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Guidelines for Conservation and Restoration of Historic Polychrome Plasterwork: the Church of St María la Blanca in Seville, Spain

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ABSTRACT

Carrying out an intervention for the conservation and restoration of architectural heritage, focused on the preservation of decorative elements such as polychromed plasterwork, implies following a methodology to study the materials and techniques used in each case to establish an intervention proposal according to the circumstances. This work offers some methodological guidelines necessary to approach the conservation of plasterwork and its polychromies, applied in a recent case study according to the criteria established by the 14th General Assembly of ICOMOS in 2003, the Law 14/2007 of Andalusian Historical Heritage, the Law 16/1985 of the Spanish Historical Heritage, and indications contained in the ECCO Guidelines. The novelty of the paper is that it presents the conservation decisions on a real case from the beginning until the end — showing the entire process and validating the proposed methodology — by using current restoration techniques and digital tools for the reconstruction of plasterwork.

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Introduction

The literature provides extensive information on ancient and historic polychrome plasterwork in relation to its characterization, the anomalies that could be present, and restoration procedures. Usually, research in this field is focused on specific topics like non-destructive testing applied to study the state of preservation of plasterwork (Torres-González et al. 2021a; Grazzini 2019; Torres-González et al. 2021b; Dominguez Vidal et al. 2012), methodologies comprising the survey, evaluation, and inspection of the preservation status of the building before the repair, replacement, and rehabilitation of gypsum plasterwork (Cotrim, do R. Veiga, and De Brito 2007; Gleeson 2002; Tsakiridis and Toumbakari 2010), the study of the polychromies that decorate the plaster (Coba Peña et al. 2016; Hernández Pablos et al.; Calero Castillo et al. 2017; Calero-castillo et al. 2021) and their cleaning issues (Vivar García, Calero Castillo, and García Bueno 2021b), and the characterization of limewash layers that frequently cover the plasterwork (Blasco López et al. 2019; Martínez-Domingo et al. 2020).

Previous research has addressed the anomalies present in historic plasterwork and its polychromies and presented proposals for their maintenance, conservation, and preservation in representative case studies such as the Alhambra (Dominguez Vidal et al. 2014; Rubio Domene 2011; Campos Suñol

et al. 2013; De La Torre-López et al. 2014; Rubio Domene 2010; Cardell-Fernández and Navarrete-Aguilera 2006) and the Palacio de la Madraza (Ramos Molina et al. 2017; Ramos Molina 2015a; Ramos Molina 2015b) in Granada and the 'Real Alcázar' in Seville (Torres-González et al. 2021a; Torres-González et al. 2021b; Blasco López et al. 2019; Blasco López et al. 2012; Campos de Alvear 2020; Blasco López, Alejandro Sánchez, and Flores Alés 2016a; Silva et al. 2019; Calero Castillo 2016). They address aspects such as cleaning methods (Vivar García, Calero Castillo, and García Bueno 2021b), conservation treatments (López Borges, Burgio, and Clark 2005), and the materials to be used in repairs and reconstructions to ensure their reversibility (*Productos – Mortero Alhambra*).

Other studies are focused on historic gypsum physical, mechanical, mineralogical, and microstructural characterization by sampling and analysis (Dominguez Vidal et al. 2014; Blasco López et al. 2012; Freire et al. 2019a; Bueno García and Medina Flórez 2004; Freire et al. 2019b; Rani, Santhanam, and Bais 2019; Blasco López 2011; Blasco López et al. 2016b; Calero Castillo et al. 2016; Blasco López and Alejandro Sánchez 2013a) or on the assessment of restoration materials compatible with the original (Freire et al. 2021; Ranesi, Faria, and do R. Veiga 2021) and/or distinguishable (*'Productos – Mortero Alhambra'*).

This work presents the methodological guidelines necessary to evaluate the current condition and approaches to the restoration of plasterwork and its polychromies, and the results obtained after the restoration intervention in a recent case study of the Church of St María la Blanca (Seville, Spain). The novelty of the paper is to present the intervention work on a real case from the beginning to the end, showing the entire process and following and validating the proposed methodology by using not only traditional but also current restoration techniques and digital tools for the reconstruction of plasterwork.

Case study: the Church of Santa María la Blanca

The Church of Santa María la Blanca (hereinafter, SMLB) is one of the greatest examples of the Andalusian Baroque style of the seventeenth century, due to the rich set of plasterwork and painting decorations (Figure 1).

The building was declared an Historic Artistic Monument¹ in 1995 and has its own level of protection.² By virtue of the degree of protection established, urban regulations determine that it must be preserved in its entirety due to its singular and monumental character and for historical-artistic reasons, preserving all its architectural characteristics.

This temple was a mosque in the eleventh-thirteenth centuries and a synagogue from 1248 until the expulsion of the Jews in 1391 (Falcón Márquez 2015; de la Torre Farfán 1666; Gil Delgado 2013a; Gil Delgado 2013b). Currently, the building has a rectangular floor plan, with an extension of the head and two bodies, also rectangular, attached to the wall of the nave of the epistle. Inside, it has three naves of similar height, divided into six sections by ten Tuscan red marble columns. On top of them, there are semicircular arches that support barrel vaults with false lunettes in the central nave and groin vaults in the lateral ones. The presbytery space is covered by a barrel vault with lunettes (Figure 2).

Regarding the interventions that have been carried out over time, most of them were caused by structural problems, which were responsible for the cracking of the vaults, and by leaks and dampness due to capillarity; finally, there was also damage caused by cleaning and sweeping the chimney (Gil Delgado 2014). As a result of the 1969 earthquake that affected not only the structure of the church but also the plasterwork, the restoration project by the architect Rafael Manzano was approved: the roofs were waterproofed and the plasterwork restored and consolidated in the vaults, domes, and arches (Gil Delgado 2014). In 2015 the restoration work involving the plasterwork and polychromies ended and the temple recovered the appearance it had in the last third of the seventeenth century.

The origin of plasterwork and its execution techniques

There is an exceptional plasterwork program developed throughout the whole extension of SMLB, highlighted by a repertoire of forms in high relief made up of plant and architectural motifs and figurative and epigraphic elements. In fact, the entire surface of the vaults, dome, and soffit of the arches is filled with a profuse and volumetric plaster decoration, which gives movement to an orthogonal architectural plan lacking dynamism.

Plasterwork attributed to the Borja brothers and to Pedro Roldán and polychromies in SMLB were not executed until 1662 (Gil Delgado 2015; Bonet Correa 1978; Falcón Márquez 2017). The technique used to execute the original plasterwork was molding: the volume of the plaster pieces was obtained thanks to molds, then – with the plaster still fresh – the geometries and specific details were carved, and finally they were fixed to the support. Additionally, there was another way of execution consisting of cutting the profile of the plaster moldings by using templates (Falcón Márquez 2017).

Regarding their fixation, plaster grouts were used after preparing the support (Figure 3) for greater grip. In elements of higher volume and weight,

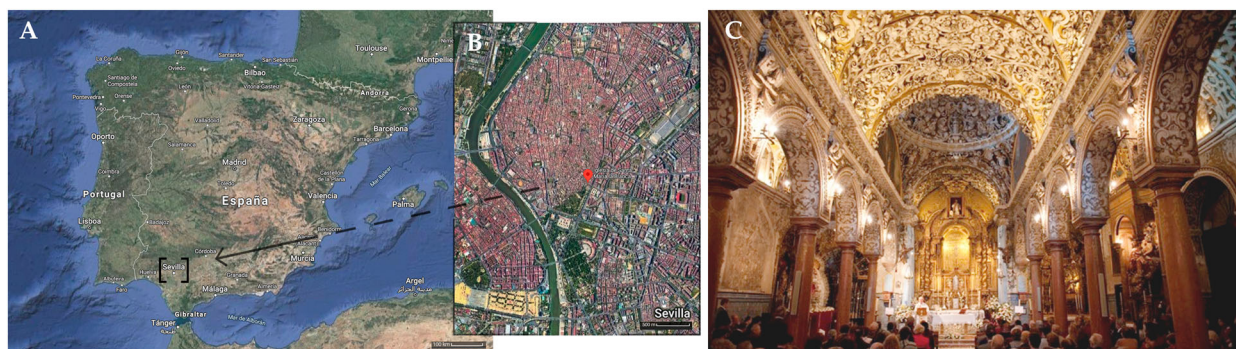


Figure 1. Location of Seville in the Iberian Peninsula (A), situation of SMLB in the province of Seville (B), and interior view of SMLB (C).

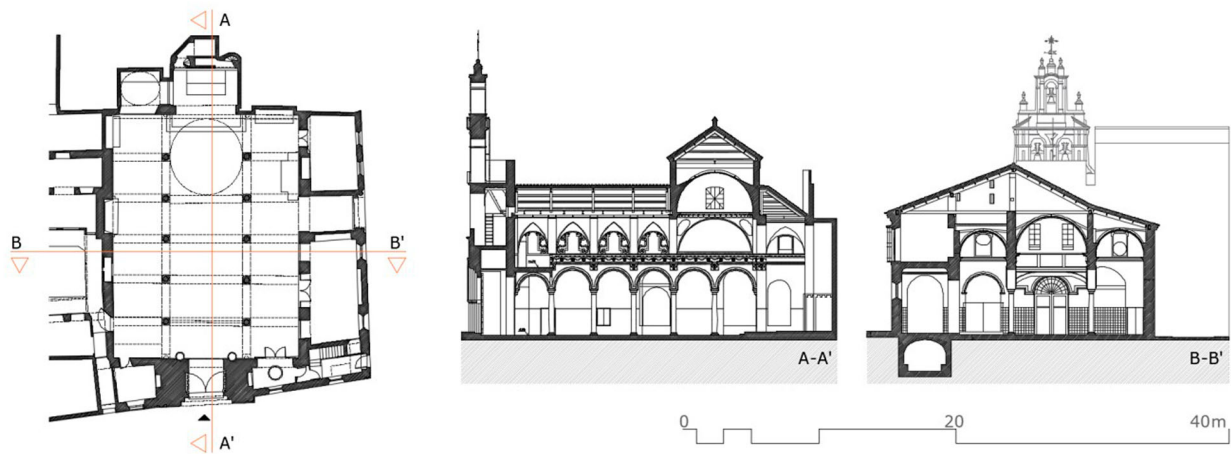


Figure 2. Plans for SMLB.

reinforcements based on nails inserted into the piece during its elaboration were used, fixed with plaster and oakum in the back of the vault (Rubio Domene 2002).

The plasterwork was executed based on previous drawings on the support and the delimitation of the spaces. After that, the smooth bands that articulate the different decorative spaces and the decorative pieces were placed. Finally, the joints were checked for burrs and a layer of plaster grout was applied to hide the joints, marks, etc., homogenizing the whole. In the case of the vaults (Figure 4), the support of the reliefs consists of a plaster layer arranged on a slatted frame and a wooden skeleton, which forms the vaults of the three naves of the church. This layer is fixed and varnished on its internal face prior to gilding.

There are clear differences between the plasterwork of the presbytery and the main arch, and that in the rest of the church. It is also known that there is a

colored base for the gilded background (a red underpainting) that does not exist in other gilded areas in the building. However, the phases and manufacturing procedures are unknown, as are other relevant data regarding the composition of materials. These topics are key aspects to determine the causes of degradation and to foresee an evolution of the materials in the short and long term. However, taking into account the morphological details of the plasterwork, the following typological classification was proposed (de la Torre Farfán 1666):

1. **High reliefs:** This group consists of the reliefs located in the main nave, dome, choir, and apse. Due to its volume and the roundness of the undulations that makes its shapes, the plastic effect achieved is even greater. This type of relief is reserved for the representation of leaves, fruits, garlands, stems, and other plant forms; human figures

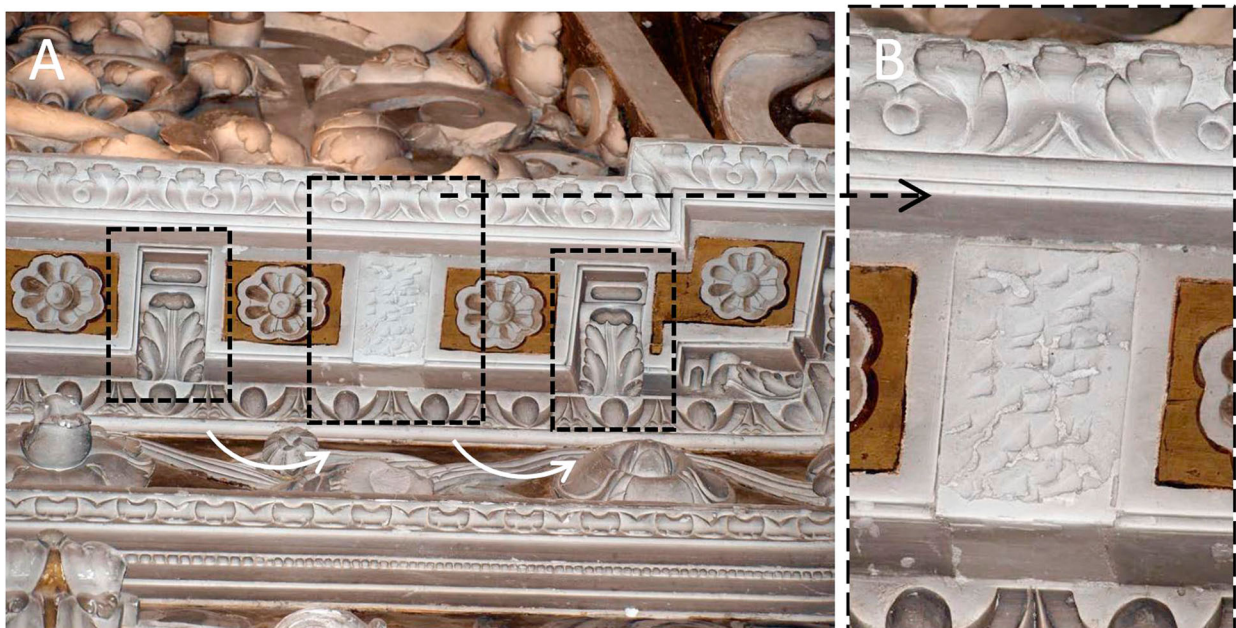


Figure 3. Cornice of the central nave (A), marks made to adhere a corbel, partially filled with the adhesion grout (B).

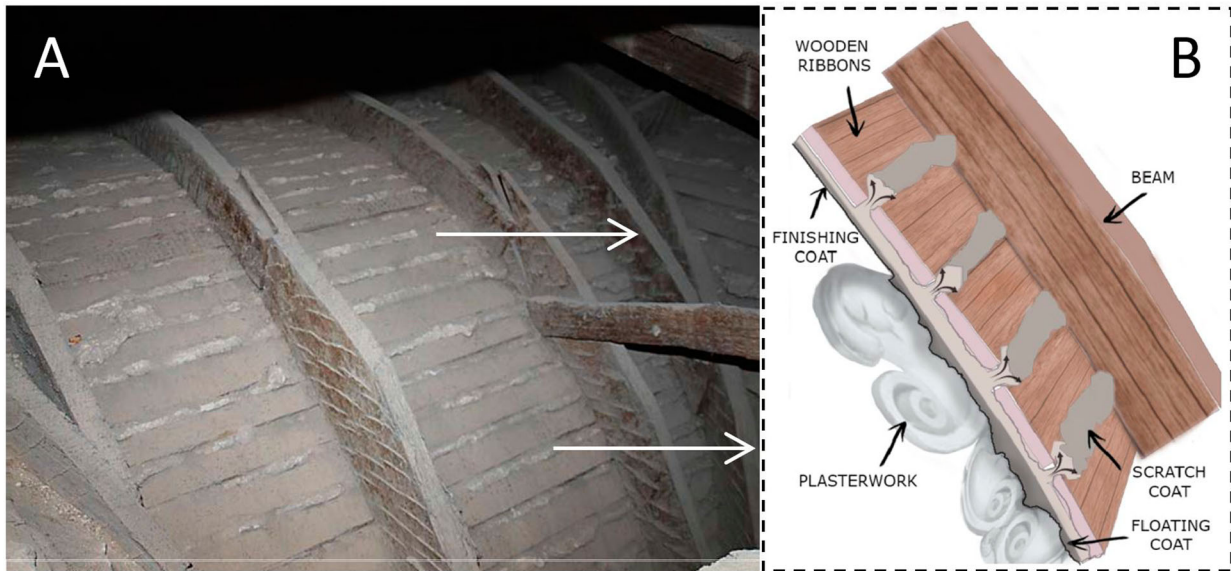


Figure 4. Sections of the vault of the lunettes of the central nave (A). The plaster burrs that appear between the decking can be seen following the scheme shown in (B).

such as angels and cherubs; emblems and inscriptions; ribbons; and scallops (Figure 5(a)).

2. **Cardboard templates:** These are geometric shapes formed by the flat bands that decorate the vaults of the two lateral naves. This type of decoration is made with mold casting techniques, according to its morphology and its symmetric

and serial character. The corner vaults of the Gospel and Epistle naves are decorated with *ferroneries* or cut-out cardboard and plaster volumes (Figure 5(b)).

3. **Gilding:** This is the surface where the rest of the ornamental motifs are found. It is a rarely used resource because of the complexity of its execution and the

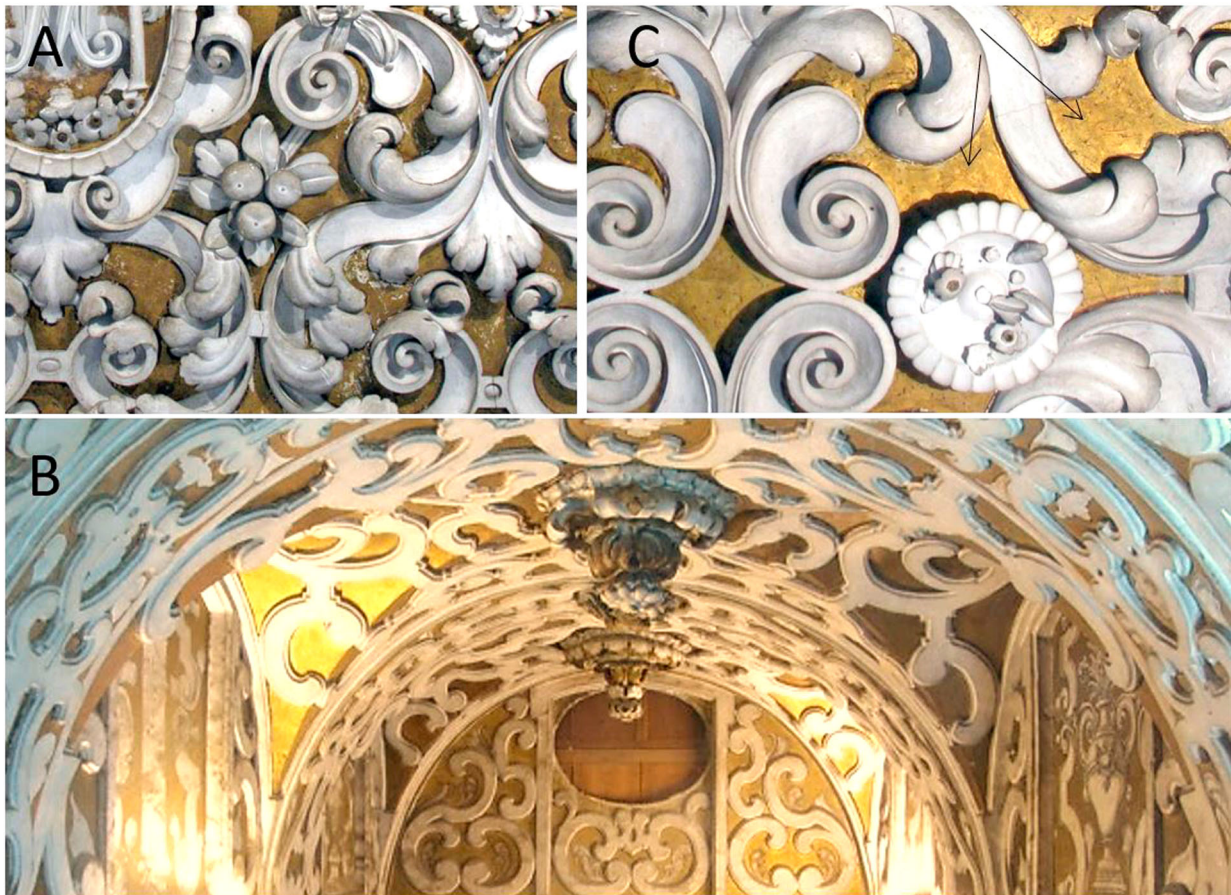


Figure 5. (A) High reliefs, (B) Cutouts from the central vault, (C) Gilding.

high material cost, which sought to create an astonishing space. The pictorial technique used is gilding with gold leaf (Gárate Rojas 2008) (Figure 5(c)).

Evaluation of the state of preservation of plasterwork

Prior to the restoration intervention, the condition was assessed in each of the areas of pictorial decoration and plasterwork by following steps suggested by Cotrim (2004) (Cotrim 2004). Damage to the interior decorations of the SMLB can correspond to movements and/or structural failures, to inappropriate previous interventions or inadequate cleaning systems, to the normal aging of the materials, the accumulation of dust and grease, and the lack of maintenance.

However, the presence of water in any of its states is the cause of generalized degradation of the decorations since the main component of plaster renders and plasterwork is gypsum. Gypsum has low hygroscopicity (Mesquita 2012; Goossens 2003) and medium-low solubility (Rubio Domene 2010) that does not represent a direct risk to the preservation of plasterwork (Torres-González et al. 2021a). Nevertheless, gypsum plaster has high capillary absorption – in this case, liquid water comes from roof leaks and some singular points – which is the main cause of degradation of these decorative elements. Additionally, the water that penetrates solubilizes any existing salts and also some gypsum, causing the formation of efflorescence at the surface when evaporation occurs. This favors the separation of the gilding layers and the degradation and deformation of the volumes in plaster, or even fracture when strength is lost (Rubio Domene 2010). Additionally, plaster is the binder in paints so its contact with water from leaks causes a washing effect of the paints.

The main damage found in the plasterwork and polychromies of SMLB are flaking, small detachments, and lifting of the layers of gilding; stains due to migration of dirt from the back of the elements – which is drawn in by the water from leaks, when it evaporates – remain on many decorative elements. Other damage includes swelling and weakening of the plaster volumes, causing breakage, a problem worsened when the pieces have metallic materials (Rubio Domene 2002) that, in contact with water, oxidize, causing an increase in volume and internal tensions that originated the fracture; and finally, the damage caused by washing of the pictorial layers, a consequence of larger leaks (Figure 6).

Methodology and characterization techniques

Over the last decades, different authors have proposed their own methodologies for the evaluation of

historical plasterwork (Rubio Domene 2011; Ramos Molina et al. 2017; Blasco López et al. 2012; Bueno García and Medina Flórez 2004; Rani, Santhanam, and Bais 2019; Cotrim 2004; Cotrim, do R. Veiga, and de Brito 2008; Blasco López and Alejandre Sánchez 2013b; Gómez et al. 1992). All proposals are linked to a particular case study that requires a specific and customized evaluation, adapted to the circumstances of the building.

Any methodological proposal applied to historical plasterwork and its polychromies must start with the evaluation and inspection of the condition of the building before repair, replacement, and restoration of the plasterwork (Cotrim, do R. Veiga, and De Brito 2007; Gleeson 2002; Historic Environment Scotland 2016), based on a 2D planimetric survey and even 3D if necessary to assist with the intervention. In most cases, historical plasterwork is found in buildings of cultural or architectural interest that are subject to a degree of legal protection. That is why non-destructive testing (NDT) methods are very useful in the field of conservation and architectural restoration, as they enable as much information as possible to be gathered without damaging the heritage materials (Tejedor et al. 2022).

After the initial inspection – necessary to know the deterioration factors, local problems, the present anomalies, and the constituent materials and techniques (Gleeson 2002) descriptive files are generated to record existing anomalies and their location, and to indicate which are related to the base or to the pictorial layer. These files constitute strong support for the development of the conservation or restoration project (Cotrim 2004).

Following the methodology indicated in Figure 7, once the state of the plasterwork and polychromies of SMLB was known and documented, the samples were chosen by following the criteria of representativeness and minimal impact.

A total of eight samples was taken for chemical characterization (Table 1). Three of these samples (N1, N2, and N3) are related to the gilded polychromy in order to know the composition of the preparation layer (inorganic base and organic binder), pigments, and the quality of the gilding. Sample N4 refers to the base mortar of the polychromies and the remaining four samples (N5, N6, N7, and N8) correspond to plasterwork at different points, with the purpose of identifying the composition of the material.

The sampling respected the preservation of the plasterwork and the quantities extracted were the smallest possible for the analyses in order to minimize the visual impact on the panels (UNE 2014). The extraction was carried out with a scalpel and the areas were recorded with photographs before and after the extraction. Gypsum samples (N5-N8) were observed using an S8 APO LEICA optical microscope, with LEICA DC300

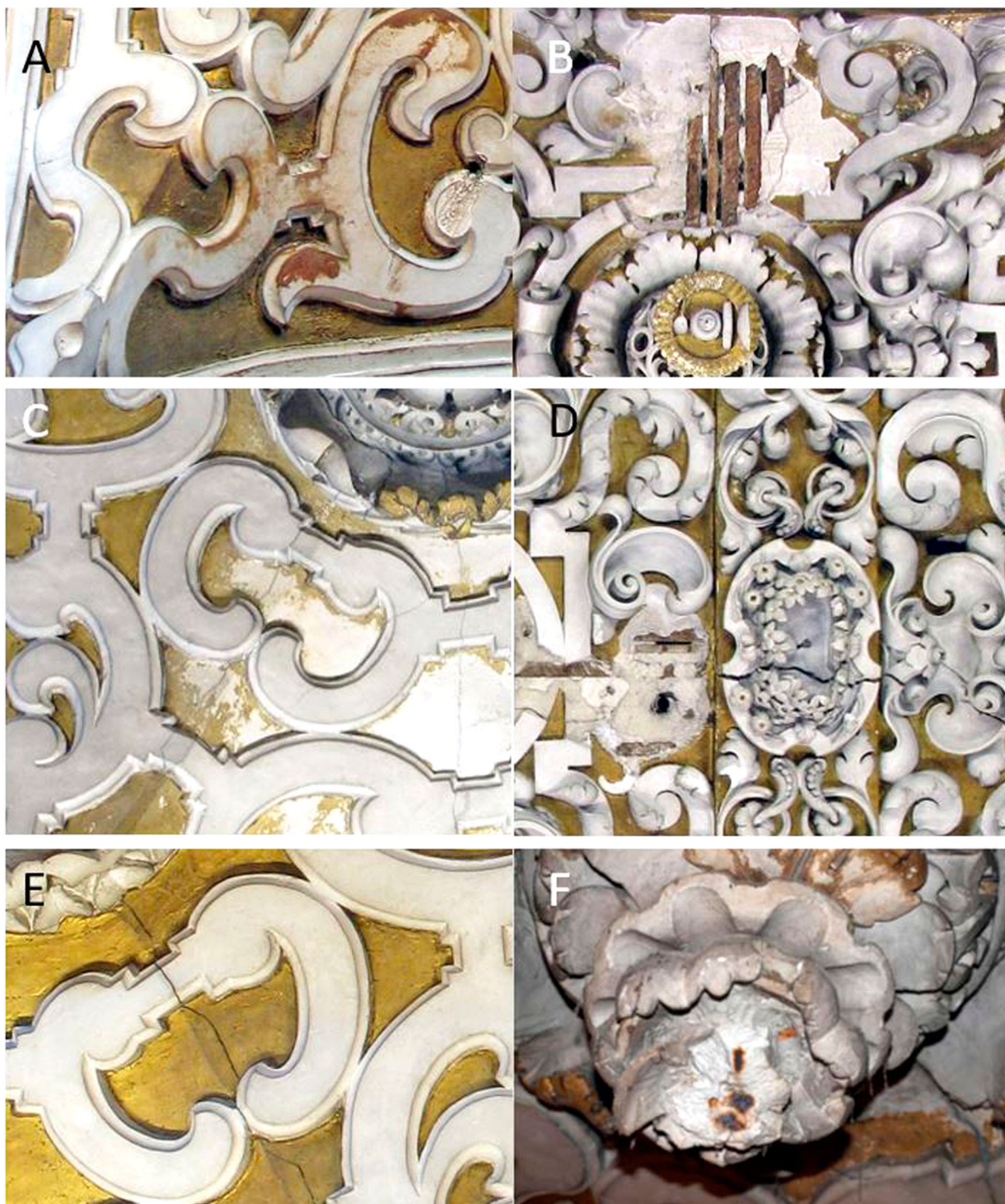


Figure 6. Alterations present in the plasterwork: damp stains (A), loss of support (B), detachment of gold leaf in the choir area (C), detachment and loss of material (D), fissures and cracks (E), and oxidation of metallic element used to fix the plasterwork (F).

video capture and Image Manager 50 software version 1.20. Cross-sections were prepared by impregnation with methacrylate resin at low pressure, then cut with a diamond blade, and finally polished. The structure and thickness of the microlayers were examined with scanning electron microscopy (SEM). A Jeol JSM 6460-LV microscope was used, equipped with an energy-dispersive X-ray (EDX) microprobe, a beryllium window ATW2, and specific software (Oxford INCA) for point semiquantitative chemical analyses. SEM images in

secondary electron mode (SE) and backscattered electron mode (BSE) were acquired using several coated of samples.

To identify the presence and type of organic binders, Fourier transform infrared spectroscopy (FTIR) was performed with a Jasco FT/IR4100 equipped with an accessory ATR Miracle™ to measure attenuated total reflection (ATR), which allows a direct measurement of samples without the need of solvents or dissolution media, which could

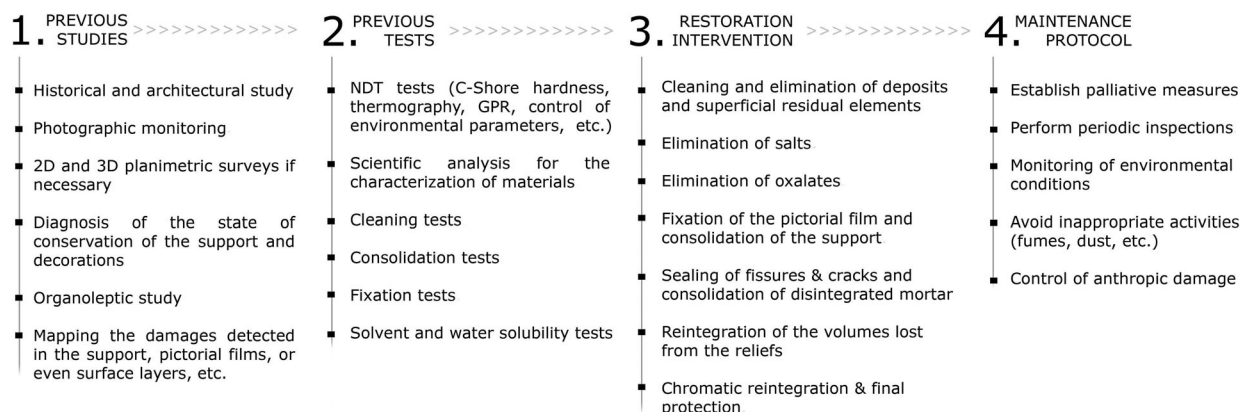


Figure 7. Methodological proposal for the study and intervention of plasterwork and polychromies of SMLB.

cause blind spots in the spectrum. Spectra were obtained with a resolution of 4 cm^{-1} and recorded between 4000 and 650 cm^{-1} .

Gas chromatography-mass spectrometry (GC-MS) was used for samples N1 and N2 in order to determine lipophilic substances, such as oil driers, resins, and waxes, and hydrophilic substances, such as proteins and gums – polysaccharides (gum Arabic and related products). A 5890A gas chromatograph (Hewlett-Packard, USA) equipped with an injection port on the column and a 5971A mass spectrometric detector model was used to separate and identify the compounds. Hewlett Packard Chemstation software (B.04.02) was used for the integration of peaks and for the evaluation of mass spectra. Samples were treated with Meth-prep II methylation reagent to analyze lipophilic substances, and hydrolysis with 6M HCl and derivatization with MTBSTFA in pyridine of the resulting fatty acids, amino acids, and monosaccharides were carried out to analyze carbohydrates and proteins.

Once the composition of the materials was known and the base support was studied, different treatments and consolidants compatible with the existing materials were tested (Rubio Domene 2010) and the effectiveness of each of them was evaluated to establish the optimal conservation criteria. In this regard, the work addressed by Vivar-García et al. (Vivar García, Calero Castillo, and García Bueno 2021a) in which they perform different tests on gypsum specimens to evaluate the effectiveness of cleaning treatments and determine which methods are most effective for lime and polychrome

plaster coatings was followed. This methodology allows establishing the action criteria and the treatments and materials to be used in each of the treatments. Likewise, it provides essential data to define the maintenance project and the complementary actions that are necessary to carry out in the future.

Results and discussion

By applying the methodology described in the previous section, the following results concerning the materials chemical characterization were obtained and suitable treatments for plasterwork and its polychromies, and the treatment criteria were established.

Characterization of polychromies and plasterwork

In N1 sample, the inner double-preparation layers are very rich in a lipid-based binder (Figure 8). It can be described that the base for gilding was achieved with a double layer of brown color. The first (layer 2) is very rich in linseed oil; another thicker layer (layer 3) was added, with a higher proportion of pigments than the previous one, but also rich in oil, onto which the gold leaf was applied.

The EDX spectrum (Figure 9) in N1 sample shows that the first white layer is essentially gypsum with a very low proportion of silicates. Layer 2, approximately $20\text{ }\mu\text{m}$ thick, has a chemical composition attributable to the presence of red earth, shade earth, white lead in a low proportion, calcium carbonate and gypsum also in a low proportion, and bone black in a very low proportion. In layer 3, which is thicker than the previous one (approximately $80\text{ }\mu\text{m}$), blue enamel appears in low proportions and azurite in very low proportions, together with those components found in layer 2 such as red earth, white lead, shade earth, and gypsum. Finally, layer 4, which is almost $1\text{ }\mu\text{m}$ thick, shows gold with 93.4%, silver 5.7%, and copper with 0.9%. Cerussite is a mineral consisting of lead carbonate (PbCO_3), and its use as a siccative suggests the use of

Table 1. Description of the micro-samples taken from the SMLB.

Designation	Type
N1	Gold. Polychromies
N2	Altered gold. Polychromies
N3	Pictorial restoration. Polychromies
N4	Base mortar for polychromies
N5	Plaster. Choir vault. Plasterwork
N6	Base mortar. Choir vault. Plasterwork
N7	Adhesion mortar. Choir vault. Plasterwork
N8	Plaster. Choir vault. Plasterwork

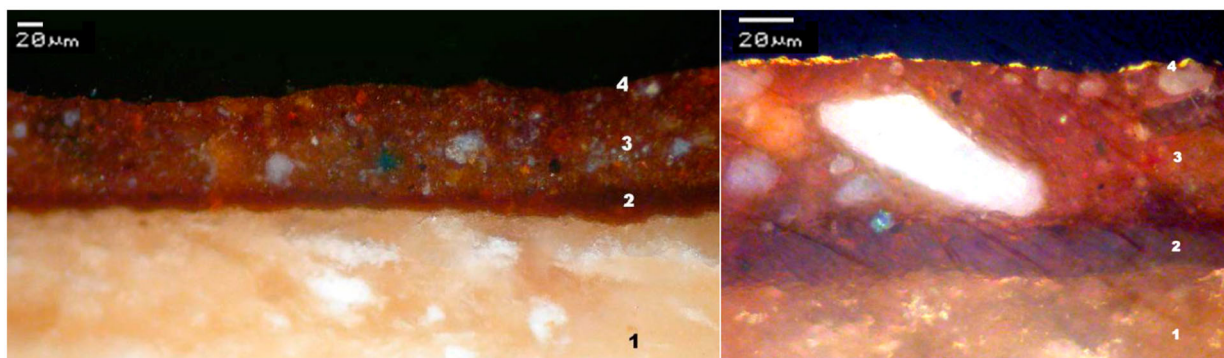


Figure 8. (A) Cross-section of micro-sample N1 obtained under a light microscope (20X / 0.40 MPlan objective); (B) (50X / 0.75 MPlan objective) partially crossed polarizers. The metallic shine of the gold leaf can be seen.

oil-based binders which, together with the plasterwork, could comprise the preparation of the gold leaf (Almagro Gorbea et al. 2010). The data show that the gilt was applied on mixture, a procedure that involves fixing the gold leaf on a prepared layer called a mordant or mixture (Mayer 1991). The mordant consists of a mixture of linseed oil (Figure 9) with compounds of lead and manganese oxides. A traditional technique of gold covering based on the application of a liquid adhesive called 'mixtion' is shown in Figure 10.

Samples N1 and N2 indicate that the gold was applied in a very thin sheet barely one micron thick, which is gilded with gold leaf, on a mixed mordant (20–80 μm) and without any other prior preparation or bole so it is possible that a light wetting of the varnish (clay or iron oxide) would adhere it (Figures 8–10). Sample N2 of altered gilding (Figure 10A), in which the stamping of the gilding is observed, is in a worse state than sample N1.

From the study by GC-MS of sample N1, it was concluded that the most transparent material, corresponding to the layer in contact with the gold, has fatty acids (palmitic acid, stearic acid, suberic acid, and azelaic acid) and terpenes (dehydroabiatic acid and 7-oxodehydroabiatic acid), compounds that reveal a linseed oil content and a conifer resin, probably rosin (Peris Vicente 2008) (Figure 11(a)).

Regarding sample N2 (Figure 11(b)), the results indicate a clear linseed oil due to the proportions of palmitic and stearic acid, with a small fraction of diterpenes. As in the case of sample N1, the relationship between the proportions of suberic and azelaic acid appears to indicate a previous cooking of the oil to increase its drying properties, or simply as a consequence of the manufacturing process of the homogeneous mixture itself.

After observation by optical microscopy and SEM of sample N3 with analysis by EDX, two layers were observed (Figure 12): Layer 1, white, with a thickness

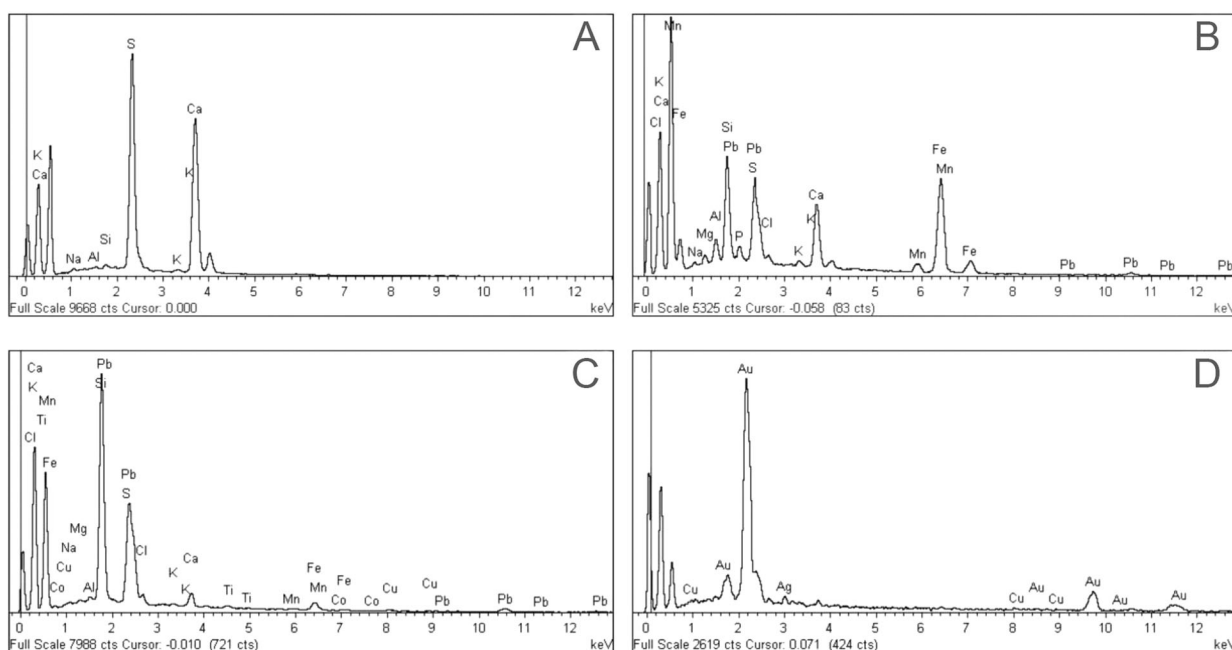


Figure 9. EDX spectrum of sample N1: layer 1 (A), layer 2 (B), layer 3 (C), layer 4 (D).

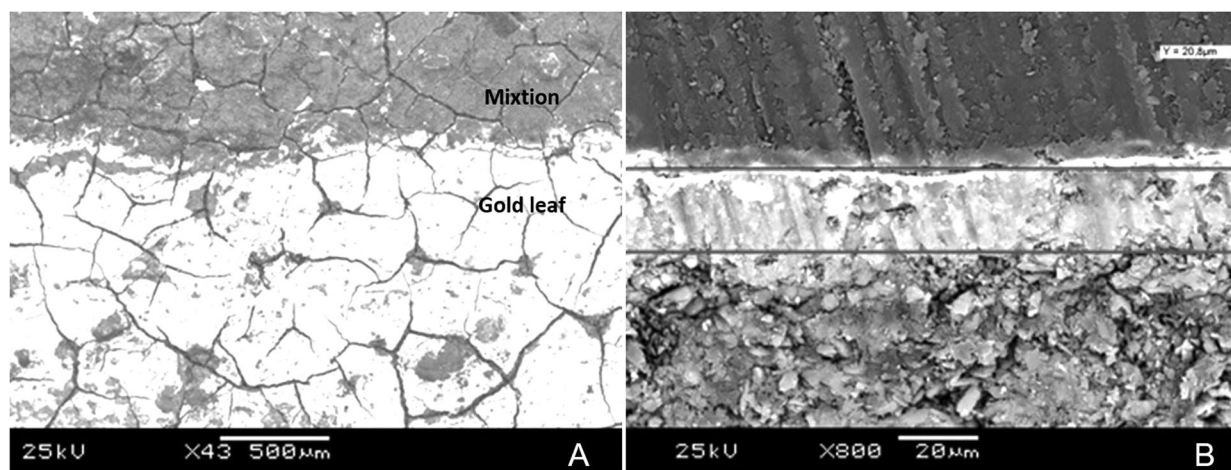


Figure 10. (A) SEM images in BSE mode of sample N2 and (B) stratigraphy of sample N2.

of approximately 450 μm , has a chemical composition mainly attributable to the presence of calcium carbonate and gypsum; and layer 2, with a thickness of around 30 μm , with a reddish and greenish color, is composed of 87.5% copper and 12.5% zinc. Therefore, the green color is assignable to a paratacamite, a hydroxychloride of copper and zinc.

The base mortar analysis showed great homogeneity and uniformity under the electron microscope, as well as in its elemental composition. The abundant presence of calcium and sulfur is associated with plaster and the identifications of elements such as aluminum, iron, potassium, and silicon are associated with the aggregate.

The infrared spectrum of sample N4 (Figure 13(b)) was clearly useful to identify gypsum (calcium sulfate dihydrate), as it shows absorption bands at 1110, 670, and 597 cm^{-1} , characteristic of the sulfate group (vibration modes of sulfur–oxygen bonds). In particular, bands over 3000 cm^{-1} (3524 and 3398 cm^{-1}) are related to water incorporated in the gypsum structure (O–H stretch vibrations), apart

from absorption peaks (1683 and 1619 cm^{-1}), likely due to vibrations resulting from the water bonds. The low proportions of calcite relative to gypsum may explain the weak absorption bands at 1417, 874, and 712 cm^{-1} that correspond to vibration modes of C–O bonds belonging to the carbonate group. The FTIR results seem to indicate that the sample contains no organic compounds.

Regarding the results of the plasterwork samples N5–N8, which were taken from the choir vault of SMLB, where the anomalies were more severe, the following results were obtained:

The infrared spectra of samples N5 and N7 (Figure 14) was clearly useful in identifying gypsum (calcium sulfate dihydrate), showing absorption bands at 1103, 1004, and 667 cm^{-1} , characteristic of the sulfate group (vibration modes of sulfur–oxygen bonds). In particular, bands over 3000 cm^{-1} (3519 and 3400 cm^{-1}) are related to water incorporated in the gypsum structure (O–H stretch vibrations), apart from other peaks of absorption maxima (1682 and 1619 cm^{-1}), probably due to vibrations resulting

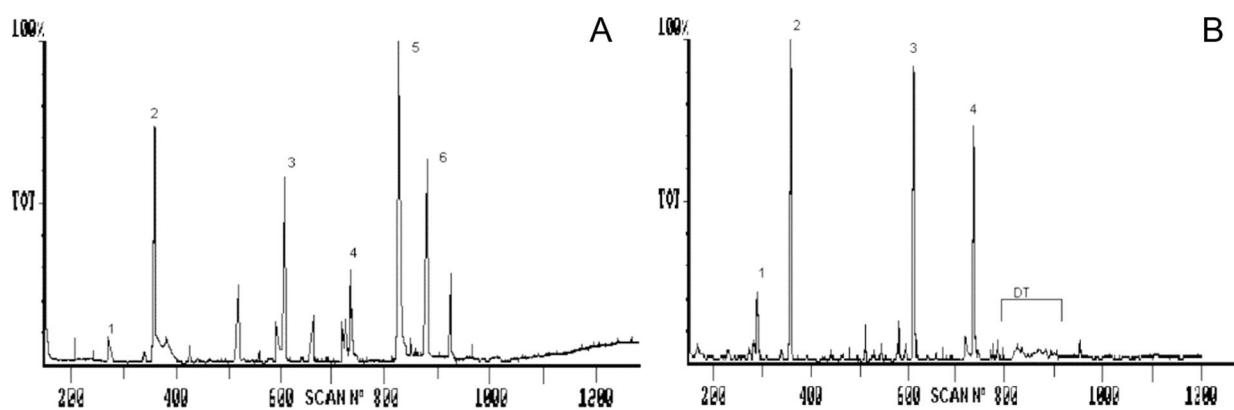


Figure 11. (A) Chromatogram obtained by GC-MS of sample N1, in which it is observed that the composition of terpenes/fatty acids characterizes the sample as a mixture of rosin and linseed oil; (B) Chromatogram obtained by GC-MS of sample N2: a minimal presence of diterpenes is observed in a linseed oil base. [1 Methyl suberate, 2 methyl acetate, 3 methyl palmitate, 4 methyl stearate, 5 methyl dehydroabierate, 6 7-oxo-dehydroabierate].

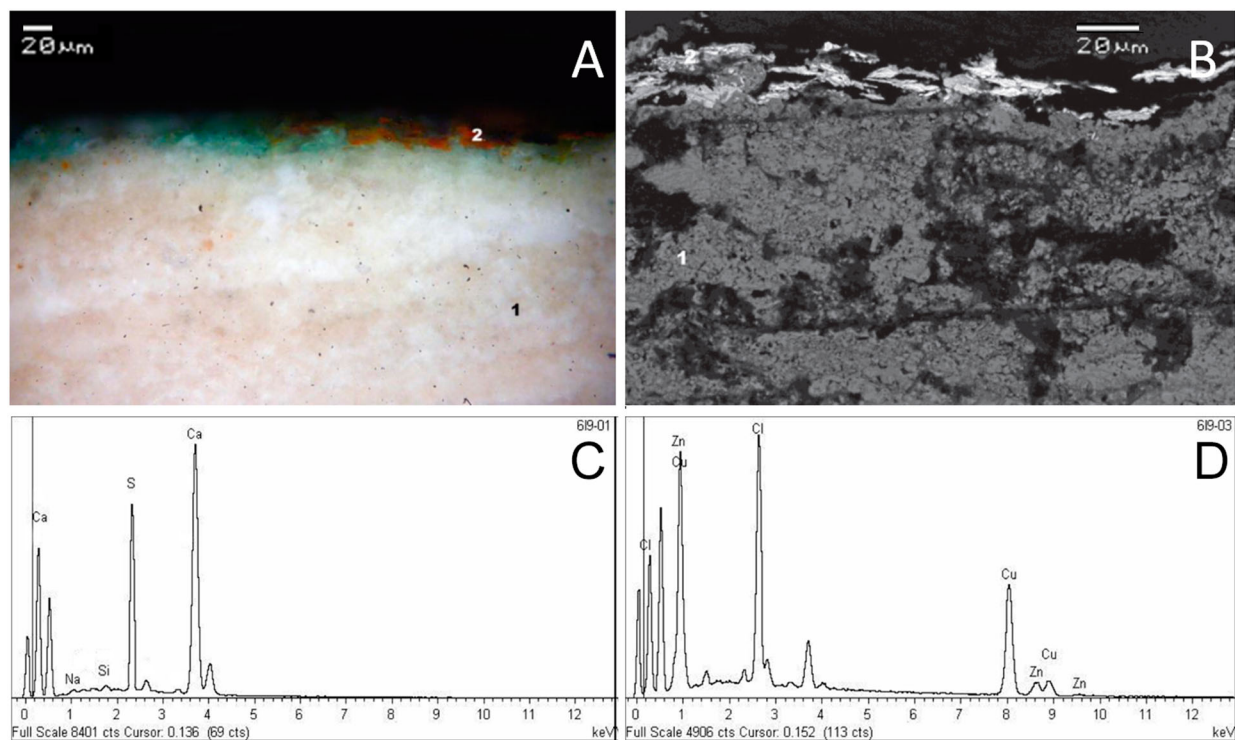


Figure 12. Sample N3 image of the cross-section viewed under a light microscope (MPlan 20X/0.40 objective) (A); SEM images in BSE mode (900X) (B); EDX spectrum: layer 1 (C), layer 2 (D).

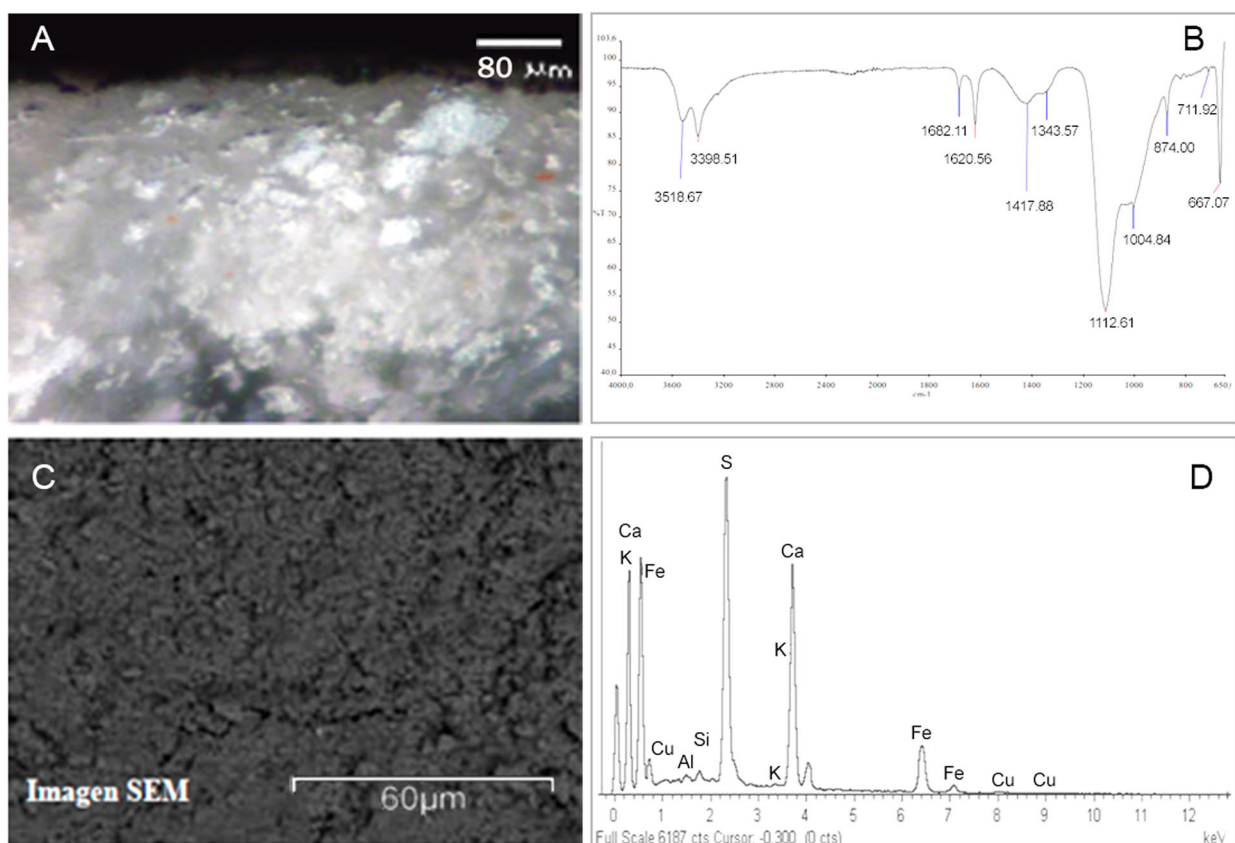


Figure 13. Sample N4 (A) Cross-section viewed under a light microscope (MPlan 20X/0.40 objective); (B) FTIR spectrum; (C) image obtained by SEM; (D) EDX spectrum.

from the water bonds. The FTIR results seem to indicate that the samples contain no organic compounds.

The infrared spectrum of sample N6 (Figure 14) reveals calcite absorption bands at 1448, 1314, 875, and 747 cm^{-1} , characteristic of the carbonate

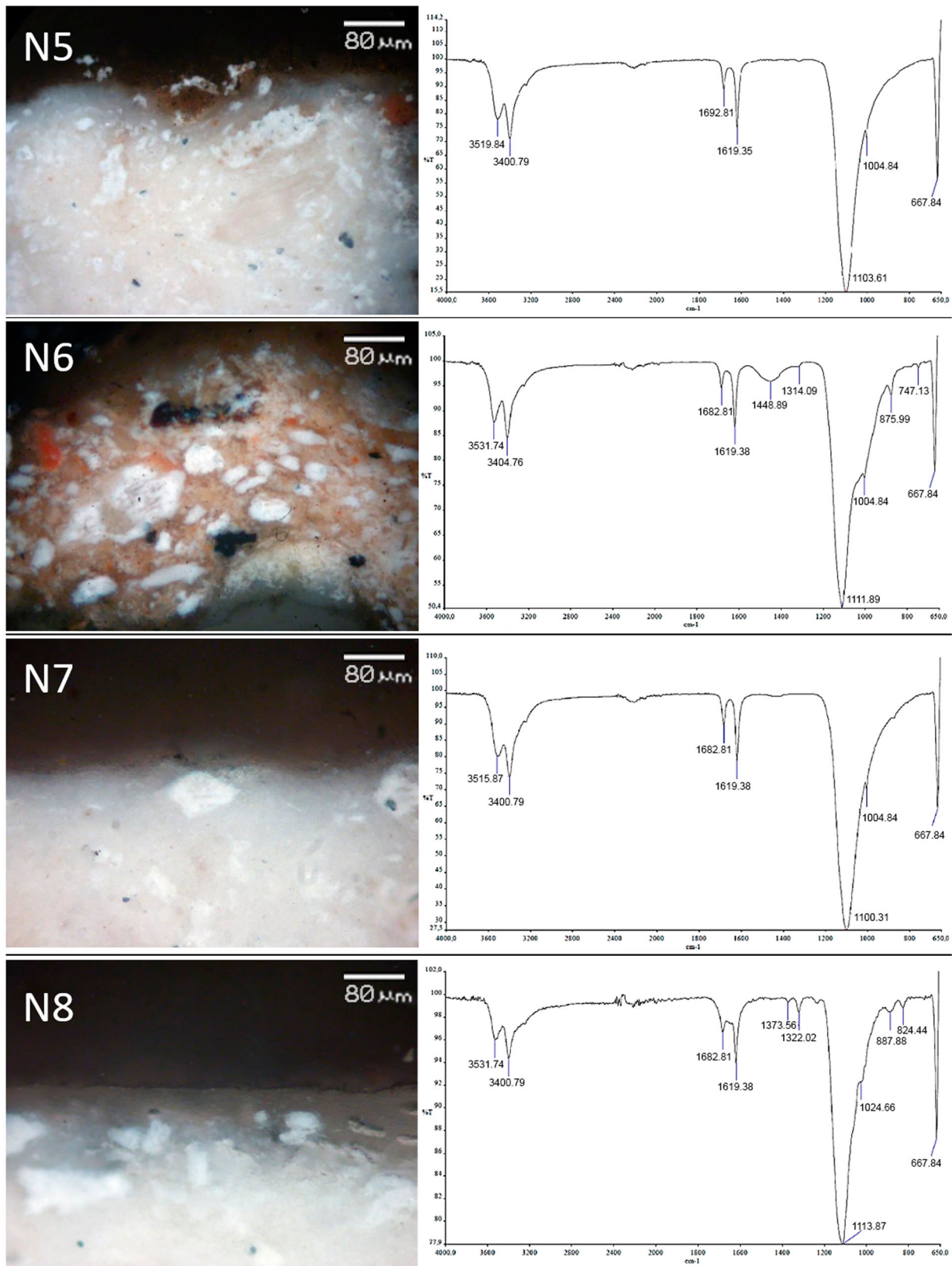


Figure 14. Optical microscopy of the cross-sections of N5-N8 (MPlan 20 X / 0.40 objective) and the respective FTIR spectra.

group, detected in low proportion. Gypsum shows absorption bands at 1111, 1004, and 667 cm^{-1} , characteristic of the sulfate group. In particular, bands over 3000 cm^{-1} at 3531 and 3404 cm^{-1} and at 1682 and 1619 cm^{-1} are probably due to vibrations resulting from the water bonds. The FTIR

results seem to indicate that the sample contains no organic compounds.

With respect to sample N8 (Figure 14), it can be observed that, along with the typical gypsum bands, as described in samples N5 and N7, other absorption bands appear at 1373 and 1322 cm^{-1} and at 887

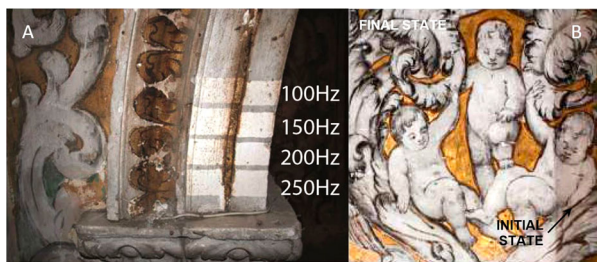


Figure 15. Cleaning tests on the plaster surface using a Nd-YAG laser (A) and consolidation with 2% Acril ME in water applied by brush interposing Japanese paper (B).

and 824 cm^{-1} , characteristics of nitrate and oxalate salts. The characteristic positions of the nitrate bands are $1380\text{--}1350\text{ cm}^{-1}$ and $840\text{--}815\text{ cm}^{-1}$ (Conely 1979).

The presence of oxalate must be considered as a bio-signature of some microorganisms that have colonized the walls and their metabolic activity (excretion of oxalic acid), due to the continuous presence of water leaks. This final cause can also explain the existence of nitrates from environmental pollution (Magurégui et al. 2008; Madariaga et al. 2014).

On-site treatment tests

Cleaning tests are defined by the level of intensity needed. In this sense, manual cleaning with a synthetic rubber sponge, with 50:50 water/ethanol solution and soft eraser was tested, giving quite effective results in cleaning plasterwork and gilding, as they gently and effectively remove the adhered soiling. Cleaning with swabs in Dowanol™ was also tested, but soon discarded because it softens the gold; and also cleaning by Nd-YAG laser at different intensities (100-150-200-250 Hz) applied at 30 pulsations, showed that intensities higher than 150 Hz damage some gilded areas (Figure 15(a)). This technique gives very good results in cleaning plasterwork; however, the complexity of the geometries and the arrangement of the volumes complicates the cleaning work considerably.

After manual cleaning of the surface where the treatment procedures were carried out, the evaluation of consolidants and layer adhesion began. First, an impregnation was applied with a brush interposing Japanese paper to avoid dragging gold flakes and the area was left to rest for 24 h. Solubility tests were repeated (Gilabert Montero 2012; Stuart 2007) and a second coat of the product was applied directly with a brush. The same procedure was carried out with Paraloid® B-72 at 3% in Dowanol™, gum Arabic at 5% in water/alcohol 50:50, Acril 33 at 3% in water, and Acril ME at 2% in water by gilding with gold leaves.

The results of the tests evaluated as the most effective products Acril ME and gum Arabic (Figure 15(b)). Both offer good results in a single application and optimal optical and reflective qualities. The use

of Paraloid® B-72 and Acril 33 were ruled out due to the fact that the former requires the use of solvents in its application and that both make subsequent cleaning difficult by requiring the use of solvents for either.

Based on all the analyses and work carried out, the type of intervention most appropriate to each pictorial area or plasterwork was determined and the treatments and conservation techniques that should be used were selected.

Intervention criteria

The restoration criteria to be followed in this case study are committed to a preventive intervention that mitigates the existing damages and guarantees that they do not appear again in the immediate future.

All actions must be as minimally invasive as possible and must adhere to minimum margins in order to ensure the authenticity of the material and pictorial elements. Thus, the intervention proposed for the restoration of the plasterwork and polychromies of SMLB is governed by the criteria established and approved by the 14th General Assembly of ICOMOS in 2003, as well as by the restoration criteria set in Law 14/2007 of Andalusian Historical Heritage³ (Dirección General de Bienes Culturales 1997) and Law 16/1985 of the Spanish Historical Heritage⁴, without forgetting the indications contained in the ECCO Guidelines⁵ and protocols for the restoration and conservation of plasterwork followed by the Plasterwork Restoration Workshop of the Alhambra Board of Trustees, an international benchmark in the monitoring and treatment of this type of property.

After the visual inspection, anomalies in plasterwork were located and drawn in the planimetric survey (Figure 16) to have an exact reference of where to carry out all the interventions mentioned below.

Cleaning and removal of deposits and surface residual elements

All superficial dirt layers, which could be removed without altering the original, were removed from the entire surface. The operation was carried out with soft brushes, paintbrushes, and the help of a vacuum cleaner, extending the operation both on the exterior surface and in all the nooks and crannies of the plasterwork set. In some areas, it was necessary to apply pressurized air, using simultaneously low-power manual compressors and a vacuum cleaner (Figure 17, left image). In the case of polychromies, their condition did not allow a general treatment of this type, and cleaning was carried out using a very soft brush.

In plasterwork with greater relief, as well as in cornices and moldings where the dust was compacted,

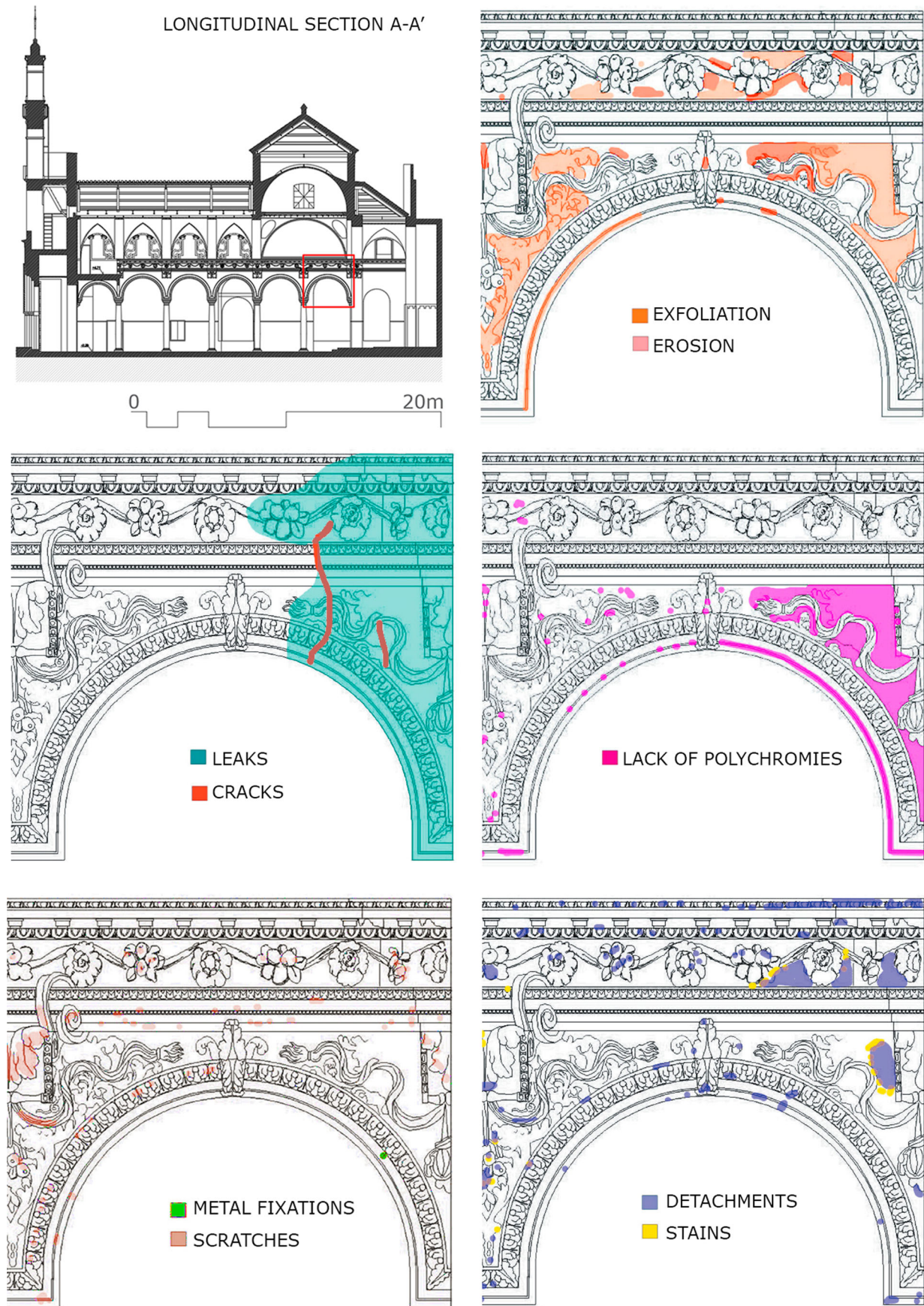


Figure 16. Planimetric survey showing the state of preservation of the plasterworks of the lateral arches of the central nave.

its removal had to be carried out using, in addition, scalpels, spatulas, and brushes for concretions and deposits more adhered to the plasterwork (Figure

17, right image). For this operation, the area to be treated is moistened with demineralized water or white spirit applied to cotton swabs. Moisture



Figure 17. Cleaning of the plaster volumes.

stains are treated with a chemical bleach applied with cotton swabs and their neutralization is controlled.

The last step to finish cleaning was to use Wishab dry cleaning sponges of different hardness and crumb gums under dry conditions. This was done both in the plasterwork in a general way and in some more established polychromies.

In the case of gilding, the adhesion fragility of the metallic layer prevented both cleaning with swabs and solvents, as well as dry cleaning with rubbers. That is why laser cleaning using the Art Light Laser was used to remove the greyish layer (Figure 18(a and b)).

To clean the salts deposited on the surfaces, mechanical processes with gentle brushing were chosen (Figure 18(c)), rejecting the use of aqueous procedures to prevent the drag of the interior salts to the surface (Figure 18(c)).

To eliminate mortars from previous interventions that were not related to the nature of the originals, these coatings were removed using manual techniques and a vacuum cleaner was used simultaneously, protecting the surrounding surface with Japanese paper if necessary.⁶ In the case of accumulations of dust and greasy deposits in the plasterwork, they were removed using soft hairbrushes and a vacuum cleaner.

Finally, in case where elements nailed to the plasterwork exceeded 10 units/m², they were removed through manual and mechanical procedures, protecting the area and the surrounding elements with Japanese paper and acrylic resin in acetone at a ratio of 10:90.

Sealing of fissures/cracks and consolidation of disintegrated mortar

The sealing of cracks, after a previous cleaning, was carried out with plaster mortar similar to the original one, in accordance with the information obtained in the previous characterization tests. In certain cases, micro-stitching was performed with fiberglass rods and epoxy adhesive, after moistening with demineralized water and cleaning the area (Figure 19(a)). The cracks were sealed with pre-moistened plaster mortar with demineralized water and applied with a spatula. The finish was achieved by the leveling of the surface and its cleaning. All these procedures were performed after analyzing the type of cracks and/or fissures present and their direct impact on the durability of plasterwork and polychromies (Silveira, do R. Veiga, and de Brito 2002).

The plaster was consolidated in areas where it was disintegrated, powdery, or lacking in cohesion, using water-based acrylic resin nanoparticle microemulsion, applied with syringes or brushes, ensuring maximum penetration; the excess was removed from the surface.

The cavities existing between the layers and on the outer surface were filled with water-based adhesive injections, after wetting the area with water/alcohol (Figure 19(b)). In larger cavities, a PLM mortar was used in order to provide a material with characteristics similar to plaster but with adhesive qualities.

Reintegration of the lost volumes of the reliefs

Three criteria were used according to the case and the impact of the intervention: the reintegration of detached fragments preserved in the rooms of SMLB

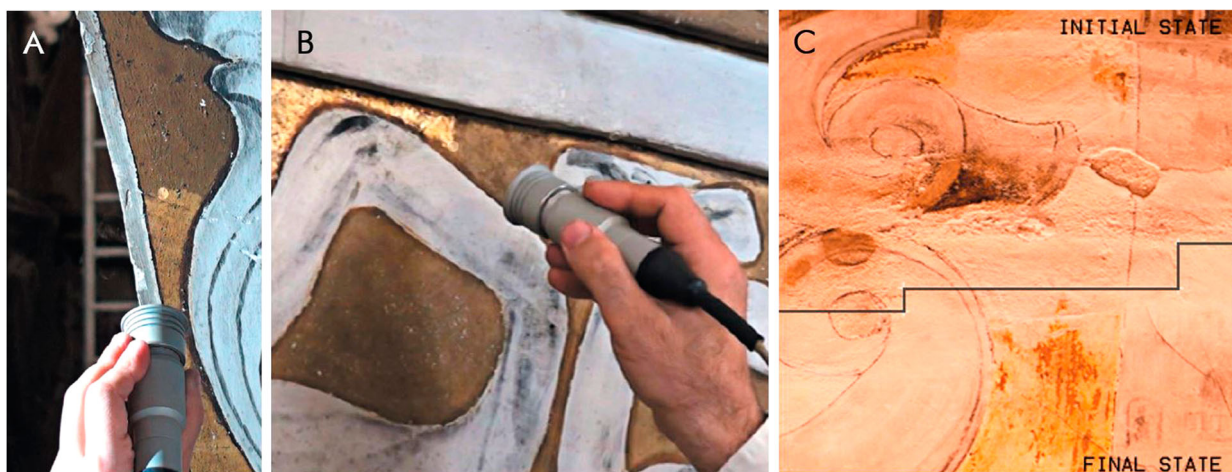


Figure 18. (A) Cleaning the gilding with a hand-held laser; (B) Visible results after cleaning the salts on the facing (C).

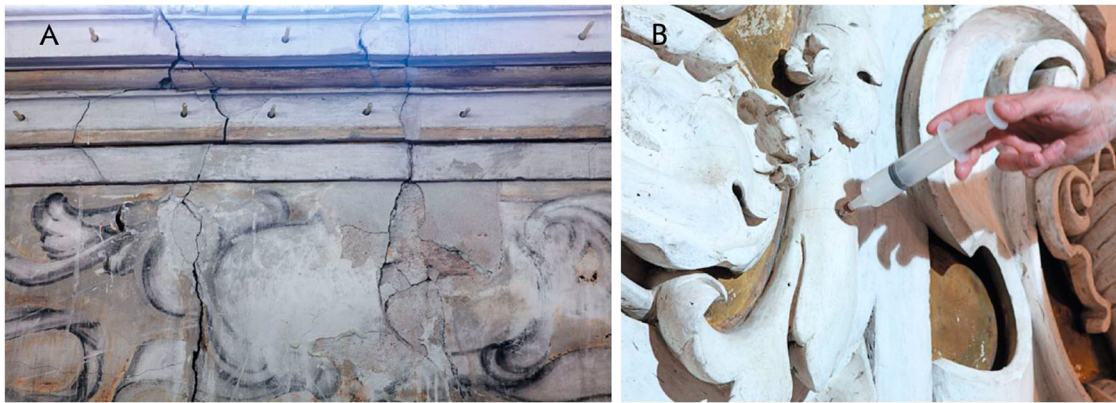


Figure 19. Insertion of fiberglass rods to secure thick plaster elements (A) and fixation of plasterwork by injection (B).

(i), the reintegration of small decorative motifs by molding the particular piece (ii), and the reintegration of larger volumes through digital fabrication of the pieces (iii).

- (i) The attachment of loose fragments was carried out with polyvinyl acetate adhesive and reinforcement with fiberglass dowels, after studying the correspondence of the existing detached fragments that were collected and stored to locate them in their correct position (Figure 20); the joints were sealed with plaster paste.
- (ii) The morphological definition of the pieces started with a specific design work for each one (Figure 21); similar motifs that exist in the set were taken into account given the symmetry that defines the composition. Only those general forms, such as scrolls, rockery, and

leaves, were reconstructed, without defining the details of the other unique forms that differentiate each piece: fruits, small flowers, and vegetable stems. These were only defined in their volume.

- (iii) Medium level reintegration is a 'differentiated reintegration' resource that enables the complete integration of the new elements into the whole, without achieving full replication of the original work and without causing aesthetic or visual conflicts that harm the general contemplation of the interior space. In this case, given the symmetry of the shapes and the repetition of the decorative patterns, 3D scanning of the vaults and significant details was carried out using a white light scanner, digitizing the model and rebuilding elements by 3D printing



Figure 20. Detached angel's arm reattachment using fiberglass dowels.



Figure 21. Volumetric reintegration (plaster + 25% lime paste) using a fiberglass structure. (A) Initial state and (B) reconstruction state.



Figure 22. Creation of new volumes in PLA using 3D printing.



Figure 23. Before (A) and after (B) the intervention in the plasterwork of the tribune (cleaning and reintegration of volumes).

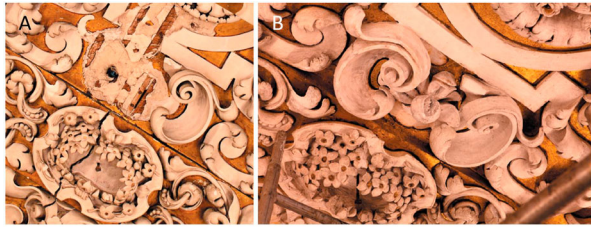


Figure 24. Before (A) and after (B) volumetric reintegration.

with polylactic acid, commonly designated as PLA (Figures 22–24) (Ávila Rodríguez 2019; Norin, Golovina, and Tikhonov 2019). For the adhesion of the printed elements, polyvinyl acetate was used, and in large volumes they were reinforced with fiberglass rods and epoxy adhesive.

Chromatic reintegration

The intervention carried out in the project for the conservation and restoration of the golden polychromies of SMLB was comprehensive in nature. All conservation problems related to the deterioration of the constituent materials were addressed, as well as aesthetic needs taking into account its technical and historical-artistic characteristics (Botticelli, Botticelli, and S Botticelli 1992; Fundación Santa María la Real 2005; Mora, Mora, and Philippot 2003).

Thus, the chromatic reintegration was carried out in order to give unity and legibility to the whole and to help a better visual reading of it. Reversible and distinguishable methods that allow the water vapour permeability required by the plasters were used for chromatic reintegration.

Fixation and settling of the gilding were carried out by applying Acril ME in a 2% solution in water, with a soft hairbrush and interposing Japanese paper, applying a second coat after a 24-hour interval in the case of areas with greater difficulty (Figure 25).

In the case of small losses of gilding in the bottoms of the vaults or walls, watercolor glazes were applied to tone and mitigate the disturbing effect of the white background; in the case of larger extensions, the metallic shine was provided with a pattern of vertical lines, made with gold mica and 22k gold in pills, bonded with gum Arabic that replaces, in a reversible and

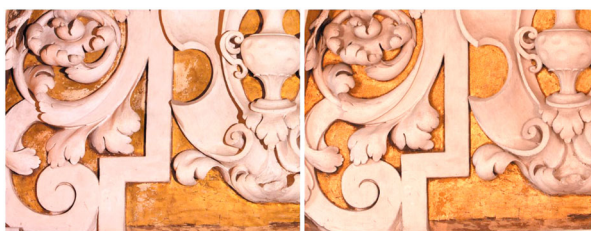


Figure 25. Before (left) and after (right) the color reintegration treatment.

differentiable way, the lost parts of the original polychromies.

Conclusions

This work offers some methodological guidelines to approach a restoration intervention of plasterwork and polychromies applied in a recent real case according to the criteria established by the 14th General Assembly of ICOMOS in 2003, the Law 14/2007 of Andalusian Historical Heritage, the Law 16/1985 of the Spanish Historical Heritage, and indications contained in the E.C.C.O. guidelines.

In accordance with previous examination, characterization tests, and on-site treatment tests, the following actions were carried out:

- Several cleaning techniques were selected depending on the area and the degradation level of the plasterwork and its polychromies. General superficial dirt was removed by using different techniques: (i) manual cleaning with a synthetic rubber sponge, with 50:50 water/ethanol solution; (ii) a soft eraser; or (iii) cleaning with a Nd-YAG laser at different intensities below 150 Hz, with results optimal in areas stained with black smoke or in the case of gilding.
- Moisture stains were treated with a chemical bleach applied with cotton swabs, controlling their neutralization, and salt deposits were cleaned by mechanical processes with gentle brushing.
- The sealing of cracks was carried out with plaster mortar similar to the original one and, in certain cases, micro-stitching was performed with fiberglass rods and epoxy adhesive. The plaster was consolidated by applying water-based acrylic resin nanoparticle microemulsion and cavities were filled with water-based adhesive injections. In larger cavities, a PLM mortar was used.
- The reintegration of the lost areas of the reliefs was made using three different methods: (i) The attachment of loose fragments carried out with polyvinyl acetate adhesive, with reinforcement of fiberglass spikes; (ii) the reintegration of small decorative motifs by molding the particular piece; and (iii) the reintegration of larger volumes through digital fabrication of the pieces in PLA.
- Regarding the polychromies, reversible and distinguishable methods that do not compromise water vapour permeability required by the plaster were used for chromatic reintegration. A double impregnation was applied with a brush interposing Japanese paper to avoid dragging gold flakes and a second coat of the product was applied directly with a brush to ensure color fixation and layer adhesion. The treatments used

were 5% gum Arabic dissolved in water/alcohol (50:50) and, in case of golden areas, 2% Acril ME dissolved in water.

Throughout the intervention process, it was possible to verify that specific tests carried out previously in several points were representative and define the composition and techniques used in the whole area. This fact contributed very favorably to complete the intervention within the term agreed in the contract and the respective budget, without causing any deviation.

Notes

1. DECRETO 186/1995, of July 25, 1995.
2. New Management Plan, Resolution of the Ministry of Public Works of the Junta de Andalucía of 19 July 2006 and published in BOJA No. 174 of 7 September 2006.
3. Law 14/2007, of 26 November, on the Historical Heritage of Andalusia.
4. Law 16/1985, of 25 June, on Spanish Historical Heritage.
5. Document promoted by the European Confederation of Conservative-Restorers Organizations and approved by its General Assembly. Brussels, 1 March 2002.
6. Whenever the protection arrangement is chosen, it will end with the removal of this protection and the elimination of the remains of the adhesive.

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Author contributions

All authors had full access to all the data and assume responsibility for the integrity and the accuracy of the data analysis.

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