Cultural heritage modelling using UAV photogrammetric methods: a case study of Kanlıdivane archeological site

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Abstract

Turkey has hosted many civilizations throughout history. Therefore, it has a diverse cultural heritage inventory. Atmospheric conditions, natural disasters and unconscious people constantly damage the structures. It is vital to document the artifacts in such circumstances in order to conserve them and transfer them to the future generations. Cultural heritage protection, preserving these assets and transmitting them to the future generations are the human duty. Remote sensing techniques such as unmanned aerial vehicle is a very beneficial tool to obtain information without touching the object. Kanlıdivane archeological site hosts many ancient buildings. Within the scope of this study, the UAV photogrammetry method was used to create the 3D point data and solid model of the Monumental Tomb of Aba built in the 2nd century AD, located in the Kanlıdivane region of Mersin province in Turkey. Images were taken with Parrot Anafi HDR unmanned aerial vehicle and a 3D model was produced. Detailed length, area, volume and coordinate measurements were made on the model obtained and verified with Agisoft Metashape and Context capture. Floor perimeter, floor area and volume of the monumental tomb are also presented in the results section. These findings can be used in restoration in future.

1. Introduction

Aba's Monumental Tomb, which is an ancient artifact built in the 2nd century AD and located in the Kanlıdivane region of the Mersin province of Turkey, has coordinates 36° 31' 38.5" north, 34° 10' 37.4" east. The location of the tomb is shown in Figure 1.

It is the most magnificent mausoleum of Kanytella. According to the inscription on the door of this monumental tomb, which was built in the type of Roman temples, it was built by a woman named Aba for herself and her husband Arios. The tomb monument was built on a low podium. There is a vaulted entrance on the front facade. There are Corinthian plaster caps on the four corners of the tomb. The tomb is dated to the 2nd century AD based on the inscription on it and other tombs [1].

The Monumental Tomb of Aba can be found north of the geological pit in the region. It is one of Kanlıdivane's most well-known landmarks. The building's principal construction method is cut stone masonry, with mortar as the binding material. The roof of the superstructure is shaped like a gable and is coated in stone. It's supported by a cut-stone barrel vault, which is subsequently filled with rubble stone to create a flat roof surface. The vault marks the main chamber's entrance on the south facade, which is topped by a pediment at roof level [2].

Figure 1. Location of the Aba's Monumental Tomb on the map of Turkey

The last row of cut-stones in masonry walls was built in architrave style, with Corinth capital styling on the corner stones. Although the architectural integrity of the building has been retained, there are serious issues with the scale of the structure. The west and north walls, in particular, have material deterioration and structural deformations. On the north wall, there are serious fissures that have split the stone components in half. This graphic depicts the likelihood of a high impulse being triggered by lateral pressures or settlement issues. The structural degradation danger has been confirmed by external forces because the monument is placed extremely close to one of the site's geological discontinuity lines. The monument should be included in an architectural conservation program as soon as possible, before it loses its structural integrity, as it is one of the few examples of architectural and structural unity that still exists [2].

In a study, Roman tombs were examined in detail and the features of the mausoleum of Aba at Kanytellis were comprehensively presented [3].

UAV photogrammetry is one of the methods widely used within the scope of documentation of cultural heritage. Generating a three-dimensional model of Gözne Castle, a medieval castle [4], obtaining a 3D photogrammetric model of a historical inn [5] mausoleum [6] and a ruin [7] are some of the examples of documenting cultural heritage with photogrammetric methods.

UAV photogrammetry also can be used in most of the engineering projects. In the last decade UAV has been used in rockfall [8], landslide studies [9-10], shoreline detection [11], pond volume [12] and energy line measurement [13] are some of the examples.

2. Method

This study consists of two phases, namely field and office work. The steps of controlling the study area, preparing it for photographing and taking images of the monumental tomb with an unmanned aerial vehicle constitute the field study phase. In the office work phase, the steps of transferring the data received from the unmanned aerial vehicle to the computer environment and interpreting and processing were carried out.

2.1. Field work

At this stage of the study, first of all, necessary permissions were obtained to fly in the Kanlıdivane region, which is the study area. Then, the flight altitudes at which images will be taken around the tomb were determined. Images were taken with a Parrot Anafi HDR drone (Figure 2a) by manually. The technical specifications of the unmanned aerial vehicle used are shown in Table 1.

The circumference of the mausoleum, which is approximately 50 km away from Mersin, is roughly 31.5 meters, and its sitting area is around 61 square meters. Every detail of the structure was tried to be captured by flying first at low altitude and then at high altitude. A total of 101 images were taken. Some of the images of the monumental tomb taken are shown in Figure 2b.

<table>
<tr><td>(a)</td><td>(b)</td></tr>
</table>

Figure 2. a) Parrot Anafi HDR UAV **b**) Images of Aba's Monumental Tomb

Table 1. Technical specifications of the UAV [14]

Feature	Value
Drone	
Size folded	244x67x65 mm
Size unfolded	175x240x65 mm
Weight	320 g
Max transmission range	4km with controller
Max flight time	25 min
Max horizontal speed	15 m/s
Max vertical speed	4 m/s
Max wind resistance	50 km/h
Service ceiling	4500m above sea level
Operating temperature	-10°C to 40°C
Lens	
Sensor	1/2.4'' CMOS
Aperture	f/2.4
Focal length (35 mm eq.)	23-69 mm (photo)
Depth of field	1.5 m - ∞
ISO range	100-3200
Digital zoom	up to 3x (4K Cinema, 4K UHD, FHD)
Photo resolution	21MP (5344x4016) / 4:3 / 84° HFOV

2.2. Camera calibration

The camera used must be calibrated beforehand so that the merging and overlay operations of the images can be of high accuracy. It was mentioned in the previous section that there is a 5.92 mm sensor in the unmanned aerial vehicle used in this study. Images have a size of 4608x3456 pixels. Camera calibration was done in Context Capture software. Figure 3 shows the distortion parameters obtained as a result of camera calibration:

	Focal Length [mm]	Focal Length Equivalent 35 mm [mm] ⓘ	Principal Point X [pixels] ⓘ	Principal Point Y [pixels] ⓘ	K1 ⓘ	K2	K3	P1	P2
Previous Values	4.00	24.32							
Optimized Values	3.83	23.30	2323.59	1729.81	-0.0019	0.0078	-0.0069	0.0034	0.0003
Difference Previous / Optimized	-0.17	-1.02							

Figure 3. Camera calibration parameters

2.3 Office work

After the completion of the image acquisition within the scope of the field work, the office work phase was started. First of all, the data obtained from the field were transferred to the computer environment. The image file obtained after the flight took up 457 MB in total. Data processing was done in Bentley's Context Capture software. The office work, which was started after half a day of field work, was completed in one day. The positions of the images taken relative to the mausoleum are shown in Figure 4.

Figure 4. The positions of the images taken

All the photos taken were used in the processes. Generic block type was chosen for the aero triangulation process of the images based on experience from previous studies. No control point was used in this study. Positioning metadata of the images were utilized for rigid registration. High key points density option was selected. This step took only 5 minutes and 17 seconds. In the aero triangulation process, 45125 tie points were formed. 31719 key points per image were detected by the software. Overlay error values of the photos are presented in the results section.

After aero triangulation step, reconstruction process was initiated by generic selection of matching pairs. Extra geometric precision (tolerance of 0.5 pixel in input photos) option was applied. In order not to deviate from the original geometry of the tomb, small hole-filling option was implemented. Finally, in this step, the spatial frame is reduced, avoiding the modeling of unnecessary regions and the use of excessive computer power. After the aero triangulation process, it took 37 minutes and 31 seconds to obtain the 3D solid model. Computer used in processes has Intel(R) Core (TM) i7-7700HQ CPU @2.81GHz processor, 16 GB of RAM capacity and GeForce Nvidia 1050 Ti 4 GB graphics card.

3. Results and Discussion

After the camera calibration, field studies and office work phases were completed, a 3D solid model of the Aba's Monumental Tomb was obtained. The surface texture was created by using photographs to add visuality to the obtained 3D solid model. Texture compression quality was selected as 100% quality and texture sharpening option was enabled. The three-dimensional model of Aba's Monumental Tomb is presented in Figure 5.

Figure 5. 3D solid model of Aba's Monumental Tomb

The resulting 3D model is in one-to-one scale with the real work. While length measurements can be taken on the model, area and volume calculations can be made at the same time.

It is possible to draw shapes on the 3D model obtained. Area and volume calculations can also be made easily on the drawn curves. As can be seen in the Figure 6a, the area and volume of each stone on the structure can be calculated. Thanks to the high-quality texture of the model, deformations, cracks, gaps and abrasions on the structure can be easily observed. In a possible restoration process, all the stones of the building can be documented in a coordinated manner and the quantities such as area, volume and slope of each stone can be calculated.

Within the scope of this study, the models obtained by UAV photogrammetry were examined separately in ContextCapture and Agisoft Metashape software. Figure 6a and Figure 6b show eight different stones and eight different points selected on the building. In the light of the data obtained from the models in both software, first of all, the coordinates and height values of the points were compared and presented in Table 2-3. In the next step, as can be seen in Table 4, the perimeter and area values of the front surfaces of the selected stones were compared.
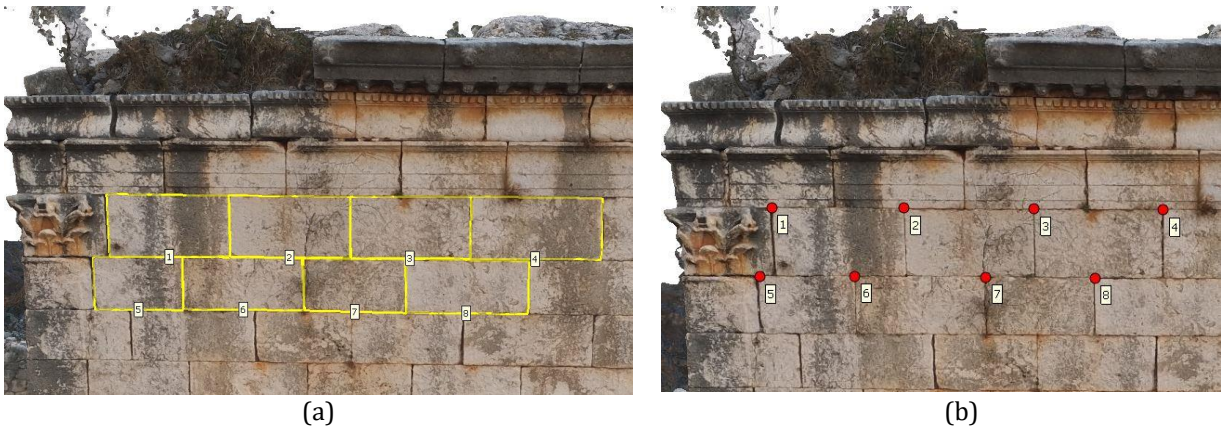
(a)   (b)

Figure 6. a) Drawings on the 3D tiled model **b)** Marked points on the 3D tiled model

Table 2. Information obtained from Context Capture

Point Number	North	East	Elevation (m)
1	36.52736	34.17705	263.35
2	36.52735	34.17705	263.35
3	36.52734	34.17705	263.34
4	36.52733	34.17706	263.33
5	36.52736	34.17704	262.72
6	36.52736	34.17705	262.74
7	36.52735	34.17705	262.73
8	36.52734	34.17706	262.72

Table 3. Information obtained from Agisoft Metashape

Point Number	North	East	Elevation (m)
1	36.52736	34.17704	263.381
2	36.52735	34.17705	263.339
3	36.52734	34.17705	263.299
4	36.52733	34.17705	263.258
5	36.52736	34.17704	262.744
6	36.52735	34.17704	262.725
7	36.52734	34.17705	262.684
8	36.52734	34.17705	262.652

Table 4. The perimeter and area values of the front surfaces

Stone Number	Context Capture		Agisoft Metashape	
	Area [m²]	Perimeter [m]	Area [m²]	Perimeter [m]
1	0.72	3.60	0.73	3.66
2	0.66	3.47	0.70	3.58
3	0.67	3.47	0.70	3.55
4	0.73	3.64	0.75	3.68
5	0.45	2.71	0.47	2.83
6	0.60	3.38	0.63	3.45
7	0.50	2.98	0.53	3.03
8	0.58	3.34	0.60	3.43

Table 5-7 show the root mean square deviation (RMSD) between the coordinate values of both programs. RMSE calculation was made according to Eq. 1.

$$RMSE = \sqrt{\frac{\sum(y_1 - y_2)^2}{n}}$$ (1)

Table 5. RMSD calculation of north coordinates (degree)

North Coordinates			
Context	Agisoft	(y_1-y_2)	$(y_1-y_2)^2$
36.52736	36.52736	2.5E-06	6.25E-12
36.52735	36.52735	2.3E-06	5.29E-12
36.52734	36.52734	2.5E-06	6.25E-12
36.52733	36.52733	2.6E-06	6.76E-12
36.52736	36.52736	1.9E-06	3.61E-12
36.52736	36.52735	2.5E-06	6.25E-12
36.52735	36.52734	2.4E-06	5.76E-12
36.52734	36.52734	2.9E-06	8.41E-12
		RMSE	2.46424E-06

Table 6. RMSD calculation of east coordinates (degree)

East Coordinates			
Context	Agisoft	(y_1-y_2)	$(y_1-y_2)^2$
34.17705	34.17704	4.3E-06	1.849E-11
34.17705	34.17705	5E-06	2.5E-11
34.17705	34.17705	4.4E-06	1.936E-11
34.17706	34.17705	4.7E-06	2.209E-11
34.17704	34.17704	4.9E-06	2.401E-11
34.17705	34.17704	5.1E-06	2.601E-11
34.17705	34.17705	4.8E-06	2.304E-11
34.17706	34.17705	4.4E-06	1.936E-11
		RMSE	4.7085E-06

Table 7. RMSE calculation of elevation values (meters)

Elevation Values			
Context	Agisoft	(y_1-y_2)	$(y_1-y_2)^2$
263.35	263.381	-0.031	0.000961
263.35	263.339	0.011	0.000121
263.34	263.299	0.041	0.001681
263.33	263.258	0.072	0.005184
262.72	262.744	-0.024	0.000576
262.74	262.725	0.015	0.000225
262.73	262.684	0.046	0.002116
262.72	262.652	0.068	0.004624
		RMSE	0.044

The 3D models obtained in both software were transferred to Rhinoceros 7 software and overlap analysis was performed. As can be seen in the Figure 7 and Table 8, 64288 of 888963 points have a high overlap ratio. Although the model dimensions are very close, the algorithms of both programs cannot produce one-to-one overlapping models. Small deviations in the coordinate values greatly affect the overlap of the models.

In addition to all these results obtained within the scope of the study, the floor perimeter, floor area and volume of the mausoleum were also calculated and presented in the Fig. 8. The floor perimeter was calculated as 28.51 meters when measured from the outside. The floor area is 50.04 square meters. The volume value of the mausoleum was calculated as 240.37 m^3.

Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEM is frequently used to refer to any digital representation of a topographic surface. DEM is the simplest form of digital representation of topography. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. Today, GIS applications depend mainly on DEMs [15]. In addition, DEM data of the mausoleum can be seen in order to show that digital elevation models of historical buildings and their

surroundings can be obtained with UAV photogrammetry. Length, area and slope calculations can be made using DEM data. An exemplary length measurement is made in the Figure 9. Slope calculation can be made by using the height difference and horizontal distance value between two points. Thus, detailed measurements of the historical building and its surroundings can be made easily. In addition, at the marked points seen in the Figure 10, stones that were separated from the building over time are seen. Measurements can also be made on these stones and can be used in possible restoration projects.

As a continuation of this study, it is planned to compare photogrammetric data with terrestrial laser scanner data. As a result of the comparison, which method is more suitable for such works will be evaluated in terms of cost, time, efficiency and applicability.
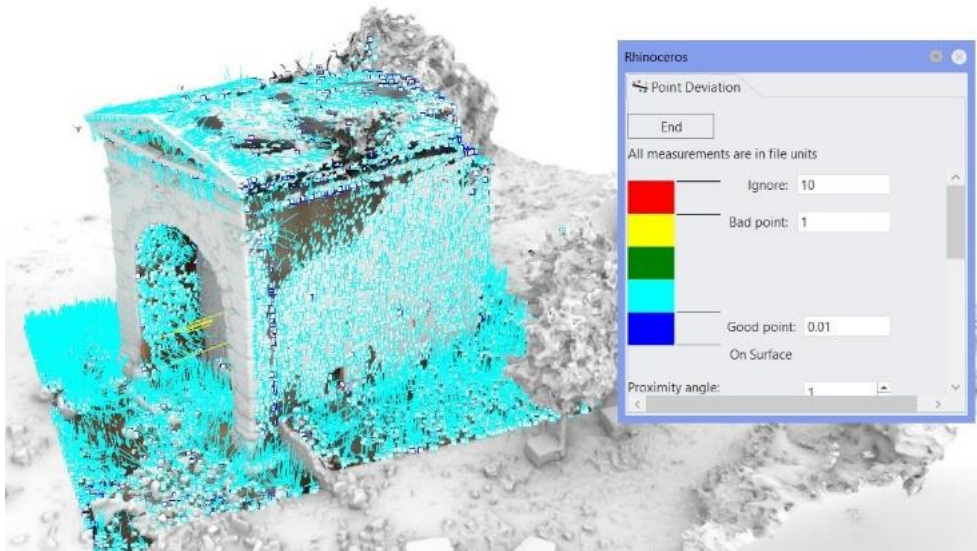

Figure 7. Overlap analysis of the 3D models

Table 8. Point test statistics (m)

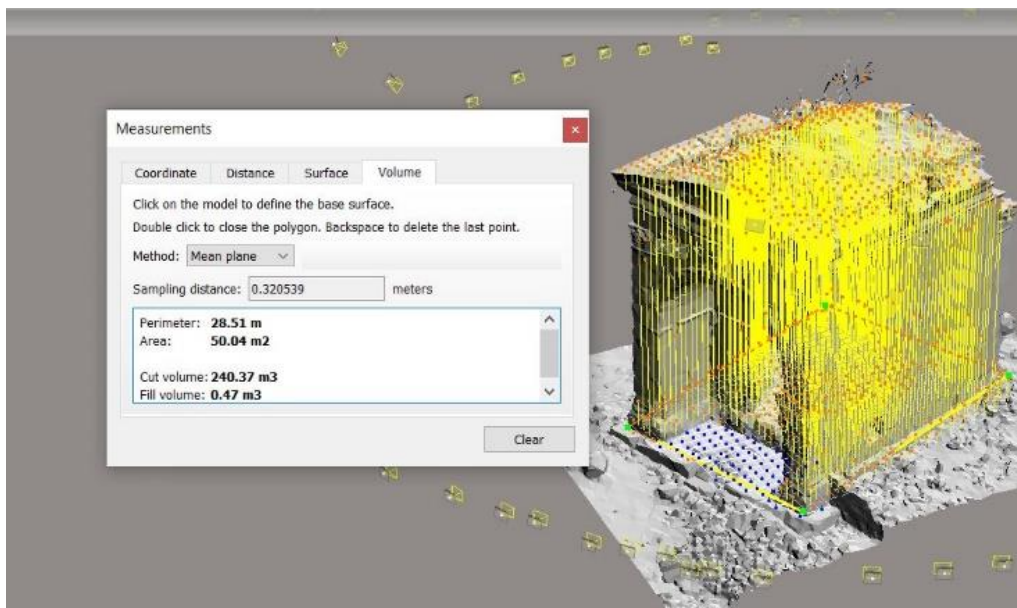|	
Total points	888963
Close point count	64288
Average distance	0.04423805
Median distance	0.03791145
Standard deviation	0.05168753
Maximum distance	1.240013
Minimum distance	2.311686E-06

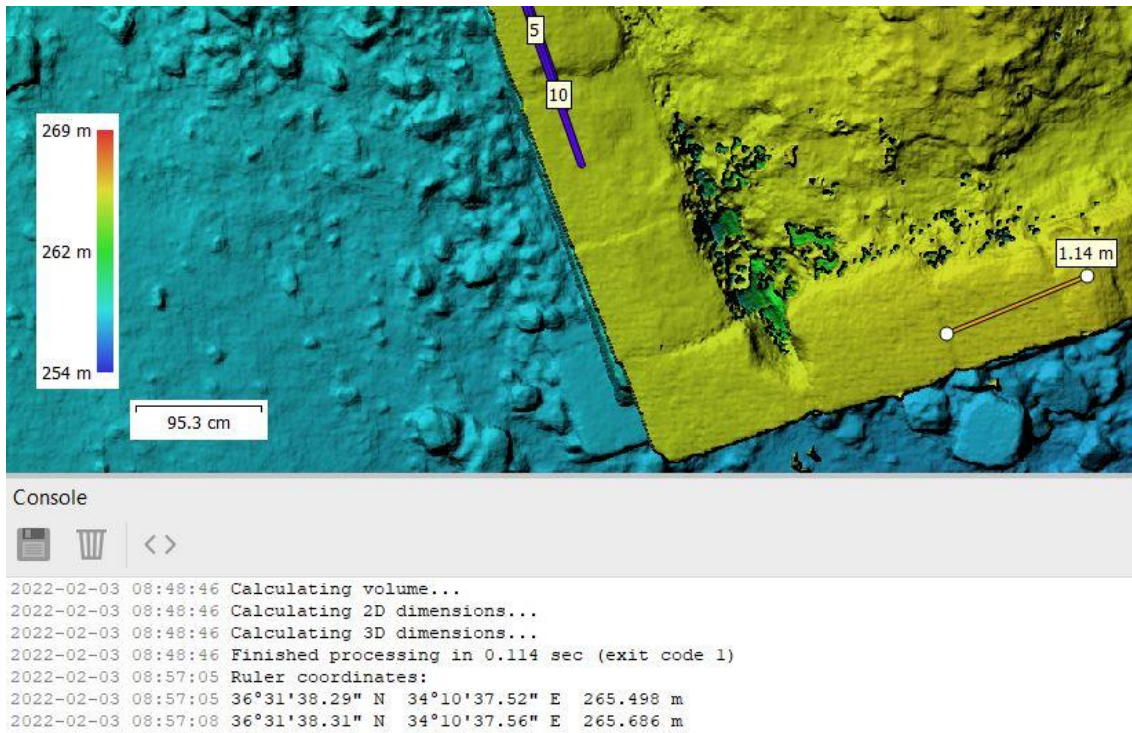**Figure 8.** Area and volume calculations of the tomb
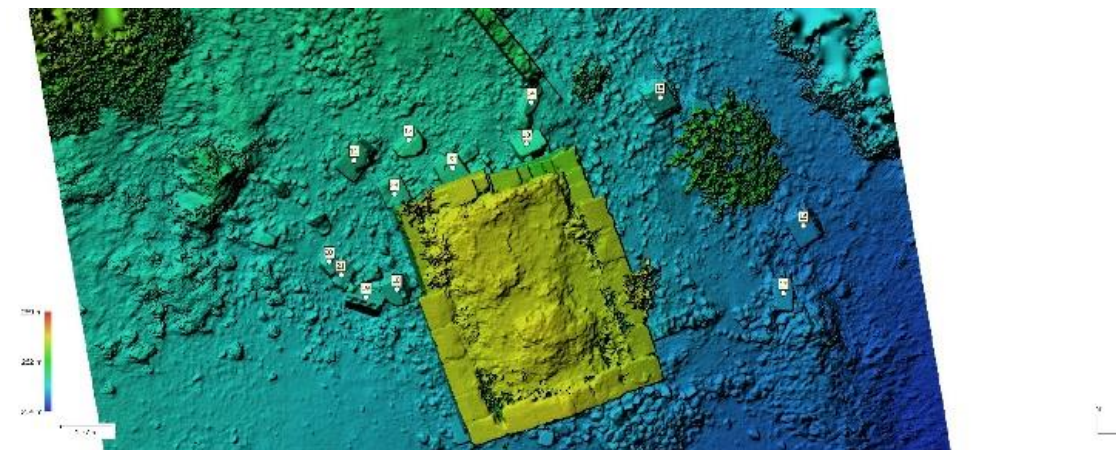
Figure 9. Measurements on DEM data

Figure 10. Digital elevation model (DEM) of the tomb

4. Conclusion

In this study, Aba's Monumental Tomb, which is an ancient artifact built in the 2nd century AD and located in the Kanlıdivane region of the Mersin province of Turkey was modeled in 3D using UAV photogrammetry. As a result of obtaining a real-scale model of this artifact, which is of great importance in terms of cultural heritage, the documentation process has been carried out. The data obtained in this study can be used in possible studies by anthropologists, archaeologists and historians. The real-scale 3D model obtained can be utilized in the restoration and repair studies. The 3D model obtained within the scope of this study will also allow the promotion of the work within the scope of tourism activities.

Author contributions

Engin Kanun: Conceptualization, Methodology, Software **Aydın Alptekin:** Data curation, Writing-Original draft preparation, Software, Validation. **Murat Yakar:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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