Project STUDEC (Stucco decorations across Europe)

Arogno (Ticino)
Church of Santo Stefano

Results of the scientific characterization of stucco decoration

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Introduction

This report describes the observation and analytical investigations conducted on the stucco decorations in the Church of Santo Stefano in Arogno, Canton Ticino. These investigations were carried out in different moments before, during and after the SUPSI educational site work, which were held in collaboration with the Parish Council of Arogno and under the supervision of the Office of Cultural Heritage of the Canton of Ticino in 2024 and 2025. The aim of these analyses was to identify the materials and techniques employed by the artists to create the church's elaborate decorative scheme. They were also intended to provide fundamental preliminary information for the conservation work. Both non-invasive methods, such as portable microscope[1], UV light[2], thermal imaging camera[3] and pacometer[4], and invasive methods, such as collecting micro-samples to characterize the original materials and types of salt present, were employed in the analytical investigations. The analyses were conducted by research professors from the Institute for Materials and Construction (IMC) at SUPSI.

The surface of the stucco decoration was carefully observed in order to detect fundamental technical details, such as the stratigraphic succession and use of structural reinforcements. Small fragments of mortars in good condition and representative of the individual layers of the various types of stucco (architectural elements, low reliefs and three dimensional decorations) were sampled.

The petrographic analysis with PLM (Polarized light microscopy) of thin sections provided a precise characterization of the aggregate and texture, preliminary information about the binder and potentially problematic elements (clays, binder content, secondary products, microcracks, etc.). SEM-EDS (Scanning electron microscope - energy dispersion spectroscopy) was used to study the elemental composition, microstructure, texture and morphology of the binder. Mortar samples and deterioration products were also chemically analyzed using ATR-FT-IR (Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy) for determination of the chemical composition.

Introduction

Samples were prepared in thin section according to standard procedures, and the stratigraphy was studied under a polarized light microscope with incident and transmitted light. A Zeiss Axioskop 40 microscope combined with an Axiocam digital camera was used. AxioCam 4.5 software was used for image acquisition. Sample description was performed according to the (UNI EN 11176:2006) standard. The ATR-FT-IR was performed with a Perkin Elmer UATR (single reflection diamond) *Spectrum Two™* spectrometer on powdered samples. The instrument uses an MIR source, a diamond crystal, an OptKBr beam splitter and a LiTa03-based detector. Spectra were acquired in the range 4000–400 cm 1 at resolutions of 4 cm 1 and with 16 scans. Thermo Scientific Phenom XL G2 Desktop SEM–EDS was used for the composition and morphological characterization of the thin section. Using a backscattered electron detector (BSD), images were acquired at 15 kV voltage and in the range 550-2450x magnifications.

[1] Dino-lite Premier AM4115T-FUW digital microscope, equipped with 4 visible LEDs and 4 ultraviolet LEDs.

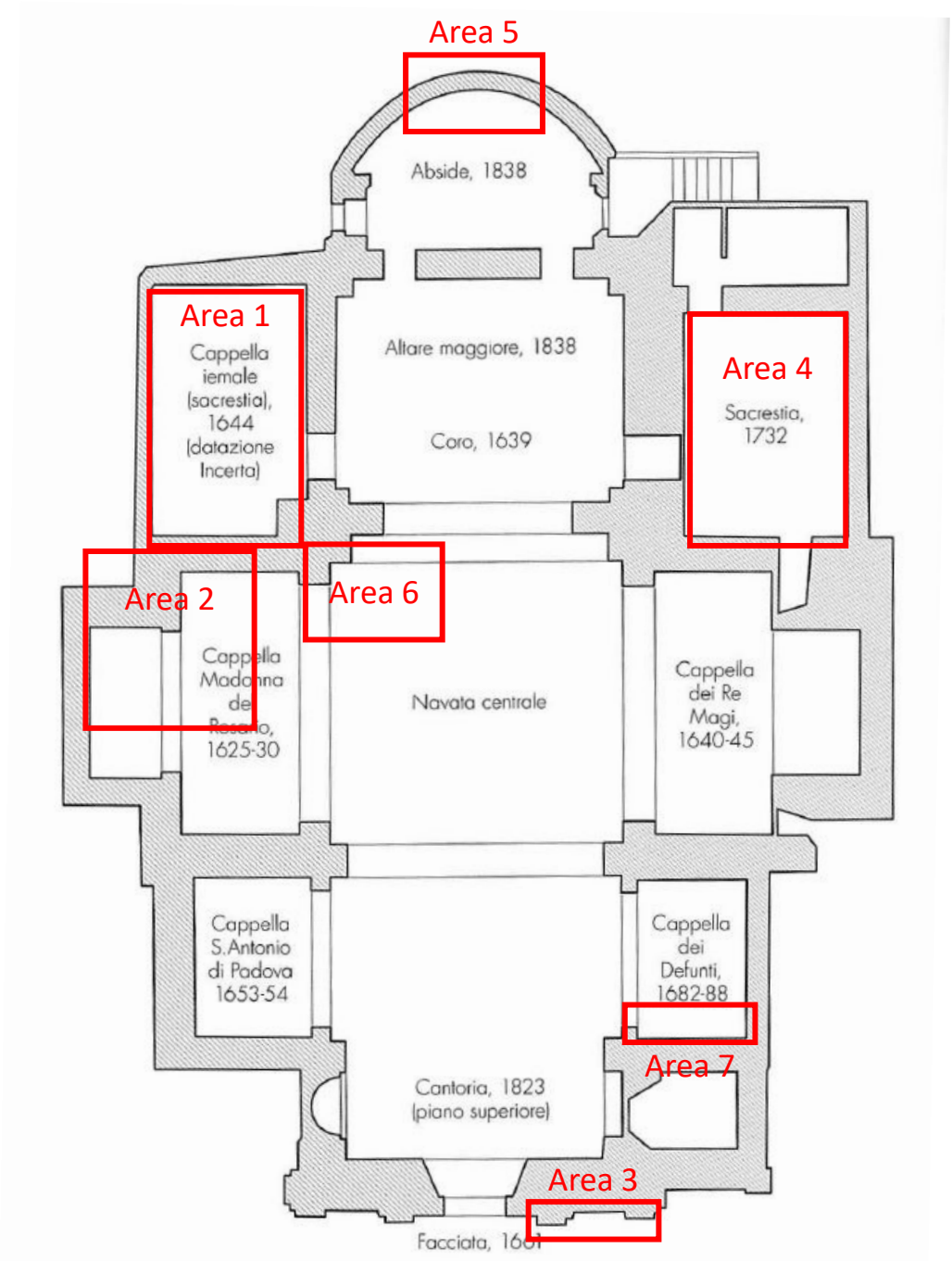
[2] UV radiation illumination was achieved using mercury vapor lamps (with maximum emission at 365 nm) equipped with a Schott DUG11 interference filter to reduce the passage of 'parasitic' visible light and emitted IR radiation.

[3] FLIR T540 thermal imaging camera, with a viewing angle of 80° and a focal length of 17 mm / 24°. Output resolution of 464 × 348 pixels (VGA). Object temperature range from -20 °C to +120 °C (from -4 °F to +248 °F).

[4] LOMVUM LW10 digital pacometer for non-invasive metal detection.

Church of Santo Stefano, sampling areas

Area 1 Iemale chapel
Area 2 Rosary chapel
Area 3 External facade
Area 4 Old sacresty
Area 5 Choir church
Area 6 Trumphal arch
Area 7 Chapel of the suffrage



Iemale Chapel's vault, sampling points

Information of samples

Sample ID	Location	Type	Analyses	Notes
AR_IE_01	South-east side	Efflorescence + stucco fragments	PLM ATR-FTIR SEM-EDS	Deteriorated part
AR_IE_02	South-east side	Salt efflorescence	Mic. observation ATR-FTIR	Deteriorated part
AR_IE_03	South-east side	Salt efflorescence	PLM ATR-FTIR SEM-EDS	Deteriorated part
AR_IE_04	North-east side	Salt efflorescence	PLM	Deteriorated part
AR_IE_05	North-east side	Stucco fragment Ground layer	PLM SEM-EDS	Deteriorated part
AR_IE_06	North-east side	Stucco fragment Ground layer	PLM	Sound part
AR_IE_07	North-east side	Stucco fragment Ground + finishing layer	PLM	Sound part
AR_IE_08	North-east side	Stucco fragment Ground + finishing layer	PLM	Sound part
AR_IE_09	South-west side	Stucco fragment Finishing layer	PLM	Sound part
AR_IE_10	South-west side	Stucco fragment Ground + finishing layer	PLM	Sound part
AR_IE_11	Central vault	Stucco fragment Finishing layer	PLM	Sound part

Results in brief

The stucco decoration of the Iemale chapel is mainly bas-relief, with some more protruding elements in the cornices and around the mural painting in the center of the vault.

The low relief stucco consists of a single finishing layer, while the high relief decoration consists of a ground layer and a finishing layer.

The ground layer contains Mg lime and gypsum as a binder, with lumps of both lime and gypsum. The amount of binder is higher than the amount of aggregate. The sand comes from a local river of the Mendrisio area and is composed of selciferous limestone, calcite and lower content of quartz-feldspar fractions.

The finishing layer is almost entirely made up of Mg-lime binder, with very frequent lime lumps (binder-related particles), without sand aggregate.

The stucco decoration, particularly in the south-east corner, is damaged by the action of soluble salts, probably due to previous roof infiltration. The salts analyzed were found to be epsomite $MgSO_4*7H_2O$, a very soluble salt that caused the disintegration and loss of material.

Rosario chapel, sampling points

The wall behind the altar in the Rosary Chapel.

Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
ST_AR_01	Foot of the prophet on the right	Ground layer	PLM	Sound part
ST_AR_01	Foot of the prophet on the right	Finishing layer	PLM	Sound part
ST_AR_02	Bust of the prophet on the left	Finishing layer	PLM ATR-FTIR	Sound part
ST_AR_03	Bust of the prophet on the left	Ground layer	PLM	Sound part

The stucco decoration of the **statues of the prophets** of the Rosario chapel are composed of a ground and a finishing layer.
The ground layer has a binder composed of magnesia lime, which often contains lime lumps. Gypsum is consistently present in the composition. The lime-to-aggregate ratio (L/A) is 1:1. The aggregate consists of coarse and very coarse sand, moderately sorted. The composition includes flinty limestone, fragments of metamorphic silicate rocks, and gypsum fragments. The porosity is medium, and the shapes of the particles are irregular, sometimes resulting in shrinkage cracks.
For the finishing layer, the binder is also magnesia lime, but with a much higher frequency of lime lumps. Gypsum is again consistently present. The lime-to-aggregate ratio (L/A) is much higher than 1, with the mixture being almost entirely binder. The aggregate is not present but there are burnt limestone and gypsum.

Rosario chapel, second sampling points

Frame stucco decoration belonging to 1700, in the Rosary Chapel.

Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
ST_AR_04	Projecting part of the cornice	Ground layer	PLM	Sound part
ST_AR_04	Projecting part of the cornice	Finishing layer	PLM ATR-FTIR	Sound part
ST_AR_05	Linear frame	Ground layer	PLM	Sound part

Samples from the lateral cornice were also analysed. For the more **projecting part cornice**, the ground layer is composed of a magnesia-lime binder containing frequent and relatively large lime lumps, with gypsum consistently present. The lime-to-aggregate ratio is approximately 1:1. The aggregate consists of medium and fine sand with good sorting, and its composition includes flinty limestone, fragments of metamorphic silicate rocks, and gypsum fragments. The material shows medium porosity with rounded pore structures. The finishing layer has a magnesia-lime binder with frequent lime lumps, and gypsum. The L/A ratio is significantly greater than 1, resulting in a mixture composed almost entirely of binder. The aggregates consist of fragments of underburned limestone and gypsum.

In the case of the **linear frame**, the ground layer is characterized by an isotropic binder. Gypsum is not detected, and the lime-to-aggregate ratio is equal to or slightly less than 1. The aggregate is medium-grained and very well sorted, composed of fragments of metamorphic silicate rocks, quartz, feldspar, limestone, and micas. The porosity is high, with pores of irregular morphology. The finishing layer is extremely thin and consists of very fine silicate and calcareous sand.

Facade, sampling points

Statue on the right external facade

Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
ST_AR_06	External right statue	Ground layer	PLM	Sound part
ST_AR_07	External right statue	Finishing layer	PLM	Sound part

The ground layer of the **external statue** consists of a magnesia-lime binder containing frequent lime lumps, with gypsum present throughout. The lime-to-aggregate ratio is approximately 1:1. The aggregate is coarse to very coarse with moderate sorting, and its composition includes flinty limestone, fragments of metamorphic silicate rocks, and gypsum particles. The stucco internal layer shows shrinkage cracks oriented perpendicular to the surface.
The finishing layer is composed of a magnesia-lime binder with frequent lime lumps. Gypsum is present, and the mixture is essentially pure binder. No aggregate is added, with the only inclusions being fragments of underburned limestone.

Old sacresty sampling points

Old sacresty, East side, external frame of the vault, sample 08.

Old sacresty, East side, frame of the cartouche (sample 09) and vault background (sample 10).

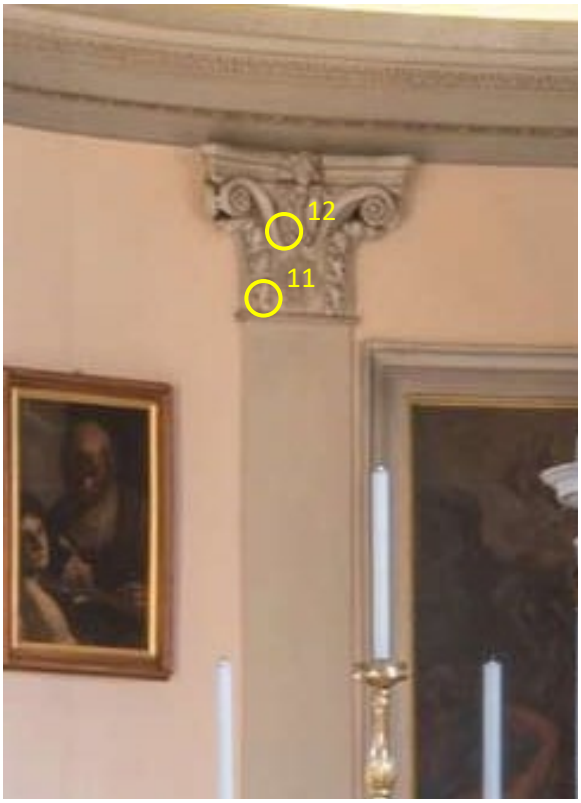
Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
AR_ST_08	Old sacristy, East side, external frame of the vault.	Stucco fragments. finishing layer	PLM	Sound part
AR_ST_09	Old sacristy, East side, frame of the cartouche.	Stucco fragments. finishing layer	PLM	Sound part
AR_ST_10	Old sacristy, East side, vault background.	Plaster fragments. finishing painted layer	PLM ATR-FTIR	Sound part

All samples taken from the vault of the old sacristy consist predominantly of a finishing layer that contains only rare, small aggregates of varied colour. The plaster and stucco samples show a high degree of similarity.
The finishing layer is composed almost entirely of a Mg-lime binder, exhibiting a markedly heterogeneous texture with spherical features associated with the Mg-rich fraction of the binder, as well as frequent lime lumps. Radial hydromagnesite formations are also present.
The few aggregates observed consist mainly of quartz and iron oxides.
The paint layers applied to both the stucco decoration and the plaster consist of whitewash.

Choir and Triumphal wall - St Peter's Statue, sampling points

Triumphal wall, San Peter's statue, G. A. Colomba



Decoration of the column capital in the choir

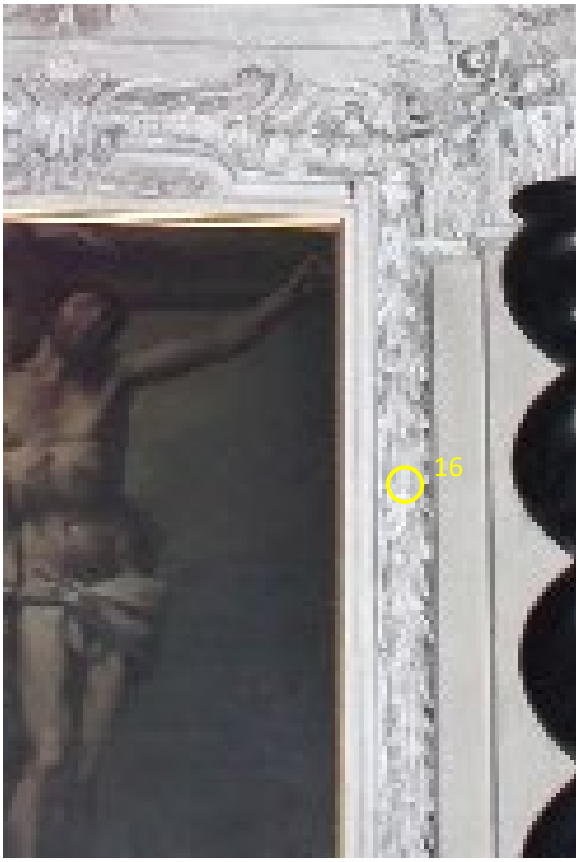
Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
AR_ST_11	Choir, decoration of the capitel of the pilaster, North side	Stucco fragments. finishing and ground layer	PLM ATR-FTIR	Sound part
AR_ST_12	Choir, decoration on capitel, North side	Stucco fragments. finishing layer	PLM	Sound part
AR_ST_13	Triumphal arch, statue of Saint Peter, book	Stucco fragments. finishing layer	Stereomicroscope observation	Sound part
AR_ST_14	Triumphal arch, statue of Saint Peter, book	Stucco fragments. finishing layer	PLM ATR-FTIR	Sound part

One sample taken from the **acanthus-leaf decoration** of the pilaster consists of a finishing layer and a ground layer. The ground layer containing quartz, stone fragments, selciferous limestone, and feldspar, showing characteristics very similar to those found in Iemale's chapel. The finishing layer is characterised by a Mg-lime binder with calcite aggregates.
A second sample from the same pilaster, collected from the central floral decoration, includes only a finishing layer, which is composed primarily of an Mg-rich binder with a small amount of calcite aggregate.
The sample taken from the statue of Saint Peter (book) consists of a finishing layer composed of an Mg-lime binder displaying radial mineral phases and an aggregate formed of metamorphic rock fragments and limestone. This sample is extremely small, so the results can be not representative.

Chapel of the Suffrage, sampling points

Suffragio's Chapel, right frame, West side



Suffragio's Chapel, altar, South side

Information of samples and results in brief

Sample ID	Location	Type	Analyses	Notes
AR_ST_15	Suffragio's Chapel, right frame, West side	Stucco fragments, finishing layer	PLM ATR-FTIR	Sound part
AR_ST_16	Suffragio's Chapel, altar, South side	Stucco fragments, finishing layer	PLM	Sound part

The samples of the altar and the lateral frames of the **Suffragio chapel** are mainly composed of a finishing layer. It is almost entirely made up of Mg-lime binder, with very frequent lime lumps (binder-related particles) almost without sand aggregate. This specific presence of underburned BRP testifies that the heat treatment of the limestone was not sufficient and not efficient.

Conclusion

The analytical investigations carried out on the stucco decorations of the Church of Santo Stefano in Arogno have provided a comprehensive characterization of the materials, techniques, and construction practices employed across the various chapels and architectural elements. Despite the diversity of decorative typologies—ranging from low-relief panels to three-dimensional sculptures—the results reveal a consistent use of Mg-lime binders throughout the complex. The binder frequently present lime lumps and, in many cases, hydromagnesite radial phases, indicating both the specific raw materials selected and the transformations occurring within the binder over time. Gypsum is recurrently present, especially in the ground layers of the models. Aggregates—when present in the ground layer—are typically derived from local geological sources and include flinty limestone, metamorphic silicate rocks, quartz, and feldspar.

The stratigraphic organization of the stuccoes is generally coherent across the church: bas-relief works tend to consist of a single finishing layer, whereas high-relief or structurally demanding elements consistently feature a ground layer combined with a finishing layer composed almost exclusively of Mg-lime binder. The rare aggregates in finishing layers and the frequent presence of underburned binder-related particles further demonstrate the artisanal nature of the mixtures and the variability in firing conditions of the raw materials. The stucco decoration in the Iemale sacristy has textural and compositional characteristics that match those analysed in the main church, indicating the source of raw materials were not changed during the centuries.

The analyses also identified deterioration phenomena of particular relevance to conservation. Salt-related degradation—especially the formation of highly soluble epsomite—has significantly affected portions of the Iemale chapel, leading to material loss and disintegration. These findings underline the sensitivity of Mg-lime stuccoes to moisture dynamics and soluble salts. Shrinkage cracks observed in several samples can be related to the material proportions and the drying processes.

Overall, the integrated use of petrographic analysis, SEM-EDS, ATR-FT-IR, and in-situ non-invasive techniques has enabled a detailed understanding of the original material composition and technical execution of the stucco decorations. These results also provide an essential scientific foundation for planning conservation measures. By clarifying both the construction methods and the causes of deterioration, the study supports the development of informed, compatible, and durable restoration strategies that respect the material authenticity of the church's decorative heritage.