

Indoor Space Measurement with a Mobile Phone Integrated LIDAR Sensor: The Case of the Aizanoi Ancient City Zeus Temple Vaulted Gallery

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While topographic measurement devices and methods continue to develop in earth sciences, some measurement tools have been adapted to consumer mobile devices. Mobile technological innovations introduced by Apple in 2020, including the iPad Pro and the iPhone 12 Pro, have facilitated reverse engineering studies with applications designed for different fields, including software for LIDAR sensor-oriented applications. 3D models of objects and structures are produced and documented in digital twin studies such as 3D models, point clouds, and measurement techniques. With the development of this technology in mobile devices, point clouds and solid models of archaeological studies and structures have started to be transferred to CAD environments in different formats. In this study, we aim to produce a coordinated and scaled plan of an archaeological architectural structure with centimeter precision in an indoor environment by using auxiliary measurement devices beyond modelling. The vaulted gallery (cellar) located under the Temple of Zeus in the Ancient City of Aizanoi in Turkey was spatially transferred to the general plan of the city. In this context, our study serves as an example of how to implement 3D imaging of an interior space where GPS data cannot be obtained, which is a common scenario in underground cities, caves, and other inaccessible sites.

Keywords:

Mobile phone, LIDAR, 3D Model, Point Cloud, Archaeology, CAD.

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1. INTRODUCTION

“Light Detection and Ranging” (LIDAR) is a method in which a sensor measures distance by calculating the return pulse from the laser transmitter to the laser receiver using light pulses [Luetzenburg et al. 2021]. Apart from measuring the distance between the object and the sensor by

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moving in different directions, it is a technology that creates and measures 3D data used in air and land [Sanchez Diaz et al. 2022]. This technology has been developed and adapted to mobile devices in mobile phones and tablets by Apple in recent years [Luetzenburg et al. 2021]. Although Apple devices with LIDAR sensors are designed to calculate the depth before the photo is taken to make the bokeh effect (the formation of depth mapping points) fast and stable, different software companies have developed 3D model and point cloud applications using this sensor and camera. Notwithstanding the fact that the "terrestrial laser scanner" (TLS) does not possess the same point density and quality as the received data, it is nevertheless capable of rapidly creating and mapping its digital twin [Di Stefano et al. 2021]. The depth calculation data of the LIDAR sensor introduced by Apple in 2020 was announced as 5 m. [Teppati Losè et al. 2022]. Despite the passage of four years since the initial announcement, the sensor, excluding camera enhancements, remains compatible with all iPad and iPhone devices released since 2020, including those equipped with the aforementioned sensor.

The method described below can be utilized to achieve this compatibility. Since archaeological excavations are interdisciplinary studies, the survey of the unearthed structures is coordinated according to the stratification in the studied area, and 2D plan drawings are made with different methods. Point measurements of these areas are measured by tacheometer, theodolite, level and a GPS Cors instrument, and the drawing is usually made on an orthophoto. Point clouds with 3D coordinates are made and data are obtained by experts in this field with ground and air laser scanners. In this paper, the high cost of traditional scanning methods has led to the adoption of low-cost geomatics tools by non-specialist users for areas with dimensions such as the Temple of Zeus [Vacca 2023]. This development is a result of technological advancement.

We would like to mention the practicality and cost benefits of 3D imaging projects by reaching conclusions such as the cost of service procurement and waiting time, the inability to measure in emergency interventions for protection purposes and the long time of data production. In ancient city excavations where archaeological work is carried out, the the utilization of measurement tools such as total stations in the excavation building, as well as mobile devices, have become a prevalent practice in contemporary excavations. Archaeologists can now participate in these endeavors by acquiring a software subscription, such as Polycam, which is a cost-effective solution for excavations in small areas, even with limited financial resources. In this paper, we demonstrate the utilization of LIDAR-enabled mobile devices designed by Apple in the scanning of a Roman Temple, followed by the transfer of the scanned data to a CAD environment using various software applications. Furthermore, the methodology for scanning immovable and movable structures of cultural heritage is discussed. This involves increasing the LIDAR measurement distance from 5' m to 8' m with the aid of an elevating pod in closed or open areas with a surface area not exceeding 1000 m² [Teppati Losè et al. 2022]. In this study, an archaeological structure and objects are scanned in a short time and after the point cloud is created, the data is transferred to the CAD environment in a coordinated manner and both two-dimensional drawings and three-dimensional scale models are produced. The aim is to make use of the benefits of technology by using the devices in the excavations and producing data in a fast way.

2. BACKGROUND

Mobile phone integrated LIDAR scanning is a technology that produces direct precise 3D models of objects [Avdan et al. 2013]. 3D models of objects are already used in many disciplines and in recent years they have become more commonplace in archaeology. Architectural elements and structures of archaeological nature are among the most visible elements of cultural heritage. Generally speaking, they are tangible assets that societies have carried from the past to the present, which have been uncovered today and are valuable to future generations [Sarıkaya 2022]. The important point is that they include not only tangible but also natural and intangible heritage. However, these resources are recognized as valuable are susceptible to destruction and therefore, once lost, they cannot be recovered. In this context, it is critical that the data or acquisitions of existing archaeological structures should be documented and preserved. One of the main reasons for the merger of cultural heritage with the concept of digitalization is the possibility of sustainable documentation processes through the transfer of heritage data to digital format with new mobile methods.

When we examine the concept of digitalization, we see that this technological progress has recently contributed to positive developments in many fields [Halaç and Öğülmüş 2021]. The utilization of LIDAR data facilitates the determination of deformations in both closed and open areas through the implementation of linearity analysis. The utilization of hand-held, portable, and mobile devices in such studies offers distinct advantages, including enhanced data reception speed [Tanduo et al. 2023]. The generation of 3D point cloud data facilitates the production of various outputs, such as plans, sections, elevation drawings, and maps of the scanned area. [Avdan et al. 2013]. The scanned objects are coordinated by using a total station and coordinated with overlapping points from the point cloud. Digital imaging with a mobile phone integrated LIDAR sensor often requires technical accommodations. For instance, if scanning is to be performed with in a closed area, more than one additional light source is required; if an area higher than 5 m is to be scanned, the phone or tablet must be mounted on a tripod; and a hand gimbal is useful if a sensitive surface model is to be scanned.

2.1 Study Area

The ancient city of Aizanoi is located within the borders of Çavdarhisar District, 57 km southwest of Kütahya Province in Turkey Fig. 1. According to Strabo, the city is one of the important cities of Phrygia Epictetus [Strabo 2000]. The construction of the Temple of Zeus at Aizanoi began in 92 AD during the reign of the Roman Emperor Domitianus (81-96 AD) and continued until the reign of Emperor Hadrian (117-138 AD). It is the best-preserved Roman Temple to Zeus in Anatolia. Aizanoi gained importance in the Hellenistic period due to its religious identity originating from the god Zeus. In this period, thanks to the lands donated to the Temple of Zeus by the kings of Bithynia and Pergamon, the city developed around the temple in political, economic and cultural terms [Lochner 2010]. During the Roman period, important buildings were built in the city, but the temple has always remained the most important building.



Figure 1. Map showing the location of Aizanoi in Turkey.

The Temple of Zeus was built on a mound in the center of the city, dating to the 3rd millennium BC [Lochner 2010]. The first person to mention the Temple of Zeus was George Ashburnham (1760-1830), 3rd Earl of Asburnham, known as the Viscount of Asaph, who visited the city on July 24, 1824 and documented the temple for the first time in his letters [Arundell 1834]. 19th century travelers mentioned the Temple of Zeus in their works. The first excavations at the temple were carried out by the German Archaeological Institute in 1926 by D. Krencher and M. Shede [Naumann 1979]. The excavations around the temple were carried out by R. Naumann between 1970 and 1982. In 1970, the temple was damaged by the Gediz earthquake. Restoration and conservation works were carried out due to the earthquake damage [Hoffmann 1987; 1988; 1990]. From 1990-2007, excavations and research continued under the direction of K. Rheidt [Hoffmann and Rheidt 2008].

When it was first built, there were 42 columns around the Temple of Zeus. The temple, which was built in the Octastylis style with a pseudodipteros plan, has eight columns on the short side and fifteen columns on the long side, and the structure sits on a podium measuring 35 x 55 meters. Under the temple, there is a vaulted gallery built of marble measuring 24.86 x 6.58 meters, which is not very common in Anatolia, as shown in Fig. 2. There are two different opinions about the use of this vaulted gallery: That the lower gallery of the temple was used for storing the offerings dedicated to the temple; and that the cult in the sanctuary of Cybele (Meter Steunene), located about 4 km south of the city, was moved here after the construction of the temple and that both Zeus and Cybele were worshipped in the temple [Naumann 1984]. Various cross motifs were engraved on the temple walls when the structure was converted into a church during the Byzantine Period [Erdoğan 2020]. Later, the Chavdar Tatars, who came to the region after the Mongol invasion in Anatolia in the 13th century AD, used the temple as a fortress [Naumann 1979; Erdoğan 2020].

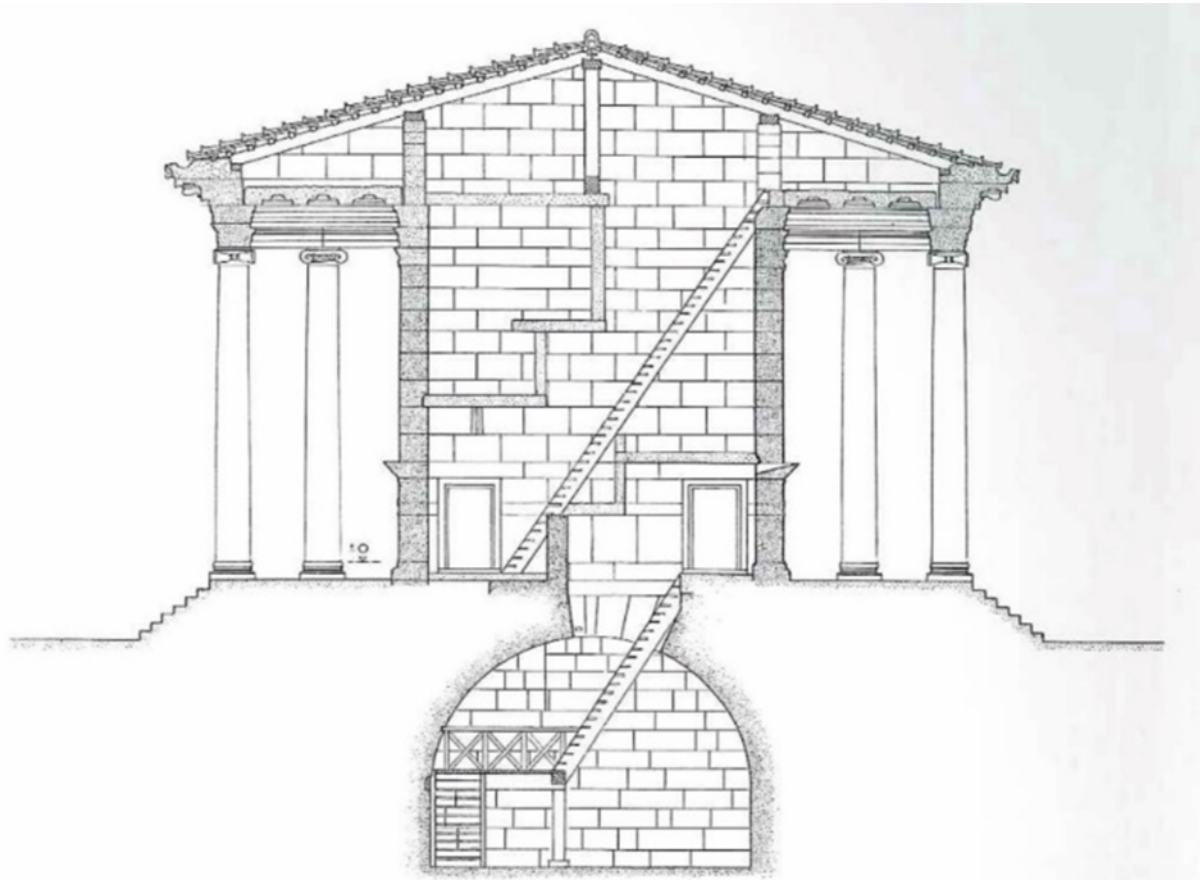


Figure 2. Aizanoi Zeus Temple and Lower Gallery [Naumann 1979:10].

2.2 Data Capture

In archaeological excavations of large areas such as the ancient city of Aizanoi, the architectural drawing team draws plans, sections and elevations by connecting to fixed coordinate points in different areas by back-cutting or by taking points with GPS Cors device, using data from Unmanned Aerial Vehicles, terrestrial photogrammetry or laser scanners. These drawings are transferred to the coordinated plan square system in a CAD environment by using different colours and pencil thicknesses according to level, period, structure and architectural elements. In this study, since the lower gallery of the Temple of Zeus is a closed area, measurements could not be made with the GPS Cors instrument. Our methodology focused on connecting this area of the site to the general plan, and drawing plans, sections, views and details of the entire area in a scaled manner. We captured data during at least 5-6 different sessions with the Total Station device, since it would take a lot of time to point the details one by one and to process the details in the CAD environment, a position that can see the fixed polygon points as shown in Figure 3 from the opisthodomos part of the temple was determined by connecting to the coordinates from 2 different points in the temenos area with the Total Station and five new points were made with a laser by providing the connection.



Figure 3. Total Station Laser Measurement and Point Transfer to the Lower Gallery Session Operations.

Afterwards, a connection was established with 3 of the 5 control points of the first session with the Total Station carried in front of the landing staircase in the opisthodomos section, and 3 points were moved to the lower gallery with a laser for the 3rd session. After the 3rd session was opened in a place that could see the points in the lower gallery and the polygon points were marked, the polygon points connected to the national coordinates were moved to the lower gallery of the temple. Seven 20 x 20 cm targets were homogeneously distributed and attached to the closed lower gallery with easily removable tape. As shown in Figure 4, the central part of the cellar was recorded for the last time with the Total Station, 33 control points were taken with the laser at the decisive places such as the base of the 4 corners, and then the target center points were completed by measuring the points with the laser beam of the Total Station.

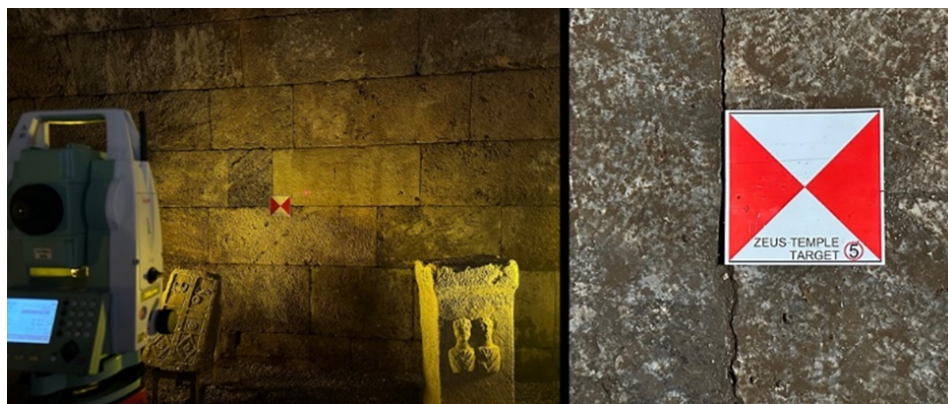


Figure 4. Target Reading Process with Total Station Laser.

The preparation phase was completed by using auxiliary illumination tools as shown in Figure 5 in the lower gallery, which can be considered as dark, with an average illuminance of (5'lx) to receive the point cloud data (The luminous intensity is 1 lx when the luminous flux of 1 Lm falls uniformly on a 1 m² surface, the unit is lux "lx").

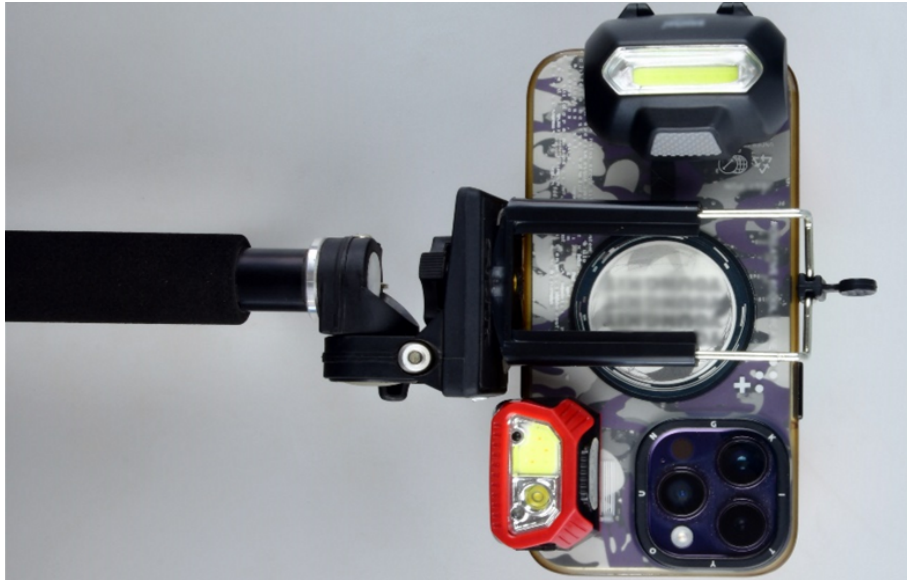


Figure 5. Iphone 14 Promax, Monopod Mount, Monopod and Two Led Lamps.

The scanning process was carried out in 9 minutes with the Polycam Pro application on the iPhone 14 Pro Max and was completed by moving up and down and walking slowly, controlling the LIDAR grids and the image on the screen instantaneously, as shown in Figure 6.



Figure 6. Scanning Process with Polycam Pro Software (Polycam Software. Available online: <https://poly.cam/>, paid subscription start: 22.01.2024).

After 7 minutes of processing, the data obtained were exported from Polycam in .las format. When it came to the next process, it was imported into the computer environment with the Autodesk Recap program Figure 7. and after the necessary point cleaning was done, it was exported with .rcp format and transferred to the Autodesk AutoCad program.

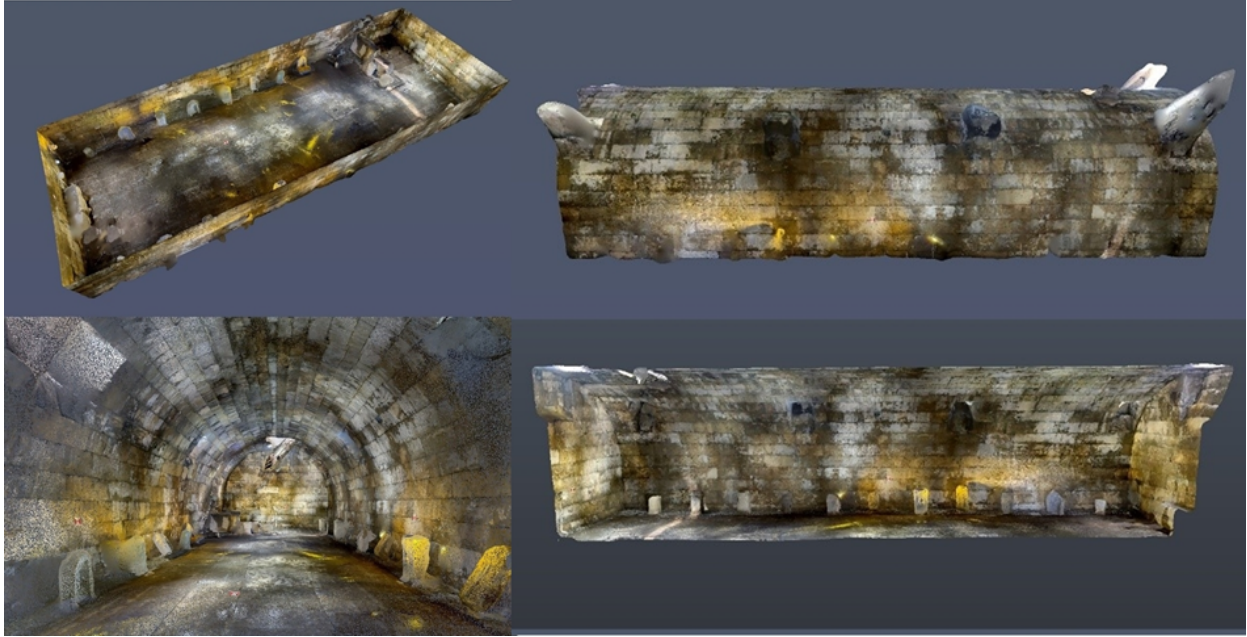


Figure 7. Point Cloud Opened with AutoDesk ReCap Pro (Autodesk ReCap Pro Education & Student Access).

2.3 Data Processing and Accuracy Analysis

The obtained data were imported and opened in a desktop version of Autodesk Recap, the point cloud was cleaned, and the project was saved in a .rcp format. Since it is a difficult process to determine the coordinates of the remains found in the closed area on the ground, they were transferred to the CAD environment. To establish the accuracy of the model, our team opened the .rcp point cloud file in Autodesk AutoCAD 2022. The .rcp point cloud file of the scan and the target points read by connecting to the national coordinate system with the total station was opened. The target points from the Total Station and the targets from the point cloud were overlapped and the point cloud belonging to the vaulted lower gallery was brought to its original coordinates on the earth as shown in Figure 8. Connected to WGS 84 national coordinate system with total station and opened .rcp point cloud file of read target points and LIDAR scan. There were some shifts between 1-3cm*** at some points, but in general terms, the target points were fit on the point cloud.

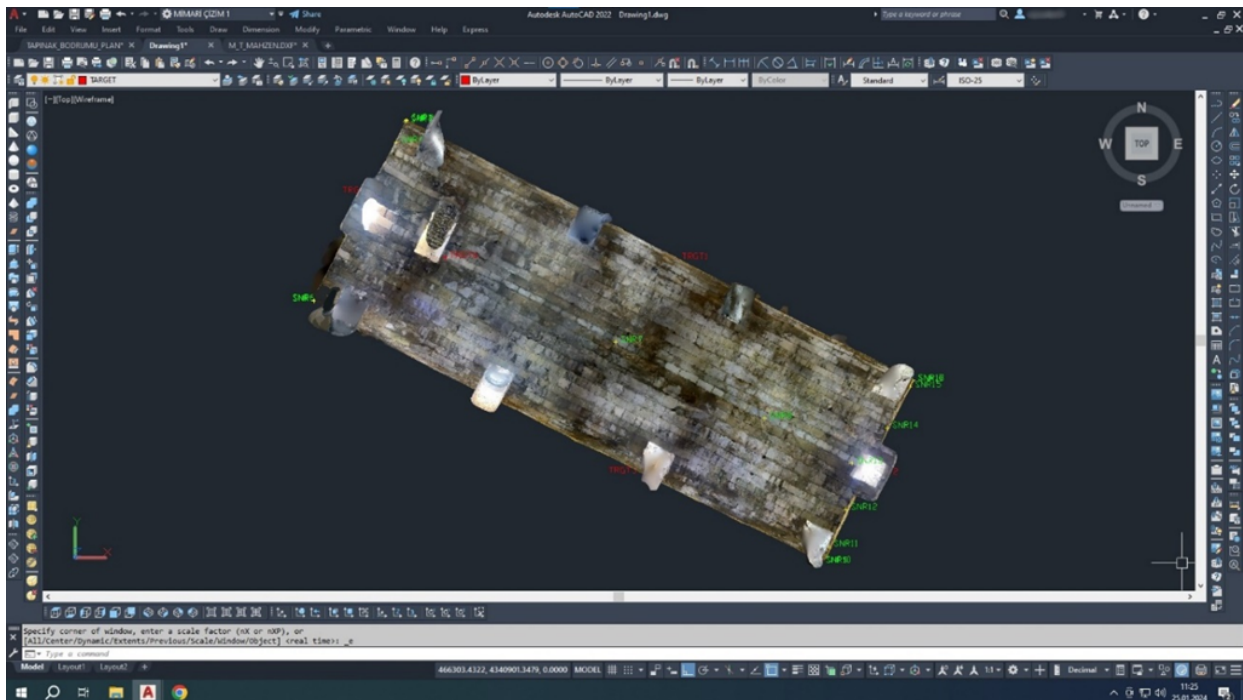


Figure 8. Registration of Target Points in the Point Cloud (Autodesk AutoCad 2020 Education & Student Access).

The point cloud data and the plan of the lower gallery (the red area is the plan of the lower gallery) were overlaid on the temple plan in coordination with the total station data from the Aizanoi excavation archive [Coşkun et al. 2022], as shown in Figure 9. Then, the point cloud of the Temple of Zeus shown in Figure 10, the cross-sectional image shown in Figure 11, and the cross-sectional orthophoto output with the point cloud plan were also produced. In addition, the 3D model of the building was animated and you can watch the animation of the temple and the lower gallery by scanning the QR code on the mobile device as shown in Figure 12.

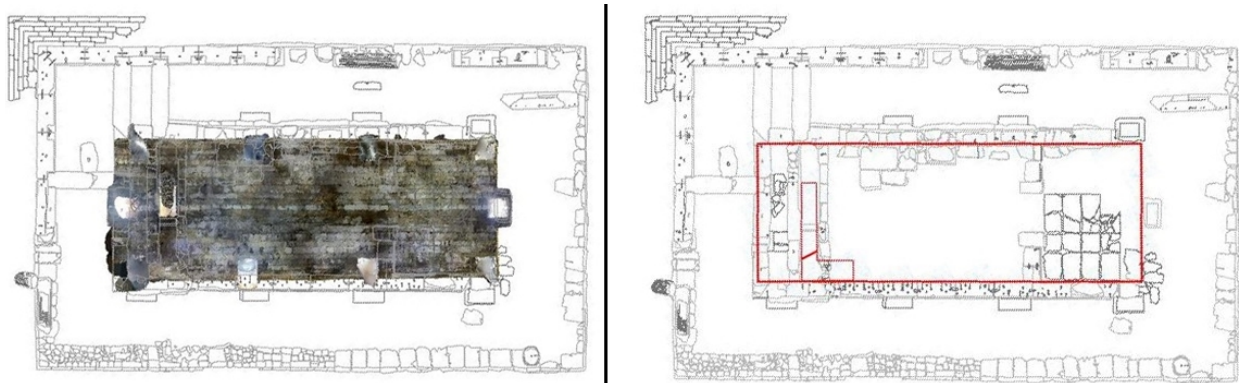


Figure 9. Temple Plan Drawing Point Cloud and Sub Gallery Plan shown in Red Area (Aizanoi Excavation Archive 2023).



Figure 10. Aizanoi Temple of Zeus Vaulted Gallery Superstructure and Vaulted Gallery Sectional View.

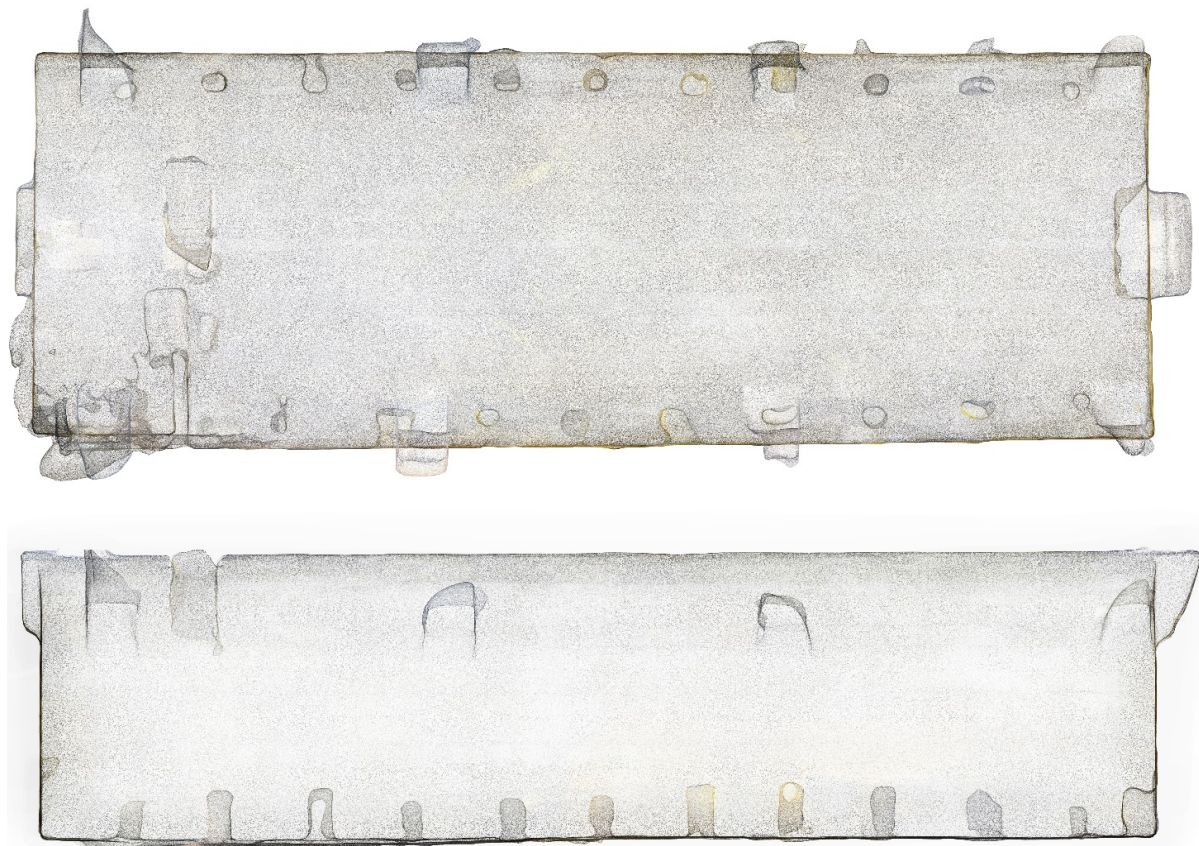


Figure 11. Aizanoi Temple of Zeus Vaulted Gallery Point Cloud Plan and Section View.

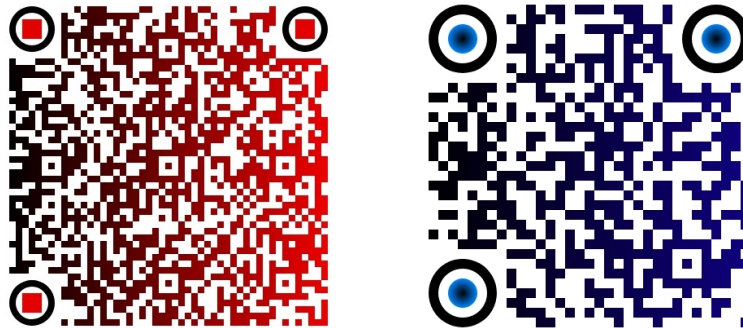














Figure 12. Temple of Zeus Vaulted Gallery Point Cloud Animation and 3D Model QR Code

2.4 Equipment and Software Used

Table 1: The equipment and software used.

			
<p>Phone Holder With Monopod Mount</p>	<p>SLiK Mono Pod II</p>	<p>Apple iPhone 14 ProMax 256 GB</p>	<p>Polycam Pro LIDAR Scanning Application</p>
			
<p>Autodesk RECAP PRO 2022 Point Cloud Software</p>	<p>Autodesk AUTOCAD 2022 CAD Software</p>	<p>Leica Total Station TS06 Plus</p>	<p>DELL T7600 Workstation</p>
			
<p>Head Lamp</p>	<p>Flashlight</p>	<p>Universal Gluable LED</p>	<p>20x20 Cellophane Paper Target</p>

3. RESULTS

The effects of the rapid development in technology in recent years are also seen in archaeological projects. Archaeologists are integrating digital methods of drawing and documentation into field using them alongside more traditional methods. In this project, we present a new workflow for georeferencing a 3D point cloud of an underground area, using control points. The 3D point cloud was obtained with an iPhone 14 equipped with Polycam and an additional lighting module to document the underground portion of the Temple of Zeus in the Ancient City of Aizanoi. After overlapping the coordinates obtained from the target points measured with the total station, they were transferred from the CAD environment to the national coordinate system and positioned on the map with an accuracy of 1-3cm. The main purpose of this study is to transfer the vaulted lower gallery of the Temple of Zeus to the general plan of the ancient city of Aizanoi with coordinates and to provide a drawing-oriented basis for the point cloud and wall details. In addition, with this study, it has been proven that 3D point clouds can be created with mobile LIDAR supported scans in closed structures and areas such as caves, rock shelters, cisterns, underground cities, tumuli belonging to cultural heritage, and coordinated plan-section-view of structures and areas can be used in archaeology with pocket-sized technology and various mobile applications. The method we have described here can be applied by archaeologists with the necessary equipment, it also facilitates the transfer of cultural assets to national coordinates in accordance with the national coordinates and aims to share cultural heritage with a wider audience in digital archiving by creating 3D scale solid models in large structures. Furthermore, thanks to 3D modelling and digital archiving, it will be possible to follow the changes made on cultural assets over time, to manage restoration projects effectively and to better understand cultural heritage. These technological methods will contribute to the sustainable conservation of cultural assets by not only documenting the current situation, but also creating a resource for future generations.

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