Multidisciplinary Investigations on the Byzantine Oratory of the Catacombs of Saint Lucia in Syracuse

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Abstract—**This paper presents the outcomes of a multidisciplinary study conducted on the fresco palimpsest of the byzantine oratory (region C) of the Catacombs of Saint Lucia in Syracuse. The 3D model was integrated with data from investigations made with portable X-ray Fluorescence Spectroscopy (pXRF), and Technical Photography (TP), in order to obtain a unified representation of the knowledge acquired. The different layers of the frescoes present in the palimpsest could then be individually identified and characterized using the data extracted from the model. The arcosolium examined here is an illustrative case study characterized by clear artistic and archaeological stratifications.**

Index Terms—**Catacombs, Laser Scanning, Digital Cultural Heritage, worship places, portable X-ray Fluorescence Spectroscopy, Technical Photography**

I. Introduction

Our study of the byzantine oratory of region C,(Fig. 1), in the Catacombs of Saint Lucia in Syracuse [1-5], is founded on an interdisciplinary approach among archaeologists, engineers, architects, and physicists. It is aimed at achieving a holistic understanding of the cultural heritage site and its artifacts to foster the conservation and fruition of the monument.

The non-invasive methodology is designed to study the spatial and architectural features of the artifacts, as well as, to integrate the 3D model with data from archaeological research, spectroscopic analysis (pXRF), and Technical Photography (TP).

II. Archaeological Topography

The history of the catacombs of Syracuse (S. Giovanni, Vigna Cassia, and S. Lucia) stretches from the Greek classic age to late antiquity. The catacombs of Saint Lucia rest under the Akradina neighborhoods and were not originally used as a cemetery. Instead they were a neighborhood of large ceramic workshops with factories located on the western side of the *Syrakò* creek, active until the Augustan age.

The funerary area under the current S. Lucia square was comprised of both a community cemetery and private spaces; andits activity spanned the period between the III and the V century AD.

The Catacombs of S. Lucia are located on the South-West side of the Basilica, outside of the confining walls, and are divided into four regions (A, B, C, D).

Regions A and B are the oldest and their architecture recalls the catacombs in Rome due to the narrow corridors and the *loculi* stacked on the walls. The other regions, C and D, date back to the post–Constantinian age and reveal tombs with *arcosolia* and large *cubicula.* Under the Byzantine age, after the cemetery was shut down, two areas of the catacombs became destinations for pilgrims: the oratory of the forty martyrs in region A and the oratory in region C.

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III. 3D ACQUISITION

The pre-existing documentation of the Catacombs of Saint Lucia consists of a floor plan made by integrating topographic survey and direct survey. These 2D graphic representations have not been updated over time (an excavation campaign in the Byzantine oratory of region C has been underway for several years now). Above all, the current records do not adequately render the spatial and architectural quality of the byzantine oratory and fresco palimpsest.

Given the complexity of the site and the need to document the particular nature of the Byzantine oratory three-dimensionally and comprehensively, we have chosen to use3D laser scanner technology. The laser scanner has the advantage of acquiring 3D data with high accuracy in a short period of time [6], from the geometry of the space to the morphology of surfaces and the state of preservation. Furthermore, we used an instrument equipped with an external axial camera, capable of capturing high-resolution images combined with metric data and automatically re-projecting them on the point cloud.

The Riegl VZ-400, integrated with a calibrated Nikon D 700 camera (focal length: 14 mm and 12 Mpixel resolution) was used. In the design phase of the survey, the accessibility issues related to the underground site were taken into account, as well as, the adverse environmental conditions, such as the strong presence of moisture in the air and the absence of natural light.

The 3D data capture phase of the project took encountered the complex and fragmented structure of the space being surveyed. Particularities encountered were due to the presence of several pillars of pressed bricks, which support the ceilings, and the varying height of the ceiling. Specific considerations for this site focused on the need to document the recent excavations of the ground and wall tombs, the fresco palimpsests on the walls, the monumental inscriptions, and the graffiti of pilgrims.

Fig. 1. Plan of the oratory with the scan positions highlighted (red dots)

In order to obtain full coverage of the space involved, we planned for 18 scans, each of which was carried out from a central position with respect to the environment being scanned (Fig. 3). In the meantime we acquired texture information by using a spotlight to brighten the environment and paying attention to cast-shadows.

The extreme fragmentation of the space, made it difficult to ensure the simultaneous visibility of at least three targets shared on contiguous scans. It was therefore decided not to use the targets, and instead to use the alignment procedure for homologous points while recording scans.

The alignments were performed using Riscan Pro software by subsequent refinements: defining the reference scan and then attaching subsequent scans to it.

We proceeded with a pre-alignment of the scans (coarse registration) using homologous points and subsequent application of an iterative procedure called automatic MSA (Multi Station Adjustment) based on an ICP algorithm.

The global model is made up of 250 million points. The global registration error reported is 2 mm.

IV. THE FRESCO CASE STUDY: ARCOSOLIUM

The *arcosolium* case study examines an example fresco exhibiting archaeological and artistic stratification. The lower part of the rock is cut sharply, and we can infer the presence of a *sarcophagus,* which was removed at a later time. Around the lunette is a palimpsest of overlapping fresco layers ranging from the byzantine era to the Norman (Fig. 2).

A. Diagnostic examinations

High-resolution visible imaging documented the state of conservation of the mural.XRF was used as a non-invasive portable tool to investigate the elemental composition of the pigments decorating the *arcosolium.* In certain locations, Technical Photography was also taken as a complementary technique for pigment analysis. The identification of material composition for pigments is an essential step to help identify different periods of application, or points of later addition or restoration.

Technical photography was performed with a Nikon D800 camera, DSLR (36 MP, CMOS sensor), modified for full spectrum acquisition by having the built-in IR filter removed. The following imaging methods were applied: Visible (VIS), Ultraviolet Fluorescence (UVF), Infrared (IR), Infrared False Color (IRFC) photography. The imaging equipment and the method are described extensively elsewhere [7] including the description of filters and lighting setup. For the examination of the palette of pigments, a handheld Bruker AXS Tracer III-SD® (Kennewick, WA, USA) pXRF unit was used. The system features, as well as, the measurement parameters have also been previously described [8].

First, the mural painting was documented with Technical Photography (VIS, UVF, IR and IRFC)in order to select areas of interest for the XRF analysis. The IRFC and UVF imaging modalities didn't reveal retouches on any of the palimpsest layers and consequently, the points for XRF were selected to include all the colors present in all the layers.

The primary colors (blue, red, and yellow) were observed, in addition to white, and violet, which is probably a mixture of red and blue. It can be seen that the major elements present in the painted layers are Ca and Fe, with considerably less amounts of Pb, Si, Sr, K, and Ba present in all of the spectra.

The minor/trace elements are present at levels consistent with geological provenance (of the plaster/pigment) and thus are not major pigment components.

The red and yellow points (Fig. 7) analyzed indicate the use of ochre ($FeO(OH){\cdot}nH_2O$ / Fe_2O_3) for these pigments. The Ca/Fe peak integrated counts ratio is <10 for these colors, and varying amounts of Fe, Ca, and Pb are found. This could depend on which layer was studied (as in how many layers of pigment were also underneath), or the particular concentration of pigment in the layer. The attribution to ochre is also confirmed by the infrared image where these pigments become transparent (Fig. 5).

Blue paints (points 4, 6, 9, 11, 17) exhibit overwhelming counts for the Ca peak are and also result in the Ca sum peak being observed at ~8keV, Fig. 8. Blue areas of pigment are shown to contain the same elements as other spectra, but in different quantities. The Ca/Fe ratio here is between 28-58, considerably higher, meaning there is comparatively less Fe content. Point 6 has the highest amount of Pb and also presents a small quantity of Ba. We do not assign any particular element to be associated with the blue colorant based on these spectra. We are instead able to rule out the presence of blue pigments based on transition metals (Cu, Co, Fe, Cr, etc.). This includes the conclusion that azurite is not present in the blue areas analyzed, since the representative Cu peak is not observed. The blue color could be of organic (C, H, N, O) or lightweight element (Na, Si, Al, Mg) base, not detectable by pXRF. The infrared image shows a strong absorption of infrared light by this blue paint and excludes historical organic pigments such as indigo.

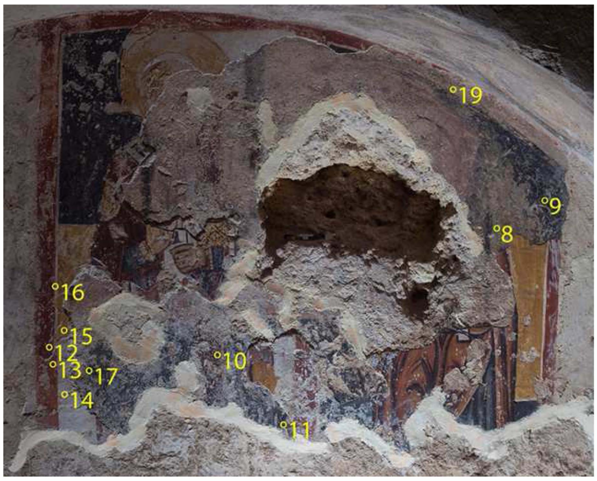

Fig. 2. Front (with XRF points map)

White pigment or "plaster" shows mainly Ca, with also the presence of Pb, Sr, Si, and S. The sulfur content signals the likely presence of $CaSO_4$, which may be a degradation product of calcite ($CaCO_3$). Points 7 and 16 represent ordinary white areas.

Point 19 is an area where "yellowish" visible fluorescence occurred when illuminated with UV light, Fig. 9. The count levels and baseline for scan 19 are considerably lower because the scan was done with less time, (due to the area being slightly out of reach), but we can still make some observations. There is an elevated presence of Pb here, and the Sr content is diminished. In fact, the Pb peaks are much taller than the Ca peak, pointing to the use of lead white here. Additionally, in point 16 versus 7 there is a greater amount of sulfur present, as well as Sr and Si. The reason for fluorescence could be due to an organic binder mixed with the lead white.

The green and violet pigments were only analyzed in one instance each. Violet is almost certainly a mix of blue and red ochre, but we can only say that it is a base of Ca and Fe in ratio approx. 1:1, further conclusions are not possible with pXRF. The green pigment is likely malachite, which was very common in use on frescoes and is a base of copper, matching the overwhelming copper signal in the spectrum. The infrared image supports this identification since malachite absorbs infrared light, appearing dark in the IR image. This property of malachite is also useful to enhance the visualization of faded malachite paint, as the figure shows.

B. 3D processing and segmentation of the fresco Palimpsest

The experiments were carried out with the purpose of integrating the diagnostic data within the 3D model [9, 10]. Specifically, the possibility to extrapolate different layers from the textured model into the layers that make up the palimpsest fresco was explored, in addition to the application of images from the TP (VIS, UVF, IR) documentation, and the annotation on the 3D model of the data obtained from the pXRF investigations.

The first step was to import the project created within RiScan-Pro within JRC-Reconstructor software.

The *arcosolium* portion was pre-processed to eliminate the noise. We then proceeded to the image calibration of the VIS, UVF, and IR images obtained previously, in order to re-project them on the model. The calibration was carried out by means of homologous points selected on both the image and the point cloud. The images we used have a resolution of 6pix/mm, with a calibration error of 3pix. Then, we proceeded to create a 3D mesh, re-projecting the images onto the mesh.

Inside JRC Reconstructor it is possible to use a tool named Virtual Scan (VS), which allows the user to make a sort of new virtual scan of the model contained within the frustum and re-obtain, from a set of overlapping meshes, a new point cloud (merge) with a detailed resolution (a function of the meshes and of the projected image).

Next, we explored the possibility to segment the new textured point cloud (VIS image) according to the various layers identified within the palimpsest fresco. In ideal conditions (flat surfaces), we could have proceeded by slicing the point cloud according to a designated thickness.

In our case, the *arcosolium* is carved into a wall, which presents horizontal and vertical irregularities, as well as a horizontal rotation of about 15°. The procedure then forecasted the creation of an orthographic frustum required for the VS by means of the creation of a best-fit plane. Then VS was carried out.

The segmentation then was carried out directly on this new high-texture range map using the 2D edit filtering tool that allows precision operations with the typical instruments for the selection of images (rectangular, lasso, polygonal).

In this way, layers with geometries actually corresponding to those of the fresco palimpsest have been identified and incorporated into the 3D model (Fig. 3),and can be switched on/off according to the needs of the study.

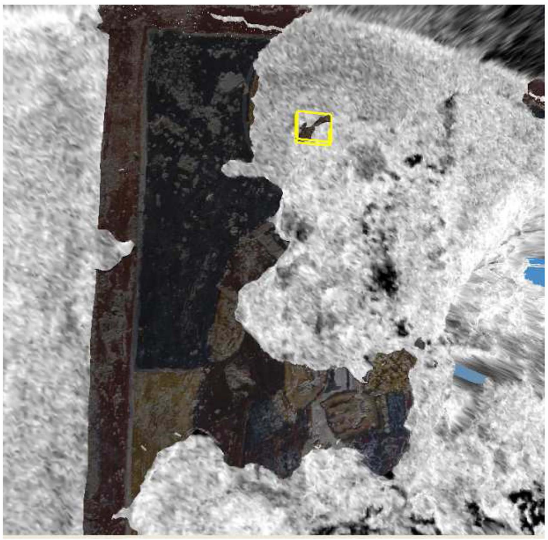

Fig. 3. Segmentation of frescoed layers on the 3D model

V. CONCLUSIONS

The study on the byzantine oratory of the catacombs of Saint Lucia permitted the definition and verification of a methodological process, which synchronized data from a multi-technique analytical approach. The case study aimed at synthesizing the documentation of the geometric-dimensional, materials and state-of-conservation characteristics of the underground site and its delicate fresco palimpsests.

The 3D model is a precise physical representation of the structure to which material, archival, archaeological and geognostic data are added. This way it is possible to obtain a 3D archive which visually and spatially documents one of the most important sectors of the catacomb, an area not yet studied exhaustively.

Technical Photography was applied along with pXRF, and together these analytical techniques were able to confirm that the frescos are made from the traditional natural pigments (ochre, calcite, malachite). Only the identification of the blue pigment will require further examination.

Finally, the methodology to process and segment the layers of the fresco palimpsests was formulated and tested. The case study described has laid out an innovative approach for the evaluation of archaeological assets able to be repeated in similar investigatory situations.

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