at the Vanderbilt residence on Fifth Avenue in New York. Then terrazzo had become a favorite art technique because of the highly skilled Italian workers [11].

Contemporary terrazzo relates a technique called *seminato* in which marble chips are used over a cementing base, then after setting the surface is polished. This technique became popular in the beginning of the 20^{th} century because of the appearance of divider strips which helps in preventing cracks and increasing durability [12]. Terrazzo pavements were used and flourished in Egypt in the period of Muhammad Ali Pasha (from 1805 until 1952 AD).

The current research represents a decorated historical terrazzo pavement in Prince Mohamed Ali museum which takes the shape of a deer in jungle *Fig. 1*.

This terrazzo pavement represents the ‘in site cast type’. It consists of three layers; the first layer is the concrete slab (the base course layer), which is covered by a thin layer of sand and insulation layer. The second layer is the underbed layer, which consisted of sand and cement, which poured on the concrete bed and before the complete setting of this layer; workers put divider strips, which act as control strips, *Fig. 2,* [13]. These strips should be non-corrosive material and they may be made of zinc or brass or any other suitable materials. The third layer is the topping terrazzo consisted of cement, aggregates, and pigments [7]. Before the complete dryness of terrazzo, workers used to grind and polish the surface through two stages, the first is by using carborundum block or disk and water, then the surface is washed and the voids were filled with fine slurry of cement. The second phase involves grinding by a disk or using a special stone [7], [13], [14].

The visual examination revealed the detection of many deterioration aspects; for example cracking, flaking, buckling, inappropriate filling by ordinary Portland cement, surface disfiguring by new paintings, dust wide spreading and the severe corrosion of concrete iron armatures [15], *Fig. 1* and *Fig. 2*.

Fig. 1. The studied terrazzo pavement of Price Mohamed Ali Museum

Fig. 2. The stratigraphic section of terrazzo pavement of Mohamed Ali Museum, 1) the concrete layer; 2) the underbed layer; 3) the topping terrazzo layer

2. Materials and methods

2.1. Sampling

Representative samples were collected carefully from deteriorated, separated and unseen parts from the stratigraphic structure of the studied terrazzo pavement, as well the divider metal strips to identify their mineralogical composition and deterioration aspects (*Table I*).

Table I

The examination and analysis of terrazzo pavement samples of Prince Mohamed Ali Museum

Sample	Type of sample	Examinations and analyses
A	Yellow mortar	SM, XRD, SEM- EDX
B1	Green mortar	SM, XRD , SEM- EDX
B2	Cement mortar	XRD
C	Purple mortar	SM, XRD , SEM- EDX
D1	Dark blue mortar	SM, XRD
D2	Cement mortar	XRD
E	Red mortar	SM, XRD, SEM- EDX
F1	Red mortar	SM, XRD, SEM- EDX
G1	Cyan mortar	SM, XRD, SEM- EDX
H	Dark red	SM, SEM- EDX
I	Yellow mortar	SM, SEM- EDX
J	Yellowish white mortar	SM, XRD, SEM- EDX
K	Metal divider strips	SM, SEM- EDX
L	Black ships	SM, XRD, SEM- EDX
M	White ships	SM, SEM- EDX
N	Shiny creamy ships	SM, USBM, SEM- EDX
O	Underbed layer	SM, XRD, SEM- EDX
P	Concrete layer	SM, XRD
Q	Metal armatures	SM, SEM- EDX

2.2. Examination by stereo microscope and USB digital microscope

Some samples of studied terrazzo pavement were examined by Binocular Olympus Stereo microscope with low magnification power started with (67 X to 450 X).The microscope helped in the studying of the morphological features of samples. Some samples of terrazzo pavement were observed using a handheld USB digital microscope (model PZ01- made by Shenzhen Supereyes Co. Ltd, China) with the following technical specification: image sensor 0.3 Mega pixels, magnification factor 10~500 times, photo capture resolution 640×480,320×240 and LED illumination light resource adjustable by control wheel.

2.3. X-ray powder diffraction

The X-ray diffraction patterns of the terrazzo powders of samples were obtained by using (A diffractometer PW 1480 Netherland), operated at 35 kV, using a Cu Ka radiation wavelength of 1.54056 Å. Generator current: 20 mA. The measurements were made at room temperature. The reference database used for matching is PDF4. Preparation of each sample consisted of grinding the dry samples on one direction, by using a mortar and pestle to obtain a fine powder. The X-Ray Powder Diffraction (XRPD) analysis was done at XRD Unit in faculty of archaeology in Cairo University.

2.4. Scanning electron microscopy with energy dispersive X-ray analysis

The chemical composition of the studied terrazzo pavement was recorded by a scanning electron microscope attached with Energy Dispersive X-ray (EDX) Unit: Model Quanta 250 Field Emission Gun (FEG) - FEI Company, Netherlands, with accelerating voltage 30 KV, magnification 14x up to 1000000 and resolution for Gun.1n), without coating of the samples with a highly conductive thin film of gold. The Scanning Electron Microscopy (SEM).EDX was done at the Egyptian Mineral Resources Authority, central laboratories sector, Giza, Egypt.

3. Results and discussions

3.1. *Examination by stereo microscope and USB digital microscope*

The observations made by stereo microscope and USB digital microscope revealed the following results resumed in *Fig. 3, Table II* and *Fig. 4, Table III.*

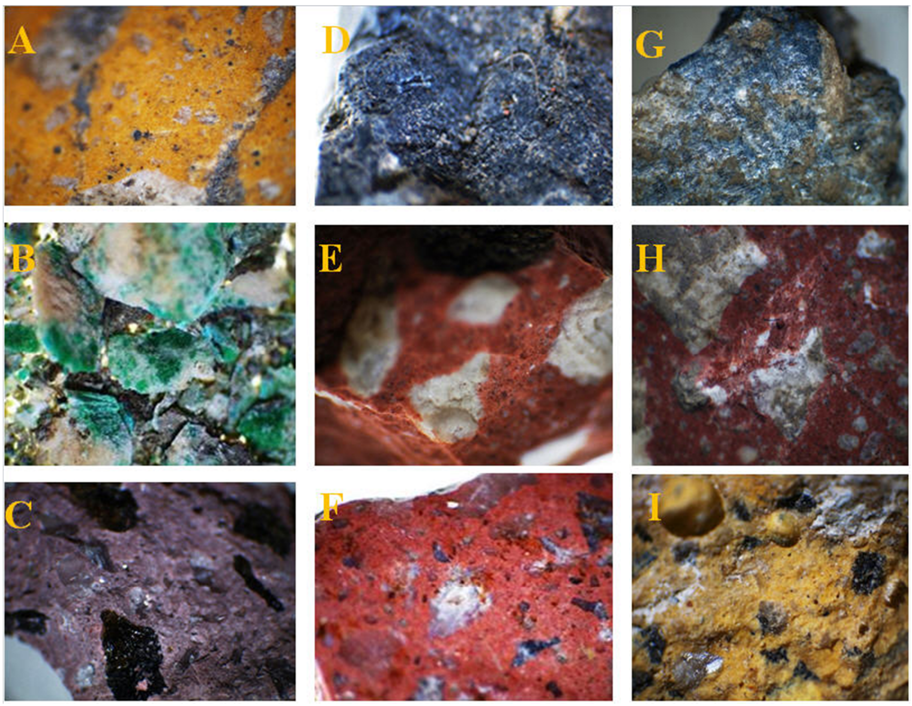

Fig. 3. Stereo microscope examination of some pigmented samples of the terrazzo pavement of Prince Mohamed Ali Museum

Table II

The stereo microscope and USB digital microscope examination results of the samples of the terrazzo pavement of Prince Mohamed Ali Museum

Figure	Stereo microscope and USB digital microscope results of the terrazzo pavement
Fig.3A	(Sample A - 450X) yellow mortar containing big white chips and small black ones.
Fig.3B	(Sample B1- 400X): green sample taken from the ground of the deer shape of the topping terrazzo contains some particles of green pigment mixed with white chips and small black ones.
Fig.3C	(Sample C- 450X): purple sample taken from the body of the small deer from the topping terrazzo layer contains big black gravels.
Fig.3D	(Sample D1- 450X): dark blue sample taken from the topping terrazzo, the image revealed that there are not any chips whether black or white.
Fig.3 E	(Sample E- 450X): sample of red mortar taken from the topping terrazzo reveals the detection of big white and black chips.
Fig.3F	(Sample F1- 450X): sample of red mortar taken from the body of the big deer from the topping terrazzo which contains big white and black chips.
Fig.3G	(Sample G1- 450X): sample of cyan mortar taken from the topping terrazzo layer contains small white chips.
Fig.3H	(Sample H- 450X): sample of dark red mortar taken from the tree roots of the topping terrazzo contains big white gravels and small black chips.
Fig.3I	(Sample I- 450X): sample of yellow mortar taken from the top of the topping terrazzo contains small black chips.

3.2. *X-ray powder diffraction*

XRPD patterns results of the analyzed terrazzo mortars and their additives are resumed in *Table IV*.

The XRPD pattern of sample A (yellow mortar) revealed the detection of Calcite (calcium carbonate), Portlandite (calcium hydroxide), Hatrurite (calcium silicate), Gypsum (calcium sulfates dihydrate), Lime (calcium oxide) and Goethite (iron hydroxide). The detection of Calcite, Portlandite, Hatrurite, Gypsum and Lime may confirm the using of white Portland cement as a binding material for of the terrazzo topping [16], [7], [17], [18], [19]. The detection of Goethite confirms its use as a yellow pigment for terrazzo topping layer.

The XRPD pattern of sample B1 (green mortar), which was taken from a small part of the topping terrazzo, revealed the detection of Greenalite (hydrated iron silicate), which was used as a green pigment. Sample B2 (cement mortar) XRPD results confirm the usage of Portland cement as a binding material in the mixture of topping terrazzo.

The detection of Hematite (Fe_2O_3) and Azurite ($Cu_3 (CO_3)_2 (OH)_2$) in the XRD pattern of sample C (purple mortar) justifies the purple colour of the sample.

The detection of Hematite in sample D1 (dark blue) as a red pigment and Magnetite as a black pigment may justify the dark blue color of the sample. While the appearance of Anorthite (calcium aluminum silicate $CaAl_2Si_2O_8$) - Anorthite is a plagioclase feldspar mineral [20], may be used with Quartz as a kind of aggregates. Anorthite may be also considered as a resulted compound of Portland cement reactions. While in sample D2 (cement mortar) the detection of Calcite, Alite (Tricalcium Silicate), Portlandite (calcium hydroxide), Lime (calcium oxide) and Gypsum confirms the usage of Portland cement as a binding material [16]. But the detection of Halite may confirm the subjection of the terrazzo pavement to saline solutions from the soil of the palace garden [20].

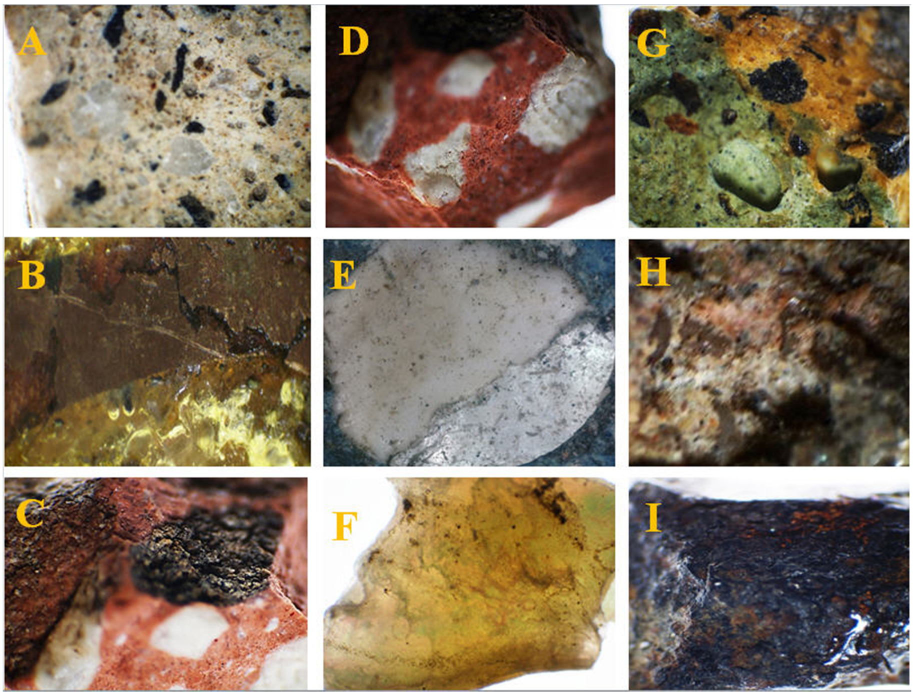

Fig. 4. A), B), C), D), F), G), H), I) stereo microscope examination of the other samples of the components of the terrazzo pavement of Prince Mohamed Ali Museum, E) the USB microscope examination of sea shells chips

The XRPD patterns of samples E and F1 (red mortars) revealed the usage of Hematite as a coloring material in the Portland cement mix.

Sample G1 (cyan mortar) XRPD pattern results revealed - as well as the binding materials (Calcite and Aragonite) [21], the appearance of Periclase, which may be used as an aggregate material [22]. Periclase may also be added as an expansive additive to control the thermal shrinkage of concrete [23].

The XRPD pattern of sample J (yellowish white mortar) revealed the detection of Calcite (calcium carbonate), Alite (Tricalcium Silicate), Gypsum (calcium sulfates dihydrate), Portlandite (calcium hydroxide) and Quartz (silicon dioxide). Calcite, Portlandite, Gypsum and Alite represent the main component of white Portland cement which was used as a binding material for the terrazzo topping. The small amount of Quartz may be used as aggregates for the underbed layer [7].

Table III

The stereo microscope and USB digital microscope examination results of the samples of the terrazzo pavement of Prince Mohamed Ali Museum

Figure	Stereo microscope and USB digital microscope results of the terrazzo pavement
Fig.4A	(Sample J- 450X) sample of yellowish white mortar taken from the ground of the topping layer which was mixed with white and black chips.
Fig.4B	(Sample K- 400X): sample taken of the divider strips used in the topping terrazzo which fixed directly within the underbed layer.
Fig.4C	(Sample L- 450 X): black aggregates taken from the topping terrazzo layer.
Fig.4D	(Sample M- 400X): white chips taken from the topping terrazzo layer.
Fig.4F &E	(Sample N): sea shell aggregates sample (*Fig. 4F*) examined by stereo microscope 450X and (*Fig. 4E*) taken by USB microscope 250X. These chips were used in some parts of the topping terrazzo layer.
Fig.4G	(Sample O- 350 X) sample from the underbed layer showing the cementing material and its aggregates.
Fig.4H	(Sample P- 450 X): sample from the concrete layer.
Fig.4I	(Sample Q- (450 X): sample from concrete steel armatures showing their heavy surface corrosion.

Table IV

The approximate XRPD analysis results of the studied terrazzo pavement of prince Mohamed Ali Museum

Sample	The approximate XRPD analysis mineralogical results						
A	Ca, +++	Go,++	Por,++	Ha,++	G,+	Li,+	-
B1	Ca, +++	Gr,++	-	-	-	-	-
B2	Ca, +++	Por,++	Li,+	-	-	-	-
C	Ca, +++	He,++	Por,+	Az,+	-	-	-
D1	Ca, ++	Qu,+	He,+	An,+++	Ma,+	-	-
D2	Ca, +++	Qu,++	Al,++	Por,+	G,+	Li,+	Hal,+
E	Ca, +++	He,+	Por,+	-	-	-	-
F1	Ca, +++	He,+	-	-	-	-	-
G1	Ca, +++	Ar,++	Pe,++	-	-	-	-
J	Ca, +++	Qu,+	Al,++	Por,+	G,++	-	-
L	An,++	Aug,++	Alb,++	Ol,++	-	-	-
O	Ca, ++	Qu,+++	Por,+	Ha,++	Li,+	-	-
P	Ca, +++	Qu,+++	He,+	Por,+	Ha,+	Li,+	-

Ca = Calcite; Qu = Quartz; Go = Goethite; He = Hematite; An = Anorthite; Az = Azurite; Por = Portlandite; Al= Alite; Ha = Hatrurite ; Ma = Magnetite; Gr= Greenalite; Ar = Aragonite; G = Gypsum; Li = Lime; Pe = Pericalase; Aug = Augite, Alb = Albite ; Ol = Olivine; Hal = Halite.

– = not detected; + = traces; ++ = minor constituent; +++ = major constituent

The XRPD pattern of sample L (black chips) revealed the detection of Anorthite (calcium aluminum silicate), Augite (calcium magnesium silicate), Albite (Al Na Si_3O_8), and Olivine (Mg Ni Si O_4). Anorthite and Albite are plagioclase feldspar minerals, [24]. The sample also contains Augite and Olivine, which represent the main minerals of basalt which is characterized by its black color [25].

The XRPD pattern of sample O (underbed layer) revealed the detection of Quartz, Calcite, Hatrurite, Lime and Portlandite. These results refer to the underbed layer, which consists of Calcite and Quartz (sand) [7], the other components of Portlandite, Hatrurite and Lime confirm the use of Portland cement.

The XRPD pattern of sample Q (metal armatures) revealed the detection of Quartz, Calcite, Hatrurite, Hematite, Lime and Portlandite. These results refer to the composition of the concrete and Hematite refers to the corrosion products of iron, which was used in the concrete.

3.3. Scanning electron microscopy with energy dispersive X-ray analysis

The EDX analysis results of samples (A, B1, C, F1, G1, H, I, J, O) proved the presence of the following elements: (C), (Ca), (Si), (Al), (Na), (Mg), (O) and (Fe), which may give evidence of the occurrence of Calcite, Portlandite, Gypsum, Hatrurite, Alite and Quartz. These resulted compounds confirm the occurrence of hydraulic binding material (white or ordinary Portland cement).These results are compatible with the XRD results of topping Terrazzo layer, underbed layer and concrete layer and confirm them [18], [19], [26], [27], [28], [29].

The detection of (Fe) element in samples A, B1, C, E, F1, H and I confirms the appearance of ferric pigments, which were detected by XRD analysis; Goethite in samples A and I, Greenalite in sample B1 and Hematite in samples C, E, F1 and H.

The detection of (Cu) and (Zn) elements in the metal sample K of the divider strips confirms that they were made of brass alloy. This alloy is characterized by its excellent properties, its high resistance to corrosion [30].

The detection of (C), (Si), (Al), (Fe), (Na), (Mg) and (O) elements in the black chips of sample L may confirm its composition of basalt.

The detection of (Ca), (C) and (O) of the white stone ships (sample M) confirms that it consists of Calcite. The examination made by naked eye and stereomicroscope of these ships confirms its composition of marble. Marble ships were widely used in the topping terrazzo as aggregates [7].

The EDX analysis of the shiny creamy ship (sample N) gives (Ca), (C), (S) and (O) elements which confirm its composition of Calcite with contaminations of sulphate compound. The examination by naked eye and stereomicroscope of these chips confirm its composition of sea shells [31].

The detection of (Fe) in concrete armatures sample (Q) confirms its composition of iron *Table V*.

Table V

The SEM-EDX analysis results of the studied terrazzo pavement
of Prince Mohamed Ali Museum

S.	The SEM-EDX analysis results								
A	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	Cl_2O +	Fe_2O_3 +	P_2O_5 +	K_2O +	-
B	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	Na_2O_3 +	MgO +	Fe_2O_3 +	K_2O +	Mo_2O_3 +	-
C	CO_2 +++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	Cl_2O +	Fe_2O_3 +	K_2O +	SO_3 +	-
E	CO_2 ++	CaO +++	SiO_2 +	Al_2O_3 +	Fe_2O_3 +	Mo_2O_3 +	-	-	-	-
F	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	Fe_2O_3 +	K_2O +	SO_3 +	-	-
G	CO_2 +++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	K_2O +	SO_3 +	-	-	-
H	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	Fe_2O_3 +	SO_3 +	-	-	-
I	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	Cl_2O +	Fe_2O_3 +	SO_3 +	-	-	-
J	CO_2 ++	CaO +++	SiO_2 +	Al_2O_3 +	Na_2O_3 +	K_2O +	SO_3 +	-	-	-
K	CO_2 ++	Cl_2O +	CuO +++	ZnO ++	-	-	-	-	-	-
L	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	Na_2O_3 +	MgO +	Cl_2O +	Fe_2O_3 +	P_2O_5 +	K_2O +
M	CO_2 ++	CaO +++	-	-	-	-	-	-	-	-
N	CO_2 +++	CaO +++	SO_3 +	-	-	-	-	-	-	-
O	CO_2 ++	CaO ++	SiO_2 ++	Al_2O_3 +	MgO +	Fe_2O_3 +	SO_3 +	BaO +	-	-
Q	Fe_2O_3 +++	-	-	-	-	-	-	-	-	-

– = not detected; + = traces; ++ = minor constituent; +++ = major constituent

4. Conclusion

The scientific study of the terrazzo pavement in the Prince Mohammed Ali Museum in El Manial allowed the obtaining of interesting information about their execution methods and physicochemical characteristics. This terrazzo pavement was cast in site by using of brass divider strips. It suffered from many deterioration aspects which led to loss of some parts. The XRPD and EDX analyses confirm that Portland cement was used in the three layers of this terrazzo pavement. Goethite, Greenalite, Hematite, Azurite and Magnetite minerals were used as coloring materials in the topping terrazzo layer. The divider strips were made of brass alloy while basalt, marble and sea shells were used as aggregates for the terrazzo mortar mixes.

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