

# Non-invasive investigation and digital reconstruction of a small catacomb complex in Rabat (Malta)

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**Abstract** – This study presents the results of a Ground Penetrating Radar (GPR) investigation combined with a photogrammetric survey of a small archaeological site in Rabat, Malta. The investigation was conducted in preparation for small but challenging road infrastructure works in view of the surrounding archaeologically rich landscape. This area is characterized by a significant concentration of Punico-Roman tombs and more extensive hypogea datable to the Late Roman and Byzantine periods. GPR survey shows anomalies in the form of elongated patterns, some of which aligned to a number of blocked entrances discovered during an archaeological investigation of the site carried out prior to the GPR survey. These anomalies are being interpreted as underground passages, known as ambulacra, of a previously undocumented Late Roman hypogeum. The newly discovered underground passages were mapped out in the obtained 3D photogrammetric model and orthophoto. Both results were plotted and analyzed together in 2D and 3D environments.

## I. INTRODUCTION

Geomatics techniques have evolved rapidly in the last few years. Progressively, more sophisticated and portable tools are being made available for 3D model generation. Particularly, unmanned aerial vehicle (UAV) photogrammetry has been demonstrated to provide a good balance between time, required expertise and results. This technique is largely used to obtain orthomosaics, point clouds and Digital Terrain Models (DTMs) in a wide range of studies [1, 2]. On the other hand, indirect geophysical approaches are capable of obtaining subsurface information from the surface. Within this category, Ground Penetrating Radar (GPR) is of common use in archaeology to investigate buried sites and features [3,4,5].

In this study, the authors present a joint research project

carried out by the Department of Geosciences (University of Malta), the Superintendence of Cultural Heritage<sup>1</sup> and Heritage Malta<sup>2</sup> utilising an array of geomatics techniques to investigate an archaeologically-rich site in Rabat, Malta. Parts of the modern town of Rabat, on the island of Malta (together with the nearby walled city of Mdina) roughly correspond to the Roman town of Melite [6]. This study will deal with part of the Abbatija tad-Dejr complex; a site located within an area characterised by a high concentration of Punico-Roman shaft-and-chamber tombs and clusters of Late-Roman and Early Christian underground rock-cut funerary hypogea that are also popularly referred to as catacombs [6]. Effectively, the site in question formed part of the vast necropolis of Roman Melite – a veritable landscape of death and burial – located outside the fortification walls of the town [6]. The Abbatija tad-Dejr complex, with its vast burial hall and unique decorative features is one of Malta's most important Early Christian underground funerary complexes[7] runs contiguous to the west of the site in question.

The site being investigated covers a small plot adjacent to the north-western corner of the main site and covers an area of about 160m<sup>2</sup> that was recently archaeologically excavated in preparation for road infrastructure works. The area under study suffered from considerable damage in the early 1990s when a number of rifled and partially destroyed rock-cut tombs and small burial chambers were discovered during illegal rock-cutting works. Other funerary remains, primarily the truncated remains of shaft-and-chamber tombs, were discovered during the

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<sup>1</sup> The Superintendence of Cultural Heritage is the Maltese state regulator entrusted with the protection of cultural heritage in Malta. One of its main tasks involves monitoring and directing rescue and development-led archaeological investigations.

<sup>2</sup> Heritage Malta is the Maltese national agency for museums, conservation practice and cultural heritage. It is the entity entrusted with the management the site subject of this study and the nearby Abbatija tad-Dejr underground complex

archaeological investigations carried out in 2020.

The planned infrastructural works consists of a number of reinforced concrete pilasters to support a short road suspended from the ground. This road is required to connect a number of residential garages to the main road without adversely affecting the archaeological remains that are located at a considerably lower level. The archaeological discoveries made on this site, coupled with the known archaeological potential for underground burial complexes in the area, led to concerns that the point loads of the proposed concrete pilasters may cause the collapse of the ceilings of yet unknown underground burial complexes which are mostly dug into the area's very soft Mtarfa Member limestone. In addition, the ceilings of these complexes can be relatively thin, sheared, stressed and structurally weak especially when they were dug at relatively shallow depths or where subsequent surface quarrying took place above them.

In order to address this concern, it was decided to carry out analysis based on non-invasive techniques to identify and map out any potential underground voids so that the planned pilasters can be placed on solid bedrock. Specialists and engineers then extracted geological cores from baulks of solid bedrock identified from the GPR analysis to determine their geo-structural qualities before finally siting the required pilasters.



Fig. 1. Site location (red square). In blue, the know catacomb system (the inset reports a photo of the main hypogeum within the complex).

## II. THE PHOTOGRAMMETRIC SURVEY

Photogrammetry is a comprehensive method that enables

2D and 3D reconstruction of terrain. It can be defined as the science of obtaining reliable information about the spatial properties of the surface and objects, without physical contact, by using some kind of image (aerial, terrestrial or subaquatic).

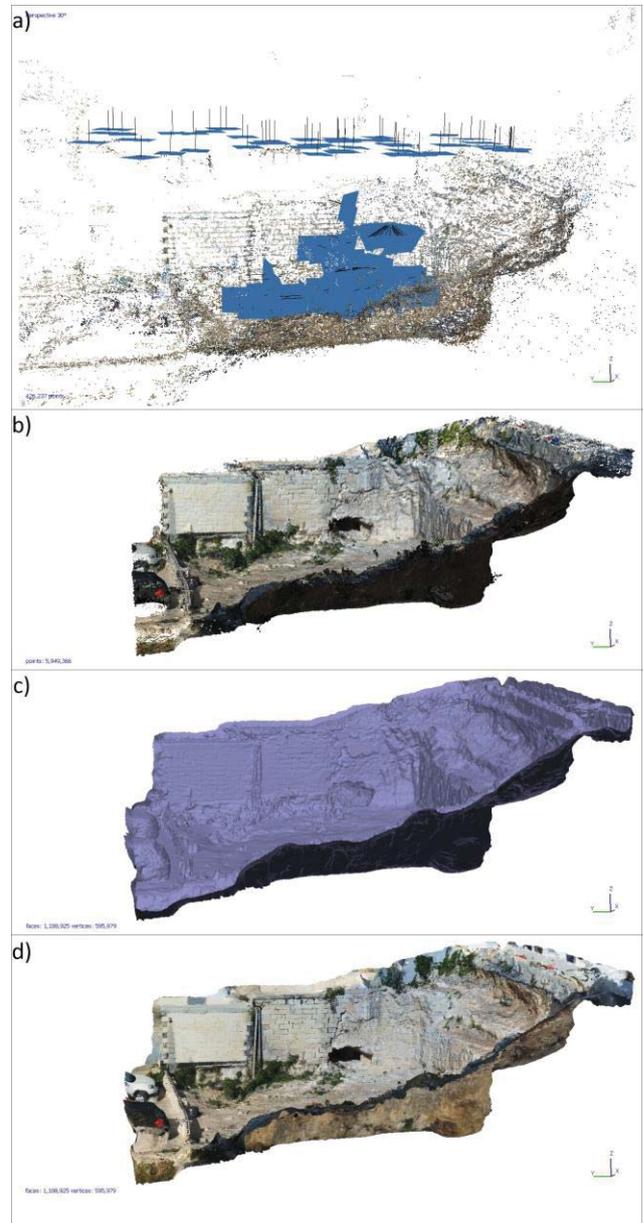


Fig. 2. Photogrammetric processing. a) Sparse point cloud and cameras position; b) dense cloud; c) 3D polygonal mesh; d) 3D textured model.

To construct a 3D photogrammetric model, were used images acquired with a DJI Phantom 4 Pro UAV. This is a relatively small device equipped with a digital RGB camera that can be steered by employing a gimbal. The characteristics of the site (presence of buildings, small

area) required the manual acquisition of the photographs. A total of 160 photographs were taken at different levels and angles to obtain a high percentage of overlap (above 70%) between successive images to ensure a correct digital reconstruction.

Agisoft Metashape [8], a commercial software that uses the Structure-from-Motion technique, was used to process the images. The model was scaled using markers of known dimensions and. The processing procedure includes five main steps to obtain a complete 3D model:

1) Image selection: after image acquisition, image selection must be performed, discarding any defective images (e.g., out of focus, bad luminosity) which could impact negatively the final product and increase processing time.

2) Camera alignment: the software searches for common points between photographs and identifies the position of the camera in each photograph. The camera calibration parameters are also refined. As result, a sparse point cloud is obtained.

3) Dense point cloud construction: a dense point cloud is generated based on the position of cameras and photographs. Once the dense point cloud is obtained, it is manually cleaned by removing defective points or points outside the area of interest. The scaling of the model can be improved at this point.

4) Mesh generation: a 3D polygonal mesh is generated from the dense point cloud, creating the surface of the model.

5) Texture making: after reconstructing the 3D geometry, the coloured texture of the model is generated.

The final product is a three-dimensional reconstruction of the studied area, on which high-precision measurements can be performed. Additionally, it is possible to extract an elevation model of the terrain (DTM) and an orthomosaic.

### III. THE GPR SURVEY

The GPR survey was performed in a flat area of 10,6 x 8,4 meters. The ground material was limestone rock (Mtarfa Member), occasionally covered by grass. The equipment used has shielded CBD antennas that transmit pulses with triple frequencies (200, 400 and 800 MHz), and an odometer that relates the sampling with the distance. The area was squared and surveyed by moving the instrument on consecutive parallel lines, with a spacing of 20 cm. A B-scan (or GPR profile) was obtained for each line.

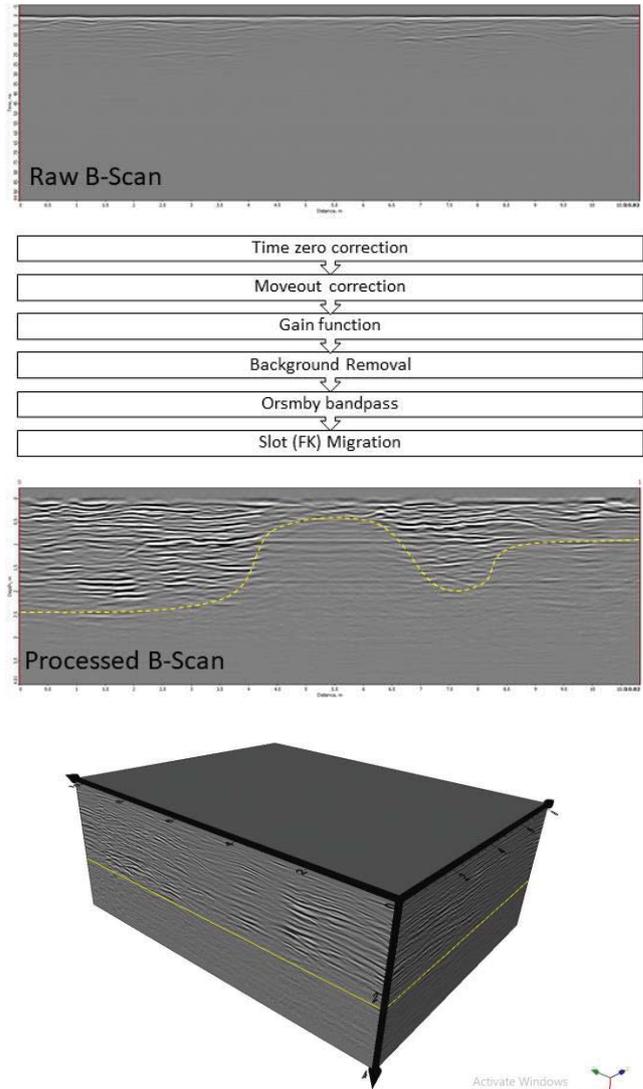


Fig. 3. GPR B-Scan general workflow and 3D cube representation.

Data processing was performed using specialized software and consisted of:

1. Time zero correction. To correct the initial time to correspond with the surface of the ground.
2. Moveout correction. To rebuild the profile as it would be if the signal were radiated and received at a point in the middle between the antennas.
3. Gain function. To equalise the amplitudes of all signals by applying a function that is inversely proportional to the signal strength.
4. Background removal. To suppress the "background" signal, horizontal lines that do not change the intensity and time position in the B-scan.
5. Ormsby bandpass. To delete the noise with different spectral values than the data. It is a band-pass filter acting along a trace. Is designed to suppress low-

frequency interference and high-frequency components of the signal.

6. Velocity calculation and Slot (FK) migration. The velocity is calculated by using the hyperbolas fitting methodology and the B-scans are migrated to obtain a reconstruction of the original shape of underground interfaces. At this point, the B-Scans were analysed individually and the main features were marked.

7. Profile alignment. To construct a 3D cube, we equalized the profiles in samples and traces by cutting the profiles to the shortest. Since all the profiles had approximately the same length and the number of traces per meter was controlled, this operation just implies deleting some centimetres of some profiles.

8. Time slices generation. To generate “horizontal” slices that show data acquired between two specified times.

#### IV. RESULTS AND CONCLUDING REMARKS

This study presents a combined GPR and photogrammetric study of a small archaeological subterranean site in Rabat, Malta.

Photogrammetry results allowed to highlight potential archeological features and other surface features such as topographic breaks in the form of truncated corridors. Three-dimensional reconstruction of the site surface represents a great advantage over other survey methods as it enables different measurements and volumetric estimations to be carried out on the site.

GPR results show good resolution up to about 2.2m, where the signal is irregularly lost in B-Scans. The time slices show anomalies in the form of elongated linear patterns, persistent from 40 cm until signal loss.

These anomalies were plotted and analysed in conjunction with surface features identified by photogrammetry in 2D environments.

In addition, the 3D cube made with the GPR measurements allowed visualising the shape of the anomalies, determining their boundaries and estimating their volume. The 3D GPR anomalies and the photogrammetric model were merged in a three-dimensional environment, allowing a deeper understanding of how the surface and subsurface elements relate to each other (Fig. 4).

On the basis of the above, the site context, and the presence of surviving (albeit truncated and deteriorated) Roman period surface tombs, the GPR anomalies were interpreted as structures that are usually associated with the underground corridors known as ambulacra that form the main passageways of Late-Roman and Early Christian subterranean hypogea. However, interpretation of other geophysical data is currently ongoing to support the findings of this study. It is indeed also the authors' aim to investigate in the near future whether the site in question is effectively an extension of the funerary complex of the

Abbatija tad-Dejr by combining UAV photogrammetric models with non-invasive geophysical inspection.

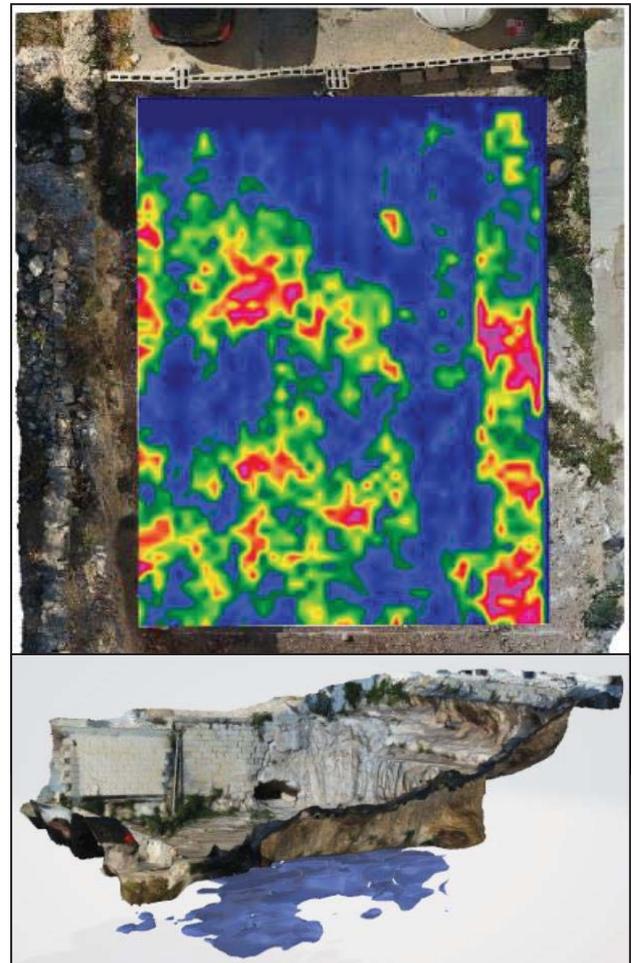


Fig. 4. Top: orthomosaic and time slice (12 ns, about 50cm). Red colours show the anomalies. Bottom, 3D textured model and 3D GPR anomalies.

#### ACKNOWLEDGMENTS

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