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# Comparing Photogrammetry and Smartphone LIDAR for 3D Documentation: Kızılkoyun Necropolis Case Study

**Emine Beyza Dörtbudak*[1], Şeyma Akça[1]**

*[1]Harranl University, Geomatic Engineering Department, 63300, Şanlıurfa, Türkiye; (beyzadbk@gmail.com; seymakca@harran.edu.tr)*

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* **Corresponding Author**
beyzadbk@gmail.com

**Abstract**

Archaeological remains and historical artifacts serve as essential records that illuminate a society's history, culture, and lifestyle. Vulnerable to damage from various factors, these artifacts pose challenges to sustainable preservation and hinder cultural and artistic comprehension. Documenting their present state and recording features become imperative to mitigate potential information loss. Photogrammetry, an image-based technique, emerges as a key method for three-dimensional documentation by merging two-dimensional images from different angles. This process utilizes cameras with diverse focal lengths and specialized software to generate 3D models from photograph surfaces. Additionally, LIDAR, employing short laser bursts and backscattering, proves invaluable for documentation. Its advantages, including high accuracy, dense point data, and rapid data collection, have been further extended with recent technological strides, allowing integration into smartphones. This study exemplifies the creation of a 3D point cloud of a relief sculpture in the Kızılkoyun Necropolis, achieved through the synergistic use of photogrammetry and a LIDAR sensor embedded in a smartphone.

## 1. Introduction

Historical artifacts and archaeological remains are significant works that provide information about a society's history, culture, and way of life. These works can be damaged by human interventions such as haphazard urbanization, war, smuggling, or natural disasters like earthquakes and floods. The resulting damages make it difficult for people to connect with the past, understand culture and art, and hinder the sustainable preservation of artistic pieces. Therefore, documenting the current state of historical artifacts, recording their features, and preserving them are crucial in facilitating their transmission to future generations and minimizing damage.

Efforts to obtain accurate and reliable data in documenting historical artifacts have led to the emergence of new techniques in the field (Korumaz et al., 2011). With advancing technology, traditional methods such as hand drawing and taking photos with analog cameras have been replaced by modern documentation techniques such as high-resolution digital photography, laser scanning, and photogrammetry for 3D modeling (Yiğit and Uysal, 2021). Photogrammetry is an image-based technique that enables the generation of three-dimensional data from two-dimensional images taken from different angles and positions (Remondino and El-Hakim, 2006). With this technique, cameras with different focal lengths and specialized software are used to make the necessary adjustments, resulting in the production of 3D models from the surface of the photographs. Photogrammetry is preferred in various application areas such as architecture, archaeology, industry, land studies, medicine, criminology, and traffic accidents. The widespread use of Computer-Aided Drawing (CAD) -based software has significantly

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expanded the application scope of photogrammetry (Hamal and Ulvi, 2022). The ability to determine the features of an object in three dimensions without physical contact and to cover the resulting model with real textures has contributed to the increasing popularity of photogrammetry (Obradović et al., 2020). Photogrammetry involves capturing photos of the study area, as well as image and object modeling steps. Due to its speed, low cost, and high data quality in terms of accuracy, it is frequently preferred for documenting and three-dimensional modeling of cultural heritage (Uslu et al., 2016; Zeybek and Kaya, 2020).

Another method that can be used in the documentation process is LIDAR. The LIDAR device sends short-duration laser beams to the surrounding objects, relying on the technique of measuring the time it takes for the beams to hit nearby objects and reflect back. The distance is determined by measuring the time it takes for these reflected beams. (Polat and Uysal, 2016; Jiang et al., 2005). LIDAR technology is a technology used in various fields today, including archaeology, urban planning, oil and natural gas exploration, mapping, autonomous vehicles, forestry, and underwater research. The working principle of LIDAR sensors is based on calculating the distance of an object by sending a beam of light and measuring the time it takes for the light to hit an object and return. In accordance with this principle, when the laser beam emitted by the sensor encounters an obstacle, the reflected light is detected by a detector in the second eye, and distance measurement is performed taking into account the reflection time. Thus, LIDAR sensors can measure the distances of objects in their surroundings with precision. The distance is calculated according to the formula Distance = c * t / 2, where c is the speed of light and t is the time it takes for the light to travel, as shown in ''Fig. 1'', illustrating the working principle of the LIDAR s**1.** The working principle of a LIDAR sensor

The advanced technologies that came with smartphones and tablets in the early 21*st* century significantly increased the use of geospatial tools and methods. LIDAR has many advantages, such as high accuracy, high point density, and the ability to rapidly collect a large amount of point data. Developments in current technology, including equipment miniaturization and sensor improvements, have enabled the integration of LIDAR into smartphones. In line with these advancements, Apple Inc. introduced the iPhone 12 and iPhone 12 Pro Max models in 2020, which were the first series of phones to feature a LIDAR sensor integrated into the camera system. This addition aimed to provide precise positioning for Augmented Reality (AR) applications and enhance depth perception (Aslan and Polat, N, 2022; Luetzenburg et al., 2021). Especially with techniques like close-range digital photogrammetry and LIDAR, there has been an increase in the generation of georeferenced surface reconstructions (e.g., digital elevation models and virtual models) (Tavani et al., 2022). These tools and data products have become increasingly preferred in research and education. The advantages provided by integrating phones and tablets into Geo/Jeo sciences have been recognized by many authors for a long time, leading to various studies. Some of these studies include:

In their study, Vogt et al. (2021) examined the advantages offered by the latest Apple device in the industrial field for 3D scanning. The study focused on both the LIDAR and the front TrueDepth camera. The TrueDepth camera system includes a range of sensors such as an infrared light source, infrared camera, front-facing camera, dot projector, and a specialized depth sensor. The authors tested these two sensors on Lego bricks and compared the results with an industrial 3D scanning system. They specifically emphasized the impact of the color of the selected bricks and the overall scanning accuracy in the scanning process. As a result, they concluded that these devices may be suitable for low-accuracy industrial applications.

In the study conducted by Luetzenburg et al. (2021), the use of Apple LIDAR for the 3D scanning of rocks and cliffs for geological purposes was examined. The team concluded that Apple LIDAR represented a groundbreaking innovation.

Gollob et al. (2021) utilized Apple LIDAR for forest inventory purposes. They compared the application results obtained through a specific acquisition strategy with the traditional measurement approach. The results suggested that LIDAR is more flexible and faster compared to traditional methods.

Murtiyoso et al. (2021) presented the initial evaluation of Apple LIDAR for documenting cultural heritage. The data obtained with the Apple device were compared with close-range photogrammetry or TLS datasets. The authors found Apple LIDAR promising for cultural heritage documentation but noted that the resulting point cloud was highly noisy.

Díaz-Vilariño et al. (2022) observed the 3D modeling capability of Apple LIDAR in two indoor rooms and an outdoor environment. They compared the data obtained with LIDAR to Building Information Modeling (BIM) and TLS, concluding that LIDAR's ability is limited for large objects but provides more suitable results for small objects.

King et al. (2022) examined the ability of Apple LIDAR to track changes in snow depth in small areas of up to 5 $m^2$. The team concluded that, by comparing LIDAR's effectiveness at low temperatures with ruler measurements, LIDAR is cost-effective and easily portable.

Balado et al. (2022) utilized Apple LIDAR for outdoor research on cultural assets and compared it with two other LIDAR sensors. The authors emphasized that Apple LIDAR provides a good balance between low cost and achieved results. However, they noted that the resulting point cloud is not suitable for curvature analysis.

The use of LIDAR added to phones and tablets for geo-spatial data has become an important tool to support the work of experts in various disciplines and reach a broader audience (Tavani et al., 2022).

In this study, our primary objective is to assess the effectiveness of the LIDAR technology integrated into the iPhone 14 Pro Max (model of the smartphone) for documenting cultural heritage, with a particular focus on the 3D point cloud reconstruction of the soldier relief located in the M16 rock tomb of the Sanliurfa Kızılkoyun

Necropolis. By comparing the point cloud obtained through the LIDAR sensor with data acquired through terrestrial photogrammetry, we aim to provide valuable insights into the applicability and potential advantages of LIDAR in the documentation of intricate cultural artifacts.

## 2. Method

In the methodology section, information about the study area has been provided, and the equipment used has been introduced; subsequently, details about LIDAR scanning and S*f*M (*Structure from Motion*) processing have been explained.

### 2.1. Study Area

Necropolises are burial grounds located outside the city center in ancient Greek and Roman cities. This term is derived from the Greek words "Nekros" (dead) and "Polis" (city). Necropolises were used by ancient societies to bury their dead and show respect to them. These burial grounds were typically situated outside the city walls and hosted various religious ceremonies. Necropolises hold significant importance in the cultural and archaeological heritage of ancient civilizations (Tel and Yüksel, 2017).

Necropolis is one of the most significant remnants of Ancient Greek and Roman culture (Öztürk Tel et al., 2017). Geologically carved from easily workable limestone, the necropolis hill contains reliefs, mosaics, wall inscriptions, and sarcophagi. The graves are dated between the $2^{nd}$ and $4^{th}$ centuries.

Sanliurfa Metropolitan Municipality has implemented an environmental arrangement and expropriation project to promote the tourism potential of Kızılkoyun Necropolis. As a result of the expropriation efforts carried out at Kızılkoyun Necropolis, 389 informal settlements were demolished. Archaeological excavations and cleaning activities conducted by Sanliurfa Museum Directorate revealed 105 rock tombs. The efforts on the area shown in ''Fig. 2'' were completed in 2017, and it was opened to visitors in 2020. Since its opening, this ancient necropolis has been visited extensively by both local and foreign tourists. The study area is depicted in ''Fig. 2''.


**Figure 2.** Study area.

Necropolis' tomb chambers are typically square planned. Within the rock tomb chambers, there are varying numbers of benches (clinai) based on the burial needs of that era. These clinai include burial beds, and the deceased are placed inside them, covered with a lid stone. Additionally, some tomb chambers feature reliefs depicting mythological and religious scenes. In these burial grounds, various gifts are left next to the deceased, and sacrificial rituals are periodically performed. Kızılkoyun, as one of the significant necropolises of Şanlıurfa, stands out with its unique characteristics in terms of tomb sizes, decorations, and artifacts.

M16 numbered rock tomb, which holds special significance within the Kızılkoyun Necropolis Area and has been selected as the study area, has the following features briefly outlined. The entrance gate of the M16 Rock Tomb is damaged. The single-chamber tomb has a square plan and includes 5 arcosolia. There is a relief in the arcosolium on the east side. In the relief, a man lying on a clinai holding a cup is depicted on the far right, a male child immediately to the left, and two women on the far left. Additionally, on the north wall of the room, there is a relief of a soldier wearing a helmet and holding a sword. This soldier relief has been selected as the bas-relief sculpture to create the point cloud. The soldier relief sculpture is shown in ''Fig. 3''.

This study focuses on the selected research area, the Kızılkoyun Necropolis Archaeological Site. Located on the slopes of Tilfindir Hill in Sanliurfa, Kızılkoyun Necropolis is bordered by the Yenimahalle archaeological area to the east, Haleplibahçe archaeological park area to the west, and Sanliurfa Castle and Balıklıgöl to the south. Its central location within the city and surrounded by archaeological sites enhances the value of the research area (Tel and Yüksel, 2017).

**Figure 3.** Historical soldier relief

## 2.2. Equipment

The production of the model is divided into two stages: fieldwork and office work. The photos of the relief sculpture located north of the M16 rock tomb were taken with a Canon EOS 2000D camera, as shown in "Fig. 4''.


**Figure 4.** Camera used.

The technical specifications of the camera are provided in ''Table 1''.

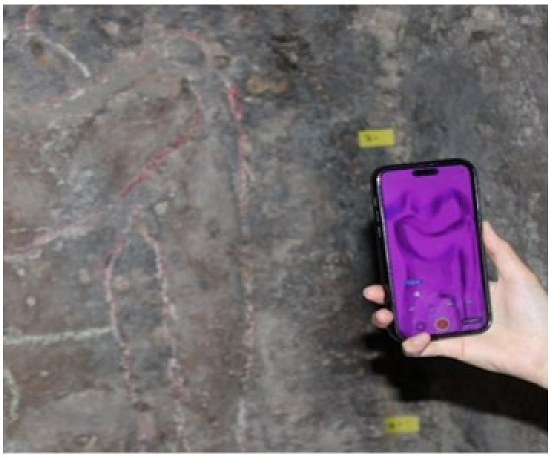
**Table 1.** Camera features

| | |
|---|---|
| Camera manufacturer | Canon |
| Camera model | Canon EOS 200D |
| F-stop | f/7.1 |
| Exposure time | 1/25 sec. |
| Focal length | 18 mm |

A total of 67 photos were taken with the mentioned camera. Care was taken to ensure that the images overlapped during the photo shoot. High-resolution photos from different angles were obtained to capture all the details of the relief. The photos obtained at this stage will form the visual dataset used in the subsequent photogrammetric modeling process. The distances between the markers attached around the relief were measured and recorded in meters at this stage.

Later, scanning was performed using the iPhone 14 Pro Max mobile device to create a point cloud that will be generated using LIDAR data. Various applications, such as Pix4D Catch, Scaniverse, 3D Scanner App, and Polycam, can be found on the Apple App Store for using LIDAR scanning. The 3D Scanner App was preferred for scanning. Among LiDAR-based applications, the Scanner App is a successful application with a user-friendly interface, quick guidance, fast processing capability that allows direct viewing of results in the field, impressive texture mapping features, and overall success in providing accurately scaled models (Tavani et al., 2022). The interface of the LIDAR sensor and the scanning application on the device is shown in ''Fig. 5''.


(a)



(b)

**Figure 5.** LIDAR sensor of the used device (a), Interface of the scanning application (b).

## 2.3. LIDAR scanning and *Sf*M processing

LIDAR scanning parameters are critical factors that impact the accuracy, details, and overall performance of the obtained data (Dörtbudak et al., 2023). Each selected parameter determines how effective LIDAR technology is in specific applications. Depending on the application needs, choosing the correct parameters is crucial. The scanning parameters used in this study are shown in ''Table 2''.

**Table 2.** Scanning parameters used.

| | |
|---|---|
| Resolution | 5 mm |
| Distance | 1,2 m |
| Processing Method | HD |

The LIDAR scanning process with the iPhone took an average of 15 minutes.

During the scanning, the following points were taken into consideration:

• The phone was held upright to ensure the front side of the sensor is visible.

• Care was taken to avoid shadow situations.

• LIDAR sensors have a specific working range, so during scanning, the sensor was ensured to be at a

• Attention was paid to avoid areas with no scanning or excessive overlap in the scanned regions.

Office work has commenced after completing field studies. In this stage, specialized software was used for processing the photos. The software analyzes the photos, identifies common points, and reconstructs three-dimensional structures based on this data. The images obtained from the camera were processed using Agisoft Metashape, an independent software that provides essential capabilities for photogrammetric processes on digital images. The software utilizes Structure from Motion (S*f*M) technique to process the photos. Structure from Motion (S*f*M) refers to the process of creating three-dimensional objects from a series of two-dimensional images (Polat and Akca, 2023). S*f*M is used in various applications such as 3D scanning, augmented reality, simultaneous localization, and mapping (*SLAM*), and mapping (Korumaz et al., 2011; Yılmaz et al., 2008). S*f*M can achieve faster results compared to other methods, model various objects regardless of their size, and utilize high-resolution images. Therefore, it is a suitable technique for tasks requiring precise measurements (Berra and Peppa, 2020).

Like any technique, S*f*M has its advantages and disadvantages. The advantages are generally as follows:

• It can create models using equipment such as cameras or phone cameras, which reduces costs due to its low equipment requirements.

• It can produce results faster compared to other methods.

• Its ability to model various large or small objects expands its range of applications.

• The use of high-resolution images makes it suitable for tasks requiring precise measurements (Dörtbudak et al., 2023).

However, there are some disadvantages:

• It requires precise parameters for alignment and overlap. Inconsistent parameters can result in low-quality models (Polat et al., 2022)

• It cannot produce reliable results in adverse weather conditions, reflections, and shaded areas.

• The data processing time is time-consuming and requires high-performance computers due to its dependence on high-resolution images (Özcan, 2017).

• Storage issues may arise for the generated data.

The evaluation and processing of images result in the creation of a point cloud.

## 3. Results and Discussion

A 3D point cloud has been created using SfM. The generated dense point cloud and the locations of the photo captures can be seen in ''Fig. 6''.

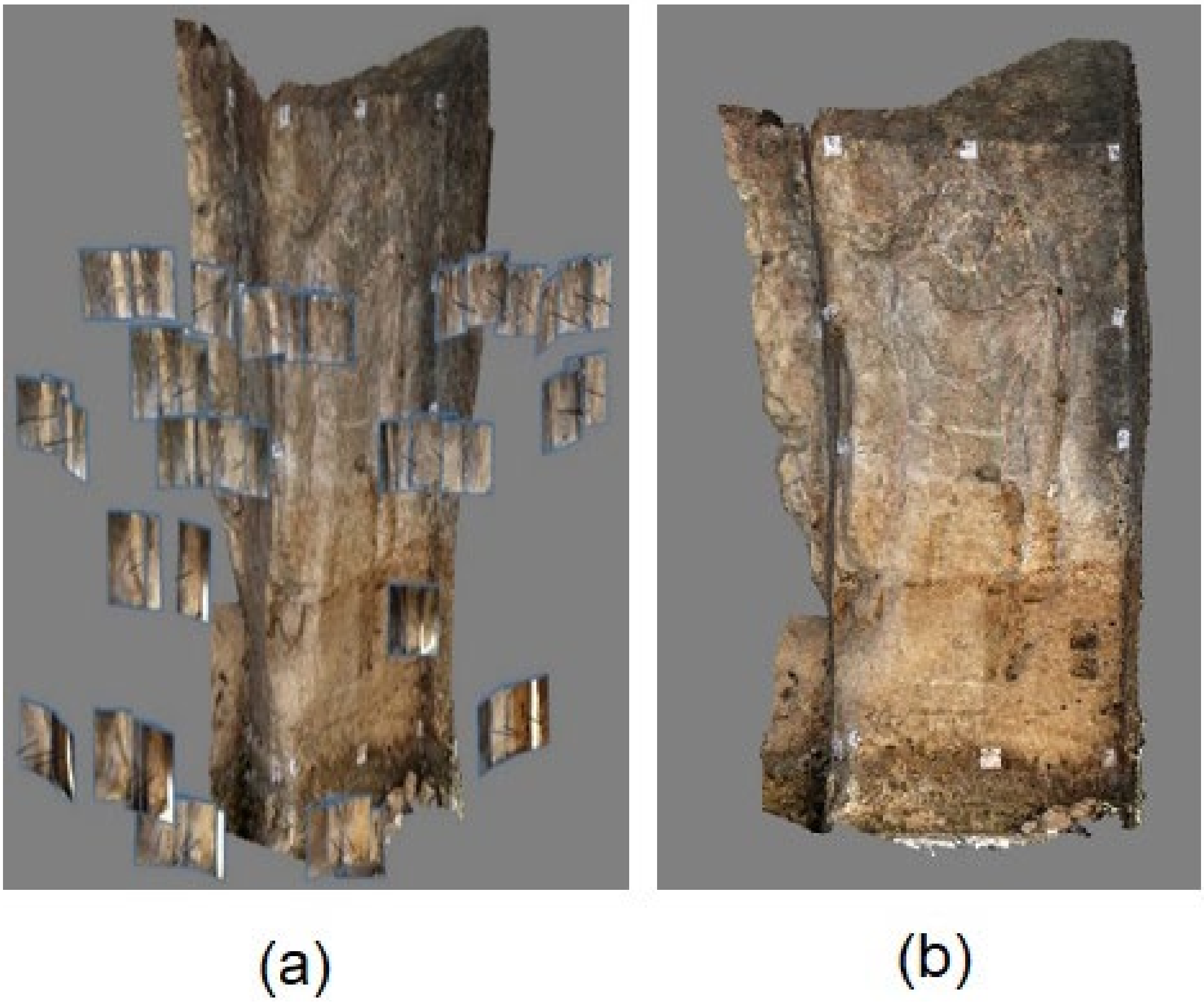



**Figure 6.** Image capture locations (a), Generated dense point cloud (b)

The point cloud created with photogrammetric technique contains more than 2 million colored points. The generated point cloud includes colored points marked with '80,000'. The same relief sculpture was scanned with the LIDAR Advanced mode of the iPhone. The resulting point cloud is shown in ''Fig.7''.

**Figure 7.** Point cloud obtained by LIDAR scanning.

The point cloud created using the iPhone LIDAR sensor is sparser compared to the *Sf*M point cloud, containing over 80,000 points.

When evaluating ''Fig. 6'' and ''Fig. 7'', it can be observed that the point cloud obtained with photogrammetry is denser.

Having more point cloud data often results in a more detailed and accurate 3D model. However, having more points doesn't always mean better; it depends on the use case and requirements. More dense point clouds can be used for detailed modeling. Having more points enables capturing the surfaces of objects more precisely and with finer details. This feature is particularly useful for accurately modeling objects with complex or intricate details. It also ensures that the obtained model is closer to real-world objects, contributing to more accurate measurements and analyses. However, obtaining more point cloud data comes with some disadvantages. More points mean larger datasets, requiring more resources for storage, processing, and analysis, which can increase the processing difficulty. Additionally, obtaining more points usually takes more time and may incur higher costs. This situation can lead to longer fieldwork or the need for more advanced equipment.

The information regarding processing time and the number of generated points for the used techniques is provided in the ''Table 3''.

**Table 3.** Processing time and number of points for used techniques.

| Technique | Processing Time | Number of Generated Points |
|---|---|---|
| Photogrammetry | 20 minutes | 2 million |
| LIDAR | 15 minutes | 80,000 |

Both datasets have been scaled using markers. The visual representation of the markers used is shown in ''Fig. 8'', and the distances between the markers are provided in ''Table 4''.

**Figure 8.** Markings on the relief statue.

**Table 4.** Distance between markers.

| Sign Number | Distance |
|---|---|
| 12-14 | 95 cm |
| 14-4 | 190cm |
| 4-2 | 106 cm |
| 2-12 | 189 cm |

The markers in CloudCompare software were used for registration. Following the registration process in CloudCompare, the Cloud-to-Cloud Distance module *(C2C)* was utilized to detect differences between overlapping point clouds. The *"C2C module"* of CloudCompare is employed to compare and analyze point clouds efficiently. This module provides the capability to compare, align, and analyze two or more-point clouds quickly and effectively. This feature can be utilized in various applications, such as determining similarities or differences between point clouds obtained at different times or with different sensors, understanding relationships between objects, or monitoring changes. In this process, the photogrammetric point cloud, being denser and more comprehensive, was considered as the reference. The C2C results are presented in ''Fig. 9'' .

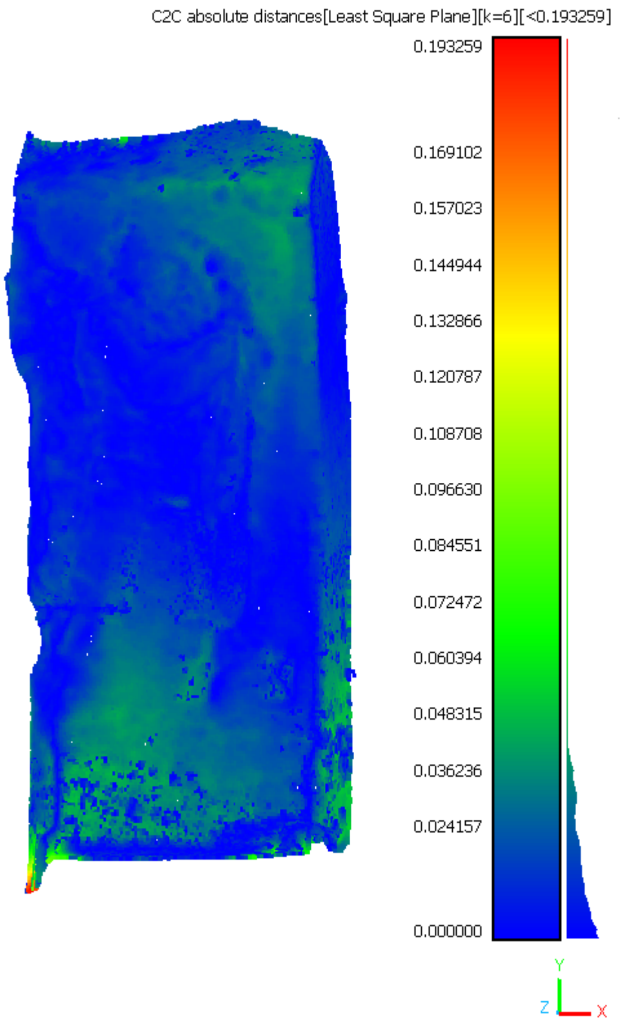



**Figure 9.** Result of C2C.

In terrain modeling, archaeology, or industrial measurement applications, a good overlap between point clouds ensures more reliable and accurate results. Upon examination of ''Fig. 9'' , it is evident that both point clouds significantly overlap. The average difference between the two point clouds is calculated as 1.5 cm, with the highest difference being 19 cm. The resulting 19 cm difference is attributed not to the relief sculpture but to the surrounding walls and floor. Therefore, the overlapping process performed using markers can be considered successful. Additionally, point clouds can be utilized for assessing the integrity of the object.

3D models also have an important place in the documentation of cultural heritage. especially with the virtual reality augmented reality internet-based virtual museum and 3D printing technology, the modeling of cultural heritage has become more important. in this context, 3D models have also been obtained from the point clouds obtained. 3D solid models are shown in ''Fig. 10''.

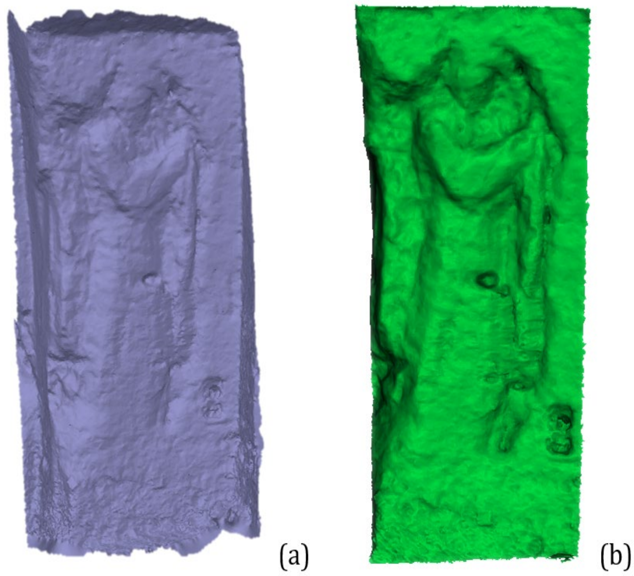



**Figure 10.** 3D solid models: (a) Photogrammetry and (b) Lidar.

when both models are examined, it is clearly seen that the integrity of the relief is ensured. In this sense, it is foreseen that both methods can be used in digital documentation. at this point, it should be noted that the point cloud can be densified according to the number of details sought. Depending on this, the level of detail in the 3D model can be also increased. Or vice versa, if a situation is sought, it is possible to obtain a coarser surface by making the point sparse or smoothing in the 3D model. This situation may vary according to the level of detail needed for the purpose of the study, the way the final product is presented and the storage capacity.

The comparison between iPhone LIDAR technology and photogrammetry in the conducted study reveals the following:

Advantages of LIDAR Technology:

- LIDAR technology enables the rapid and precise measurement of distances, allowing for the creation of detailed point clouds and 3D maps.
- iPhone LIDAR is effective in low-light conditions, providing an advantage, especially in night photography.
- iPhone LIDAR can be utilized for more accurate object perception, particularly in augmented reality (AR) applications.
- The fast data collection capability of LIDAR allows for quick scanning of scenes.
- iPhones typically have multiple cameras, providing the opportunity to capture images from various angles.

Advantages of Photogrammetry:

- Photogrammetry can create detailed models using high-resolution images and might be preferred for projects requiring high resolution.
- Photogrammetry results can be influenced by sunlight and shading conditions.

Challenges and Considerations:

- Traditional photogrammetry methods may require more time and effort for data collection and processing.
- The use of LIDAR technology can increase the cost of the device, making LIDAR-equipped iPhones generally more expensive.
- LIDAR technology is not universally applicable in all applications, limiting the available options for users.
- LIDAR sensors may experience sensitivity issues due to the reflective properties of surfaces and objects, especially when working with objects with low reflectance capacity. Performance issues may arise, but these challenges may be addressed or mitigated as technology and applications evolve.

## 4. Conclusion

This study delves into the vital endeavor of documenting historical artifacts and cultural heritage, focusing on innovative techniques for precise and reliable data collection. Centered on the Kızılkoyun Necropolis, the research employs photogrammetry and LIDAR techniques. In the photogrammetric process, we captured overlapping high-resolution photos, while LIDAR scanning was executed using the iPhone 14 Pro Max equipped with a LIDAR sensor and a dedicated scanning application.

The results demonstrate successful data collection, revealing minimal differences in point cloud data between the two methods. Utilizing 62 photos, photogrammetry generated a dense point cloud, whereas LIDAR scanning produced a point cloud with meticulous details. Integration of markers into both datasets proved effective in achieving high accuracy and integrity. Comparative analysis indicates an average difference of only 1.5 cm, primarily attributed to the surrounding walls and floor rather than the relief sculpture itself.

Each method presents distinct advantages and disadvantages, catering to specific contexts. LIDAR excels in speed and precision, while photogrammetry stands out for its extensive image range and detailed resolution. This study underscores the potential of modern technologies like photogrammetry and integrated LIDAR in smartphones for cultural heritage documentation.

Furthermore, it stresses the importance of these methods in providing an easier, faster, and more effective way to document cultural heritage sites compared to traditional methods. Photogrammetry significantly contributes to precise and efficient documentation through accurate point cloud creation, while integrated LIDAR in smartphones introduces a new perspective with its portability and user-friendly interface.

Looking ahead, future studies should delve into refining these methods, addressing encountered limitations, and exploring new approaches for cultural heritage preservation. Reflecting on these findings, this study contributes not only to the specific cultural site investigated but also to broader discussions within the field of cultural heritage documentation. Acknowledging limitations, the research maintains transparency, while emphasizing the potential societal impact through public outreach and education. By minimizing the risk of damage to historical artifacts, this study ensures the intergenerational transfer of knowledge, fostering appreciation for cultural heritage.

## Author contributions

The authors declare that they have contributed equally to the article.

## Conflicts of interest

There is no conflict of interest between the authors.

## Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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