Rapid Speleological Survey Procedures for Hermitages. The Cave of the Angel in Montesano (SA)

Valeria Cera

Dept. of Architecture, University of Naples Federico II, Naples, Italy – valeria.cera@unina.it

Keywords: fast survey, rapid mapping, solid state Lidar, micaelic hermitage, cave survey.

Abstract

The paper presents an experiment having the objective of verifying the use of low-cost sensors such as solid-state Lidar embedded in a smartphone for cave surveying. The case study is a micaelic hermitage in *Montesano sulla Marcellana* (Italy) and is part of a research that deals with the analysis and digitization of rupestrian architecture, especially, hermitages dedicated to the cult of St. Michael present in Campania (Italy). In order to evaluate the application potential of Lidar for cave surveying, comparisons were made between the results of different surveying campaigns performed both with traditional speleological techniques and by TLS sensors. The experimentation provides quantitative assessments of the possibility of using these new sensors that would make the acquisition steps even faster. In addition, the outcomes of the survey shed light on previously unknown aspects of the case study.

1. Introduction and State of Art

The survey of rupestrian architecture has always been a challenge for two main reasons. On the one hand, the conservation conditions in which cavities often occur and which can also pose a danger to the safety of the surveyor; on the other hand, the possibility of greater or lesser spatial movement. In fact, the latter motivation influences the availability and suitability of employing specific instruments for recording data, mainly metric. For these considerations, the presence of caves with complex geometry imposes the use of integrated surveying techniques, which make use of the processes and acquisition systems proper to speleology (Carnevali and Carpiceci, 2020).

In this framework, the survey of caves is conventionally attested on the use of traditional measuring instruments being the objective of such a survey the simple determination of the development of the caves under investigation (Yamaç and Tok, 2015).

More specifically, the traditional speleological survey technique is the so-called “tape-compass-clinometer”. The survey consists in a space polygonal chain witch each vertex represents a “station”, a physically identified reference point; each station must have a sightline to the next and the previous ones. From each station, the survey team measure the distance to the next station – taken with the tape, the direction – taken with the compass, and the inclination from the horizontal – taken with the clinometer, then the name “tape-compass-clinometer”, and manually recording the data on a field notebook. Additionally, the distances to the surrounding walls are also measured to obtain the cross-section dimensions: left, right, up, down data – LRUD. The survey teams also record additionally details, such as the shape of walls and the presence of significant features and phenomena. The plan and profile views of the space polygonal chain – the centerline – shows the main path thought of the cave. By adding the representation of the LRUD data to the line-plot is possible to depict the overall geometrical features of the cave. The plan and profile views are also improved by the additional data recorded during the survey and then artistically represented (Club Alpino Italiano, 2003). This procedure working well for serpent-like caves, namely when the path-along distances are significantly greater than the cross-section dimensions; in the presence of open spaces, the so-called “halls”, it is necessary to set one or more than one stations where it is possible to spot a certain number of points to describe the space geometry and for each target record the distance, direction and inclination. Through the year’s laser distance meters has replaced the tape and the personal digital assistant (PDA) devices has replaced the field notebook. The “paperless systems” are widely employed by caving surveyors all over the world. It is an integrated electronic cave-surveying tool consists of combined laser distance meter/compass/clinometer and a PDA to store and manage the data acquired directly from the measurement instrument, typically by Bluetooth connection. The PDA is equipped with a software that permits to view the data acquired, sketch on to it and adding additional information’s. The combined laser distance meter/compass/clinometer is obtained by modifying a particular model of commercial available laser distance meter of a famous brand: Beet Heeb develops the so-called DistoX and its evolution, DistoX2 (Heeb, 2014, 2009).

During the last decade, more advanced surveying techniques and instruments were successfully applied (Promneewat and Taksavasu. 2024). Indeed, there is no absence of cases where it was decided to employ more advanced sensors, such as active optical sensors of the TLS *Terrestrial Laser Scanner* type. These are situations in which the dimensions of the cavities were to allow the movement and functionality of this type of equipment (De Waele et al., 2018; Carpiceci et al., 2015). Clearly, the use of laser scanners also turns out to be closely linked to the value of the caves surveyed, which are often connoted not only by remarkable speleothems but also by noteworthy decorative apparatus or sculptural elements (basins, tombs, altars, etc.). Then, with the advent of increasingly high-performance sensors and computational algorithms on the market, more accurate but at the same time capable of acquiring data in a short time (e.g., Lidar with SLAM), there has been a renewed interest in experimenting with digitizing caves (Farella, 2016; Rodríguez-Gonzálvez et al., 2015).

Several experiences documented in the literature report applications on the use of both range-based and image-based sensors in this sector, evaluating their performance and metric accuracy in comparative studies (Spadaro et al., 2024; Del Vecchio et al., 2017). In addition, interesting developments are also emerging in the design of purpose-built acquisition systems for digitizing narrow spaces where the issue of operator

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-2-W8-2024-85-2024

accessibility and mobility is crucial (Elalailyi et al., 2024; Perfetti et al., 2024). What the experiments that define the state of the art have in common is the search for compact but accurate instruments that can capture the geometric specificities of excavated environments, facilitating metric surveying operations even in caving. It is necessary to consider, in fact, that the highly costly devices can be out of reach of the majority of caving clubs, often non-profit enthusiast organizations. Moreover, caves are unwelcoming places where it can be difficult to bring in such advanced and expensive instruments, especially in narrow and arduous passages. The stationing of the TLS can be impossible in vertical passages that require descend and ascend methods, frequently using the single rope technique. In such situations, the use of more maneuverable instruments like the DistoX2 permits to splay shots even with the surveyor suspended on the rope.

This paper is part of this field of investigation, describing an experiment conducted on the use of a low-cost, solid-state Lidar integrated on an iPhone 15 smartphone for the rapid speleological survey of sub-horizontal caves.

2. Aim of the work

The research presented here is part of the activities conducted under the Scientific Collaboration Agreement signed between the Urban/Eco Interdepartmental Research Center of the University of Naples Federico II and the Diocese of Teggiano-Policastro. This agreement has as its object a widespread analysis of the phenomenon of micaelic hermitism in Campania, with a focus on the specificities of cultic architectural expressions in caves.

The study of the hermitages dedicated to the Archangel, conducted within the framework of the Agreement, has in recent years concerned a variety of aspects of the relationship between religious devotion and its expression in rupestrian architecture, on which a considerable number of publications have reported (Cera and Origlia, 2024; Cera, 2023; Cera and Falcone, 2023; Cera, 2022; Cera, 2021; D’Agostino et al., 2020).

In this paper, the actions taken for the digitization of a case study characterized by the presence of a narrow cavity dug into the rock are outlined. The characteristics of such a cavity influenced the choice of data capture techniques and tools to be employed, facing aspects of speleological nature. As will be discussed in the next section, this is a sub-horizontal trending cave with extremely small dimensions; in particular, the entrance way and some passage points are little wider than a person of average body size. As a consequence, digitization could not make use of instrumentation now established in other contexts (e.g., a TLS or a dynamic SLAM Lidar) but resort to speleological practice. However, due to the geometric and dimensional characteristics, the traditional speleological surveying technique would have been not very expeditious as well as limited to recording the metric characteristics of a small number of points from which to derive the geometry of the cave. For this reason, the use of a low-cost Lidar, embedded in a mobile device, the iPhone 15, was used to digitize the cavity.

The reason for the choice lies in the intention to balance some important aspects in surveying practice: (i) rapidity of the surveying operations, an important factor when working in contexts that are not always safe for the operator's security, such as hermitages and caves; (ii) manageability of the acquisition instrument, which is fundamental in surveying areas of restricted dimensions where there is often no space except for the single, kneeling surveyor; (iii) cost-effectiveness of the acquisition tool, the cost parameter being an aspect that influences the feasibility and replicability of survey operations; (iv) accuracy of the metric datum, a founding issue in the practice of surveying, which should always be evaluated according to the digitized context and the purpose of the operation. In the present case, since it is a rupestrian architecture, the evaluation of the metric reliability of the survey acquired with the Lidar of a smartphone was conducted considering the specificity of the architecture studied. A hermitage, in fact, has a completely unique genesis: it is born as a cave i.e. a space that is configured as a void, a subtraction of volume. A process, therefore, completely opposite to architecture proper. As a result, the physical boundaries of the space whose shape and size are to be determined by surveying are not regular but natural surfaces such as rocky parts whose geometry is extremely complex. Assessing, therefore, the accuracy of measurement of such elements requires a certain degree of flexibility. It also, as will be discussed below, requires the use of comparative methods that take into consideration the specific nature of the architecture under consideration.

3. Case study: the hermitage of *San Michele* in Montesano sulla Marcellana, Italy

The case study is the hermitage of San Michele located in Montesano sulla Marcellana, a small town in the province of Salerno, Italy (Figure 1).

Known as the “Cave of the Angel,” the rock sanctuary stands in the locality of 'Eliceto,' at an elevation of about 709 m above sea level, a short distance from the Montesano thermal complex. The history of this site is very incomplete. It is believed that the cave was transformed into a place of devotion in connection with the presence of Italo-Greek monastic communities in the area. Montesano was, in fact, the site of a dependency of the Italo-Greek monastery of Santa Maria di Rofrano (Papaleo, 2020).

More generally, the settlement of Italo-Greek communities in the Diano Valley is recorded from the 10th century onward (Caffaro, 1996). Verisimilarly this could be the time of the implantation of the micaelic cult or at any rate of a revival of devotional practices related to it. However, the first certain evidence of use of the sanctuary at Montesano sulla Marcellana dates only to the late 17th century. In a report of the pastoral visit of 1687, the chapel is mentioned as the “church of S. Michele Arcangelo in Criptis,” erected by physicist Dr. D. Vincenzo Cestari. Similarly, in the documents of the 1718 pastoral visitation of Vicar Apostolic Solomon, it appears as Chapel “S. Michele Arcangelo in Cripta.”

Figure 1. Montesano Hermitage. Photos of the first area.

Finally, documents report its use not only as a *Michaelion* but also with a sepulchral function. Therefore, the Angel's Cave constitutes a site of considerable archaeological interest. Currently, however, the entrance is closed by a gate. In addition, the sanctuary, which is municipally owned, is in a state of neglect and degradation; in recent years it has literally been defaced by vandalistic hands.

https://doi.org/10.5194/isprs-archives-XLVIII-2-W8-2024-85-2024

Today, the rupestrian chapel is divided into two spaces: the first is aligned with the entrance, is marked by an upward staircase carved in the rocky bank that leads to a small area equipped with a small altar. The second space is located to the left of the entrance, is very large and is undercut with respect to the entrance elevation. In this area there are the remains of niches, chapels and altars, as well as some graffiti along the side walls. In this very area, along the left side flanking the access steps, there is a hypogean 'work', that is, a natural cavity with a geometric complexity typical of karst caves, with a sub-horizontal trend (Figure 2).

Figure 2. Sub-horizontal cavity entrance.

4. Methodology, data acquisition and processing

Digitization operations were divided into three phases, depending on the spatial characteristics of the rupestrian architecture: (i) acquisition via TLS of the metric and color information for the two largest environments; (ii) traditional speleological survey of the sub-horizontal cave, with tape, compass and clinometer; and (iii) expeditious speleological survey via iPhone Lidar, of the same sub-horizontal cave.

4.1 TLS survey

The survey of the hermitage was carried out with a phase modulation laser scanner, the FARO FOCUS3D S 120. Based on the spatial conformation of the Montesano architecture, no. 21 scans were made, distributed between the two main rooms into which the sanctuary is divided: no. 6 for the entrance room, no. 11 for the second room. An additional scan was carried out outside the entrance gate. Another no. 3 scans were recorded for some small cavities located laterally on the left side of the main room. The acquisition of range maps was set with a discretization step of 8 mm over 10 m and a triple repetition of the measurement. The stations were located according to a sequential path, from the main space to the lower space. In this second environment, the color data was not acquired as it was completely dark. In contrast, for the entrance room, both metric and color data were acquired: in fact, there is an uncovered upper portion in this area that allows effective entry of natural light. Final recording of individual scans was done in the proprietary software, FARO Scene, employing only natural references for roto-translation of range maps (Figure 3).

4.2 Traditional speleological survey

For the cavity located along the right side of the second environment of the hermitage, a speleological survey was carried out, at first of the traditional type (Figure 4).

The cave is a small karst cavity aligned along a plane with a certain dip angle, and a narrow, low ceiling hall morphology with three main elongations. Numerous speleothems enrich the cave, especially in the deepest parts, where can be found stalactites, stalagmites and columns, as well as some sinter pools. Some interconnected narrow passages are also present. The overall geometry is sub-horizontal, so no ropes are needed but only free climbing and crawling. A traditional tape-compass-clinometer survey has been carried out, with calibrated instruments. The survey team has located the first station at the entrance of cave, then, multiple stations have been fixed to define the main centerline throughout the cave. Anyway, the open space and complex morphology required numerous additional measures from each station, not only the LRUD dimensions, but also measurements of significant details. All the details were portrayed on drawings made in the cave to scale.

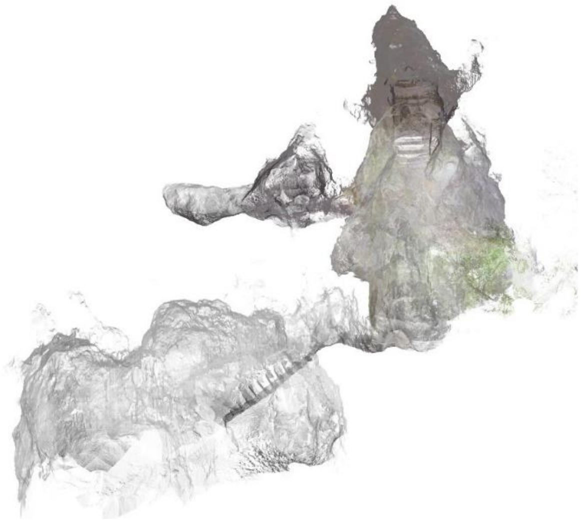

Figure 3. TLS point cloud.

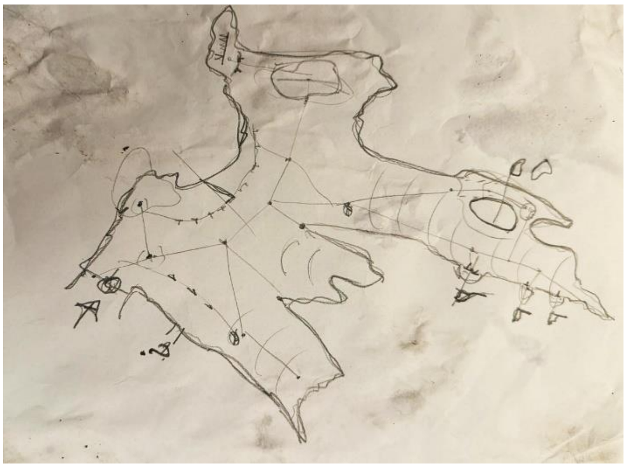

Figure 4. Field sketch.

4.3 Speleological rapid survey with a solid-state Lidar

For the same cave, the digitization process was also carried out using a Lidar integrated into a smartphone. Specifically, the cave was surveyed with the Flash Lidar - a solid-state Lidar - integrated into the iPhone 15 through the "3D Scanner" app. Given the complexity of the cave, the setting for the acquisition was set to a polygonal mesh with a discretization step of 40 mm.

Then, the operator walked through the entire cavity again, recording the information with the smartphone.
The path followed was clearly influenced by both the operator's possibility of movement and the maximum acquisition distance possible with the iPhone Lidar. The sensor, in fact, works well over maximum distances of 5 m. As it was a very dark environment, the recording was done by taking advantage of a wearable flashlight to promote minimal illumination. This fact is clearly to be taken into account when evaluating the final product acquired with the Lidar. In fact, as is well known, the mobile application allows the user to record information by taking advantage of the range-based sensor while taking photographs (Figure 5).

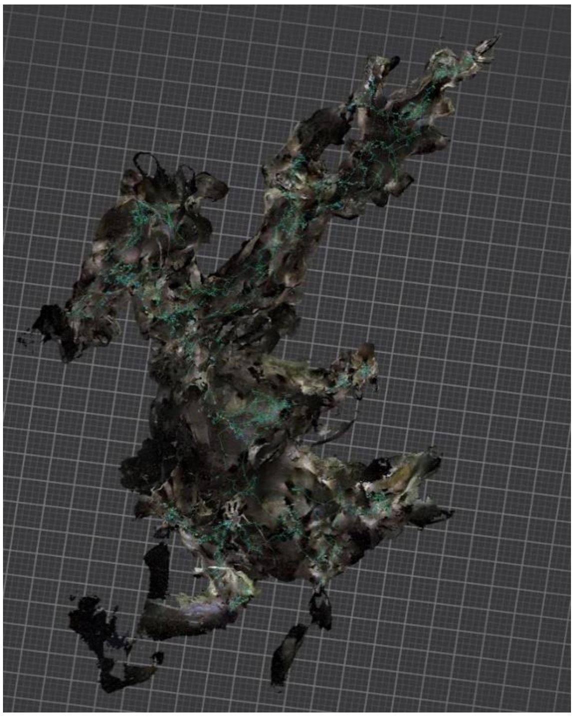

Figure 5. Trajectory of speleological survey with Lidar.

4.4 Some considerations for data integration

As outlined, the objective of this work is to evaluate the appropriateness of employing a low-cost sensor for expeditious speleological surveys of rupestrian architecture. To accomplish this objective, comparisons were made between the results of the aforementioned survey with the products obtained with the other two techniques. For this purpose, significant portions of the two main spaces of the hermitage were acquired with Lidar. This was necessary because it was not possible to employ TLS for digitizing the cavity, as it is quite narrow. Specifically, the following were acquired with the smartphone: 1. the portion of the stairs with its altar, located in the first room; 2. the sub-horizontal cave access wall, in the second room (Figure 6).

5. Analysis and discussion of results

The TLS survey of the Montesano hermitage returns the general conformation of the rupestrian architecture. And in fact, two-dimensional representations of a traditional type were drawn from the overall point cloud, from which an architecture articulated in two main rooms is evident. The first one - of access - has a West-East orientation; the second one is rotated with respect to the first one by about 90 degrees and has a walking height placed at -9.73m, with respect to the access. This height difference is overcome by 13 steps of varying heights, shaped into the rocky bank (Figure 7).

Figure 6. Altar. TLS point cloud (left), point cloud from Lidar (right).

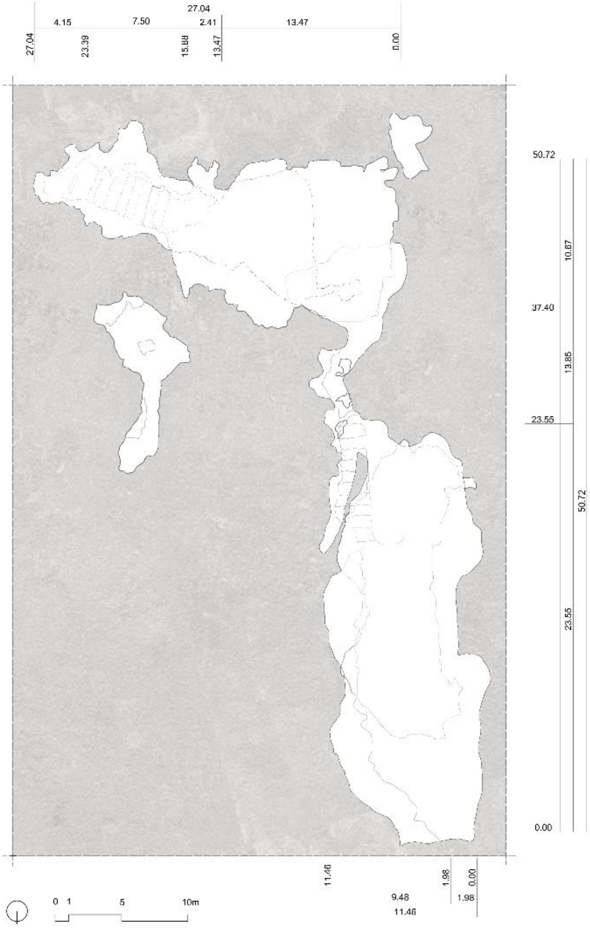

Figure 7. Plan of the hermitage obtained by TLS survey.

On the eastern wall of the second room, at an elevation of about +3.89m from the relative footing, is the access hole to the sub-horizontal cave. The graphic restitution of this cavity was made possible by the two speleological surveys carried out.

First, point clouds acquired and processed with the iPhone 15 Lidar, were exported in .e57 format. They appear significantly dense in information and with a fair quality of color data, considering what was highlighted in the survey phase (Figure 8).

Figure 8. Model details acquired with Lidar.

The point cloud of the cave was aligned with the TLS point cloud, taking advantage of areas in common. The alignment shows a development of the karst cavity that extends in a north-south direction, with a 21° dip angle (Figure 9).

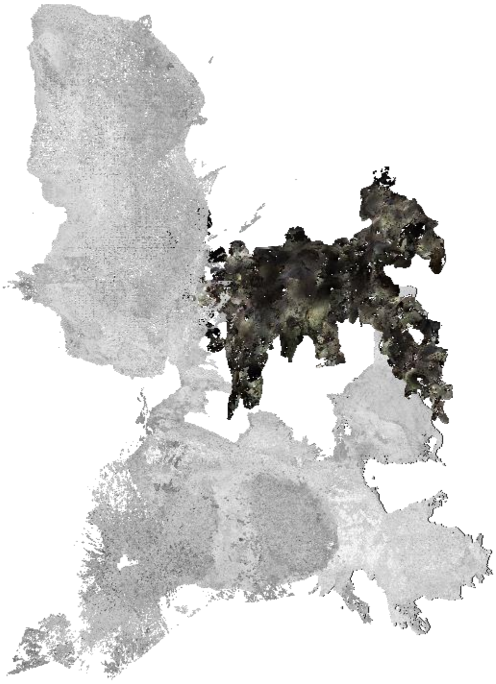

Figure 9. Final alignment of the two point clouds, TLS in gray scale, Lidar in RGB colors. Top view.

The positioning of the natural portion of the karst cavity debunked the popular belief, passed on throughout the centuries, according to which, the cave of the Angel and the former Saint Sophia Church are connected by a subterranean walkway; the full exploration of the cavity, and the survey, of course, show that this hypothetical connection does not exist now and never. In fact, there's no unexplored possible continuation towards the Church or collapses that could have instructed the passage, nor any sign of human activities of dub paths. Anyway, this kind of tales about the caves, especially for artificial cavities, are often orally tradition widespread.

Following this, in Cloud Compare, portions of the hermitage recorded with Lidar were compared with corresponding portions digitized via TLS. Metrically, the results collected are encouraged and support the validity of the approach. Assuming some control points in the area in common between the two surveys, the metric accuracy after bundle adjustment was evaluated. The RMSE values, in a local reference system, are 2.1 cm, 1.5 cm and 1.8 cm for X, Y, Z axes.

Since this is a complex architecture, however, the comparison was not limited to evaluating the accuracy of specific measurements. This is because it is necessary to consider the difficulty of recognizing points to be taken as control points when working on rock surfaces. Consequently, the comparison was also performed with an evaluation of the geometric deviation of larger portions of the acquired volume through Cloud-to-Cloud computation. The result is an almost complete fit between the two clouds, Lidar and TLS (Figure 10).

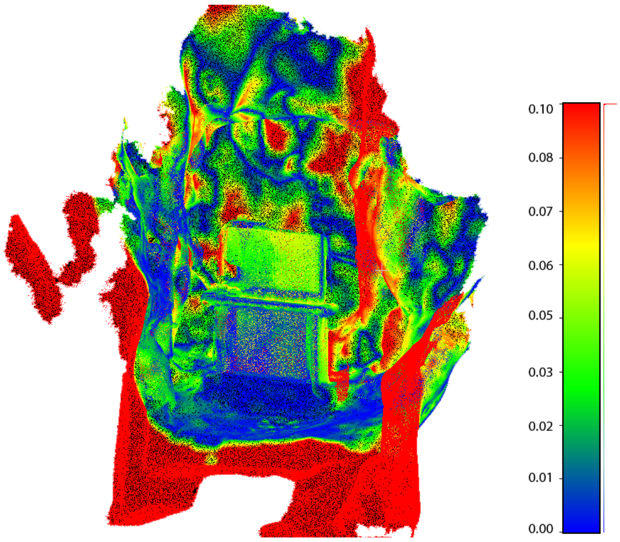

Figure 10. Geometric deviation between TLS and Lidar point clouds computed on a portion of the model related to the altar.

Finally, the cavity survey obtained with Lidar and the same one carried out with the conventional caving approach was compared (Figure 11).

The precision and accuracy of a speleological survey can be indicated by the UIS Mapping Grades, a system adopted by the *Union Internationale de Spéléologie* (International Union of Speleology), the international commission created to "encourage and facilitate the systematic collection and responsible use of the cave, karst and related data on an international basis". The current version of the grading system is the version 2 published on 2012-09-14. The system provides grades for the survey, the map details and additional qualifying suffixes (Table 1). The survey grades rages from grade 1 to 6, with the additional grade X for survey by theodolite or comparable means, and grades -1 and 0 for, respectively, no map available and ungraded survey, which are used for database purposes. The survey grades are assigned depending on the employed instruments and are based on the traditional speleological surveying technique by tape, compass and clinometer (Table 2). The survey grades are summarized in the following tables.

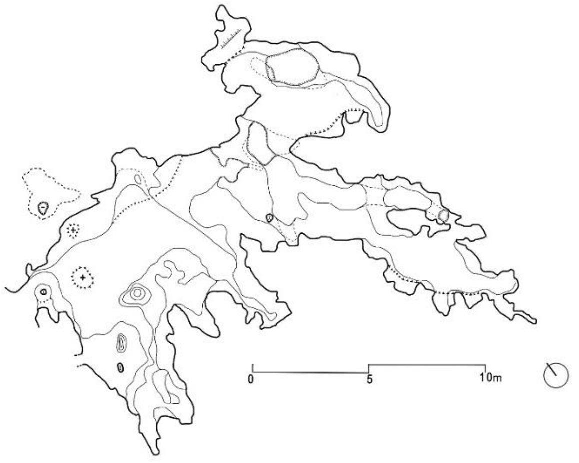

Figure 11. Cavity plan.

Grade	Precision			
	Lenght	Compass	Clinometer	Error
-1	-	-	-	-
0	-	-	-	-
1	-	-	-	-
2	-	-	-	-
3	0.5m	5°	-	10%
4	0.1m	2°	2°	5%
5	0.05m	1°	1°	2%
6	0.02m	0.25°	0.25°	1%
X	Variable	-	-	Variable

Table 1. UIS Survey Grades.

Grade	Description
-1	No map is available
0	Ungraded
1	Sketch from memory, not to scale
2	Map compiled from annotations, sketches and estimates made in the cave. No instruments used
3	Directions measured by compass, distances measured by cord, pace, or body dimensions Significant slopes estimated
4	Compass and tape survey, using deliberately chosen and fixed stations. Slopes measured by clinometer or horizontal and vertical components of line
5	Compass and tape survey. Directions and slope by calibrated instruments, distances by fibreglass or metallic tape, or tacheometry
6	Survey or triangulation using calibrated, tripod-mounted instruments for directions and slope. Distances by calibrated tape, precise tacheometry, or calibrated DistoX type
X	Survey by theodolite or comparable means

Table 2. UIS Survey Grades description.

The map details rages from grade 0 to 4:
0-ungraded; 1-sketch from memory. Not to scale, but indicates approximate proportions; 2-details from annotations, sketches and estimates of directions and dimensions made in the cave; 3-Details from drawings made in the cave. The drawing has not to be to scale, passage dimensions can be estimated. Significant details have to be drawn with sufficient accuracy; 4-Details from drawings made in the cave to scale, based on measurements of significant details with respect to surveyed points, usually at least grade 4. All details of general speleological interest should be shown with sufficient accuracy so as not to be appreciably in error at the mapping scale. Passage dimensions measured.

The UIS Mapping Grades additional consider qualifying suffixes, indicated with the letters A-F, provided by the system to specify further actions done to improve the certainty of accuracy:

A-nothing has been done to obtain additional certainty of accuracy; B-Survey loops are closed and adjusted; C-Survey is dependend on instruments and people which have been checked and corrected for the effects of possible anomalies; D-Survey is checked and corrected by electromagnetic methods; E-Survey data has not been transcribed manually, but has been downloaded electronically; F-Entrances have been precisely measured.

The use of the UIS Mapping Grades to indicate the precision and accuracy of a speleological survey can be annotated according to the following grading format: UISv2 3-4-BC is the agreed notation for a survey grade 4, map details 2 and additional qualification B and C. The traditional caving survey carried out by in the Cave of the Angel in Montesano sulla Marcellana (SA), as described in section 4.2, is a UISv2 5-4-C grade, while the Lidar technology survey can be qualified as X grade, moreover, the map details easily obtained with the Lidar survey are far beyond those achievable with traditional survey.

In the comparison between the traditional caving survey and the expeditious Lidar survey, aspects related to the issues of orientation and magnetic declination correction were taken into account. Clearly, in this operation, the objective of the comparison was not the quality of the metric data as much as the verification and validation of the cave development, obtained with the traditional speleological survey, depending also on the acquisition times that differentiate the two approaches.

Specifically, the geometry of the cave reconstructed by traditional cave survey, with a campaign phase of about 4 hours, appears to be aligned with the development returned by the Lidar point cloud, acquired in about 1 hour. Moreover, the Lidar technology allowed surveying the continuations too narrow for human access and, of course, traditional survey, and so, expanding the overall knowing of the cavity. In addition, for comparison purposes it must be considered the drafting time required in the case of the traditional survey.

6. Conclusions and future outlooks

The approach described in this research and initial evaluations of the results encourage the use of inexpensive instruments for surveying hypogeal constructions such as caves. The inexpensiveness of the instrumentation also promotes speed of execution where the time factor can be significantly reduced. In addition, the use of a range-based sensor offers the advantage of capturing a considerable amount of points whose spatial information is known, with a fair margin of accuracy. As a result, this type of acquisition makes it possible to derive from the same survey output not only the development of the cavity but also its volumetry.

Furthermore, in addition to metric data, this type of instrumentation also makes it possible to record other information resources such as, for example, reflectance values. This parameter can be of effective support for the analytical investigation of rupestrian architecture: the careful study of the response by surfaces to the infrared light emitted by a Lidar sensor can, in fact, inform on the presence of traces of pictorial representations, not visible to the naked eye. Precisely in this direction, the next in-depth investigations will move where an initial analysis of the data acquired for the hermitage of Montesano suggests the existence in the past of frescoes, which have now been lost. A final consideration concerns the opportunity to capitalize on the discrete models, acquired with these expeditious and inexpensive sensors, for detailed speleological analyses. The possibility, in fact, of having three-dimensional models, even in mesh form, can facilitate several geological, structural, etc., studies that could hardly be carried out with traditional speleological surveys.

Acknowledgements

The author would like to thank arch. Michele Sanseviero and Dr. Settimio Rienzo for supporting the survey operations. Thanks are extended to the mayor of Montesano sulla Marcellana, Dr. Giuseppe Rinaldi, for his availability and access to the site. Additional thanks are expressed to Francesca Ascione for help in editing Figure 7.
Warm thanks to Professor Massimiliano Campi for his guidance and support of the research as well as to Don Giuseppe Radesca for his trust and availability.
Finally, a sincere thanks to engineer Alfredo Massimilla for his huge support for the speleological survey.

References

Caffaro, A., 1996. *L'eremitismo e il monachesimo nel Salernitano. Luoghi e strutture*. Salerno: FAI Fondo per l'Ambiente Italiano, Delegazione Salerno.

Carnevali, L., Carpiceci, F., 2020. *Sante e Santi in criptis. Architetture rupestri nell'Italia centro-meridionale,* Roma: Sapienza Università di Roma.

Club Alpino Italiano, 2003. *Manuale di speleologia,* Bergamo:Quadrifoglio S.p.A.

Cera, V., 2021. La manipolazione di modelli discreti di rilievo architettonico per orientare l'indagine diagnostica per il restauro. In R.A. Genovese (Ed.), *Il Patrimonio culturale tra la transizione digitale, la sostenibilità ambientale e lo sviluppo umano*. Napoli: Giannini Editore, 167-190.

Cera, V., 2022. Multisensor Data Fusion for Cultural Heritage Assets Monitoring and Preventive Conservation. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLVI-2/W1-20222023, 151-157

Cera, V., 2023. 3D survey technologies to document and support micaelic rupestrian architecture preservation. A case study. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-M-2-2023, 397-403.

Cera, V., Falcone, M., 2023. A knowledge system for Micaelic rupestrian architecture in Campania (Italy). In C. Gambardella, M. Natale & R. Parente (Eds.), *Dwelling on Space. Representation and safeguarding of its tangible and intagible heritage*. Roma: Gangemi Editore, 203-207.

Cera, V., Origlia, A., 2024. Monitoring Systems Design with Real Time Interactive 3D and Artificial Intelligence. In A. Giordano, M. Russo & R. Spallone (Eds.), *Beyond Digital Representation. Advanced Experiences in AR and AI for Cultural Heritage and Innovative Design.* Cham: Springer Nature Switzerland AG, 721-738.

D'Agostino, P., Cera, V., Campi, M., 2020. I siti micaelici nel sud della Campania. Una rete di conoscenza. In S. Bertocci & S. Parrinello (Eds.), *Architettura Eremitica. Sistemi progettuali e paesaggi culturali*. Firenze: Edifir-Edizioni Firenze, 76-81.

De Waele, J., Fabbri, S., Santagata, T., Chiarini, V., Columbu, A., Pisani, L., 2018. Geomorphological and speleogenetical observations using terrestrial laser scanning and 3D photogrammetry in a gypsum cave (Emilia Romagna, N. Italy). *Geomorphology,* 319, 47-61.

Del Vecchio, U., Santagata, T., Damiano, N., 2017. Rilievo 3D in grotta: comparazione di diverse metodologie. *Proceeding of III Convegno Regionale di Speleologia "Campania Speleologica 2017", June 2-4, Napoli,* 67-76.

Elalailyi, A., Perfetti, L., Fassi, F., Remondino, F., 2024. V-SLAM-aided photogrammetry to process fisheye multi-camera systems sequences. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-2/W4-2024, 189-195.

Farella, E. M., 2016. 3D mapping of underground environments with a hand-held laser scanner. *Proceeding of 61° Convegno Nazionale SIFET, June 8-10, Lecce,* 48-57.

Heeb, B., 2009. An all-in-one electronic cave surveying device. *CREG Journal,* 72.

Heeb, B., 2014. The next generation of the DistoX cave surveying instrument. *CREG Journal,* 88.

Yamaç, A., Tok, E., 2015. Surveying some of the touristic underground cities of Cappadocia (Turkey). *Hypogea 2015. Proceedings of International Congress of Speleology in Artificial Cavities*, 86-91.

Papaleo, F., 2020. *Il culto micaelico nella provincia di Salerno. La Grotta dell'Angelo di Pertosa-Auletta*. Pertosa (SA): Fondazione MidA.

Perfetti, L., Fassi, F., Vassena, G., 2024. Ant3D—A Fisheye Multi-Camera System to Survey Narrow Spaces. *Sensors* 2024, 24, 4177.

Promneewat, K., Taksavasu. T., 2024. Performance of Affordable 2D Cave Scanning Technique from LiDAR for Constructing 3D Cave Models. *Advanced LiDAR,* 4 (1), 1-8.

Rodríguez-Gonzálvez, P., Nocerino, E., Menna, F., Minto, S., Remondino, F., 2015. 3D surveying & modeling of underground passages in WWI fortifications. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-5/W4, 17-24.

Spadaro, A., Piras, M., Grasso, N., Lollino, P., Parisi, A., Giordan, D., 2024. Three-dimensional modelling of artificial caves for geomechanical analysis. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-2-2024, 401-407.