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Preliminary results from remote sensing surveying at the Abbattija *tad-Dejr Catacombs* (Rabat, Malta)

Tanasi[1] D., Cardona[2] D., Hassam[1] S., Kingsland[1] K., Trapani[3] P., Calderone[3] D., De Giorgi[4] L., Leucci[4*] G.

[1]*University of South Florida, Tampa (USA), dtanasi@usf.edu*
[2] *Heritage Malta, Malta, david.cardona@gov.mt*
[3] *University of Catania, Italy, paolino.trapani@phd.unict.it*
[4] *Institute of Heritage Sciences, National Research Council, 73100 Lecce, giovanni.leucci@cnr.it*
** corresponding author,*

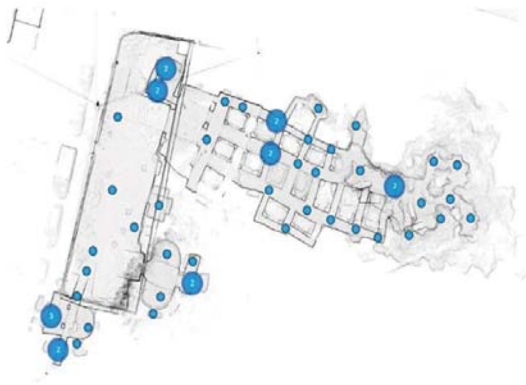
***Abstract* –Multidisciplinary remote sensing surveying techniques were employed at the site of Abbatija tad-Dejr Catacombs in Rabat (Malta) as part of a collaborative research project of University of South Florida's Institute for Digital Exploration (IDEx) and Heritage Malta aimed to map the complex for interpretation and conservation purposes and to assess the eventual presence of further hypogea in the areas surrounding the site. In this study, terrestrial laser scanning and hand-held digital photogrammetry were employed to map the entire complex in 3D and digitize specific architectural and artistic features found in the Catacomb I, in particular. Ground-penetrating radar (GPR) and electrical resistivity tomography (ERT) were used to verify the presence of hypogeal structures and tombs and the preliminary results have showed how the prospection has identified anomalies of possible relevant archaeological interest.**

I. INTRODUCTION

Among the many relevant catacomb complexes of Late Roman and Byzantine Malta, is the lesser-known hypogeal complex of Abbatija tad-Dejr at Rabat. Dug into a scarp in the south-western outskirts of the city (latitude 35°52'55.10"N, longitude 14°23'35.76"E), it comprises a variety of contexts ranging from Roman to Early Christian, and from the Byzantine to Late Medieval periods, due to frequent episodes of reuse. The name of the site, which means 'abbey or monastery of the Christian' in Maltese, is rooted deeply in tradition and speaks to a specific phase to a specific phase of its long life.

The site was recorded for the first time in 1647 by Giovanni Francesco Abela [1] and was inspected again by Antonio Annetto Caruana in 1881 [2], who later published a monograph with plans and sections by Filippo Vassallo, in 1898. The first archaeological excavation took place decades later, in 1926-7 when Sir Themistocles Zammit explored a group of four hypogea (I, II, III, IV), set along two sides of a rectangular quarried enclosure. In 1933, a further excavation, directed by Lewis Upton Way, focusing on the initial portion of Catacomb I, uncovered a partly-troglodytic Medieval church interpreted, on the basis of extant frescoes, as that of the Nativity of the Virgin. This last excavation marks the beginning of a long period of oblivion for Abbatija tad-Dejr, culminating in a series of damages sustained by the site between 1970 and the 1980 due to the sudden urban expansion of Rabat and to looters. In 2005 a protocol between the governmental authority Heritage Malta and other cultural heritage trusts was signed envisioning a new course of action for the management of the site.

Based on the shape and typology of a number of shaft-and-chamber tombs, it appears that the first phase of occupation of the site dates to the late Punic and Roman periods. This was followed, between the 5th and (possibly) 9th century CE, by the excavation of the more famous underground Byzantine hypogea. The final phase is represented by the transformation of the outer part of Hypogeum I into an oratory and chapel equipped by a built portico within the outdoor quarry in the post-Muslim era. Despite the importance of Abbatija tad-Dejr for Late Roman, Byzantine and Medieval Malta, after the Zammit and Upton Way excavations, it was never excavated again. The only overall study, based on the reappraisal of the previous work and observation of the evidence in its current state, was that carried out by M. Buhagiar [3, 4, 5]. In 2019, a collaborative research project of University of South Florida's Institute for Digital Exploration- IDEx (www.usf.edu/idex) and Heritage Malta was initiated to use remote sensing and digital mapping tools to map the complex for interpretation and conservation purposes and to assess the eventual presence of further hypogea in the areas surrounding the site.



a

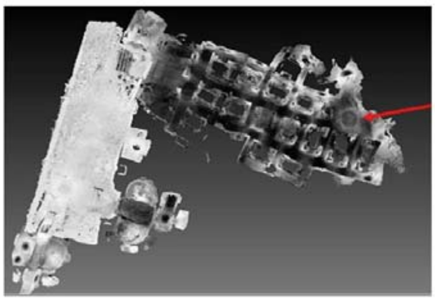
b

Figure 1: a) Plan of the catacomb complex extracted from the 3D point cloud, with indication of the scanning stations; b) Terrestrial laser scanning in progress inside of the complex.

II. 3D DIGITIZATION

With respect to the first goal, mapping the site, two Faro Focus x330 terrestrial laser scanners were employed to digitize the entire underground complex in 3D through a total of 53 scans (Figs. 1 a-b). Scans were taken at ¼ resolution with 4x quality, meaning that each scan captured has an accuracy of up to six millimeters. Scans were taken inside and outside the tombs and the complex itself, capturing the entrance to the catacombs as well as certain features on the ceilings and entrances to certain burial chambers. Due to lack of lighting, the scans were done without pictures; therefore, the resulting point cloud contains no color information.

a



b

Fig. 2. a) Screenshot of the feature on Tomb 20 in the uncolored TLS point cloud; b) *Location of the circular feature in the point cloud*

The point cloud was processed in Faro Scene 2019.1 where default settings were used. A small amount of manual cleaning was needed to remove stray points, like those associated with the movement of insects in and out of the scans and "ghosts" of the technicians as they were walking away from setting up the scanner. The resulting 1.7 billion points in the point cloud remain in Faro Scene for ease of access to the model in virtual reality (VR) through Faro Scene's onboard "VR View" tool. The point cloud was also exported and decimated for use and analysis in other software and archiving.

These scans have revealed several items of interest. Due to limited lighting conditions, certain features and decorations that can be difficult to spot during sight visits, unless one is specifically looking for them. One such feature was a bit of decoration related to Tombs number 20 and 24 (Fig. 2a). This peculiar decoration was also documented via hand-held photogrammetry. Another feature of particular interest is the evidence of a circular feature in an open space of the catacombs (Fig. 2b).

This area is without tombs, but the feature is barely visible on the ground. Though initial thoughts about this spot were that it was an artifact related to the scanning of the tomb, as well as evaluation of scan positions in the area, show that this data is not a result of scanning. Therefore ground-truthing at the site has been planned for summer 2022 to shed light on this matter.

The point cloud data were ultimately imported in AutoCAD to generate a new more accurate and complete plan that was then imported into ArcGIS to create visualizations aimed at addressing open research questions. In addition to the TLS survey, hand-held digital photogrammetry was employed to capture specific architectural and artistic features presented by certain tombs. Large datasets of high-quality digital photographs were processed with Agisoft Metashape v.1.8.0 (build 13257). In the largest of the complexes, Catacomb I, 3D models of the Baldacchino-tomb 20 (Fig. 3a), 22 and 24 and the *arcosolium* tomb 30 (Fig. 3b) were produced and uploaded to Sketchfab. In addition, the Vestibule and the rock-cut Chapel were also digitized and the Siculo-Byzantinesque style fresco, with Christ on the cross, between the Madonna and Saint John and at both extremities of the painting are the Archangel Gabriel and the Virgin Mary forming the Annunciation scene, once in the apse of Chapel and now at Museum of Fine Arts of Valletta (MUZA), was virtualized and recontextualized in a 3D environment (Figs. 3 c-d).

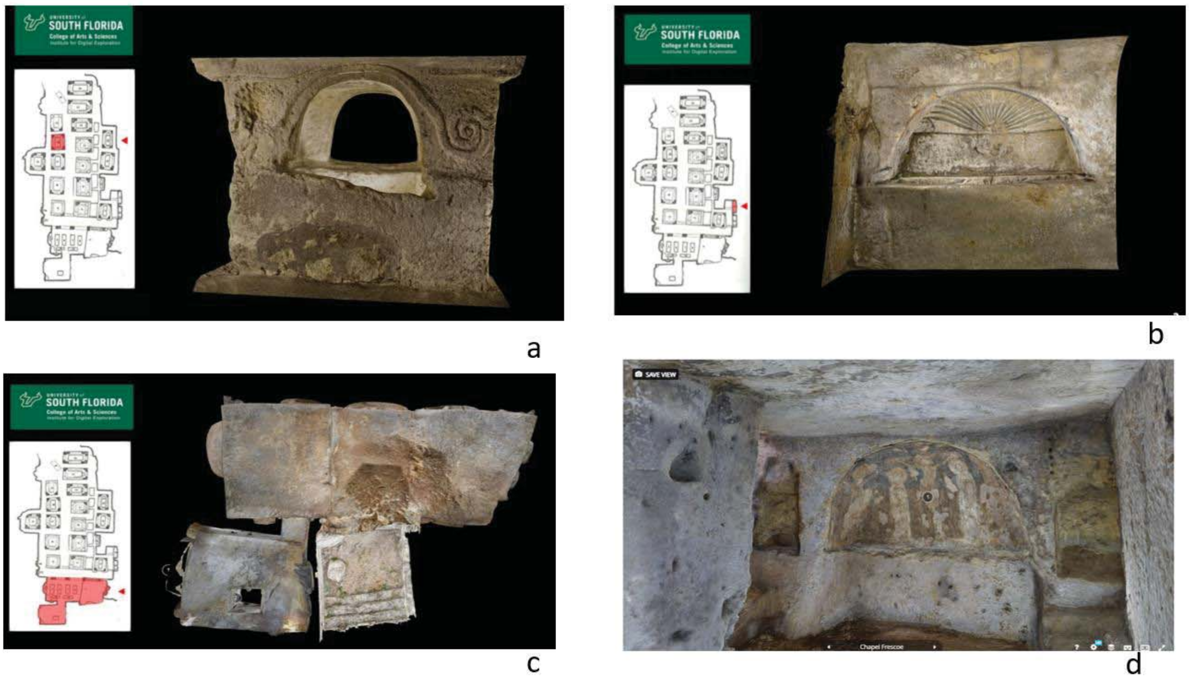


Fig. 3. a) 3D model of Baldacchino tomb no. 20 (https://sketchfab.com/3d-models/catacomb-i-baldacchino-tomb-no-20-eed16b51b978450aa784157e00fee8fa); b) *3D model of the arcosolium no. 30 (https://sketchfab.com/3d-models/catacomb-i-arcosolium-no-30-ce4e1f6ae6c04925a108d3ed982e108e); c) 3D model of the Vestibule and Chapel (https://sketchfab.com/3d-models/oratory-chapel-with-frescoes-446f7db7036e44ea990bea4b4131c7db); d) Virtual recontextualization of the fresco of the Chapel*

III. GEOPHYSICAL SURVEY

In order to verify both the presence of further hypogeal structures and tombs beyond the traditionally known complex, integrated geophysical surveys were undertaken, using ground-penetrating radar (GPR), and electrical resistivity tomography (ERT), at and around the site. GPR was performed in 6 areas (A, B, C, E, Fa and Fb), and ERT focused just on area (D) The surveyed areas are shown in Fig. 4.

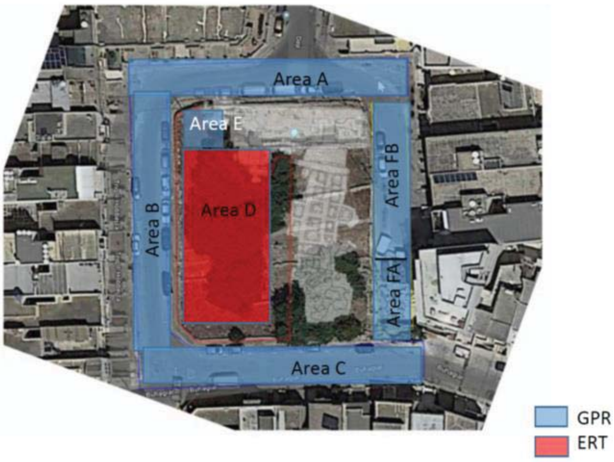


Fig. 4. Areas surveyed with GPR and ERT.

The GPR data were collected along grids with parallel profiles set 0.5 m apart, using the Cobra georadar system with the 400MHz and 70MHz antennae. These GPR data were processed in 3D using GPR-slice software [6]. In order to eliminate a small noise component and make it easy to interpret the GPR data, the following processing sequence was applied: 1) zero-time adjust (static shift), in order to associate zero-time with zero-depth;
2) frequency filtering, in order to remove high-frequency noise; 3) Migration, in order to correct the shape and dimension of reflection events related to the structure present in the subsoil.

GPR data were visualized in 3D using both time slice and iso-surface amplitude [6]. In this work, the time-slice technique has been used to display the amplitude variations within consecutive time windows of width Δt = 5 ns. Three-dimensional amplitude iso-surface rendering displays amplitudes of equal value in the GPR data volume. Shading is usually used to illuminate these surfaces, giving the appearance of real archaeological structures. In this case, the threshold calibration is a very delicate task in order to obtain useful results. Electromagnetic (EM) wave velocity was used to define the depth of archaeological remains [6], using the characteristic hyperbolic shape of a reflection from a point source (diffraction hyperbola).

ERT data were collected in a 3D mode along non-conventional profiles [7] using a Dipole–Dipole array [8] and 1.5m electrode spacing. The ELECTRA, multichannel digital resistivity meter (Moho srl) with 32 active channels was used for geoelectrical measurements. The ErtLab inversion software (http://www.geostudiastier.it) was used for 3D total volume resistivity data distribution in the subsurface. Results of area A are presented here.

In Area A, 12 GPR profiles were measured. The results are shown in Fig. 5. The reflection events labelled “P” are probably related to the pipeline. Other reflection events were generated by the probable presence of buried tombs (“T”). They are located at depths ranging from 0.8m to 1.3m. The reflection event represented by a dashed yellow line (rock) is probably related to the base rock. It is located at a depth ranging between 0.4m and 1.0m. Marked with the letter “C”, is a clearly visible reflection event at depth ranging from 1.7m and 2.0 m. This event could probably be related to the presence of a cavity. The reflection events labelled “M” are related to metal objects present at the ground surface (manholes). The time slices between 0.3m and 2.7m depth are shown in Fig. 6.

In the slice ranging from 0.4 to 0.8 m depth, relatively high-amplitude alignments (dashed dark line) are clearly visible. Particularly evident is the correlation between the reflection event labelled “P” in 2D radar sections. At between 0.9 and 1.0m of depth the high amplitude event “T” is visible. Between 1.4 and 2.2m of depth the high amplitude event “C” is visible.

In Fig. 7 the same data set is displayed with iso-amplitude surfaces using a threshold value of 40% of the maximum complex trace amplitude [9]. Obviously, lowering the threshold value increases the visibility of the main anomaly and smaller objects, but also of heterogeneous noise. Relatively strong continuous reflections are visible on the threshold volumes. This visualization technique enhances the visibility of the anomalies related to the archaeological features (the tombs and cavity).

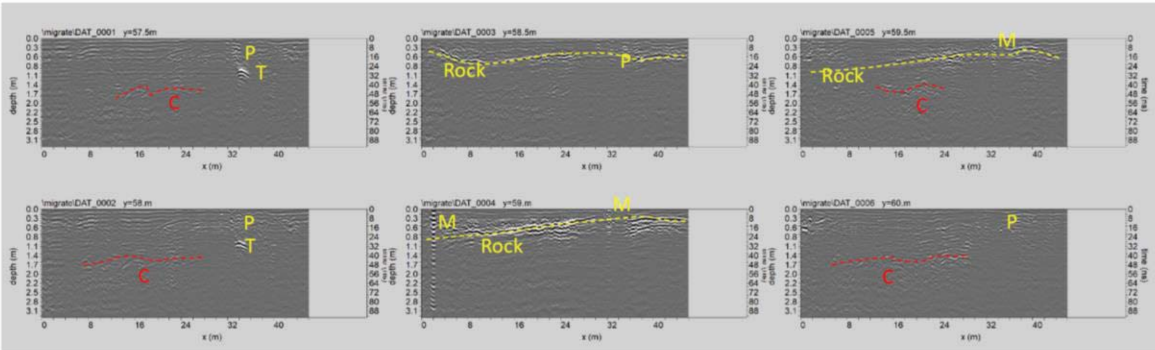


Fig. 5. GPR processed data

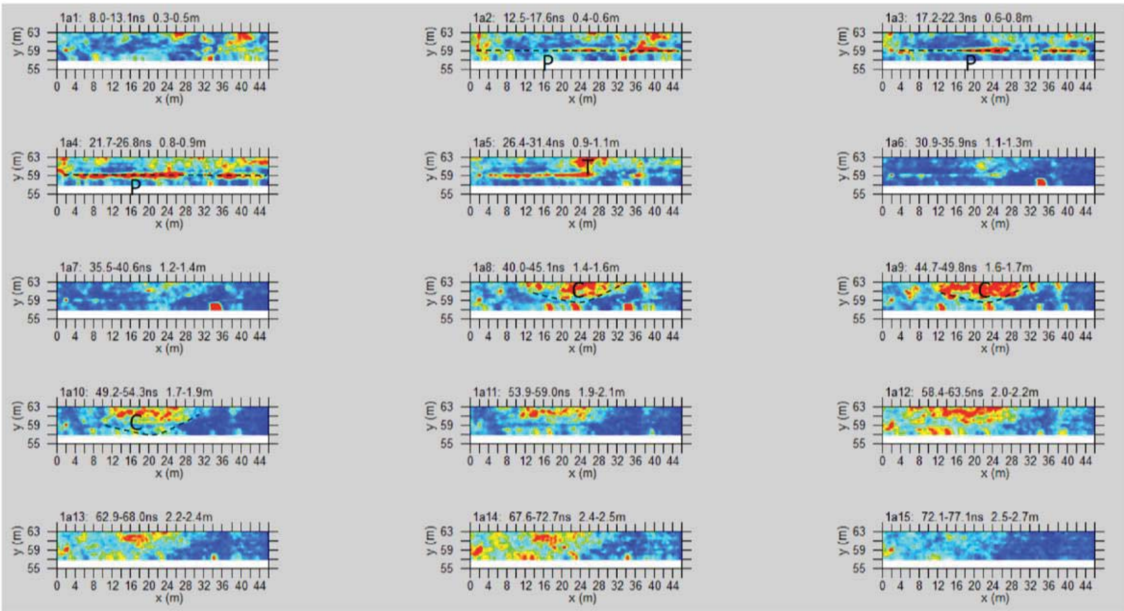


Fig. 6. GPR depth slices

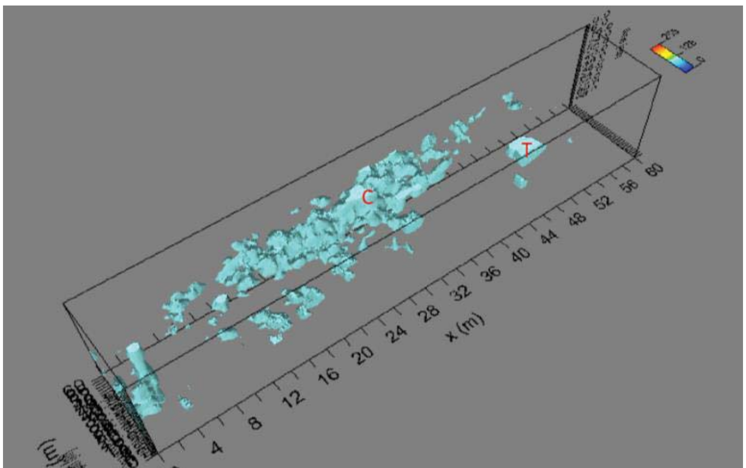


Fig. 7. GPR iso-surface

IV. CONCLUSIONS

The remote sensing campaign conducted at the Abbatija tad-Dejr Catacombs resulted in the creation of the first overall 3D representation of the entire complex that will be an invaluable tool for the institution tasked with the preservation of the site and will become the new starting point for future interpretative studies. The updated plan, extracted from the TLS data, has allow us to revise and correct technical errors present in the traditional one and create a GIS platform to generate ad hoc visualizations to address spatial and archaeological research questions. The availability of 3D model, from both TLS and digital photogrammetry, can now also be used for specific public outreach programs guaranteeing virtual accessibility to the site. With respect to the geophysical investigations, the visualization in 3D time-slice maps, used mainly to enhance the horizontal relationships between amplitude anomalies found in the standard two-dimensional GPR and ERT sections, point to several anomalous zones, interpreted as buried features, probably tombs and a cavity. Furthermore, the integration of the acquired data allows for monitoring and planning future excavations.

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