Journal of Cultural Heritage 68 (2024) 254–262

Contents lists available at ScienceDirect

Journal of Cultural Heritage

journal homepage: www.elsevier.com/locate/culher

Case study

Construction technology and raw materials for the restoration of Gian Lorenzo Bernini's Cornaro Chapel Vault, Rome (Italy)

Luciana Randazzo[a], Michela Ricca[b,*], Giuseppe Mantella[c], Mariella Nuzzo[d], Chiara Scioscia Santoro[d], Mauro Francesco La Russa[b]

[a] *University of Palermo, Department of Earth and Marine Sciences, Via Archirafi, 26, 90123 Palermo, Italy*
[b] *University of Calabria, Department of Biology, Ecology and Earth Sciences, Via P. Bucci, Cubo 12B, 87036 Arcavacata di Rende (CS), Italy*
[c] *Giuseppe Mantella Restauro Opere D'Arte, Circonvallazione Paparo 25, 88060 Isca sullo Ionio, Italy*
[d] *Soprintendenza Speciale Archeologia Belle Arti e Paesaggio di Roma, Piazza dei Cinquecento, 67, 00185 Roma, Italy*

ARTICLE INFO

Article history:
Received 12 January 2024
Accepted 12 June 2024

Keywords:
Gian Lorenzo Bernini
Cornaro Chapel
Frescoes
Microscopy
Multidisciplinary approach
Stucco

ABSTRACT

The scientific and multidisciplinary approach to the restoration of Bernini's Cornaro Chapel, at Santa Maria della Vittoria church in Rome, is reported as a fruitful example of the synergic cooperation between scientists and restorers for the planning and implementation of suitable conservative interventions.

This study reports the cycle of scientific and diagnostic investigations carried out on the great Baroque masterpiece before the restoration started in 2020.

Before the restoration, the technique of execution, the raw materials, and the state of preservation of Bernini's extraordinary sculptural cycle were scrupulously investigated with different and complementary analytical techniques on suitably selected micro-samples. Specifically, the original constituent materials were characterized, sometimes together with those resulting from decay processes or previous restoration interventions, through different techniques such as polarizing optical (OM) and fluorescence microscopy (FM), Electron Probe Microanalyses (EPMA) coupled with Energy Dispersive Spectrometry (EDX) and Fourier Transform Infrared Spectroscopy (FT-IR).

Particular attention was paid to the frescoed vaulted ceiling of the chapel, enriched by scenes modeled in white stucco and gilding, to better understand the manufacturing as well as the accuracy adopted by Bernini in layering, investigating from the most superficial to the innermost layers.

Scientific and diagnostic analyses were successfully performed to design the most convenient restoration intervention, to verify its correctness and ensure the use of non-invasive cleaning and conservative procedures. The results obtained from nine micro-samples, mainly composed of stucco and fragments of frescoes, contributed to dispelling the doubts raised by restorers, especially regarding the use of specific raw materials (notably the gilding, type of binder and aggregates, superficial patinas, etc.) and the presence of retouches in certain areas of the masterpiece, deriving from previous conservation interventions. The identification of these raw materials and the layering of the samples supported cleaning and restoration interventions through the use of suitable materials compatible with the originals.

1. Introduction and historical background

In Rome, the Cornaro Chapel located in the shallow arm of the left transept of Santa Maria della Vittoria (Fig. 1) is hailed by many art historians as one of the greatest masterpieces of the Baroque [1,2]. As such, the extraordinary artistic and sculptural cycle also represents one of Gian Lorenzo Bernini's major achievements and finest efforts [2], commissioned by Cardinal Federico Cornaro of Venice in 1647 for his burial chapel. The client's request was to create a commemorative architecture in the transept of the church in memory of the Cornaro family, beyond a common sepulcher chapel. Hence Bernini's invention of conceiving the chapel as a small theater and of staging the mystical experience of St. Teresa of Avila while Cardinals and Doges of the Cornaro family watch the scene from flanking box seats. The whole chapel is enriched by architectural elements, sculptures, paintings, and marble intar-

---

[*] Corresponding author.
E-mail address: michela.ricca@unical.it (M. Ricca).

https://doi.org/10.1016/j.culher.2024.06.009
1296-2074/

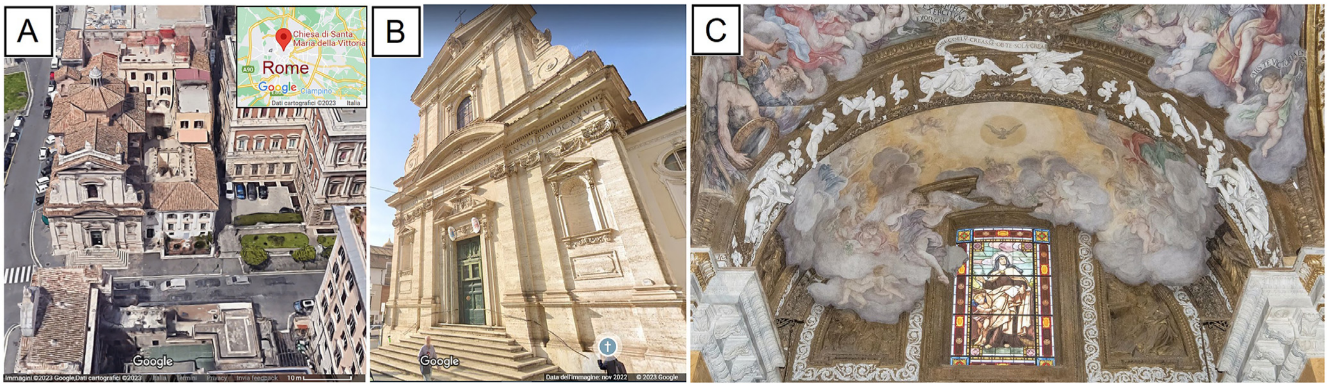

Fig. 1. General aerial (A) and front (B) view obtained from Google Earth of the Santa Maria della Vittoria church in Rome, and detail of the Cornaro Chapel (C).

sia, and decorated with stuccos and frescoes which converge in a harmonious space, to frame a scene of intense spiritual fervor that depicts the mystical vision of St. Teresa, which the artist created together with a consolidated group of trustworthy collaborators.

In Bernini's conception of the vision, St. Teresa, carved in white marble, seems to float weightlessly beneath a golden light accompanied by an angel in a niche above the altar, both lit by natural light that comes from a hidden window, showing a perfect harmony between architecture, warm light, and decorations [3]. The space in which the scene takes place emerges from the rear wall and it is framed by paired columns, isolating the scene from the rest of the chapel while highlighting it as the centerpiece. Below, along the sidewalls of the chapel, there are marble reliefs representing eight members of the Cornaro family, who kneel in prayer. The ceiling of the chapel is also frescoed to give a vision of heaven where angels on cloud banks circle around the dove of the Holy Ghost. Aside from the frescoes, the ceiling vault is enriched by figures modeled in white and gilded stucco on the arch that frames the chapel, while four stuccoed scenes, depicting moments from Teresa's life, decorate the back and side walls under the vault [4,5].

In this paper, particular attention was devoted to the study of the chapel's vault that, at the beginning of the latest restoration intervention, led in 2020 by the "Soprintendenza Speciale Archeologia Belle Arti e Paesaggio" of Rome and performed by the company "Restauro Opere d'Arte", was rather damaged, with both the frescoed ceiling and figures modeled in white and gilded stucco being altered. Although several restoration interventions had been carried out in the past, following the fire that struck the church in 1833, many critical issues had not yet been addressed.

A scientific approach was therefore necessary to correctly address the entire restoration process, starting from the study of the state of conservation of the artifact and planning the most appropriate scientific investigations to carry out.

The diagnostic investigations to support the restoration were also aimed at characterizing the materials, their originality, and evaluating any raw materials/products deriving from previous restoration work [6]. To this end, different samples from the vault (i.e., stuccoes, frescoes, and finishing layers) were investigated.

2. Research aim

The main purpose of the diagnostic campaign was to characterize the raw materials, in order to provide restorers with the necessary information for the planned restoration project in areas of the Chapel suffering from a serious state of deterioration. The methodological approach adopted involved: i) choosing the study area in line with the requests of the experts and restorers in charge of the Church maintenance; ii) an in-situ inspection and evaluation of selected areas to be sampled; iii) a micro-sampling campaign followed by laboratory investigations.

3. Sampling and analytical methods

3.1. Sampling

During the restoration intervention at the Cornaro Chapel, which began in 2020 and continued in 2021, various micro-fragments of stucco decorations were retrieved from the

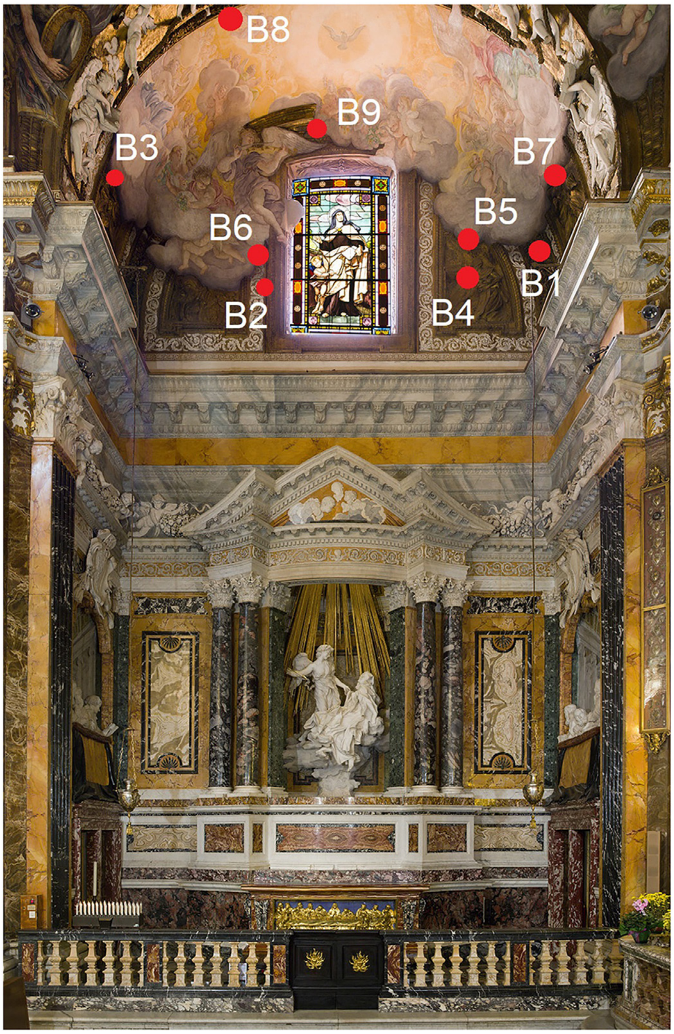

Fig. 2. Sampling points from the Cornaro Chapel vault.

Table 1
List of the examined micro-fragments, brief description, and purpose of the investigations to answer the restorers' questions.

Sample ID	Brief description	Purpose of the investigation and requests from restorers
B1	Whitish stucco micro-fragment with a thin brownish finishing layer from the scroll-form	- To characterize the stratigraphy and raw materials from a compositional point of view; - To evaluate whether they are original materials or deriving from past restoration interventions.
B2	Golden micro-fragment with a thin brownish superficial patina from the scroll-form	- To characterize the stratigraphy and raw materials from a compositional point of view, with particular attention to the finishing layer; - To evaluate whether they are original materials or deriving from past restoration interventions; - Application of the mission gilding technique?
B3	Golden micro-fragment with a thin brownish superficial patina from the crown	- To characterize the stratigraphy and raw materials from a compositional point of view, with particular attention to the finishing layer; - To evaluate whether they are original materials or deriving from past restoration interventions; - Application of the mission gilding technique?
B4	Golden micro-fragment with a thin brownish superficial patina	- To characterize the stratigraphy and raw materials from a compositional point of view, with particular attention to the finishing layer; - To evaluate whether they are original materials or deriving from past restoration interventions; - Application of the mission gilding technique?
B5	Greyish micro-fragment from the edge of a painted area	- To characterize the stratigraphy and raw materials from a compositional point of view, with particular attention to the mortar and the finishing layer; - Compare with sample B6; are they both original materials or could the B5 sample come from a previous restoration?
B6	Colored fresco micro-fragment from the edge of a painted area	- To characterize the stratigraphy and raw materials from a compositional point of view.
B7	Stucco micro-fragment from the hair of Christ	- To characterize the stratigraphy and raw materials from a compositional point of view; - To evaluate whether they are original materials or deriving from past restoration interventions.
B8	Golden micro-fragment from the festoon of the triumphal arch	- To characterize the stratigraphy and raw materials from a compositional point of view.
B9	Micro-fragment of rough coat layer from a frescoed area, right side of the angel	- To characterize the stratigraphy and raw materials of the mortar from a compositional point of view.

monument to study the raw materials used, their state of conservation, and the artist's technique of execution. This information would be useful for a greater knowledge of the artwork and to support the most appropriate design of the restoration work.

The sampling activity was performed with the assistance of the restorers in charge of the conservation of the artwork, to define the most suitable areas to investigate and to collect representative samples whose study would be decisive in choosing the most appropriate conservation interventions. Minimally invasive sampling procedures were adopted for the collection of 9 micro-fragments (dimensions less than $\simeq$ 2.5 mm^2) from different areas of the sculptural cycle, and were undertaken using suitable stainless-steel tools such as small tweezers and micro-scalpels. Specifically, samples were taken near existing detached and micro-cracked areas, so as not to cause further visible damage. A summary and a brief description of the micro-samples examined are given in Table 1. The same table also reports (for each sample) the aims of the investigations and the questions posed by the restorers, for use in the subsequent restoration work. Fig. 2 highlights the documentation and the sampling points inside the vault.

3.2. Analytical methods

The samples were subjected to a complementary analytical approach, specifically involving polarizing optical (POM) and fluorescence microscopy (FM), Electron Probe Microanalyses (EPMA) coupled with Energy Dispersive Spectrometry (EDX), and Fourier Transform Infrared Spectroscopy (FT-IR). The polarizing optical microscopy (POM) studies of thin stratigraphic sections were conducted in order to define the mineralogical and textural features of the examined micro-fragments, such as type, grain size, and distribution of the sandy aggregate, along with properties of the binder, by using an Axiolab microscope coupled with a digital camera to capture images.

Electron microprobe analysis (EPMA), fitted with a brand-new EDX system, was used to examine the layers' microstructure and the major element compositions of the samples. The measurements were performed on polished thin sections coated with a thin and highly conductive graphite film.

UV epi-fluorescence microscopy (FM) was used to locate any possible organic compounds present within the samples' stratigraphy. UV fluorescence emission for each layer may enable a detailed study of the sample's inner structure and this is particularly useful when samples exhibit multiple layers in cross-sections. Observations were performed using an FL-800 Optech epi-fluorescence microscope.

FT-IR spectroscopy was used to obtain information about both the organic components and the inorganic materials through the interpretation of the characteristic vibrational modes of the functional groups when they interact with NIR light [7-9]. Infrared spectra acquisitions were performed in Attenuated Total Reflectance (ATR) mode using a Perkin Elmer Spectrum 100 spectrophotometer, in the 500–4000 cm^{-1} wavenumber range, with a resolution of 4 cm^{-1}. Due to the complexity of the FT-IR absorbance profiles, the samples' bands were also compared with those of standard inorganic and/or organic compounds from databases [10] and literature [11] for a reliable assignment of the absorption peaks.

4. Results and discussion

4.1. Optical microscopy (OM) results

The petrographic results are described for each sample, highlighting their main features, so as to group them. Some representative photomicrographs are shown in Fig. 3, while Table 1 in the Supplementary Materials reports the main petrographic features detected for each sample, as follows: (i) samples B1, B3, and B8 are micro-fragments of stucco characterized by a brownish micritic binder in CPL (crossed polarized light), in which the aggregate fraction is well sorted and mainly constituted by angular mono and polycrystalline calcite fragments (spatic calcite), probably deriving from marble crushing. The aggregate shows a packing of about 60–70 % (area) [12] with sizes ranging from coarse silt (0.04–0.06 mm) to fine sand (up to 0.25–0.30 mm). In addition, traces of bioclasts have been recognized in the binder of sample B8, probably deriving from the incomplete calcination of the limestone/biocalcarenite used for lime production; (ii) samples B2 and B4 have mineralogical and petrographic properties very similar to the previous samples (i.e., B1 and B3), differing from the latter ones in for the presence of glassy scoriae fragments in addition to calcite grains; (iii) as far as sample B5 is concerned, investigations allowed us to distinguish between two main layers: a) the main core and b) a finishing layer superimposed on the previous one. The finishing layer (b) shows similar compositional properties to samples B2 and B4, presenting a micritic binder and an aggregate consisting of abundant calcite crystals and a few fragments of glassy scoriae. The packing of the sandy aggregate is about 80 % (area) [12] with particle sizes in the order of coarse silt (0.04–0.06 mm). Otherwise,

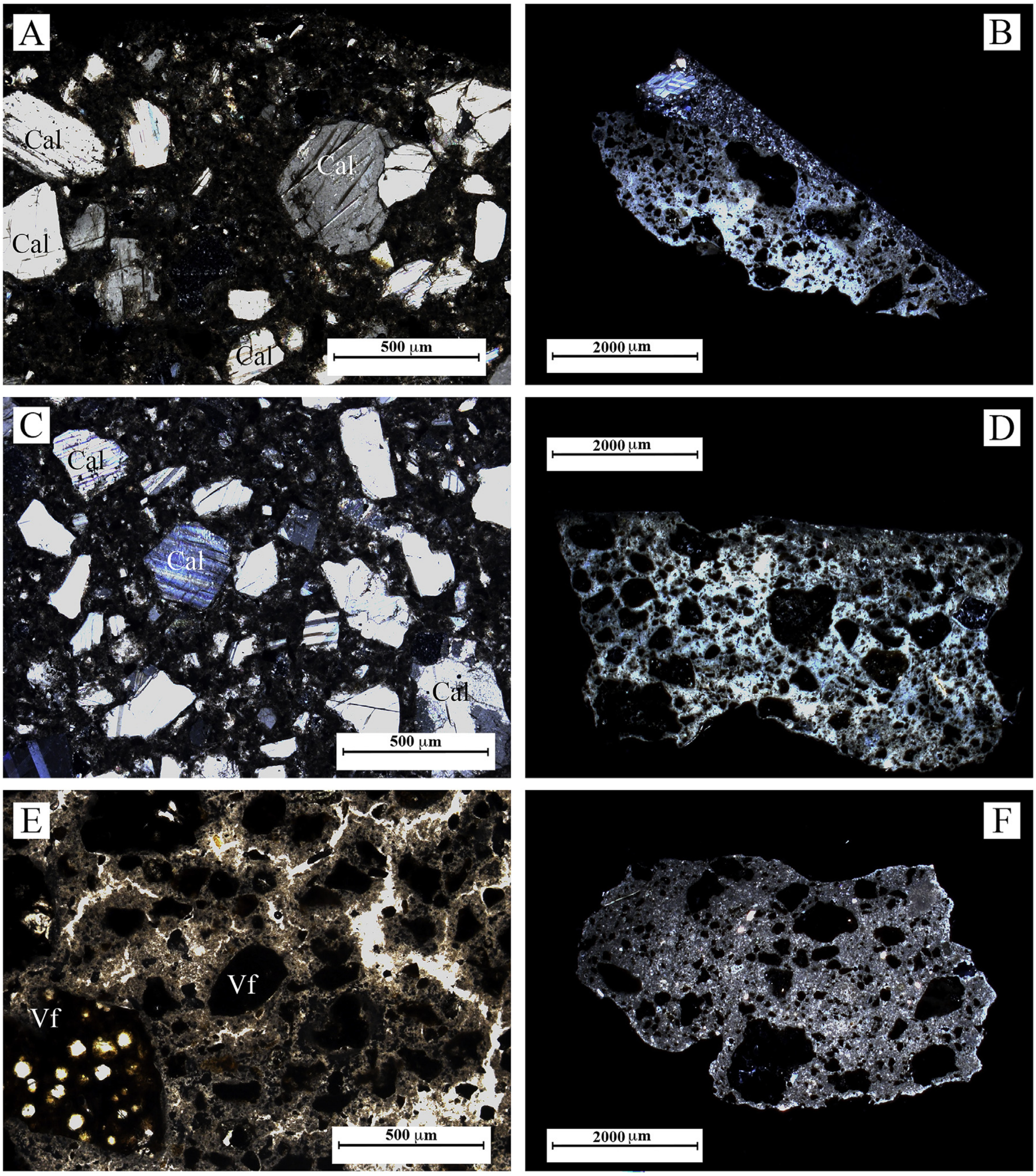

Fig. 3. Representative photomicrographs of the studied samples; A) Sample B3 (CPL); B) Sample B5 (CPL); C) Sample B8 (CPL); D-E) Sample B6, respectively CPL and PPL; F) Sample B7 (CPL). Legend: Cal = Calcite; Vf = Volcanic fragment.

the main layer (a) looks completely different. The petrographic observation shows a poorly sorted aggregate with a heterogeneous distribution mostly made of volcanic fragments (mainly glassy scoriae), varying in size from coarse silt (0.04–0.06 mm) to coarse sand (up to 1–1.5 mm). The micritic binder also displays clear reaction rims due to the pozzolanic reaction with the volcanic fragments; (iv) as for samples B6 and B7, they are both characterized by a brownish micritic binder, in which the aggregate is poorly sorted and principally composed of volcanic fragments. In B6 fragments of calcareous rocks were also observed. The aggregate shows a packing of about 60–70 % (area) [12] with dimensions varying from coarse silt (0.04–0.06 mm) to coarse sand (up to 1.5 mm). Bioclasts traces have been recognized in the binder, most likely deriving from the incomplete calcination of the limestone used for making lime. Reaction rims with volcanic fragments, lime lumps, and thin shrinkage cracks are also observed; (v) finally, sample B9 exhibits a poorly sorted aggregate with a heterogeneous distribution predominantly made of volcanic fragments, varying in size from coarse silt (0.04–0.06 mm) to coarse sand (up to 1–1.5 mm). The micritic binder also shows clear reaction rims with the volcanic components and thin shrinkage cracks.

4.2. EPMA-EDX results

The investigations made it possible to study both the morphology of the micro-fragments, paying attention to the finishing layers, and their chemical composition (in terms of major elements). Given the diversity in the finishing layers, which was not clearly distinguishable employing OM, the samples are discussed separately, as follows:

Sample B1 shows two further layers (A and B) superimposed on the stucco. The most superficial layer (A, *scialbatura*), probably the finishing one, shows thicknesses ranging from 5 to 10 μm, while

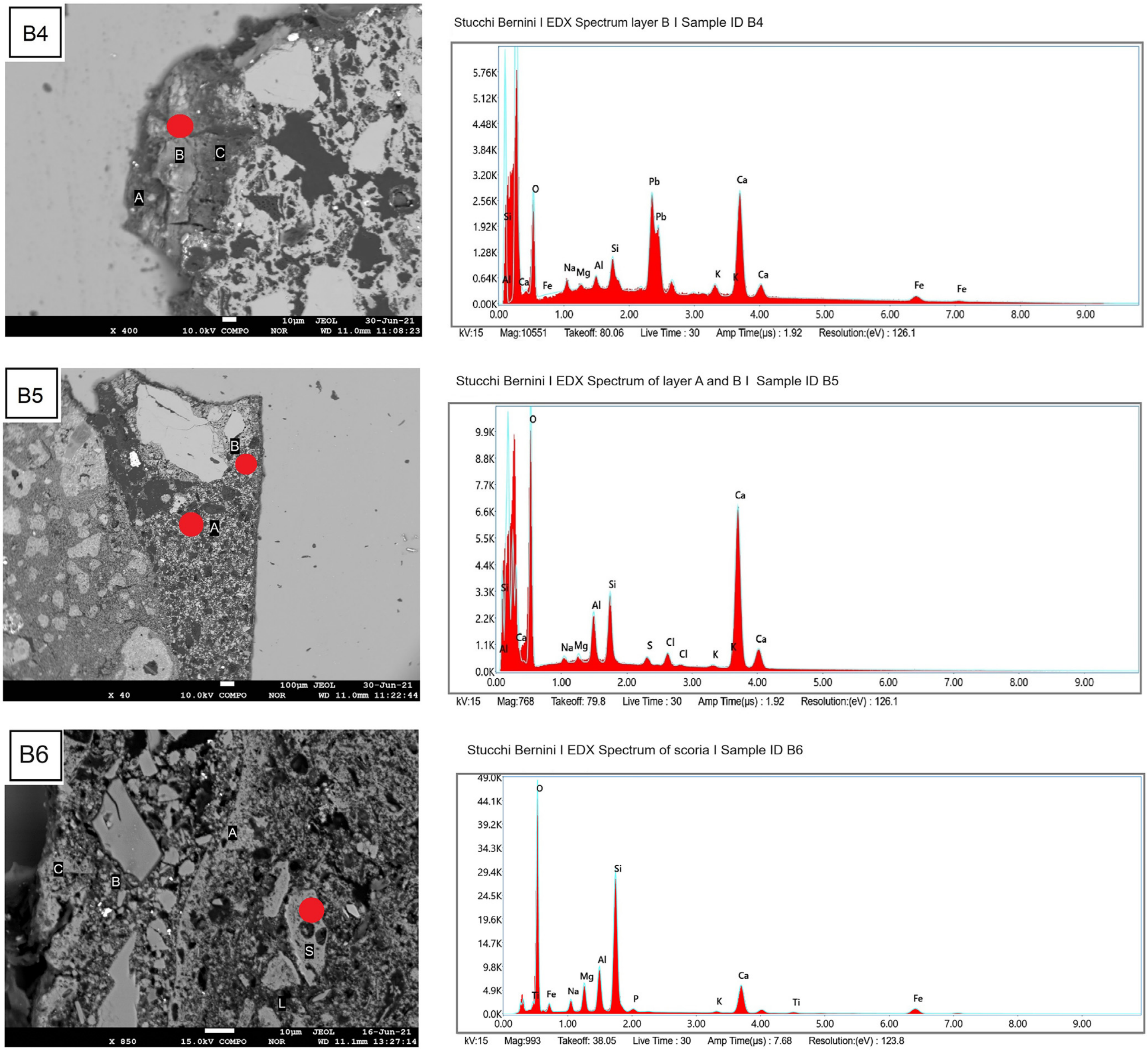

Fig. 4. EPMA-EDX images of thin sections showing the stratigraphy and details of representative samples; Sample B4 with evidence of three layers named (A), (B) and (C) and EDX spectrum related to layer (B) made of lead white; Sample B5 with evidence of two layers named (A) and (B) and EDX spectrum representative for both layers and consisting of an aerial lime; Sample B6 with evidence of three layers named (A), (B) and (C) and EDX spectra related to a scoria (S).

the immediately underlying layer (B) is about 30 µm thick and displays continuity with the underlying stucco portion. From a compositional point of view, the EDX reveals the presence of calcium oxide (CaO) as the only compound for layer B, suggesting the use of an aerial lime binder, while in layer A a low percentage of silica (SiO_2) was also detected.

Regarding sample B2, it shows (Fig. 4) four layers that overlap the stucco (A-E), with thicknesses between 10 and 30 µm. Compositionally: **1)** the stucco layer (A) and the immediately overlying layer (B) consist of calcium oxide (CaO) and a small amount of magnesium oxide (MgO), suggesting the presence of a weakly magnesian aerial lime. Furthermore, the same layers show a fair content of silica (SiO_2), probably deriving from the finest fraction of sandy aggregate (mainly quartz granules), further confirming the observations by OM; **2)** also in layer **C**, CaO and MgO were detected in addition to fair quantities of phosphorus (P) and iron (Fe). Such elements suggest both the presence of a black pigment obtained from the pyrolysis of animal bones, mainly composed of carbon and organic phosphates (i.e. bone black or bone white, Ca-P with variable amounts of organic material), and that of a reddish pigment mainly consisting of hematite; **3)** layer **D** is composed almost exclusively of lead white ($(PbCO_3)_2{\cdot}Pb(OH)_2$) with small amounts of Ca and K, and finally **4)** the finishing layer **E** is almost exclusively made of gold (Au) with a very small amount of SiO_2, suggesting a gold finish layer (i.e., gilding) [13].

In addition to the stucco layer, sample B3 is superimposed by: **1)** a preparatory layer for gilding, in which 2 further sub-levels (A1-A2) are distinguished; **2)** a level of browning (B), and **3)** a superficial layer (C1-C2). As for the preparatory layer, it consists exclusively of CaO in the portion in contact with the stucco (A1) and lead white $(PbCO_3)_2$ $Pb(OH)_2$, with small amounts of Ca and Si in the level below the gilding (A2). Layer B consists almost exclusively of Au with a very small amount of CaO and SiO_2, while the most superficial level shows a similar composition in the two investigated areas (C1-C2) with slight differences for the compounds identified. In particular, the presence of Cu, which suggests that the use of silico-aluminate mixtures of Na, Mg, and K, known as green earth and widely used in antiquity and up to the 19th century, is evident. However, further investigation is needed to confirm this hypothesis.

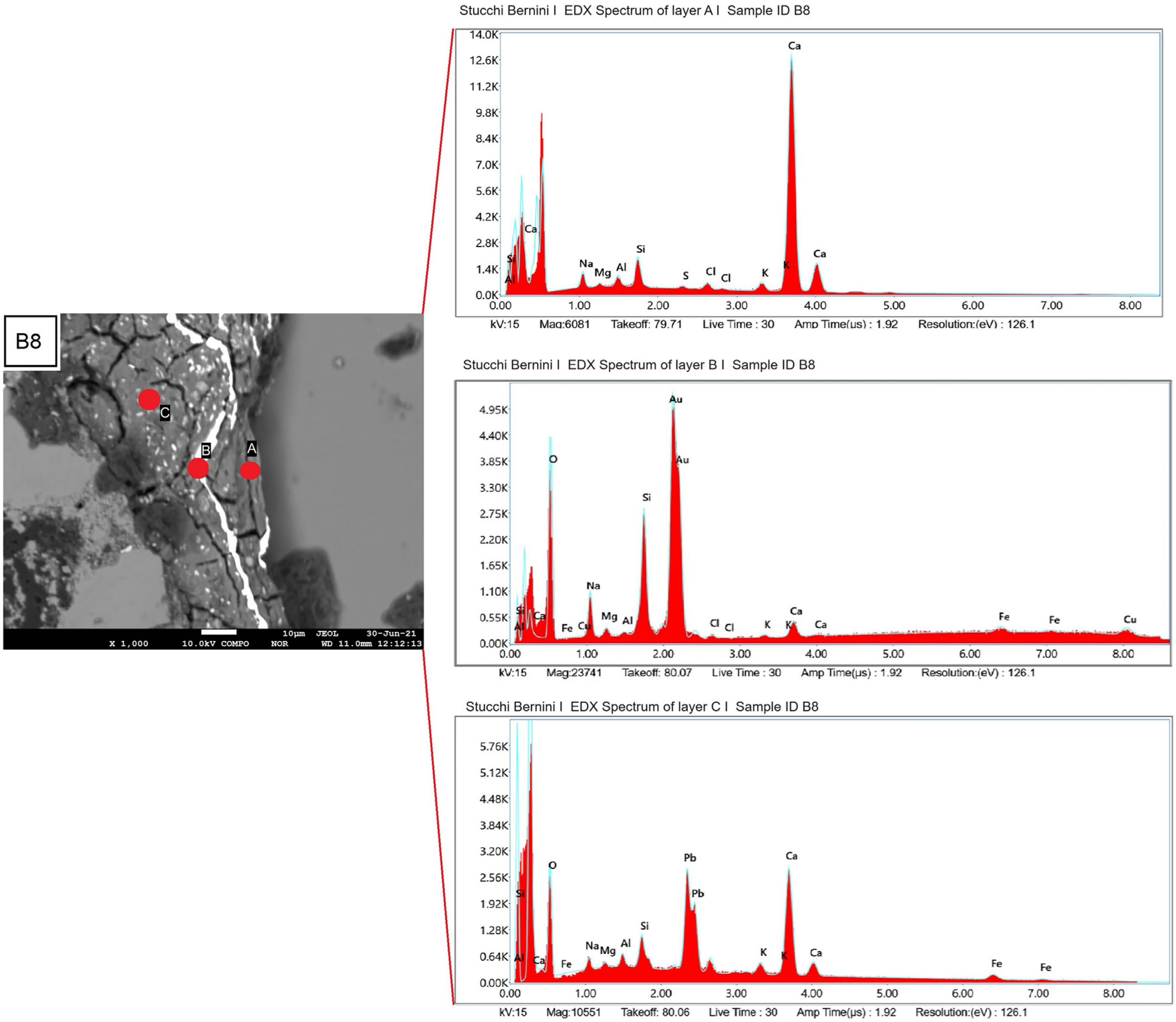

Fig. 5. EPMA-EDX image of thin section showing the whole stratigraphy and details of samples B8 with evidence of three layers named (A), (B) and (C) and EDX spectra related to layers named (A), (B) and (C) where the brightest features in (B) represent the gilding layer.

Table 2
Synthesis of data detected by EPMA-EDX.

Sample ID	N. layers	Main chemical composition by EDX	Identified materials
B1	2 (A-B)	A: $CaO+SiO_2$ B: CaO	Lime-based scialbatura.
B2	5 (A-B-C-D-E)	A: CaO+MgO B: $CaO+MgO+SiO_2$ C: CaO+MgO+P+Fe D: $(PbCO_3)_2{\cdot}Pb(OH)_2)$ E: Au	Low magnesium aerial lime-based binder for the preparatory layers (A-B-C), with carbon and organic phosphates (bone black or bone white) and a red pigment consisting of hematite (C). Preparatory layer (D, lead white) for gilding (E).
B3	4 (A1-A2-B-C1/C2)	A1: CaO A2: $CaO+(PbCO_3)_2{\cdot}Pb(OH)_2)$ B: Au C1=C2: Cu+silico-aluminates of Na, Mg, K	Aerial lime-based binder (A1). Preparatory layer (A2, lead white) for gilding (B). C1-C2: Green earth.
B4	3 (A-B-C)	A: C+N B: $C+(PbCO_3)_2{\cdot}Pb(OH)_2$ C: C+CaO	Organic layers (A+C). Preparatory layer with organic component + lead white (B).
B5	2	A=B: CaO	*Marmorino* (crushed marble + slaked lime)
B6	3	A: $CaO+SiO_2+Al+K+Mg$ B: $CaO+SiO_2+Al+K+Mg+(C+P)$ C: $CaO+SiO_2+Al+K+Mg$	Aerial lime-based binder with evidence of pozzolanic reactions with the volcanic glassy scoriae (A+C). The additional presence of organic compounds containing C and P (B).
B7	2 (A-B)	A: $CaO+SiO_2+Al+K+Mg$ B: CaO	Aerial lime-based binder with evidence of pozzolanic reactions with the volcanic glassy scoriae (A). Aerial lime-based binder (B).
B8	3 (A-B-C)	A: $CaO+SiO_2$ B: Au+Ca, Pb and Si C: $CaO+SiO_2+Al2O_3+FeO$	Aerial lime-based binder with evidence of pozzolanic reactions with the volcanic glassy scoriae (C+A), (B) mixed preparatory layer made of CaO and lead white + gilding (Au).
B9	1 (B)	B: $CaO+SiO_2$	Aerial lime-based binder with evidence of pozzolanic reactions with the volcanic glassy scoriae.

Sample B4 shows three layers (Fig. 4) above the stucco (A-B-C). Layer C in contact with the stucco consists exclusively of C associated with very small quantities of CaO, suggesting the presence of a preparatory layer of organic nature. The intermediate level (B) also shows an organic composition with small amounts of lead white $(PbCO_3)_2{\cdot}Pb(OH)_2$. The outermost layer A also exhibits an organic coating.

Sample B5 confirms the observations under OM with the presence of a single layer above the substrate made of CaO, suggesting the presence of an aerial lime (Fig. 4).

Apart from the fresco layer, already identified under optical microscope observation, sample B6 shows three further superimposed layers. All layers (A, B, and C) are made up of an aerial lime-based binder that has reacted with the vitreous scoriae constituting the sandy aggregate (pozzolanic-type reactions). Furthermore, in layer B, small quantities of carbon (C) and phosphorus (P) have been detected and are probably attributable to the presence of organic compounds.

The stucco sample B7, very similar to the previous one (B6) in its compositional properties, has only two layers, a layer (B) characterized by aerial lime and the second (A) with the presence of vitreous aggregate, which also in this case gave pozzolanic reactions.

In addition to the stucco layer, sample B8 shows three further layers (Fig. 4). Regarding their chemical composition, the innermost layer (C) and the most superficial one (A) both consist of an aerial lime-based binder given the main presence of CaO, followed by lower amounts of SiO_2, Al_2O_3, and FeO. The latter components seem to be linked to the aggregate fraction. The intermediate layer (B) is characterized by the presence of a gilding layer (Au), which was most likely spread over a preparatory layer (i.e. *bole*, gilding preparation layer) [14] based on aerial lime and white lead, given the presence of elements such as Ca, Pb and Si.

Sample B9 (Fig. 5) confirmed observations with OM that showed a volcanic fragment (B, probably a glassy scoria) surrounded by a layer of stucco (A). Regarding the composition, the innermost layer B consists of SiO_2, CaO, Al_2O_3, MgO, K_2O, and FeO, which can be associated with volcanic aggregates. Layer A, on the other hand, appears to be made up of an aerial lime-based binder with a modest% of SiO_2, probably deriving from grains of sandy aggregate.

The main chemical composition and features detected for each sample are shown in Table 2, while some representative images are given in Figs. 4 and 5.

4.3. Epi-fluorescence microscopy (FM) results

Observations under fluorescence microscopy were preliminarily performed to verify the possible presence of organic compounds such as binders or varnishes, attributable to previous protective treatments [15]. When observing samples by fluorescence microscopy with a UV excitation light, different compounds can exhibit characteristic colors and fluorescence intensities, which can provide information on their spatial distribution within the cross-section layers. However, while the fluorescence images indicate the possible presence of fluorescence matter, they do not allow univocal identification [16-19], so in the present study, the method was useful as a qualitative examination as concerns the detection of organic matter within the layers, offering valuable data before the restoration. Although all nine samples were investigated, fluorescence in the visible range only occurs in samples B2, B3, B4, and B8 (see Supplementary Materials, Fig. S1). Understanding these has been extremely helpful in studying the artist's technique better, despite the limitations associated with the technique. The results achieved by UV Epi-Fluorescence Microscopy, while ascertaining the presence of organic-based compounds, clearly underline the necessity to apply further analytical techniques to allow the identification of the organic matter observed under UV fluorescence.

4.4. Fourier transform infrared spectroscopy (FTIR) results

FTIR analysis allowed for the identification of both inorganic and organic compounds from the samples' surfaces and further strengthened the investigations performed by EPMA-EDX. Due to the small amount of material, samples B7 and B9 could not be analyzed.

In all the analyzed samples (see Supplementary Materials, Fig. S2), the stretching vibrations of calcite, which peaked at ≃ 1409, ≃ 875, and ≃ 711 cm^{-1}, could be ascribed to the preparatory layers (in the case of samples B1, B5, B6) and/or to the binder (in the case of samples B2, B3, B4 and B8), as also suggested by the EPMA-EDX analysis.

The absorbance band that peaked at ≃ 1020 cm^{-1} was recognized in all samples except for fragment B8. This can be ascribed to the stretching of the Si–O bond, suggesting silicate compounds, probably deriving from sandy raw materials used as inert in the preparatory layers or as pigmenting agents (ocher).

Samples B2 and B3 also showed signals due to the presence of calcium oxalate (whewellite), respectively peaked at ≃ 1630, 1320, and 781 cm^{-1}.

In addition to inorganic compounds, the FTIR spectra of samples B2, B3, and B8 also confirmed the stretching bands of the C–H group, which peaked at ≃ 2852 and 2922 cm^{-1}, suggesting the presence of an organic substance that is probably correlated with a protein-based binder.

5. Discussion and conclusion

Diagnostic investigation of cultural heritage generally provides the clarification of stylistic and conservation problems and knowledge of raw materials and techniques, both the original ones and those used in previous restoration interventions. The main purpose of the present research was to establish adequate conservation procedures based on the properties of the materials and alteration deposits, and to promote the suitable preservation of such a masterpiece. Specifically, in this study, a multimethod approach based on different and complementary analytical techniques was successfully applied to what is considered to be one of Gian Lorenzo Bernini's great Baroque masterpieces, the Cornaro Chapel, in the church of Santa Maria della Vittoria in Rome, Italy.

The analytical investigations performed on nine micro-samples from the Cornaro Chapel, mainly consisting of stucco and fresco fragments, allowed us to obtain valuable information for the restorer in charge of the conservation intervention. In fact, in the context of scientific studies conducted on Cultural Heritage, this approach represents a necessary prerequisite for designing the best restoration plan. A systematic and integrated approach should always be a pillar requirement for the preservation of cultural heritage, prior to planning and management of any restoration interventions.

As far as the study of the raw materials is concerned, the optical microscope investigations highlighted the presence of a micritic binder in which the dominant mineralogical component is calcite in almost all the samples. There are also fragments of rocks, volcanic and rarely carbonate, except for B1, B3, and B8. In particular, volcanic rocks, mainly as glassy scoriae, were observed in samples B5, B6, B7, and B9. Samples B6, B7, and B8 also show remains of bioclasts. Among other things, the B6 sample seems to be a fragment collected from an original portion of the stucco according to the first survey made in situ by the restorers.

A comparison of the results obtained by all the analytical techniques used made it possible to respond to the requests of the restorers (Table 1). More specifically:

Sample B1 is a whitish stucco micro-fragment (A) with a thin brownish finishing layer (B). The layering appeared clear on EPMA-EDX, showing a composition of CaO and SiO_2 for layer A and CaO only for layer B. It is a lime-based *scialbatura* [20], which is compositionally similar to B6 due to the presence of dominant CaO, although in B6 the composition of the layers also contains components such as SiO_2, Al, K, and Mg related to the pozzolanic reactions with the glassy volcanic scoriae present in the sample. B1 is also stratigraphically different from the original sample B6, above all in the absence of volcanic inclusions, and bioclasts.

Samples B2, B3, B4, and B8 are golden micro-fragments with a thin brownish superficial patina, sampled from different areas of the artifact. They are very similar from a minero-petrographic point of view, with the presence of calcite as the dominant mineralogical phase. The samples' stratigraphy is different and quite complex, but the presence of a preparatory layer made of CaO along with organic compounds and lead white is always detected. The gilding layer is clearly visible only on B2, B3, and B8. Given the presence of organic components, the investigations suggest the application of the mission gilding technique [14,21,22].

Sample B5 is compositionally and stratigraphically different from B6. Sample B5 shows a single layer, above the substrate, made of CaO, suggesting the presence of an aerial lime compatible with a *marmorino* plaster (crushed marble + slaked lime) [23,24]. Sample B6, on the other hand, has a more complex stratigraphy with a finishing layer of organic nature.

Sample B7 is very similar to the original sample B6 from a minero-petrographic point of view. However, in B7 no organic compounds are detected.

B9 is a micro-fragment of a rough coat layer from a frescoed area. It consists of an aerial lime-based binder with evidence of components deriving from the pozzolanic reactions with the glassy volcanic scoriae present in the sample.

The diagnostic investigations, the characterization of the raw materials of the micro-fragments, and the knowledge of the different layering made it possible to resolve many of the doubts the restorers had before the restoration. The results from the multi-analytical approach adopted allowed us to discern the originality of the majority of samples, which were composed of similar raw materials, and to understand their distributions within the samples' layering. Regarding the technique for execution, the mission gilding technique was ascertained. Thanks to the information acquired, the restorers were able to choose the appropriate materials/compounds for each phase of the restoration, including the initial cleaning step, as well as subsequent reintegration, consolidation and protection.

Acknowledgement

We would like to thank the "Soprintendenza Speciale Archeologia Belle Arti e Paesaggio" of Rome for the invaluable input and support throughout the research process. This work was also financially supported by the "Fondo Finalizzato alla Ricerca di Ateneo (FFR)" of the University of Palermo (FFR 2023_Randazzo L).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2024.06.009.

References

[1] R. Wittkower, Gian Lorenzo Bernini: The Sculptor of Roman Baroque, Phaidon Press, London, 1955.

[2] A.J. Ladd, Bernini's Cornaro Chapel: visualizing mysticism in the age of reformation [Master's thesis, Kent State University]. Ohio LINK Electronic Theses and Dissertations Center, 2012. http://rave.ohiolink.edu/etdc/view?acc_num=kent1342488915.

[3] J. Montagu, Bernini and the unity of the visual arts, Burlingt. Mag. 124 (949) (1982) 240–243.

[4] G. Warwick, Bernini (1598–1680): sculpting sainthood, Stud.: Irish Q. Rev. 104 (416) (2015) 444–455 http://www.jstor.org/stable/24640794.

[5] M.R. Lagerlöf, Life transformed: performative meaning, analogy, and the art of Bernini's Funerary Chapel decorations, Konsthistorisk tidskrift/J. Art Hist. 81 (2012) 2–30.

[6] M. Ricca, M.F. Alberghina, N.D. Houreh, A.S. Koca, S. Schiavone, M.F. La Russa, L. Randazzo, S.A. Ruffolo, Preliminary study of the mural paintings of Sotterra Church in Paola (Cosenza, Italy), Materials 15 (2022) 3411, doi:10.3390/ma15093411.

[7] A. Nevin, The use of micro-FTIR with attenuated total reflectance for the analysis of wall painting cross-section, Zeitschrift für Kunsttechnologie und Konservierung 19 (2) (2005) 356–368.

[8] F. Izzo, C. Germinario, C. Grifa, A. Langella, M. Mercurio, External reflectance FTIR dataset (4000–400 cm$-^{1}$) for the identification of relevant mineralogical phases forming Cultural Heritage materials, Infrared. Phys. Technol. 106 (2020) 103266, doi:10.1016/j.infrared.2020.103266.

[9] A. Casoli, Research on the organic binders in archaeological wall paintings, Appl. Sci. 11 (19) (2021) 9179, doi:10.3390/app11199179.

[10] S. Vahur, A. Teearu, P. Peets, L. Joosu, I. Leito, ATR-FT-IR spectral collection of conservation materials in the extended region of 4000-80 cm^{-1}, Anal. Bioanal. Chem. 408 (13) (2016) 3373–3379, doi:10.1007/s00216-016-9411-5.

[11] M.R. Derrick, D. Stulik, J.M. Landry, Infrared Spectroscopy in Conservation Science, Getty Conservation Institute, Los Angeles, CA, USA, 1999.

[12] A.J. Matthew, A.J. Woods, C. Oliver, Spot before the eyes: new comparison charts for visual percentage estimation in archaeological material, in: A. Middleton, I. Freestone (Eds.), Recent Developments in Ceramic Petrology, British Museum Occasional Paper, London, 1991, pp. 211–263. 81.

[13] J. Brocchieri, C. Sabbarese, Thickness determination of the gilding on brass materials by XRF technique, in: Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 496, 2021, pp. 29–36, doi:10.1016/j.nimb.2021.03.018.

[14] D. Hradil, J. Hradilová, P. Bezdička, C. Serendan, Late Gothic/early Renaissance gilding technology and the traditional poliment material “Armenian bole”: truly red clay, or rather bauxite? Appl. Clay. Sci. 135 (2017) 271–281, doi:10.1016/j.clay.2016.10.004.

[15] A. Pelagotti, L. Pronti, E. Massa, M. Galeotti, A. Ca, Felici, multispectral reflectance and UV fluorescence microscopy to study painting’s cross sections, Conf. Ser.: Mater. Sci. Eng. 364 (2018) 012064, doi:10.1088/1757-899X/364/1/012064.

[16] I.C.A. Sandu, S. Schäfer, D. Magrini, S. Bracci, C. Roque, Cross-section and staining-based techniques for investigating organic materials in painted and polychrome works of art: a review, Microsc. Microanal. 18 (4) (2012) 860–875, doi:10.1017/S1431927612000554.

[17] I.C.A. Sandu, I. Joosten, LN, Optical imaging applications for the study of cultural heritage artifacts, in: Akira Tanaka, Botan Nakamura (Eds.), Optical imaging: Technology, Methods and Applications, Nova Science Publisher Inc, 2012, pp. 65–108.

[18] I.C.A. Sandu, L.U. Afonso, E. Murta, M.H. De Sá, Gilding techniques in religious art between East and West, 14th - 18th centuries, Int. J. Conserv. Sci. 1 (1) (2010) 47–62 http://www.ijcs.uaic.ro/pub/IJCS-10-06_Sandu.pdf.

[19] D. Magrini, S. Bracci, I.C.A. Sandu, Fluorescence of organic binders in painting cross-sections, Procedia Chem. 8 (2013) 194–201 ISSN 1876-6196, doi:10.1016/j.proche.2013.03.025.

[20] M. Ricca, A. Donato, M. Cirone, S.A. Ruffolo, A. Costanzo, F. Buongiorno, G. Mantella, M.F. La Russa, L. Randazzo, Building materials and decay assessment of the Gerace Cathedral (Reggio Calabria, Southern Italy), Case Stud. Construct. Mater. 19 (2023) e02225, doi:10.1016/j.cscm.2023.e02225.

[21] J. Brocchieri, E. Scialla, A. Manzone, G.O. Graziano, A. D’Onofrio, C. Sabbarese, The gilding technique on lead objects of the royal palace in Caserta (Italy) studied by pXRF, Mediterranean Archaeol. Archaeometry 22 (1) (2022) 29–43, doi:10.5281/zenodo.5906713.

[22] Osticioli, L. Capozzoli, B. Salvadori, M. Banchelli, A. Lavacchi, P. Matteini, S. Siano, L. Gallo, The “oro di metà” gilding in the fifteenth-century: a multi-analytical investigation, Heritage 2 (2019) 1166–1175, doi:10.3390/heritage2020076.

[23] A. Bakolas, R. Bertoncello, G. Biscontin, A. Glisenti, A. Moropoulou, E. Tondello, E. Zendri, Chemico-physical interactions among the constituents of historical walls in Venice, in: MRS Online Proceedings Library (OPL), 352, 1995, p. 771, doi:10.1557/PROC-352-771.

[24] R. Piovesan, C. Mazzoli, L. Maritan, Production recipes of mortar-based materials from ancient Pompeii by quantitative image analysis approach: the microstratigraphy of plasters in the Temple of Venus, J. Cult. Herit. 59 (2023) 57–68, doi:10.1016/j.culher.2022.11.002.