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Integrated survey for the modeling of complex environments. *La Grotta di San Michele Arcangelo a Olevano sul Tusciano, Salerno.*

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***Abstract* – The possibility of integrating digital technologies facilitates the documentation and, consequently, the management of complex environments such as the Hypogean Heritage. The *Grotta di San Michele Arcangelo*, a natural cave located in the municipality of Olevano sul Tusciano, in the province of Salerno, is being selected as a case study to test the integration of different digital surveying technologies. Through the combined use of SLAM-based techniques, used for the acquisition of the interior space, and LiDAR-UAV techniques, for the exterior, an integrated point cloud was obtained from which accurate geometric information could be extracted, necessary for three-dimensional modeling of the analysed environment. The purpose was to provide the academic community with updated multidimensional information of the hypogean scenarios, defining good practices for their application. The database becomes an essential tool for the understanding, monitoring and management of these complex environments and also lends itself to actions of valorisation and promotion of virtual accessibility to this heritage.**

Keywords: HYPOGEAN HERITAGE, REMOTE SENSING, HBIM, CONSERVATION

I. INTRODUCTION

The combination of art, history and architecture that characterizes the religious complex composed of chapels dating back to the X and XI centuries, built in the particular natural environment of the interior of the *Grotta di San Michele di Arcangelo* in Olevano sul Tusciano, in the province of Salerno, makes it a unique heritage in the territory of southern Italy. Unfortunately, despite these qualities, a strong absence of territorial, architectural and environmental documentation has been evidenced, which often limits its proper management, monitoring and enhancement [1].

These cavities in the subterranean are accessible to human exploration [2], but their mapping is often an arduous task, conditioned by complex environmental factors. Factors such as poor lighting, uneven surfaces, inaccessible areas, narrow pathways and articulated routes represent a challenge for the documentation and digitisation of these underground environments.

In Italy, the level of interest of these sites varies considerably from one region to another, generally depending on the diffusion and the importance or richness of the cavities. In the world the situation is different, the International Union of Geological Sciences (IUGS/UNESCO) devotes an increasing focus to the exploration of archaeological sites due to the urgent need to deepen their knowledge, both on a territorial and urban scale. Currently, national and international research on Cultural Heritage is concerned with data acquisition, monitoring and management, using new digital information and communication technologies. Numerous projects propose interesting visualization and digitization experiments, such as Athena, OpenHeritage, E-RHIS and even interactive ones such as Emotive, Inception, Arches and Time Machine [3–9]. These investigations, however, involve a heritage from which hypogean realities are often excluded.

Starting from these premises and through a multidisciplinary approach, the aim is to investigate the hypogean heritage with its multiple characteristics, and thus satisfy the common need to give value to places that are little known but which represent, for the territories that preserve them, a strong element of identity [10].

The *Grotta di San Michele Arcangelo*, in Olevano sul Tusciano, province of Salerno, Italy, is an hypogean heritage that includes religious structures built in a natural cave (Fig. 1). It was born as a place of worship and pilgrimage center in the early Middle Ages. The sanctuary is one of the best preserved early medieval settlements in Europe and one of the earliest dated records of it dates to the 9th century AD, as it was a stop on the pilgrimage routes of monks traveling to the Holy Land.

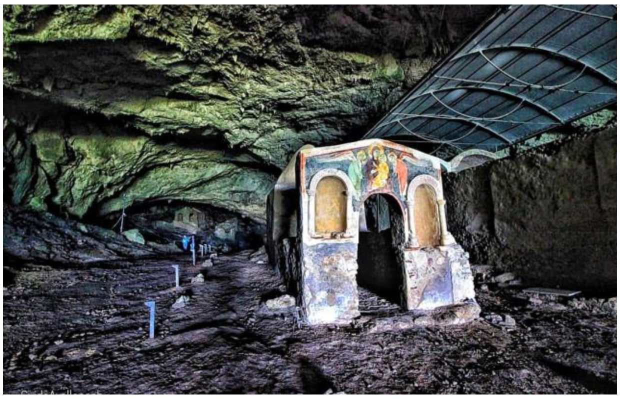

Fig. 1 Image of the Grotta di San Michele Arcangelo, Olevano sul Tusciano. Photo by Guido Avallone.

The complex includes two distinct functional spaces: one external, consisting of the remains of a monastery and defensive walls; the other, the sanctuary itself, which is located inside the *Grotta*, characterized by frescoes of outstanding artistic value. It consists of five buildings of historical and architectural relevance because they bring together languages that reveal different cultural traditions, called *martyrion*; there are also a basilica with a single room with frescoes from the Lombard period, two sanctuaries with a courtyard, a church and an oratory. These small architectures mark out a devotional path that extends inside the *Grotta* for about 900 meters.

The *Grotta di San Michele Arcangelo*, that still today remains the destination of numerous peregrinations, listed by the World Monuments Fund as one of the hundred most important monuments in the world; it preserves its historical and artistic continuity between the past and the present, a rare treasure of the Middle Ages, worthy of being known, researched and safeguarded.

II. METHODOLOGY

The University of Salerno, together with the *Parco dei Monti Picentini Authority* and the *Municipality of Olevano*, developed a project of relevant national interest. The main objectives of the research are to optimise the management processes of the hypogean heritage through the use of digital information systems, as well as to ensure universal access to it. Thus, visual content was generated for greater dissemination of the heritage, not only aimed at the academic-scientific community, but also to the broad public through the creation of open access databases. The research developed a three-dimensional digitization methodology, considered a common practice for documentation, visualization and conservation purposes. Although there is a wide variety of data acquisition methodologies, according to the characteristics of the environment to be digitized, or even the output to be obtained, the digitization method used will depend on the type of result and the quality of the data obtained [11]. There are limitations derived from geological, geotechnical, static and environmental conditions that do not allow the application of traditional approaches; the complete descriptive geometry of this heritage is the first step to obtain knowledge and provide a reliable 3D image of the underground environments [12–14].

A data integration strategy has been implemented: for the internal recognition the laser scanner with SLAM (Simultaneous Localization and Mapping) technology has been used and for the external recognition the UAV LIDAR (Light Detection and Ranging) system. Thanks to them, it has been possible to obtain a complete point cloud of the whole *Grotta*.

Through a portable and lightweight laser scanning system, the GeoSLAM ZEB Horizon is characterized by its usability in indoor spaces, tunnels and underground environments, as it does not require GNSS signal and light for its operation. For outdoor environment data acquisition, a DJI M300 professional UAV quadcopter, equipped with GNSS RTK receiver, was used as a platform to mount the DJI Zenmuse L1.

The main features of both result in the post-processing phase in the integration in a point cloud, as shown in Fig. 2, a non-invasive digital acquisition of metric-formal data capable of being used as a source of information for the registration and cataloging of the hypogean heritage [10,15].

From the integrated point cloud, an HBIM model was created, which stands for Historic Building Information Modeling, a methodology applied to existing buildings. The topographic survey and its subsequent digital restitution are the first step in the implementation of a 3D data and information management system. In this detailed 3D models all components are intelligent and parametric objects with well-defined semantics, whereby objects representing natural and architectural elements are built from historical data. These elements, information about the building, its components and all its features, including details, are accurately recorded in a point cloud that, once modeled, can be updated, replaced and implemented over time.

Fig. 2 Integrated point cloud of the Grotta di San Michele Arcangelo. Author's elaboration.

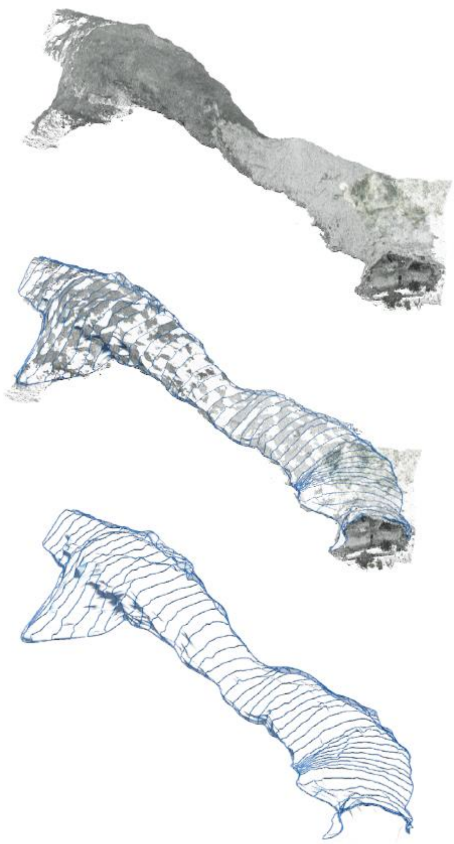

Fig. 3 HBIM modeling process of the Grotta di San Michele Arcangelo, Olevano sul Tusciano, using Autodesk Revit software. Santiago Fernandez's elaboration

The HBIM methodology applied to built heritage and the natural environment simplifies collaboration and coordination between professionals, maintenance planning, ensuring efficient management of heterogeneous data and monitoring of the state of conservation over time [16].
The complex environment was the subject of study, analysis and digitization. On one hand, the built heritage was modeled using the HBIM strategy, as shown in Fig. 3; on the other hand, the natural heritage, the inner surface of the *Grotta*, was modeled by designing a new workflow for complex environments interoperating in different software interfaces (Fig. 4). Using Autodesk Revit software, the interior point cloud, imported through Recap, was sectioned every four meters, thus generating cross sections in the *Grotta*, from which the natural profile was copied in each section. Then, selecting all the profiles created, a three-dimensional surface was generated. Using 3DStudio Max software, importing the geometry in OBJ format, it was possible to texture and apply various filters achieving similarity with the reality of the *Grotta*, placing elements such as rocks and taking its three-dimensionality to its highest expression.

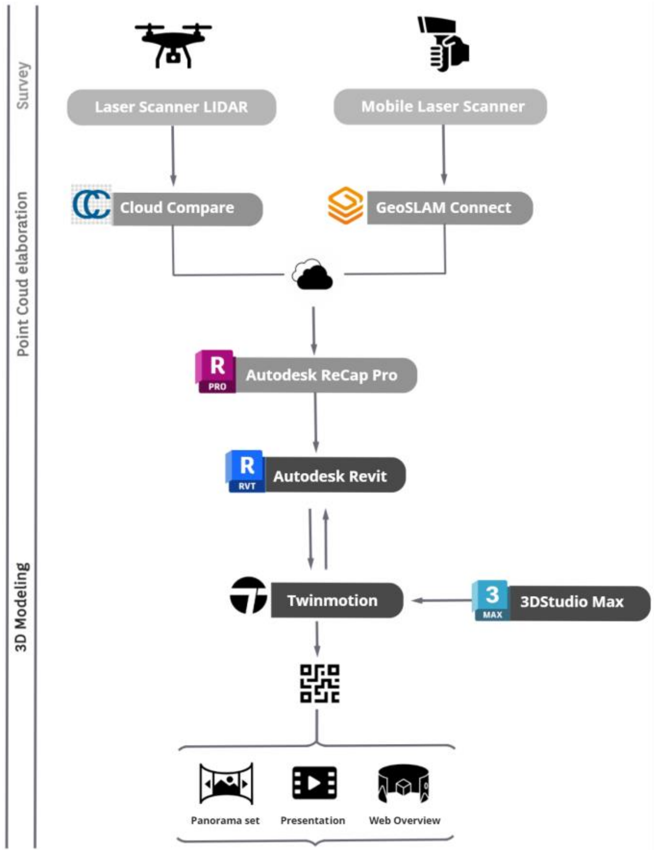

Fig. 4 Workflow: Interoperability between different interfaces. Author's elaboration

Once RVT geometric modeling was completed, the accuracy control was performed, analyzing the deviation of the respective surfaces from the point cloud. Two different methodologies were used for this purpose, one for the modeling of the built heritage, through an Autodesk plugin, Point Layout, establishing a Level of Accuracy (LOA) 20, which indicates results on a color scale with geometric displacements between 0.015 and 0.05 meters, and another methodology for the natural heritage. In the case of the latter, Cloud Compare software was used with the same comparison parameters (Fig. 5). After verifying the accuracy of the HBIM model, an add-in called Datasmith Exporter produced by Epic Games was used. This add-in features a functionality called Direct Link that allows real-time synchronization of the model generated in Revit with the Twinmotion visualization tool, a 3D immersive software that produces high quality images, panoramas and standard or 360° VR videos. Images were generated from various points of the *Grotta* in which it is possible to identify the internal constructions and the morphology of the natural heritage. In addition, it was possible to create a video showing the interior of the *Grotta*, generating a virtual tour, where the user has the possibility to use commands of movements and rotation of the camera.

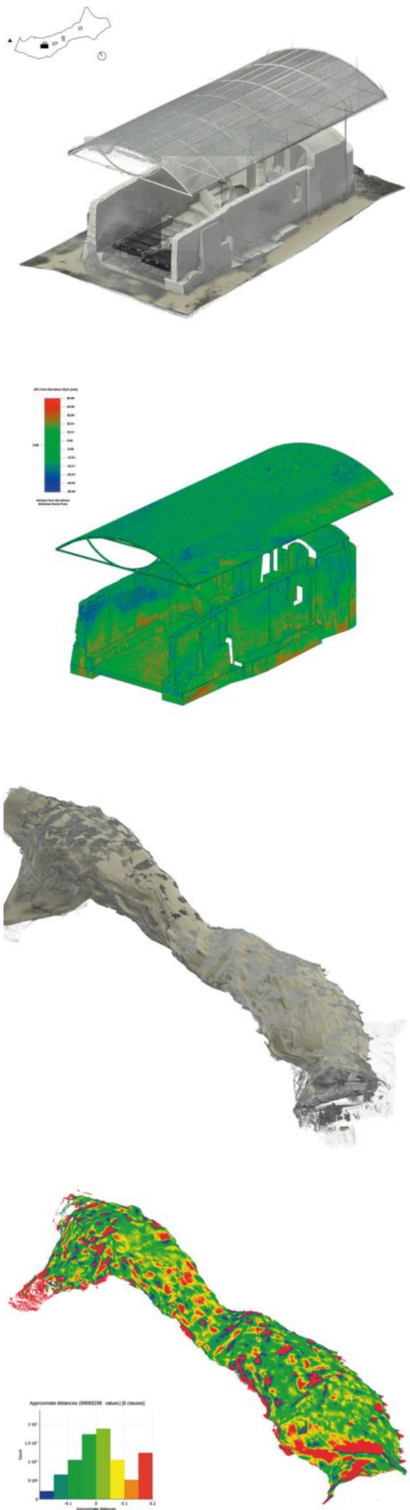

Fig. 5. Analysis of the accuracy of the main chapel, obtained by the Point Layout plugin, and of the inner surface of the cave, obtained by Cloudcompare. Santiago Fernandez's elaboration

The conversion of the data into semantic models enhances the digital simulations and offers an alternative means of access to the heritage, allowing a wider audience of visitors and tourists to experience these spaces, immersing themselves in the virtual environment and visit them remotely. This last possibility is also offered to the so-called weak users, with difficulties to physically access these spaces, and even allows to give visibility to heritage in an international scope, widening the audience and attracting new users; in this way, it will be possible to preserve cultural memory, opening new horizons in the field of digital representation (Fig. 6).

III. CONCLUSIONS

In recent times, the impact of new information and communication technologies in sectors such as architecture, engineering and construction (AEC) has provided tools that have changed the structure of the design, production, management and monitoring of buildings. There are also many potential applications and implications of the use of digital technologies in reference to the documentation and dissemination of cultural heritage, such as the underground sites, less known to the general public because of their inaccessibility.

The idea of structuring semantic digital models, which allow processing and correlating different types of data [17], offers new perspectives to the scientific community and opens new horizons in the process of storing data, to be able to under certain conditions (such as terrain and rock stability, topsoil and subsoil, accessibility, etc.) transmit these data in interoperable 3D models [18], allowing technicians and experts to decode and fully understand the investigated heritage, provide specific interventions for safety, manage information flows in an integrated and updatable way and thus ensure a concrete use of these spaces.

The potentialities in the implementation of data in semantic models, that fully exploit the visual power of digital simulations [19], offers a possibility of alternative access to the hypogean heritage. This allows a wider audience of visitors to remotely experience these spaces [20], through the use of appropriate systems able to geolocate the heritage and everything related to it. Through the development of interactive maps, the user can access multiple information, disseminated by digital tools [21], making the underground heritage accessible to all, in situ or remotely [22], which means that many sites today little known, are included in broader tourist circuits, defined as systems of goods and services necessary to satisfy needs and interests of an economic, infrastructural, cultural and social nature [23].

HBIM technology makes it possible to create and periodically update the information database on the state of conservation of the property, which facilitates its management over time. The usBIM platform facilitates the consultation, transmission, and management of the state of conservation, the drafting of degradation sheets and the definition of a protocol for each restoration intervention.

Fig. 6. Render of the Grotta di San Michele Arcangelo, Olevano sul Tusciano. Santiago Fernandez's elaboration.

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