2022 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
University of Calabria, Italy, October 19-21, 2022

Hydraulic preservation of archaeological hypogeum based on digital survey techniques

Valeria Pennisi[1*], Graziana D'Agostino[1], Marianna Figuera[2], Gloria Russo[1]
Mariateresa Galizia[1], Pietro M. Militello[2] & Rosaria E. Musumeci[1]

[1] *Department of Civil Engineering and Architecture, University of Catania, Italy*
[2] *Department of Human Science, University of Catania, Italy*
* *valeria.pennisi@unict.it*

***Abstract* – Archaeological heritage protection starts with a complete understanding of the area's morphology and the risk that threatens its integrity. With this aim, a multidisciplinary approach is applied. A hydraulic analysis based on a digital terrain survey is implemented to respond to archaeological questions. The case study is the Hypogeum of Calaforno (Ragusa, Sicily). This site is a unique representation of rock-cut architecture in terms of size and morphological features that render it one of the most important prehistoric monuments in Sicily. The analyses are performed to show the importance of a detailed digital survey, which allows an accurate investigation of the monument to determine the flow direction and identify the water accumulation zone. This study will help optimize flood risk mitigation measures inside the Hypogeum.**

I. INTRODUCTION

The safeguard of archaeological sites and the desire to make them accessible increasingly affect more and more stakeholders. Recent studies highlight the relevance of fully understanding all the aspects that threaten these sites [1][2][3][4], involving several disciplines to ensure an optimal methodology of heritage preservation.

The Hypogeum of Calaforno was chosen as a case study for its particular historical, archaeological, and cultural characteristics, as well as for its intrinsic fragility and criticality associated with hydrogeological factors. The monument is located in the province of Ragusa and offers a unique representation of rock-cut architecture in terms of size and morphological features that render it one of the most important prehistoric monuments in Sicily [5][6]. The monument has significant problems of flooding which render the survey activities more difficult and, at the same time, complicate its archaeological interpretation.

The present work aims to implement the preservation of this archaeological site from hydraulic risk by integrating different professionality. Regarding modern maintenance, our attention is focused on archaeological area analysis to accompany and assist general preservation and conservation efforts from hydraulic risks. Based on laser scanning methodologies, a digital survey is implemented to achieve a depth of knowledge of the site, which could give important information on the optimal drainage methodologies. A Digital Terrain Model (DTM) is built to allow an accurate knowledge of the area. In the GIS environment, hydraulic analyses of the DTM are carried out, and the main water paths inside the Hypogeum are reconstructed.

II. THE HYPOGEUM OF CALAFORNO

The Hypogeum of Calaforno (Fig. 1) has a monumental entrance formed by a sort of dromos, a complex external corridor built from large blocks, while all the rest of the monument is carved into the rock: the main entrance room (ca. 12 x 4 m) and an irregular route (100 m ca.) consisting of 35 rooms. A second entrance was added in the vicinity of room 17. All the rooms are circular in plan and vary in diameter from 1.5 to 3 m and height from 1.6 to 1.8 m, have concave floors and walls curve slightly up to the ceiling, which is perfectly flat.

The Hypogeum had different uses interspersed with periods of neglect. Its construction spanned from the Late Copper Age (ca. 2700-2200 BC) to the Early and Middle Bronze Age (ca. 2200-1250 BC) and was used until the final collapse of the entrance (ca. 1050 AD). It was initially used as a burial site, later becoming a ritual area to honor ancestors, and finally partially reoccupied as a cemetery and an industrial and stockage area or an animal shelter.

Notwithstanding its monumentality, after its identification in the 1970s by Lorenzo Guzzardi [7] the Hypogeum did not undergo systematic investigation until 2013, when archaeological research recommenced under the direction of P. Militello of the University of Catania [6][8] and, outside the Hypogeum, under the direction of S. Scerra and A.M. Sammito of the Soprintendenza BB.CC.AA. Ragusa [9].

During the archaeological research activity, among the problems of a practical nature, the researchers encountered some difficulties in surveys related to the presence of water in some rooms like the main entrance and the rooms from numbers 1 to 5 [10] [11]. Nowadays the Hypogeum presents significant problems of waterlogging, which are more intense during violent floodings, such as those that occurred in 2017 and 2018. Although the preliminary archaeological excavation activities were concentrated on rooms not visibly subject to periodic flooding (nn. 1, 13, 17, 24, 26, 29, 30, 34, 35), in many cases the stratigraphy appeared partially altered not only by human activity but also by water infiltrations [8]. Therefore, sometime in the past, the presence of water may have affected a part of the Hypogeum, as well as the presence of a drain dug in the floor level of the main entrance room of the Hypogeum seems to confirm. It was probably functional to the outflow of water, demonstrating that already in the initial phase of use of this monument in the Late Copper Age [9], in this area of the Hypogeum a solution to the problem of periodic floods had to be sought.

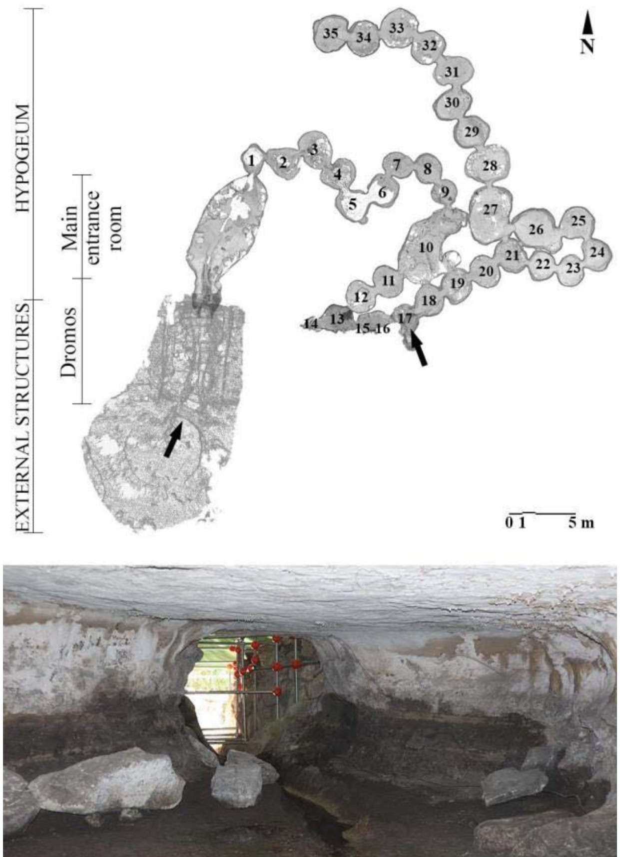

Fig. 1. On the top, Calaforno Hypogeum top view by laser scanner digital survey (2022); on the bottom, the main entrance of the Hypogeum with the drain functional to the water flow.

III. METHODOLOGY

In the view of the situation described above, the morphological characteristics of the Hypogeum required a multidisciplinary collaboration. Indeed, an interdisciplinary working team is essential to investigate the different research topics discussed in this paper and, in particular, to assess the potential hydraulic risk of the sites, and preserve heritage for the future by individuating the optimal mitigation measures.

The disciplines involved belong to the archaeological and engineering fields. The archaeologist analyzed the terrain stratigraphy to determine the historical use of Hypogeum. Moreover, those studies allow understanding of the chronological evolution, which leads to the current geomorphological shape of the terrain. However, the complex geometric characteristics of the site required the use of a laser scanner to solve the problems associated with traditional surveying techniques because of the very narrow interior spaces.

The application of digital survey techniques with mobile and terrestrial laser scanners allows us to document and analyze the complex spatiality of the Hypogeum. Moreover, a three-dimensional model is obtained to monitor archaeological sites subject to geological and hydraulic risk. In a GIS environment, by realizing a Digital Terrain Model (DTM), the main direction of the water inside the archaeological area is studied. Furthermore, the zone where water could accumulate is determined.

The proposed methodology aims to investigate the reasons for the current presence of water backwater in the interior rooms through an analysis of water outflows in the Hypogeum. The methodological proposal could be summarized in the following stages: 1) archaeological investigation of the site; 2) digital survey and 3D modelling; 3) DTM and GeoTIFF creation; 4) water flow direction analysis.

IV. DIGITAL SURVEY TECHNIQUES FOR THE CREATION OF THE HYPOGEUM DIGITAL TERRAIN MODEL

Digital survey techniques

The use of digital surveying technologies for metric acquisition, such as laser scanning, now makes it possible to obtain highly accurate three-dimensional models, which are especially useful in underground sites that present a complex configuration, characterised by narrow spaces and lack of light. For the Hypogeum survey, different types of laser scanners have been used and tested [12] [13] [14] [15]:

- the Leica Geosystem's P30 terrestrial laser scanner (scan rate: 1 million pts/sec, accuracy: 3mm at 50m; 6mm at 100m, ranges: up to 270 m, size: 238mm × 358mm × 395mm, weight: 12.25 kg), which produced a highly accurate point cloud of the interior rooms of the Hypogeum (about 230 million points);
- the Leica Geosystem's BLK360 Imaging Laser Scanner (scan rate: 360.000 pts/sec, accuracy: 6mm at 10m / 8mm at 20m, ranges: up to 60 m, size: H 165mm,

D 100mm, weight: 1 kg) for the survey of the dromos and the external structures of the Hypogeum;
- the Leica Geosystem's BLK2GO mobile laser scanner (scan rate: 420,000 pts/sec, ranges: up to 25 m, size: H 279mm, D 80mm, weight: 775 g), which generated at high speed a less detailed point cloud of of all interior rooms of the Hypogeum (about 4,8 million point).

Measuring six geodetic ground control points in the open-air area near the two entrances using the Leica GS18 GNSS-RTK allows us to georeference the point cloud (geographical coordinate system: WGS84, 33N). Integrating the laser scanner results with the georeferenced points, we were able to build the DTM of the Hypogeum ground surface.

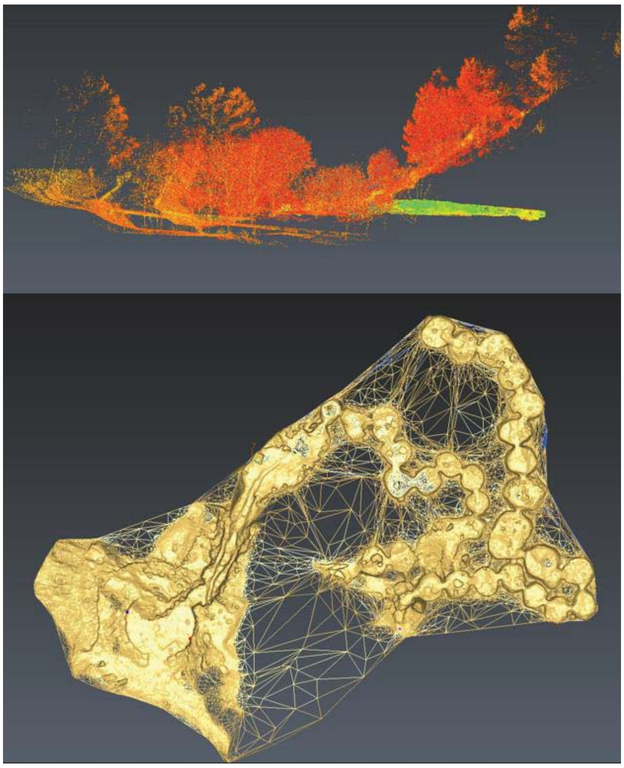

Fig. 2. On the top, point cloud seen from the east; on the bottom, poligonal model of the hypogeum's ground plan.

From point cloud to Digital Terrain Model

For the DTM of the Hypogeum underground and the external access areas, it was decided to use the point cloud obtained from the integration of the results of the three laser scanner adopted for the digital survey, as it presents not only the internal but also the external access areas to the Hypogeum. Figure 2 shows the final point cloud seen from the east, where the relation between the terrain orography and the underground part of the Hypogeum can be seen. Using Leica Geosystem's 3DR software, it was possible to create the polygonal model of the hypogeum's ground plan, setting the parameters of maximum ground slope, mesh detail level and output type. This made it possible to automatically remove the top of the interior rooms, external vegetation and particularly noisy points (Fig. 2).

For the later water flow direction analysis to be conducted in a Geographic Information Systems (GIS) a Geotiff file of the area was used, obtained by CloudCompare open-source software. The digital survey allowed us to obtain a Digital Terrain Model (DTM) with different soil resolutions, specifically, 1,00 meters, 0,5 meters, and 0,2 meters (Fig. 3).

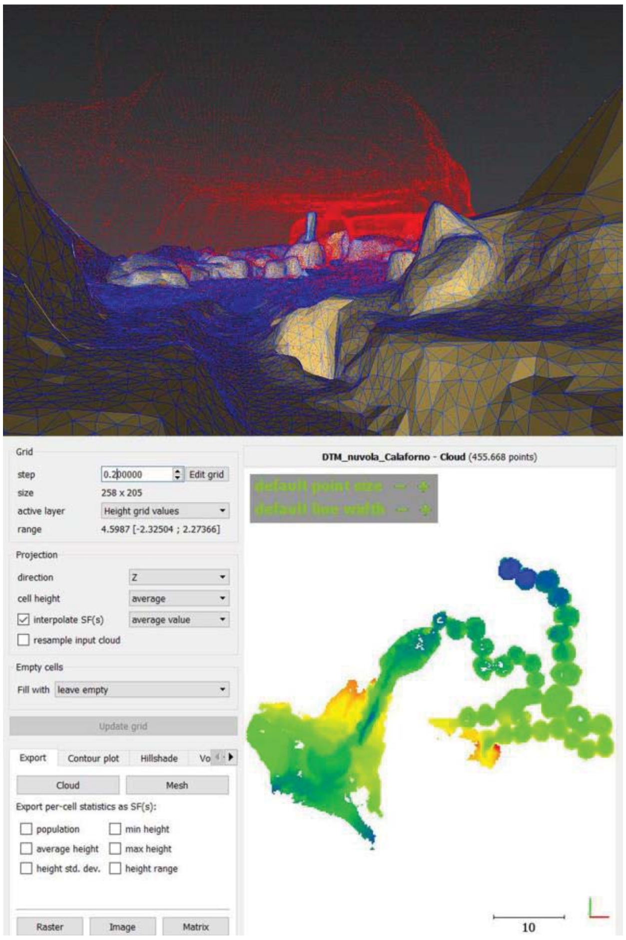

Fig. 3. On the top, in blue/yellow the DTM obtained by the point cloud of the Hypogeum (in red); on the bottom, the Geotiff settings interface in CloudCompare software.

V. RESULTS

The Digital Terrain Model (DTM) obtained is studied in a Geographic Information Systems (GIS) environment, as shown in Fig.4.

Analyzing the DTMs in a Geographic Information Systems (GIS) environment, the flow directions and the accumulation flow were determined in the whole basin and inside the Hypogeum. Those features enable the individuation of the minimum soil level.

Considering a 300 years return time value, the numerical simulation performed on the whole basin [10] showed that the water rods rise to 2.5 m, reaching the hypogeum area. Moreover, the flow directions and the accumulation flow determined allowed us to reconstruct the soil profile inside the Hypogeum by joining these lowest points. The analysis results are shown in Fig.5.

Fig. 4. Calaforno Hypogeum localization in GIS environment.

The terrain profile in Fig.5-A showed that, before the Hypogeum entrance, there is a little laver (between points B and C). Then, there is a downward slope toward the inner part of the Hypogeum (point D, which corresponds to room 5). Point F is the second entrance of the Hypogeum. From point B to point D the terrain slope is about 3,56 %; from point F to point D, the terrain slope is about 7,52 %. It is immediately noticed that, in the West rooms of Hypogeum, the water that goes inside from one of the two entrances, or maybe by infiltration from the terrain above, cannot get out. A similar situation exists on the East part of the Hypogeum (Fig. 5-B). The slope of the ground tends to the inner part of the monument. The slope between point B to point H is about 7,44%.

These preliminary pieces of information will be used to implement a suitable methodology to mitigate the flood risk inside the Hypogeum and to make it more accessible.

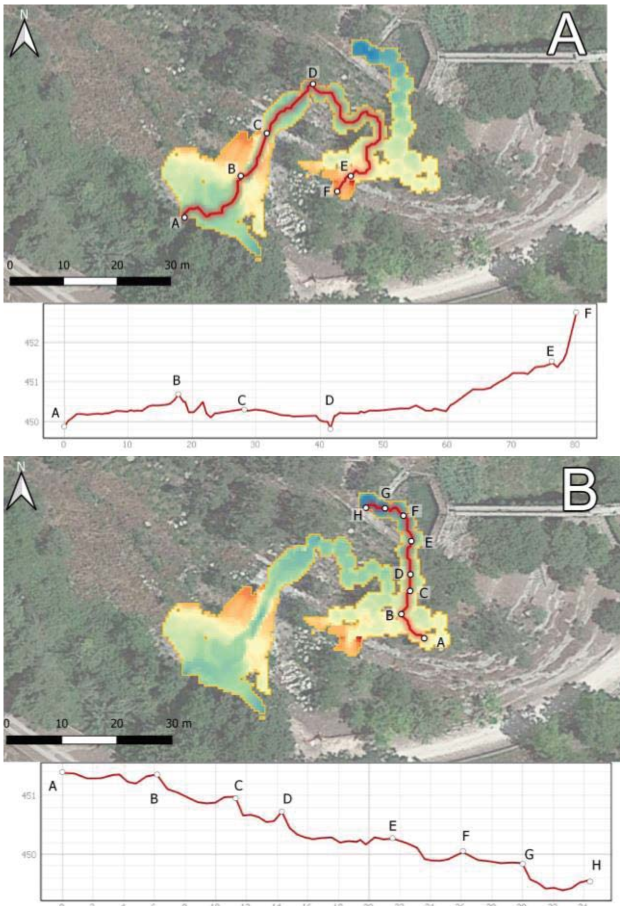

Fig. 5. The planimetric view of the lowest points inside the Hypogeum and the altimetric profile of the terrain.

VI. CONCLUSIONS

The research conducted on the Hypogeum revealed the importance of an interdisciplinary methodological approach on a site of high archaeological relevance, of difficult access and with flooding problems that require accurate investigations.

To mitigate the flood risk, it is essential to accurately know the internal geometric configuration and understand how the water goes inside the Hypogeum. Moreover, from the archaeological point of view, to highlight differences between the actual and the past waterlogging conditions.

The analyses were done to help in understanding some aspects until now observed by archaeologists, such as the constant presence of stagnant water in the first part of the Hypogeum. Considering the above, the downward slope towards room 5 can explain the drain dug in the main entrance room, excavated to facilitate the water outflow.

The use of digital surveying technologies made it possible to investigate the perfect morphology of the interior and exterior environments of the Hypogeum and to obtain a georeferenced three-dimensional model of the entire site useful for current and future archaeological and hydraulic investigations.

The previous analyses [10] proved that only considering a 300 years return time value, the water can reach the Hypogeum entrance and flow inside it.
Archaeological research highlighted the existence of soil layers altered by water infiltrations in many rooms, which demonstrates how, sometime in the past, the presence of water may have affected the entire Hypogeum or at least a good part of it. By observing the surrounding area, it was possible to notice that Calaforno is located under an accumulation reservoir used to power an old mill. This element, along with the terrain configuration and the intense vegetation, allows us to assume that the water table is over the Hypogeum. It means that the water goes inside by infiltration. However, nowadays it is extremely complicated to determine the past water table conditions. Indeed, the water table level could be influenced by different vegetation densities. For example, if this area had been arid in the ancient period, the water table would have been lower than the Calaforno area, this monument would have been dry, and it would have been used for burial functions without water infiltration problems.
In the light of the analyses presented, future works will aim to plan an optimal pumping system that will ensure a dry condition inside the Calaforno area.

VII. AUTHOR CONTRIBUTIONS

Introduction, Methodology, Conclusions: G.D., M.F., V.P.; The Hypogeum of Calaforno: M.F.; Digital survey techniques for the creation of the Hypogeum Digital Terrain Model: *Digital survey techniques:* G.D. and *From point cloud to Digital Terrain Model*: G.D., G.R.; Results: V.P.
Supervisors: M.G., P.M.M., R.E.M.

VIII. ACKNOWLEDGEMENTS

This work has been partially funded by the project “An Early Warning System for cultural heritage. eWAS -” (PNR 2015–2020, cod. ARS01_00926 - PON 2014–2020) and by the project VARIO and project “Storage: dai dati al Web”, funded by the program Pia.Ce.Ri. of the University of Catania.

REFERENCES

[1]D.R.Dassanayake, A.Burzel, H.Oumeraci, “Evaluation of cultural losses, Xtrem RisK Progress Report. Leichtweiß-Institute for Hydraulic Engineering and Water Resources”, Technische Universität Braunschweig, 2012, pp.1-44.
[2]M.Murthy, “Heritage and resilience. Issues and opportunities for reducing disaster risks” UNISDR, 2013.
[3]I.C.Nicu, “Natural Hazards vs Cultural Heritage Encyclopedia of Global Archaeology”, Springer, New York, 2019, pp.1-12.
[4]R.E.Musumeci, E.Foti, D.Li Rosi, M.Sanfilippo, L.M.Stancanelli, C.Iuppa, V.Sapienza, W.Yang, M.Cantarero, D.Patanè, “Debris-flow hazard assessment at the archaeological UNESCO world heritage site of Villa Romana del Casale (Sicily, Italy)”, International Journal of Disaster Risk Reduction, vol.64, October 2021, 102509.
[5]M.Figuera, “Patrimonio diffuso, comunità locali. La “riscoperta”: per una ipotesi di valorizzazione innovativa dell’ipogeo di Calaforno”, Archivio Storico per la Sicilia Orientale, 2018(1), pp.5-23.
[6]P.M.Militello, “Calaforno I. Le indagini 2013-2017”, Archaeopress, Oxford, 2021.
[7]L.Guzzardi, “Un ipogeo preistorico a Calaforno e il suo contesto topografico”, Sicilia Archeologica, No.42, 1980, pp.67-94.
[8]P.M.Militello, G.Di Stefano, “Calaforno (Giarratana, Prov. di Ragusa). Indagini 2013-2014”, Notiziario di Preistoria e Protostoria, 2(II), 2015, pp.63-65.
[9]P.M.Militello, A.M.Sammito, S.Scerra, “Calaforno (Giarratana, RG). Notiziario di Preistoria e Protostoria”, 5(II), 2018, pp.90- 93.
[10]G.D’Agostino, M.Figuera, V.Pennisi, G.Russo, M.Sanfilippo, P.M.Militello, R.E.Musumeci, “Hydraulic risk assessment in archaeological sites supported by an integrated digital survey – CFD (Computational Fluid Dynamics) monitoring approach”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-M-1-2021, 2021, pp.155–163.
[11]M.Figuera, “Sicilian Landscape and A-structural Architecture from Survey to Virtual Reconstruction: the case of the Calaforno Hypogeum”. In D. Panagiotopoulos & P.M. Militello (Eds.), Modelling Archaeological Landscapes, in press.
[12]P.Clini, R.Nespeca, R.Angeloni, R.Mammoli, “The integrated survey of narrow spaces and underground architecture: the case study of Campana Cave bas-reliefs”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W9, 2019, pp.277–282.
[13]D.Ebolese, M.Lo Brutto, G.Dardanelli, “The integrated 3D survey for underground archeological environment”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W9, 2019, pp.311–317.
[14]G.D’Agostino, M.Figuera, G.Russo, M.Galizia, P.M.Militello, “Integrated 3D survey for the documentation and visualization of a rock-cut underground built heritage”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-2/W1-2022, 2022, pp.167-174.
[15]D.Giordan, D.Godone, M.Baldo, M.Piras, N.Grasso, R.Zerbetto, “Survey Solutions for 3D Acquisition and Representation of Artificial and Natural Caves” Appl. Sci., 11, 2022, 6482.