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Research paper

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Use of terrestrial laser scanning point cloud in the inventory of Mechowo Caves

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Summary

An inventory is a set of technical operations for obtaining reliable information about a site in order to prepare technical and descriptive documentation, presenting the current state of objects. One of the measurement technologies allowing for the acquisition of reliable and comprehensive information about a site is terrestrial laser scanning. A point cloud from terrestrial laser scanning generates both 2D surveys and 3D models of various types of objects. The scope of research work included the application of terrestrial laser scanning (TLS) technology in the inventory of the Mechowo Caves – a cave in the village of Mechowo. The survey of the area in front of the cave and its part accessible to visitors was carried out using a Leica P40 laser scanner. Due to the highly varied shape of the cave (multiple low and narrow passages) and its unique character, the measurement had to be performed in a non-standard way – with the use of numerous measuring stations with different combinations of measuring instrument settings and variable scanning parameters. As a result of the work, a point cloud was generated, based on which cross-sections presenting the spatial layout of the Mechowo Caves were created, as well as a 3D model of the area covered by the survey.

Keywords

cave inventory • TLS • geospatial data • technical documentation • point cloud

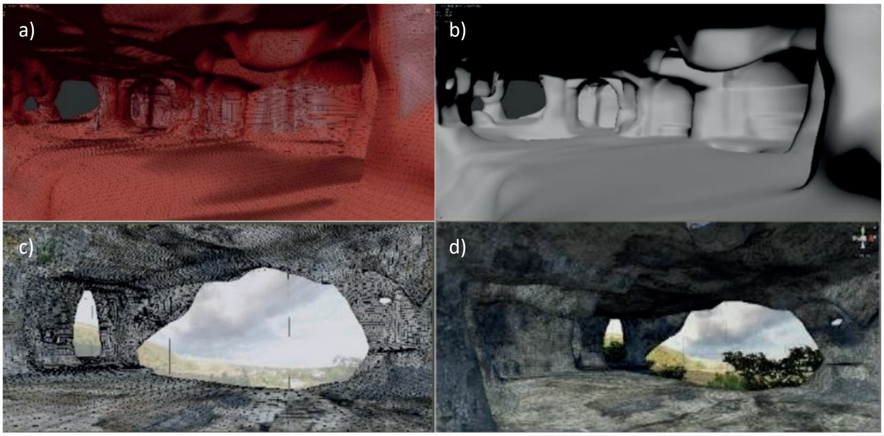
1. Introduction

Underground and rocky sites, such as pits or caves, require constant inventorying and monitoring to ensure the safety of visitors or workers [Duży et al. 2014]. Among the methods currently used by researchers to perform this type of work are: photogrammetric methods, tacheometry, the cross-section method or inventorying with laser pointers [Pielok 2011].

The cross-section method is used to calculate the volume of earth masses, to inventory linear objects [Jagielski 2012], and to determine the shape of river and reservoir beds. The whole idea behind the method is based on measuring landmarks, bends and edges at specific intervals, which allows the exact shape of the object to be reconstructed [Ciszewski and Artur 2013]. Tachymeters, theodolites, GNSS receivers or laser scanners are used to measure with this method, depending on the needs and the site. Tacheometry allows the position of points to be determined by recording vertical and horizontal angles and distances [Maciaszek and Gawakiewicz 2006]. With modern tachymeters, very high measurement accuracies can be achieved [Karsznia 2009], which is used in the inventory of the bottom and ceiling of caves. Before the development of this technology, the orthogonal method was used, which, despite its low cost and high availability, was superseded due to labour intensity and low accuracy [Kowalczyk et al. 2016]. The tachymeter-based cross-section method was employed during a survey of underground caves in the Kadzielnia site in Kielce. With no laser scanner available, it allowed a high degree of automation of the work and a significant number of points measured in a short time. The measurement interval was set at 5g, which, however, was not sufficient to accurately image the shape of the cave [Kowalczyk et al. 2016]. In contrast, the article 'From model to numerical spatial map' presents a method for generating a 3D model of mine infrastructure. This technique is based on data from the projections of the individual levels, which can be obtained using various tools, e.g. a tacheometer, and using information contained in maps (digitisation method) [Maciaszek et al. 2010].

In mining conditions, laser pointers are also used to monitor the corridors, signalling the situational and elevation details of chambers. By measuring horizontal and vertical angles from two independent stations, a spatial forward indentation is made to allow an inventory of the excavation of any shape. This method is characterised by the need to signal the point in the form of a visible laser spot, but the availability of mirrorless rangefinders of the 'Disto' type on the market has meant that this method is not used today [Pielok 2011].

Inventory by photogrammetric methods (especially laser scanning) is considered to be a very efficient source of spatial data, which is widely used in the measurement of a variety of buildings, monuments or objects with complex structures [Pałys and Siejka 2004]. For example, it is used in measurements of objects with complex shapes (such as caves or caverns), as it accurately captures their form in a short period of time. Due to the irregular structure of rocks, it is a method often chosen during inventories of caves, caverns, mine workings and geological formations. Laser scanning is a non-contact measurement method that results in a multimillion-point set with defined coordinates called a point cloud [Matwij et al. 2013]. The scanner measurement is based on a mirrorless distance measurement of the laser beam sent in different directions by a rotating head. Precise point coordinates are determined from the measured distances and angular values [Palys and Siejka 2004]. In addition to the coordinate values, the point cloud includes, among other things, information about the reflectance intensity, as well as RGB values, which are responsible for colouring the cloud with the actual colours [Klapa and Mitka 2017]. The point cloud from TLS enables the modelling of different types of surfaces, even for objects with complex and varied geometry and structure [Bayarri et al. 2020]. Inventories of caves, caverns and excavations using point clouds from TLS result in files and documents such as three-dimensional models, animations, longitudinal and transverse sections, projections and various types of maps [Dyczko and Krawczyk 2013]. Unmanned aerial vehicles are also increasingly being employed to inventory various types of rock formations. Indeed, photogrammetric data from a drone is a valuable source of data on these types of objects due to the reliability of the information, numerous advantages in terms of safety, economics, speed of data acquisition and the ability to work in dangerous and difficult to access areas [James and Robson 2014, Pagan et al. 2020]. Photogrammetric methods can also complement each other as detailed in an article from the inventory of the Ochtinská Aragonite Cave. In order to obtain data of the highest possible quality, terrestrial laser scanning and structure-from-motion algorithms using photogrammetric digital images were used during the survey. The result of the team's work was a cloud of 121 million points with a scanned area of 1335 m^2. The measurements were used to generate projections and cross-sections, as well as 3D models [Pukanská et al. 2013]. Terrestrial laser scanning technology was also applied during the inventory of the İnceğiz caves in Istanbul. A scanner measurement of an area of 3500 m^2 generated 636 million points with a resolution of 2–3 mm. Photographs taken during the measurements were used to colour the point cloud. The studies resulted in 2D drawings, 3D models, and a virtual reality model (Fig. 1). These visualisations provide a comprehensive and real-space embedded inventory of the İnceğiz cave [Büyüksalih et al. 2020].



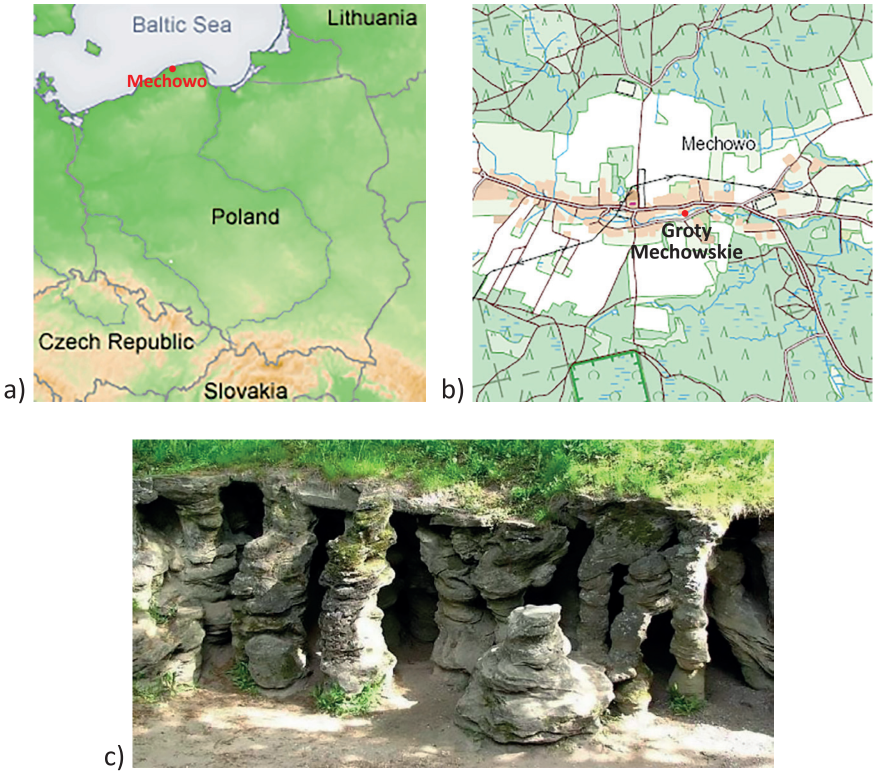
Source: Büyüksalih et al. [2020]

Fig. 1. Modelling process of the cave – meshing (a), rendering (b) and texture mapping (c) in 3Ds max and the final coloured Unity scene of the VR application (d)

Another example of the use of laser scanning in the underground is the measurement of the 'Chessboard' cave. The data obtained was used to build a 3D model, create figures such as projections, cross-sections and profiles, and compare changes to the site over time [Gruchlik 2015]. Meanwhile, in 2012, researchers used laser scanning to inventory Denisova Cave in the Altai Mountains. A textured 3D model reflecting the object was created from an approximately 50 million-point set [Leonov et al. 2014].

2. Research site

The site of the research was the cave in Mechowo (Fig. 2c), also called: Mechowo Grottoes. This cave is located in the northern part of Poland (54°42'49"N 18°17'06"E) (Fig. 2a), in the village of Mechowo (Fig. 2b). The estimated length of the cave is 61m, with an absolute height of 56m a.s.l. Thanks to its uniqueness, the site was recognised as a valuable monument of inanimate nature and entered in the register of legally protected objects (Dz. Urz. WRN no. 1, item 4, 1955 r.; Urban et al. 2022; https://jaskiniepolski.pgi.gov.pl/Details/Information/390).



Source: Authors' own study

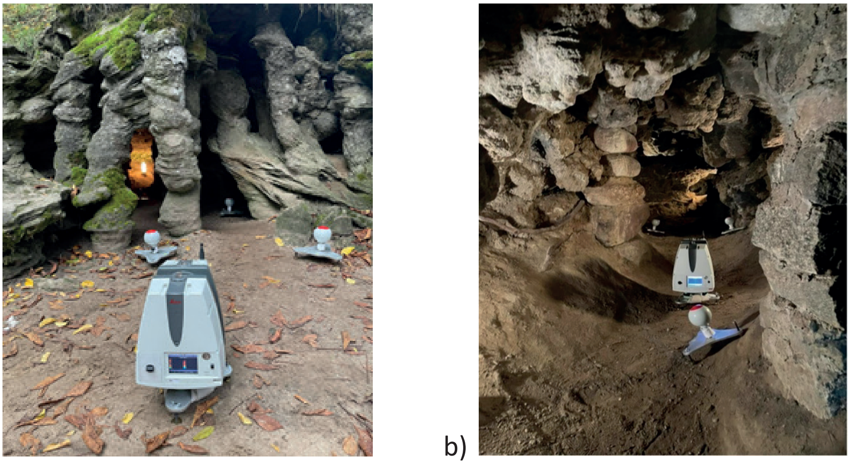
Fig. 2. Research site – Mechowo Grottoes: (a) Mechowo against the map of Poland, (b) Mechowo Grottoes against the map of Mechowo village, (c) entrance to the cave

The cave in Mechowo is located on the Polish Baltic Sea coast near Gdynia and is the longest cave in the Polish Lowlands. The cave consists of a low chamber with pillars of natural sandstone and a low horizontal gallery about 25 metres long. It was formed under a horizontal layer of sandstone, which is solid in the entrance part, but slightly less cemented in the passage zone. Outside the escarpment there are numerous sandstone pillars, and in two parts of the gallery water infiltrates (flows) into the cave and collects in small pools [Urban et al. 2007, Urban et al. 2022; https://jaskiniepolski.pgi.gov.pl/Details/Information/390].

3. Methodology of the survey

The survey was conducted using a Leica ScanStation P40 terrestrial laser scanner (Fig. 3). The inventory covered the part of the cave open to the public. The varied relief of the caves, the numerous low and narrow passages, as well as the small stalactites and rock ribs required a specialised approach to both the measurement and the layout of the scanning stations. Therefore, the measurement was performed from 47 scanner stations. The scanning resolution was selected individually for each station, keeping the point density to within 2–3 mm on the object wall. Spheres and reference markers were also used for the measurement, allowing the individual measuring stations to be connected later.

a)



b)

Source: Authors' own study

Fig. 3. Survey work: (a) measuring the exterior of the site, (b) measuring inside the cave

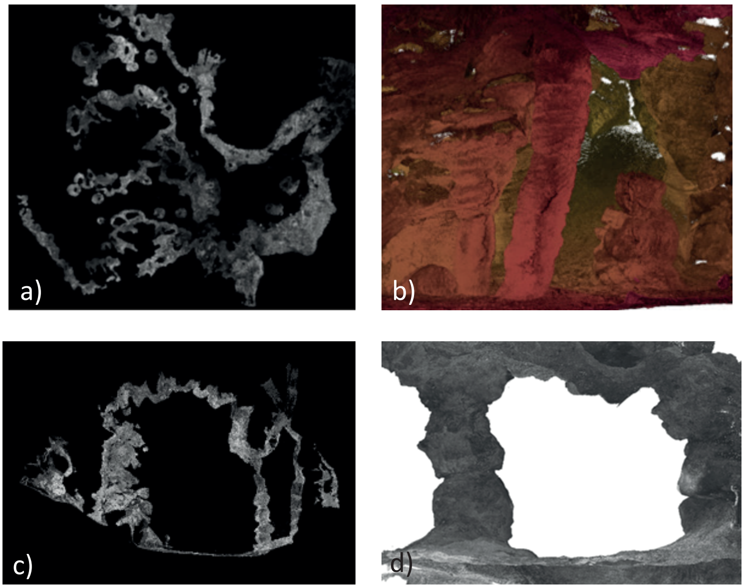
The survey resulted in a point cloud that was generated by the laser scanner. Each point of the point cloud was assigned X, Y, and Z coordinates and intensity values. In order to obtain a coherent image of the Mechowo Grottoes area, the scans from all sites were combined and the point cloud was cleaned. For this, Leica Cyclone software was used to remove redundant points and generate a uniform point cloud (Fig. 4).

Source: Authors' own study

Fig. 4. Point cloud – actual visualisation of the cave in three-dimensional form

4. Results and discussion of the survey – site inventory

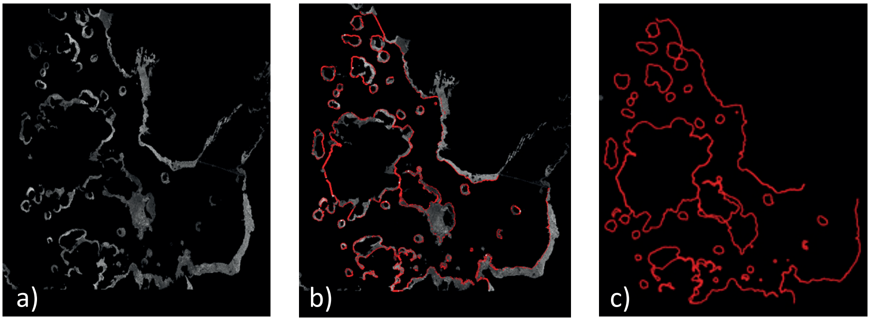
As part of the inventory of the site, cross-sections through a point cloud were created to identify the spatial distribution of geological formations and flowstone forms (stalactites, stalagmites and stalagnates). This allowed the isolation of individual forms (Fig. 5b, 6d) and the inventory in horizontal (Fig. 5a) and vertical space (Fig. 5c) of individual cave elements.



Source: Authors' own study

Fig. 5. Inventory by visualising the object: (a) horizontal cross-section, (b) visualisation of the cave interior, (c) vertical cross-section, (d) rock column

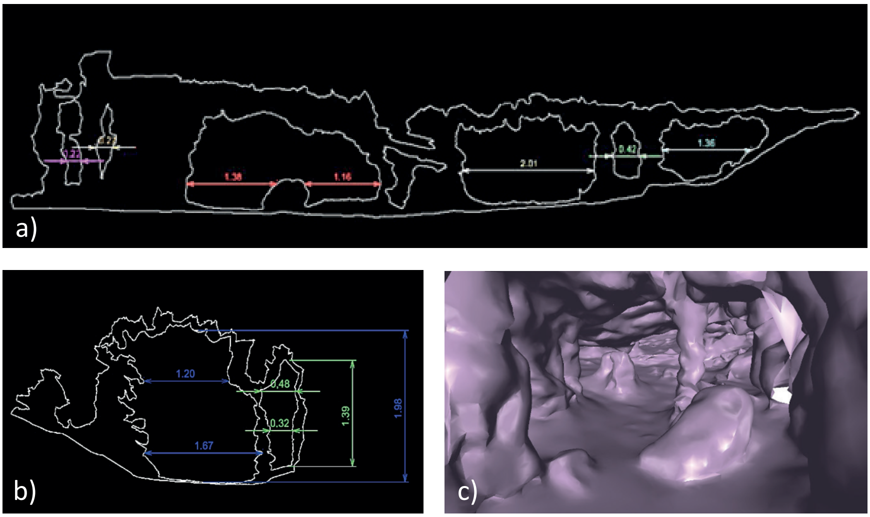
The point cloud was also used to generate cross-sections that show the spatial layout of the cave. The cross-sections from the point cloud are two-dimensional images that are created by cutting a virtual plane from the three-dimensional point cloud (Fig. 6a). Based on the cut and vectorisation of the visible elements (Fig. 6b), a vector documentation (cross-section) of the analysed area (Fig. 6c) is produced.



Source: Authors' own study

Fig. 6 Generation of cross-sections: (a) horizontal cut through the point cloud, (b) vectorisation of visible elements, (c) generated image

Based on the cross-sections generated by the point cloud, technical drawings were developed to enable a detailed inventory of the individual rock formations and their spatial distribution. Documentation was obtained for the longitudinal section (Fig. 7a) and the transverse section (Fig. 7b) for the main cave passage.



Source: Authors' own study

Fig. 7. Inventory results for the Mechowo Grottoes cave: (a) longitudinal cross-section, (b) cross-section, (c) 3D model

A 3D model of the surveyed area was also created from the point cloud (Fig. 7c). A 3D visualisation of the cave was developed using mesh generation tools (Leica Cyclone 3DR). The model is a digital representation of the site, it allows for an easy and precise spatial representation of the cave as well as for an accurate analysis of all details of the cave.

The point cloud from terrestrial laser scanning ensures the acquisition of high-quality spatial information on caves. TLS can be used in areas that are difficult to access for traditional surveying methods. This long-distance, non-contact measurement capability allows information to be obtained about areas that are difficult to access and potentially dangerous to humans [Pfeiffer et al. 2022]. The cloud recording of the survey points allows for a highly accurate inventory. The inventory of caves and surrounding areas has many important applications. Not only does it support scientific research by comprehensively recording the entire site in three-dimensional form, but it also enables efficient site management. Thanks to detailed documentation, it is possible to establish rules for responsible touring along with the protection of tourists, and it avoids the potential exposure of the caves to unchecked increases in tourist traffic, which could have a negative impact on their ecosystems. The protection of natural heritage is another way in which the documentation produced by the cave inventory can be used. Caves are unique environments that often harbour valuable geological formations. Inventory documentation helps to identify areas of special natural interest, which makes it easier to undertake measures to protect them [Urban et al. 2007, Bar and Faldrowicz 2010, Urban et al. 2022].

5. Conclusions

Cave inventories involving classical (traditional) survey tools and methods are difficult to carry out. The difficulties of reaching narrow and low areas prevent specialised measurements. The variety of forms and shapes in the caves makes it additionally difficult to visualise them accurately, especially in three-dimensional space.

Laser scanning ensures the acquisition of information in a non-contact way, which in a short period of time allows the generation of a multi-million point cloud that accurately reflects the image of each cave feature. In addition, the technical documentation generated from the TLS point cloud is characterised by the high accuracy and reliability of the information provided.

By preserving the actual dimensions in the cloud, a complete image of the measured object is available and stored in the computer's memory. Therefore, carrying out spatial analyses, generating technical documentation or 3D models and visualising the object using the point cloud with TLS is a straightforward procedure, which ensures the acquisition of materials at the highest possible level of accuracy.

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