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Frescoed wall conditions assessment with non-invasive GPR survey: the case of the Crypt of San Francesco in Irsina (Basilicata, Southern Italy)

Capozzoli L.[1] Boccia M.P.[3], De Martino G.[1], Gizzi F.T.[2], Sileo M.[2], Masini N[2]

[1] *CNR- IMAA (Institute of Methodologies for Environmental) Tito (PZ), Italy,*
luigi.capozzoli@imaa.cnr.it gregory.demartino@imaa.cnr.it

[2] *CNR-ISPC (Institute of Heritage Science) Potenza (PZ), Italy,*
fabrizioterenzio.gizzi@cnr.it maria.sileo@cnr.it nicola.masini@cnr.it
[3] *Conservation scientist*

Abstract – In the field of the conservation of cultural heritage, non-invasive tests often represent the only way to monitor the conservation state of monuments and work of arts. Ground penetrating radar (GPR) plays a fundamental role in identifying and assessing the presence of failures and degradation affecting cultural heritage. This paper deals with the use of this geophysical technique to investigate some portions of deteriorated frescoed walls in the Crypt of San Francesco Church in Irsina (Basilicata, Southern Italy). Results allowed to identify several anomalies already distributed in the shallower parts of the investigated walls demonstrating unequivocally the bad conservation state of the frescoes. The GPR survey provided results in accordance with the decay and microclimate monitoring data, as derived from a previous study, and certified the needs of substantial restoration interventions.

I. INTRODUCTION

The planning of the restoration of architectural and archaeological monuments to date requires not only a detailed study of construction techniques and materials, but it also implies to obtain analytical information to identify the health state of heritage. This involves the mapping of the degradation, the localization of damage and identification of their causes as well as the environmental monitoring of the physical parameters potentially involved in the degradation processes [1].

In particular, the detection and mapping of voids and cracks in masonry structures and detachments and alterations of the plaster are fundamental steps both to verify the stability of the load-bearing structures and evaluate the state of conservation of the architectural and pictorial surfaces. In the past, this information was obtained by coring samples and other destructive inspection techniques. Today, the higher and renewed awareness of the historical and artistic values and the well-known fragility of the artefacts is increasingly orienting on the use of non-invasive investigation techniques. Over the past two decades, the development of technologies associated with geophysical methods, the improvement of the performance and resolution of sensors and devices and the growing availability of intuitive software for analyzing, processing and interpreting data have led to a growing interest in the use of in situ non-destructive testing (NDT). In this way it is possible to give an answer to the various problems, respecting the value and fragility of the product [2].

In recent years, the use of GPR for cultural heritage has been increasing, for the diagnosis of the state of conservation of architectural monuments [3-6] and works of art such as rose windows, mosaics and wall paintings [7-9]. The interest in geophysical technologies is due to the improvement of sensors and data processing tools, as well as to the greater awareness that investigating the resources of cultural heritage is possible but only using non-invasive technologies. With respect to the investigation of wall paintings, GPR effectiveness is greater the more it is integrated with other investigation methods such as the mapping and monitoring of degradation pathologies, as in the case of investigations carried out on the frescoes of San Francesco in Irsina, whose results are shown and discussed in this paper.

II. THE CASE STUDY

The crypt, founded in the early twelfth century [10], is located under the apse of the Church of San Francesco d'Assisi in Irsina (Basilicata, southern Italy) and has a semicircular barrel shape (Fig.1). The crypt was rediscovered in 1901 by the local historian Michele Janora and was carefully described by Countess Margaret Nugent in her book [11]. The frescoes that cover the walls and the vault of the crypt have been attributed to the painters of the Sienese school who carried out their works around 1370 [12-13].

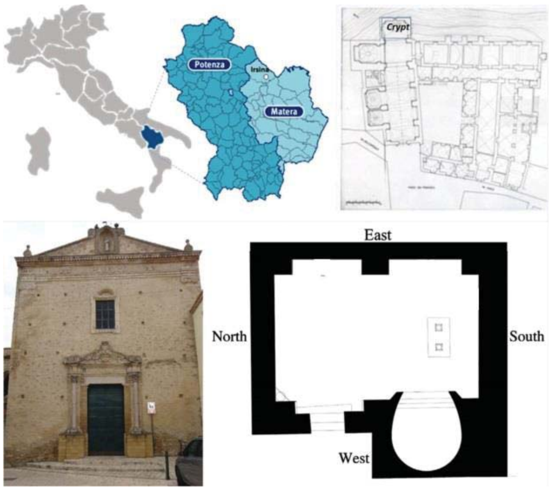

Fig. 1. Geographical background and plan of the crypt of St. Francesco d'Assisi in Irsina, modified by [14].

During the 20th century and the last decade of the 21st century, the frescoes were restored several times [10-13]. In particular, the consolidation of plasters and colors with the cleaning of the surfaces was made in 1927. In 1978-1979 some restorations and investigations were carried out, such as the fixing of crumbled plasters and layers of paint, the monitoring of the microclimate, the cleaning tests, and stratigraphic sections, the analysis of the surface water content and the analysis of soluble salts. During the restoration carried out in 1996 some consolidation and protection interventions were carried out against the detachment of the plaster and the formation of soluble salts. Despite these interventions, the underlying decay problems have never been adequately addressed and resolved. Today, the frescoes show the same decay problems recorded historically, such as the presence of salts and biological material and the cracks and detachment of the plaster. However, the forms of decay of the frescoes show an extension and a degree of gravity that seem lower than those documented in historical periods, but from the investigations conducted by Sileo et al 2017 [14], through a mapping of forms of degradation [15] and micro-environmental monitoring prolonged it emerged that some problems are still present (Fig.2).

III. DECAY MONITORING AND MAPPING

The degradation mapping study revealed that the different types of decay as efflorescence; fracturing, gap, lack of parts and scaling are widespread on the frescoes in particular in the lower parts of the walls where the presence of water and humidity is stronger. In fact, from the monitoring of the environmental parameters, it has been ascertained that the presence of large quantities of water is due to condensation on the walls in the cold winter and spring periods [14], infiltration from above due to percolation from the flow system of the waters not always effective especially in the periods of the most intense thunderstorms (spring and autumn).

In order to understand to what extent water has played an important role in the pathologies of fresco degradation, with particular reference to detachment phenomena, it was decided to integrate the data obtained from monitoring with GPR prospections.

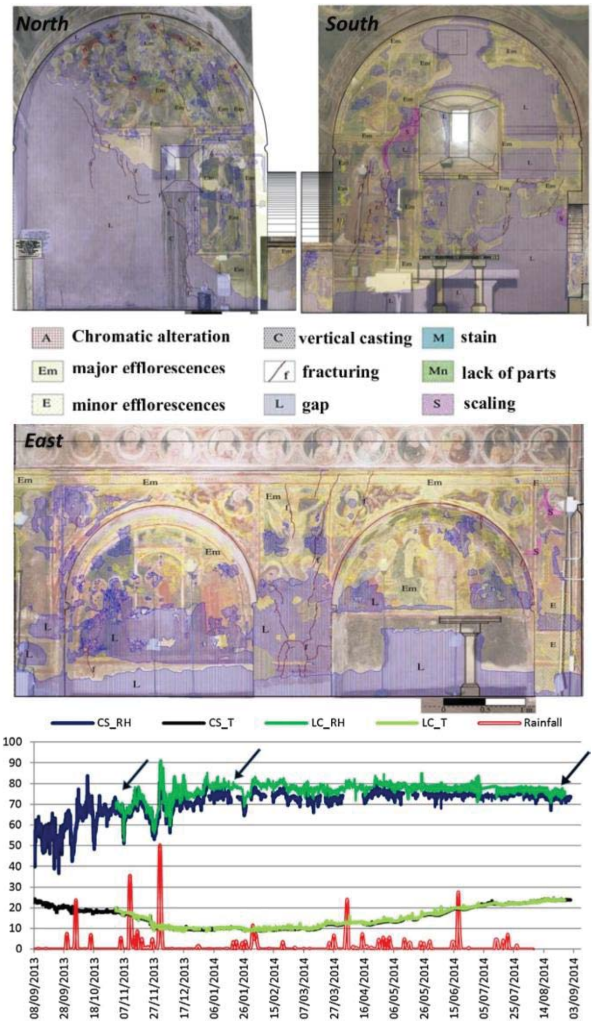

Fig. 2. Mapping of the decay forms on the ortho-rectified photo of the walls and thermos-hygrometric condition into the crypt, modified by [Sileo et al 2017] .

IV. GPR INVESTIGATIONS

IV.1 GPR data acquisition and processing

Data were gathered in only one direction through the acquisition of radargrams located according to a grid including parallel lines equi-spaced only 0.05 m. The frequency adopted was used for providing the best resolution for the investigation of the first 30 cm of the walls, in order to identify the areas characterized by advanced deterioration phenomena. Three panels and a column are investigated as showed in Figg.3 and 4.

Investigations were carried out with the SIR-3000 GPR System (GSSI Instrument) coupled to the 2000 MHz antenna and a metric encoder measuring wheel (Fig. 3). To avoid damaging the frescoes and achieve a high accuracy, for the manual acquisition, a towel including a grid was placed on the investigated areas and the antenna was moved directly on its surface. The acquisitions are performed recording the profiles along the longer size of the panels, from left to right and from the bottom to up (Fig.3b and 3c).

Fig. 3. a) Localization of the areas investigated with the GPR on the South panel (Panel A), b), c) acquisition phases and the geophysical adopted set-up.

The raw-data have required a processing to improve the ratio signal noise and making easier the interpretation. Therefore, the data were processed using standard two-dimensional processing techniques by means of the software Reflex-W [16]. Processing steps can be summarized as follows: i) i) amplitude normalization; ii) dewow filtering to eliminate a possible low frequency part of the signal; iii) background removal; iiii) bandpass filtering; v) energy gain function application; vi) a gainly, a bandpass frequency filtering; vii) Kirchhoff 2D-velocity data migration with a velocity estimated quantitatively using the diffraction hyperbolas generated by the objects placed in the subsoil (em velocity=0.10 mns-1); vii) B-Scans interpolation for reconstructing a 3D model representing the most reflective anomalies to link to voids, detachments, material heterogeneities, etc. and generate the depth slices used for the degradation assessment of the frescoed walls. For the sake of brevity, only the results obtained with the Panel A will be presented and discussed.

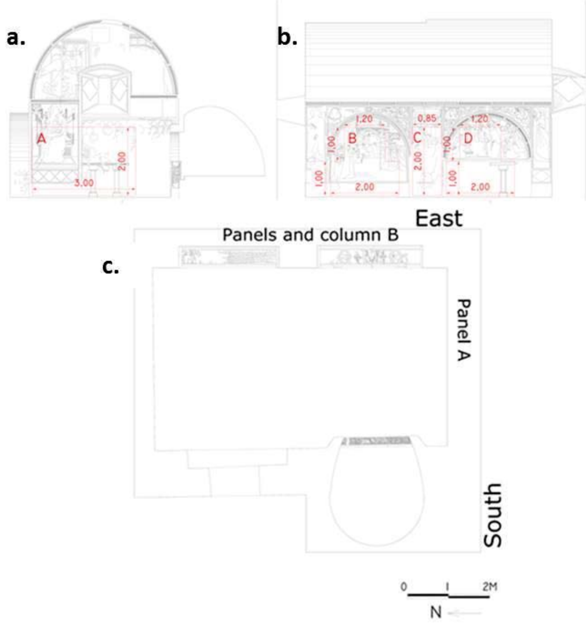

Fig. 4. Schematic map of the frescoed walls investigated in the Crypt: a) the panel A investigated on the south wall; b) the masonry elements (panels B and D, column C) investigated on the east wall; c) the plan of the Crypt with indication of the investigated areas.

IV.2 GPR result interpretation

B-Scans carried out on the panel A, have permitted to detect different reflections chaotically distributed in the full thickness of the wall. The data obtained have allowed to investigate the walls for a total thickness of 40cm, approximately, showing the presence of punctual reflections associable, presumably, to voids, detachments and fractures in the panel (red arrows in Fig.5). Moreover, some linear reflective layers, highlighted in figure with yellow dashed lines, are identified at different depths. They are, supposedly, to be associate to discontinuities charactering the walls and constitute a non-negligible risk for the safeguard of the structure. Finally, for all the acquired datasets, we have noted a stronger attenuation of the e-m signal in proximity of the bottom portion of the radargrams, due to a higher water content and a lower drying capacity of the walls in these areas.

The depth-slices highlighted the reflections imputable to the discontinuities (red arrows) present in the panel that are often aligned according preferential directions inclined of about 45°-50° (red dashed lines) (Fig.6). Furthermore, it is evident the presence of areas less reflective where it is expected a higher water-content (blue dashed circles). Similar results are obtained as regarding the panel B confirming the presence of a widespread decay characterizing all the masonry structures of the Crypt, also confirmed by the decay surveys realized in the past and affecting the frescoed surfaces here present.

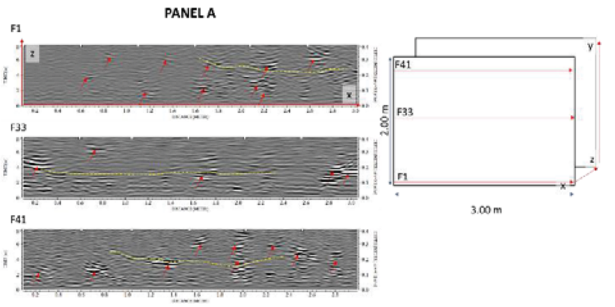

Figure 5: B-Scans F1, F33 and F41, acquired at the different heights of 5cm, 1.55cn and 1.95m of the Panel A (on the left) with their localizations (on the right)

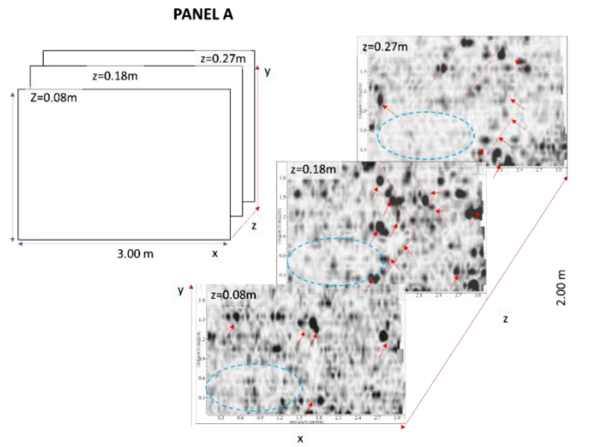

Figure 6: Depth slices extracted every 10 cm, approximately (as showed in the sketch plotted on the left) by the C-Scan of the Panel A with indication of the most evident anomalies occurring at the depths of 8cm, 18cm and 27cm (more details in the text).

V. DISCUSSION AND CONCLUSIONS

GPR survey allowed to investigate the conservation state of the frescoed wall(s). We identified the presence of both water and voids, fractures, and detachments. These data are in accordance with the decay and microclimate monitoring date as derived from a previous study. The case study confirms the usefulness of the GPR non-invasive technique to identify the pathologies of artistic heritage as well as argue about their possible causes.

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