Topographic Survey with Disto x and 3D Representation of the Caves by Laser Grammetry, Case of the AZIZA Cave, Errachidia, Morocco

Hicham Benani1,5,*, Lalla Amina Ouzzaoit1,5, Larbi Boudad1,5, Hassan Rhinane2, Ayoub Nehili3,5, Yahya El Khalki3 and Nadia Slimani4

1 Department of Geology, Faculty of Sciences, Mohammed V University, Rabat, Morocco
2 Department of Geology, Faculty of Sciences, Hassan II University, Casablanca, Morocco
3 Faculty of Letters and Human Sciences, Sultan Moulay Slimane University, Beni Mellal, Morocco
4 Topographic study office SITOPO, Marrakech, Morocco
5 Moroccan Explorers Society, Casablanca, Morocco

* Correspondence: hicham.benani@um5r.ac.ma

Abstract

From the middle of the 19th century, speleological topography became a discipline, if not an art, which supported the work of both explorers and scientists. Underground explorations in Morocco remain an area to be discovered and developed. The Moroccan 99,890 km² limestone surface, represents 14% of the total surface which potentially contains a large number of caves, only 3 of them are developed. This under-exploitation is explained by the lack of evaluation of the richness of Morocco’s karst and cave heritage, the topographic maps of Moroccan Caves are poorly carried out or absent, the last inventory of Moroccan Caves dates from 1981. The objective of this study is to represent the AZIZA Cave virtually, appreciate its volume, and optimize the topography of the latter based on 3D technologies. Two methods were used, the topography of the cave by a DISTO-X, and the results of the 3D projection of the cave were carried out on the software VISUAL TOPO. Secondly, we carried out 3D modeling by lasergrammetry using a TLS FARO FOCUS 70, to scan the main entrance, the main axes, and the large rooms of the AZIZA Cave, the final rendering was provided by the scene software. Laser grammetry gave us the possibility of having a virtual representation of the cave and also of important details that conventional methods cannot give because of this heritage dimension, conservation conditions are essential, also given the potential to be appreciated that the cave and its environment offer, which can constitute a typical example of the exploitation of karst heritage and its environment.

Keywords: Lasergrammetry; Topographies; Photogrammetry; Cave; 3D modeling; Caving metrics

1. Introduction

Physical and chemical agents act an important role in the formation of caves (Awadh et al., 2013). After the discovery of the Aziza Cave, several teams looked at its topography in 2D. The first topography was carried out by the Moroccan Society of Speleology teams in 1953 according to the speleological inventory of Morocco. A second topography was carried out by the team of BERNARD LIPS B CAHUZAC in 1981, for a total of 1540 meters of development, then a third topography was carried out by the Italian team of GSV GGM BOLZANETTO GS SAT VILLANZANO which testifies to a DOI: 10.46717/igj.55.1D.2Ms-2022-04-18
development total of 3500 meters (Openspeleo, 2006) (Bernard 1981; di Alberto, 2003; 2004). Indeed, 3D digitization experiments have developed, especially in underground environments and the third dimension has always been a major difficulty in reproducing the graphic representation of Caves (González-Aguilera et al., 2009; Sadier, 2013; Grussenmeyer et al., 2015). This work highlights the recent discovery of the continuity of the Aziza network and also addresses a cutting-edge methodology in highlighting the Moroccan Cave heritage and especially the exceptional heritage offered by the AZIZA Cave, the need for a 3D representation was needed. A century and a half of representation of caves, whether through cavalier views or more recently productions associated with photogrammetry and lasergrammetry.

Indeed, lasergrammetry offers a more precise and more scientific field of action in the topographical and spatial approach of the Cave, faced with the impossibility of restoring the whole of the Cave (more than 4000 m of development), only the modeling 3D of certain parts of it, centered on the entrance to the Cave and the walls of the large hall, have been reproduced by lasergrammetry. From the start of the AZIZA cave study project, we set ourselves the objective of implementing a 3D topographic survey of the entire cavity guaranteeing the visualization of the network, the georeferencing of various types of information (structural, biological, geological, hydrogeological) recorded in the various galleries of the cave. Our project is based on the idea of integrated and interdisciplinary research, this geometric model needed to constitute a research tool that can later be used by all partners and scientific teams. To this end, we used the FARO scanner to scan the first part of the Cave and to create a mesh of georeferenced points, allowing the aggregation of information acquired both outside and inside the network. This work was carried out with a total station and a differential GPS. A Geographic Information System (GIS) is used to process the data and to assess the general public interest in developing the Aziza Cave and making it a pilot model to revive ecological tourism in the region. The precise graphical information of the site and its main structures is essential to obtain a model of the Cave, and the different shapes and structures that compose it. For this, we proceeded to manually record points with a laser to put DISTO-X over the entire Cave apart from two side branches and the extension beyond the newly discovered fourth siphon. Admittedly, this modeling technique used is classic and does not allow the details and precision of the lasergrammetry to be reproduced, but allows an overall appreciation of the development of the cave, the azimuth, the inclination, and the distances of the main branches. The study should also be carried out on the site near the Aziza Cave.

In Morocco the karst represents a large area, which potentially contains caves, there are only 3 developed caves, 2 of which are closed to the general public. This under-exploitation is explained by the absence of 3D modeling of the caves and the topographies are little or not carried out, we also note the lack of the use of GIS data in the exploration of the caves and their interests in the volumetric modeling of the caves. Unfortunately, the most recent inventory dates from 1981, and several caves are neither described nor topographic.

2. Presentation of the Study Area

2.1. Administrative Location of the Aziza Cave

The study area is located in the Tazzouguert Plateau administratively belonging to the commune of Oued Naam in the province of Er-Rachidia, region of the great Drâa Tafillalt towards the east of Morocco (Lebedel et al., 2013; Audra, 2017) (Andreu et al., 2013) (Fig.1).
2.2. Description of the Cave

The Cave object of our study bears several names namely Grotte Aziza, Kef Aziza, Grotte Tazzouguert. The Aziza Cave is located in the Moroccan Eastern High Atlas about 80 kilometers from the town of Errachidia. The entrance is on a terrace above the Oued Guir River. This site also includes an oasis. The cavity opens about 30 m above the bed of the Oued Guir, follows an axis of direction SE-NW, and has a predominantly sub-horizontal route; it appears poised on a generating fracture, which one constantly observes at the height of the rooms, and has a purely phreatic morphology, with mixed domes which follow one another ceaselessly on the vault. The entrance to the cave is located at an altitude of 1059 meters above sea level, and the deepest point reached in March 2019 is 969 meters, with a total depth of 90 meters. The last topography carried out by Lasermetter DISTO X Leica in March 2019 attests to the development of more than 4000 m fully georeferenced with a total of 4 siphons represented on the final topography compared to only two in 1953. A new branch is to be explored beyond the 4th siphon. Many passages of the Grotto are currently flooded with water without a strong flow but do not stagnate, some traces indicate a probable reversal of water flow. In the first part, the dimensions are impressive. In some sections, there are clear indications of vadose activity. In the second part, the Grotto is small, and ramifies several times, while maintaining a phreatic morphology, the evidence of a vadose phase is gradually accentuated. Many branches of this area are currently invaded by water that does not have an obvious flow, but which does not stagnate; in addition, some traces indicate a probable reversal of the water flow (Ben-Said, 2015; Mohamed, 2012; Ouhdan, 2016) (Openspeleo, 2006).

2.3. Geological Setting

The study area is located in the Eastern High Atlas. Morphologically, the region presents a mountainous topography with moderate reliefs in the form of carbonate plateaus of Upper Cretaceous
age with an altitude of 1029 m, this slightly undulating zone reveals the anticlinal structure, marked by important morphological alignments of direction overall ENE to EW. From a geodynamic point of view, the study area belongs to the Atlas range and is part of a Meso-Cenozoic orogenic system built on the northwest edge of the African Plate, it is a belt of intracontinental folds. The first phase of compression is highlighted there from the Upper Cretaceous, before the deposits of the Eocene age. The study area is part of the Akarbous Formation of the Upper Cenomanian – Turonian (Hafida, 2020) (Andreu et al., 2013). (Fig.2). In detail, several marine incursions occurred, reflecting phases of flooding of the platform concerning the relative rise in sea level. These Turonian limestones, made from Cenomanian gypsiferous marls, constitute a well-developed aquifer system and give rise to a few sources; punctual flow rates generally remain low. (Ghenim et al., 2019; Aït Boughrous, 2007; Sadiki, 2012).

![Geological map of the study area](image)

**Fig.2.** Geological map of the study area.

### 3. Cave History

The oldest explorations of the Aziza Cave date from 1925 by Beloin according to the report on the Tazzouguert Cave published in the Archaeological Bulletin of the Committee for Historical and Scientific Work (Alberto Buzio et al., 2003; di Alberto, 2004) (Openspeleo, 2006). Subsequently, other explorations followed one another, among which that of the members of the Moroccan Society of Speleology in 1948, reported by Camus J. and Villard L in "5 years of underground exploration in Morocco", it seems that approximately 2800 meters deep the cavity was explored of which only 1500 meters published in 1953 (Figs. 3 and 4). In 1970, a Spanish expedition explored the cave at 1000 m. In 1972-1979, an expedition financed by the Keimer di Basilea Foundation confirmed the length of 1500 m. In 1981, Croatian Cavers published the length of 1541 m. In 1983, the Slavic group of Zagabria Cavers visited the Cave.

In 2000, the Imperiese team's Italian expedition explored this cave to study the microclimate and in 2002 another small group of four of Cai Varese Milano's teams surveyed the terrain up to 1700m. In April 2003, members of Cai Varese's team, including a speleologist from Bolzano, led an expedition to complete the work that started in 2002 and carry out bio speleological, mineralogical, and geomorphological research, the relief described is around 2,500 m. In December 2003, some of the
people from the previous year’s expedition and the Bindesi Villanzano team, a total of 12, carried out extensive work. Some topographic inconsistencies in previous measurements have been revised, new meanders investigated and new 1000 meters added. The total length of the Cave is approximately 3,500 meters. Biological studies have also been carried out.

From 2017 to 2020 the torch is taken up by the Moroccan Explorers Society team which georeferenced the entire Cave and arrives at a 4th siphon which leads to a new branch that is not topographed yet. The entire development of the Cave would reach over 4000 m (Fig. 5).

3.1. Chronology of Surveys of the Aziza Cave

The first topographic survey of the Aziza cave was carried out in 1953 by the Moroccan company of speleology. Uncertainty about georeferencing. The network is developed over a length of 1540 m with a simple estimate of the height and width of the galleries. The topography describes only two siphons.

![Fig. 3. Survey of the Aziza Cave in 1953](image3)

The second topography of the Aziza Cave was carried out in 2004 by Italian Cavers GSV-GGM-GS Boltzaneto GS- SAT Vilanzano. Uncertainty about georeferencing. The network is developed over a length of 3500 m more important description of the cave.

![Fig. 4. Survey of the Aziza Cave in 2004](image4)
4. Methodology of Data Analysis and Processing

The data used to arrive at the 3D modeling of the Aziza Cave was based on Raster and vectors type data, we made use of the digital terrain model DTM of the study area. The GIS data allowed us to facilitate the analysis of the terrain and to understand the routes leading to the cave as well as the hydrogeology of the region. For the DISTO-X modeling we had used a conventional GARMIN GPS to geo-reference the entrance to the cave, then we had to calibrate the Lasermetter DISTO-X, following which several conventional “right-left high and low” points are taken by the DistoX for each station and transmitted to a TRIMBLE JUNO PDA which directly generates the recording of the points by specifying the distance between two successive stations, the width, the height, the azimuth, and the inclination, all the points recorded will be projected on the software VISUAL TOPO to generate a rendering in the plan, or in the project.

The modeling by lasergrammetry was provided by a TLS “terrestrial laser scanner” brand FARO FOCUS 70, the same data were used, the final rendering was projected on the SCENE software for a final rendering of the point cloud, other software, like SketchUp, 3D MAX and AUTOCAD was used for the 3D graphic rendering of the cave (Fig. 6).

5. Results and Discussion

5.1. Topography by DISTO-X Leica and Processing by Visual Topo

The DistoX is an electronic topography device for cavers. It consists of a Lasermetter that measures distances. The built-in three-axis compass enables azimuth measurements in all directions, regardless of the tilt and roll of the aircraft’s main plane, with virtually no degradation in azimuth accuracy. Visual Topo is the topography software used, it allowed us to display the topography of the cavity in 2D and
its visualization in 3D (Bussa et al., 1997); (Reinhart, 2017); (Marchand et Ros, 2018); (Cassou and Bigot., 2007); (Trimmis., 2018).

Fig. 6. Data analysis and processing methodology

The method used for the topographical survey of Aziza Cave results from the joint use of planimetric and altimetric procedures. The method aims to be able to determine the position of a point by its three coordinates (X, Y in planimetry, and Z in altimetry). To do this, we used the usual method in speleological topography, which is that of the route or the open polygon without losing control. The 3D projection of the Aziza Grotto from the Disto X gives us several details on the distance traveled, the height and width of the large room, the height differences along the route as well as the general orientation of the Grotto (Fig. 5). The views are displayed in the software and are drawn on the screen (directly transferred to plan and section mode, with station numbers).

The morphological analysis of the AZIZA Cave is therefore represented by several sections, in projected mode, in plan mode, and in 3D graphic representation, these presentations although they give us a fairly precise aspect of the length of the Cave from its direction, and its ramifications and sinuosities, they give us no details as to the complexity of the geometric shapes of the dome, the main branches, and the stratigraphy. Various notes or drawings can complete this information, each one remains linked to the aims and subsequently available in the programs. Finally, in return, the data can be exported directly into various survey and vector graphics programs. Arc Scène allowed us to overlay several layers of data in a 3D model of the environment. Rasters and vectors data are placed in 3D. Each layer in the 3D view can be treated differently. The three-dimensional display of data opens up new perspectives and allows us to obtain views that are often impossible to visualize using a planimetric map. The visualization of the AZIZA Cave is indeed a typical example. (Reinhart, 2017; Marchand et Ros, 2018; Peytavie et al., 2008; Trimmis, 2018; White, 2019; Courbon, 2013)

The morphological analysis of the AZIZA Cave is represented by several sections, in projected mode, in plan mode, and in 3D graphic representation, these presentations give us a fairly precise aspect of the length of the cave, the directions and the ramifications, they do not tell us any details about the complexity of the geometric shapes of the dome, the main branches, the stratigraphic layers. The surveys of arbitrary and random points allow at best to give an overall appearance of the Cave, and the use of more modern methods is necessary to appreciate the volumetry in all its splendor. Lasergrammetry devices which have a high resolution that can go up to 2 million points per second, give better results as we will see.
In total

- Rendered the topography of Aziza Cave by Lasermetter DISTO X Leica
- Development of the network 3500 m
- Altitude starting point of the Cave 1059 m
- Altitude of remote point 969 m
- Total depth of 90 m
- Siphons
- Discovery of 3 new branches to explore.

Reading the results of the 3D topography by Disto-x (Figs. 5,7), therefore, provides us with information on several elements of the cave, the entrance culminates at 1059 in height, the development goes down to -90 m, the large rooms are about 350 m from the entrance, with a height of 9.11 m and a width of 6.34 m. The part that is easy to access and possibly visitable by all stretches up to 750 m.

The last point reaches a depth of 90 m from the entry point of the cave, hereinafter a stage arc modeling. These sights are displayed in the software and are drawn on the screen (directly transferred to the scale in plan and section, with station number); all you have to do is draw with the pen. The drawing to scale on the site is very comfortable, the environmental measurements give you precise marks, you can zoom in with the scale grid, several colors are available, you can move around to visualize better, no risk of forgetting at the exit. Various notes or drawings can complete this information, each one remains linked to the aims and subsequently available in the programs. Data can be saved in triplicate (DistoX + internal PDA memory + memory card). Finally, in return, the data can be exported directly into various survey and vector graphics programs for sharpening. Arc Scène allowed us to overlay several layers of data in a 3D model of the environment. Raster and Vector data are placed in 3D. Each layer in the 3D view can be treated differently.

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5.2. 3D Modeling by lasergrammetry at TLS FARO FOCUS

TLS FARO FOCUS readings have an excellent resolution of up to 2 million dots per second. The point clouds come from 24 stations, spaced 10 to 20 m apart, and distributed over the entire site with 6 min per station for black and white scanning for 21 stations and 15 min for color scanning for 3 stations. (González Aguilera et al., 2009; Sadier, 2013; Grussenmeyer et al., 2015; Pamart et al., 2019; Melnikova et al., 2015; Leonov et al., 2014; De Waele et al., 2018; Jaillet, 2014; Robert et al., 2014; Maumont, 2010). The range of the used scanner could be up to 70 m, with a vertical rotation of 300 degrees and horizontal of 360 degrees, and approximately 1,000,000 dots/second. Consolidation and colorization were performed using Faro Scène software, after adjustment.

For the acquisition of point clouds, the scanner was configured with a spatial resolution of 1 mm at 70 m, so the distribution of the stations allows to obtain a very dense point cloud. (Jaillet et al., 2011, 2014, 2019). Filtering functions by a set of treatments are applied to the raw 3D data. This automatic filtering cleaning consists of removing the points that are too far from the theoretical surface, by filtering the points concerning neighboring points. The result of these treatments is always a delicate operation but important for the quality of the final rendering.

Terrestrial laser scanning is a technique for the rapid and automatic acquisition of three-dimensional data using laser light to measure directly, without contact with the object and in a regular pattern. Lasergrammetric techniques and methods are suitable for the direct collection of a large number of 3D points, thanks to the information medium that is laser light. Unlike conventional surveying methods, acquisition involves scanning entire areas, instead of acquiring individual points selected to describe an object. In our context, this concerns the recording of points from the main entrance to the cave and from the main branch to the large cave rooms which can be visited by the general public. This work aims to assess the volumetry of the large sections of the cave and the large rooms that compose it, the project was initiated with the help of the SITOPO design office in Marrakech to carry out the lasergrammetry of the main branch and the large ones. rooms that compose it.

The scanner used was the TLS FARO 70 previously configured to obtain a reasonable resolution, a point cloud between the different stations is obtained, and a distance of 10 to 20 meters between two stations has been respected. the scan by station lasted 6 to 10 minutes, the photogrammetry was also obtained, in black and white for the main branch and color for the large rooms. (Figs. 8, 9, 10 and 11). A total of 24 stations were scanned with photogrammetry, including 21 black and white stations and 3 color stations.

The setting is made to have:
• Accuracy of distance measurement
• Good spatial resolution
• Target-based scan
• A referenced point cloud for efficient post-scanner processing on the Scene processing software.

We preferred to scan large rooms in color to visualize the height, width, and depth of the rooms.

The range of the used scanner could be up to 70 m, with a vertical rotation of 300 degrees and horizontal of 360 degrees, and approximately 1,000,000 dots/second.

On the ground we had chosen to put:
6 min per station for black and white scanning and 15 min for color scanning.
Fig. 8. Lasergrammetry of the major axes of the Aziza Cave

Fig. 9. Point cloud of the large halls of the AZIZA Cave

Fig. 10. Lasergrammetry of the main entrance to the Aziza Cave
Fig. 11. Modeling of the large chamber of the Aziza cave by Lasergrammetry

6. Discussion

Lasergrammetry by terrestrial laser scanners is the best way to capture measurements of complex media; a Cave, chasm, small or large abyss, and therefore to document the morphology in 3D. The limits of conventional topographic methods carried out by manual lifting or by DISTO X lie in the long time they take, which sometimes exceeds several days or even weeks. We also note the problem of susceptibility to errors and gaps concerning important details on the morphology of the Cave due to the spacing between stations, but also the constraints of the rugged terrain which prevents regular measurements.

Reading the results of the 3D topography by DistoX-x, therefore, tells us about several elements of the Cave, the entrance culminates at 1059 m in height, the development goes down to -90 m, the large area is about 350 m from the entrance, with a height of 9.11 m and a width of 6.34 m. The part that is easy to access and possibly visitable by everyone extends up to 750 m. The last point reaches a depth of 90 m from the entry point of the Cave (Figs. 8, 9 and 10). Arc Scène allowed us to overlay several layers of data in a 3D model of the environment. The Rasters and Vectors data are placed in 3D.

The three-dimensional display of data opens up new perspectives and allows us to obtain views that are often impossible to visualize using a planimetric map. The visualization of the AZIZA Cave is indeed a typical example. Conversely, the terrestrial laser scanner allowed us to obtain photorealistic images (Fig.10) and point clouds processed in precise and complete 3D in just a few minutes despite the complexity of the environment. The integrated digital camera takes several photos that can then be used for photogrammetry but also to re-locate the true colors in the recovered point cloud. This 3D scanner allowed us to fully digitize the underground volumes, the latter was carried out as part of a methodological investigation, by comparing several volume recordings processes, (Fig.11).

The role that 3D modeling can play, beyond volumetric restitutions and the creation of a digital model of the Cave, lasergrammetry also makes it possible to integrate archaeological, bio speleological, hydrological data for example such as objects present in the wall and on the ground, the engraved and painted sets, the traces of the bats, their migration count. (Dujardin, 2013) (Burens-Carozza et al., 2013) (El-Hakim et al., 2004),(Grussenmeyer et al., 2014) (Burens et al., 2011a) (Berenguer-Sempere et al., 2014) (Hoff Meister, 2017) (Fritz et al., 2010) (Buchroithner and Gaisecker, 2009) (Poux, 2013)
6. Conclusions

Lasergrammetry by the terrestrial laser scanner is the best way to capture the measurements of complex environments, small or large cave abyss and therefore to document in 3D the morphology of caves. The limits of conventional methods can take several days or even weeks. This is the case with topography carried out by manual lifting or by DISTO X. Another drawback, the data collected is also likely to contain errors or be incomplete, the stations are spaced 5 or even 10 or 15m apart at a time and therefore risk missing important details on the morphology of the cave. Conversely, land-based laser scanners allow us to obtain accurate and complete 3D photorealistic images and point clouds of any complex location in just a few minutes. These 3D laser scanners are as easy to use as digital cameras.

Extreme precision and range through the combined use of sensor technologies with detailed scanning of specific areas. The integrated digital camera takes several photos which can then be used for photogrammetry but also to restore the true colors to the recovered point cloud. The place of 3D tools is growing in the study of the spatial dimension of caves and their morphologies. They allow the total digitization of underground volumes. This digitization was carried out as part of a methodological investigation, by comparing several volume recordings processes. The role that 3D modeling can play, beyond volumetric restitutions and the creation of a digital model of the cave, lasergrammetry also makes it possible to integrate archaeological, bio speleological, hydrological data for example such as objects present in the wall and on the ground, the engraved and painted sets, the traces of the bats, their migration count, etc.

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