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3D modeling of historical artifacts with terrestrial photogrammetric method: Roman sarcophagus and tomb stele example

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Abstract

Many societies, civilizations and states have lived on the lands of Anatolia, the cradle of cultures and civilizations, from the past to the present. Each of these civilizations and states has left many works. It is very important to protect the material and moral works left to us, and transfer them to the next generations. Documentation studies should be carried out for this purpose. There are many methods for performing documentation work. The most important of these methods is the studies in the field of photogrammetry. With the photogrammetry method, the objects are modeled in three dimensions (3D) and recorded in the computer environment, and these data can be used at any time for the repair or reconstruction of the work in case of any deformation. The concept of 3D is the concept that emerges by knowing the width, height and height dimensions of the objects. One of the methods that can be used to model objects in 3D is the terrestrial photogrammetry method. With the terrestrial photogrammetry method, after the necessary data are collected from the objects, a 3D model is obtained using various software in the computer environment. In the modeling phase, it is very important to find the appropriate software. In this study, it was aimed to model the sarcophagus and tomb stele from the Roman period in Aksaray Museum using two different software. Agisoft Metashape and Pix4d software were preferred for 3D modeling. The results obtained from the software was compared in terms of the number of photos and the number of point clouds used and location accuracy. It has been observed that the error values found by the square mean error method in Agisoft software are lower than in the Pix4d software. It was observed that the Pix4d software produced more point clouds while modeling. An equal number of photographs were used in modelling.

1. Introduction

Our cultural heritages are assets that bridge between the past and the future and shed light on the past (Yakar & Doğan, 2017). Protecting historical artifacts is everyone's common responsibility. Today, there is still not enough effort to protect our cultural heritage, and many assets were destroyed due to various disasters, neglect or indifference (Yakar & Kocaman, 2017). Therefore, it is very important to document and record these works. At this point, photogrammetry technique has been used frequently for years because it provides data and methods in a fast, efficient, economical and reliable way in archaeological measurements, documentation and 3D modeling applications of cultural heritage (Uslu & Uysal, 2017; Yakar & Yılmaz, 2008).

Many institutions are working to protect the existing historical monuments, to research the past, and to transfer them to future generations in a solid way. The most important places where historical artifacts are exhibited are museums (Güleç, 2007). There are many museums throughout Turkey. It is necessary to protect the works in museums and open spaces from possible harm. These damages can be natural or human factors. It is necessary to make good documentation of historical artifacts against possible damages (Kanun et al. 2021). All of these processes are called documentation. (Georgopulos & Ionnidis, 2004) described documentation of cultural heritage as "measurement, evaluation, recording and presentation processes necessary to determine the current situation, new size, shape and location of a historical or cultural structure in

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a three-dimensional space" (Yakar & Kocaman, 2017). There are various documentation methods used in documenting historical and cultural heritage (Böhler & Heinz, 1999). These methods are; classical manual documentation method, topographic methods, photogrammetric methods and scanning methods (Böhler & Heinz, 1999; Scherer, 2002; Yakar & Kocaman, 2017). The most important of these is the work done in the field of photogrammetry. Photogrammetry means drawing using light. It is to have information about the object and its environment by analyzing and interpreting the sent energy without touching the objects.

The history of photogrammetry dates back to ancient times (Yaşayan et al., 2011). The foundations of photogrammetry were laid with the first photograph taken. One of the most common uses of photogrammetry is the documentation of cultural heritage. Terrestrial photogrammetry method is a highly preferred method in this regard. With the development of digital technology, terrestrial photogrammetry has become more economical and more efficient. Three-dimensional solid models and textured images help to better recognize complex structures (Atkinson, 1996; Bozdoğan et al., 2022).

The advantages of terrestrial photogrammetry method are that the measurement time is short, the results can be reused at any time, and measurements of a distant object can be made (Duran, 2017). Three-dimensional models are obtained by evaluating the energy sent to the objects. Three-dimensional modeling is the modeling of a 3-dimensional object in digital environment (Oruç, 2021).

There are many historical and cultural monuments, including mosques and churches in the city of Aksaray, which was under the rule of Rome, the Seljuk State, many principalities and finally the Ottoman Empire. The software used in documentation is as important as documenting these works. In this study, necessary data were collected from historical artifacts of different sizes with the terrestrial photogrammetry method and these data were modeled in two different software, Agisoft and Pix4d. The results obtained from the software were evaluated in terms of the number of point clouds, the number of photographs and location accuracy.

2. Method

Photogrammetry technique, photographs of the object to be measured and its immediate surroundings or terrain are taken. Desired information can be obtained by measuring their images on the photograph, or these photographic images can be converted into maps or plan formats by using special hardware and software (Yaşayan et al, 2011).

The photogrammetric method applied when the reception center is a point on the ground is called terrestrial photogrammetry. In terrestrial photogrammetry, images obtained by analog or digital recording of electromagnetic rays reflected from objects are evaluated (Yakar & Mohammed, 2016). Terrestrial photogrammetry has been a preferred method for many years. Terrestrial photogrammetry has many applications. One of them is the documentation of cultural heritage and historical artifacts.

In practice, the modeling of the sarcophagus from the Roman period and the tomb stele from the Roman period in the Aksaray Museum were discussed. Aksaray Museum is located in the province of Aksaray Aksaray Museum first operated in the Zinciriye Madrasa in 1969, then moved to its reconstructed building.

The tomb stele used in modeling is located in the garden section of the museum. It was discovered in Musagi/Bozcayurt village. The work made of marble is 100 cm high and 33.5 cm wide. The upper part of the stele, which is in the form of a rectangular prism, is in the form of a saddle. It has a relief bust and 4 rows of inscriptions on it. The face is long and bearded. The forehead is wide. Hair not specified. The eyes are given in the form of almonds. It is surrounded by thick lines. The neck is thick. The body part is carved in low relief (Figure 1).

Figure 1. The tomb stele with three-dimensional modeling.

The sarcophagus is located in the garden section of the museum. Aksaray Ulu Mosque was found in front of the old fountain in 1973. It has dimensions of 153 * 100 * 40 cm. The white thick-grained marble Sarcophagus is rectangular in shape. The monolithic sarcophagus was built without a cover. The front and side faces of the sarcophagus are decorated, while the back is left plain without processing. An evacuation hole was opened on the front side of the sarcophagus in order to be used as an ablution trough at the back. There is calcification on the surface and abrasions especially on the bull heads and upper part. In the upper part, the discharge channel is located at the rear and on the short side on the right. Leaving the reverse side untreated indicates that the sarcophagus was placed against the wall in the necropolis or where it was used (Figure 2).

Necessary permissions were obtained from Aksaray Museum Directorate and Aksaray Provincial Culture and Tourism Directorate before the field studies.

2.1. Field Study

Topcon GPT 3007N Total Station instrument with reflectorless measurement feature was used to obtain the coordinates of the detail points in the field studies (Figure 3), (Table 1).

Figure 2. The sarcophagus with three-dimensional modeling work.

Figure 3. Topcon GPT 3007N Total Station

Table 1. Topcon GPT 3007N Total Station instrument features.

Field of view	1 ° 30
Min. Focal Distance	1,3 m (4,29 ft.)
Measuring Range	1,5 to 250m (5 to 820 ft.)
Measurement Screen	11 digits
Laser Class	Class 1 (for dismount measurement) Class 2 (Laser Mark On)
Battery	4400 mAH
Max working time	Including distance measurement: Approx. 5 hours Angle measurement only: Approx. 10 hours
Charging time	4 hours

Nikon D3500 camera was used to take pictures of the sarcophagus and tomb stele (Figure 4) (Table 2).

Figure 4. Nikon D3500 Camera

Table 2. Technical specifications of the camera

Sensor	24.2MP DX-Format CMOS Sensor
Image Processor	EXPEED 4
video recording	60 fps'de Full HD 1080p
Bluetooth Connection	SnapBridge
ISO	Native ISO 100-25600

Before starting the measurement works, first of all, 7 control points on the tomb stele and 12 control points on the sarcophagus were established with the help of easily distinguishable sign plates in order to determine the coordinate and location accuracy. Point 2 on the grave stele was not included in the analysis studies as it moved during the measurement (Figure 5 and 6).

Figure 5. Checkpoints located on the sarcophagus

Figure 6. Checkpoints on the tomb stele

While determining the points, care was taken to establish the control points homogeneously, taking into account the location, dimensions and shape of the object. Then, 2 polygon points were determined around the objects and random coordinates were given to them.

After the coordinates of the points, the photographs of both objects were taken in an overlay manner. All the data obtained were transferred to the computer environment and the modeling and analysis phase was started.

2.2. Office Work

Agisoft and Pix4d softwares were used for evaluation and 3D modeling for both historical artifacts.

2.2.1. 3D modelling with Agisoft

Agisoft is a software developed to obtain 3D models by using fixed images. The resulting result can be obtained in various formats to evaluate the products in different software (Çağlayan, 2020).

Initially, the photos were transferred to the software. 35 photographs were used for the tomb stele and 127 photographs were used for the sarcophagus. After the orientation process, it was started to mark the points. Afterwards, point clouds and 3D models were obtained by performing other steps (Figure 7, 8, and 9).

Figure 7. Solid model and tiled triangular model created in Agisoft software for the tomb stele.

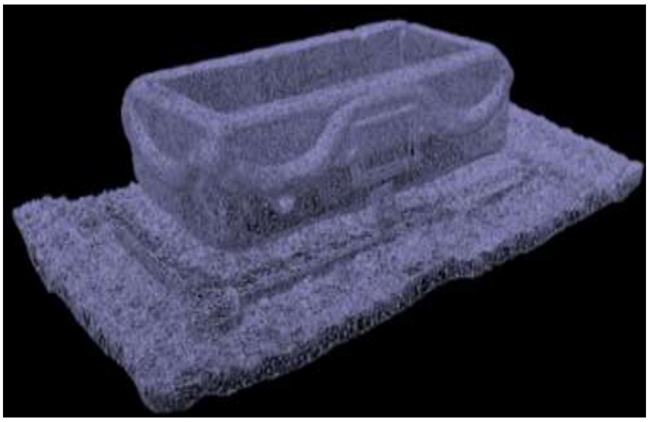

Figure 8. Triangle model for sarcophagus created in Agisoft software

2.2.2. 3D modelling with Pix4D

It is a package software group with various features that uses digital algorithms to model the earth and objects in 3D. It can perform various operations with RGB, NIR, JPG, TIFF and many similar image formats. After the processes, products in various formats can be obtained (Çağlayan, 2020).

The photos have been transferred to the software. 35 photographs were used to model the tomb stele and 127 photographs were used to model the sarcophagus. Detail points are automatically extracted from the photos. Reciprocal points matching has been performed. Afterwards, the balancing process was started. Other stages of the software were applied and point clouds and 3D models were created (Figure 10 and 11).

Figure 9. 3D model for the sarcophagus created in Agisoft software.

Figure 10. 3D model for the tomb stele obtained in Pix4d software

3. Results

The values obtained from the field and the modeling results were compared in terms of the number of point clouds, the accuracy of the coordinates and the ease of use of the software.

Both works were modeled in Agisoft and Pix4d programs. Different numbers of point clouds were obtained from each modeling. The numbers are given in "Table 3".

Figure 11. 3D model of the sarcophagus obtained in Pix4d software

Table 3. Number of point clouds in tomb stele and sarcophagus

	Tomb stele point cloud	Sarcophagus point cloud
Agisoft software	952.233	2.637.960
Pix4d software	2.613.369	8.136.240

The mean square errors of the points were calculated by using the coordinate values (X) obtained from the field and the coordinate values (L) obtained from the software. First, the differences of the coordinates were taken (Equation 1), then the mean square errors were found (Equation 2) using the differences (V) and measurement numbers (n), and finally the mean squared errors in the x, y, z directions (Equation 3) were calculated.

$$V = L - X \tag{1}$$

$$m = \pm\sqrt{\frac{[VV]}{n-1}} \tag{2}$$

$$m_{xyz} = \sqrt{m_x^2 + m_y^2 + m_z^2} \tag{3}$$

The coordinate differences of the tomb stele obtained from the field and Agisoft software are given in Table 4. Mean square errors are given in Table 5. Coordinate differences obtained from Pix4d software are given in Table 6. Mean square errors are given in Table 7.

Table 4. Coordinate differences of the tomb stele obtained from the land and Agisoft software

	Vi Differences (mm)			ViVi Differences (mm)2		
	Vx	Vy	Vz	VxVx	VyVy	VzVz
1	-1.7	3.4	-4.4	2.89	11.56	19.36
3	0.6	0	4.4	0.36	0	19.36
4	0.9	1.4	0.8	0.81	1.96	0.64
5	2.3	0.9	-2.7	5.29	0.81	7.29
6	-1.8	-1.8	-2.4	3.24	3.24	5.76
7	-0.4	-4.6	4.8	0.16	21.16	23.04

Table 5. Accuracy analysis results of the 3D model of the tomb stele for Agisoft software

	Vi Differences (mm)		
	Vx	Vy	Vz
Vmin	0.4	0	0.8
Vmax	2.3	4.6	4.8
Vavg	1.3	2.1	3.3
m	1.60	2.78	3.88
mxyz	±5.03		

Table 6. Coordinate differences of the tomb stele obtained from the field and Pix4d software.

	Vi Differences (mm)			ViVi Differences (mm)2		
	Vx	Vy	Vz	VxVx	VyVy	VzVz
1	-6	5	-5	36	25	25
3	-3	0	3	9	0	9
4	4	1	-1	16	1	1
5	4	3	-3	16	9	9
6	-6	-4	1	36	16	1
7	3	-5	9	9	25	81

Table 7. Accuracy analysis results of the 3D model of the tomb stele for Pix4d software.

	Vi Differences (mm)		
	Vx	Vy	Vz
Vmin	3	0	1
Vmax	6	5	9
Vavg	4.3	3	3.7
m	4.94	3.90	5.02
mxyz	±8.05		

The coordinate differences of the sarcophagus obtained from the field and Agisoft software are given in Table 8, mean-square errors in Table 9, coordinate differences obtained from Pix4d software in Table 10 and mean-square errors in Table 11.

Table 8. Coordinate differences obtained from the land of the sarcophagus and Agisoft software.

	Vi Differences (mm)			ViVi Differences (mm)2		
	Vx	Vy	Vz	VxVx	VyVy	VzVz
1	-0.3	0.6	0.2	0.09	0.36	0.04
2	-0.3	0.4	0.4	0.09	0.16	0.16
3	2.2	-0.9	-1.3	4.84	0.81	1.69
4	1.5	1.7	-0.9	2.25	2.89	0.81
5	-1.3	1	0.8	1.69	1	0.64
6	3.8	1	0.3	14.44	1	0.09
7	-0.8	1.3	0.1	0.64	1.69	0.01
8	-1.7	0.4	-1.2	2.89	0.16	1.44
9	1.9	1.5	2	3.61	2.25	4
10	1.9	-2.1	1.6	3.61	4.41	2.56
11	0.8	-2.5	1.7	0.64	6.25	2.89
12	-2	-1.3	1.4	4	1.69	1.96

Table 9. Accuracy analysis results of the 3D model of the sarcophagus for Agisoft software

	Vi Differences (mm)		
	Vx	**Vy**	**Vz**
Vmin	0.3	0.4	0.1
Vmax	3.8	2.5	1.7
Vort	1.5	1.2	1
m	.1.88	1.44	1.22
m_{xyz}	±2.66		

Table 10. Coordinate differences of the sarcophagus obtained from terrain and Pix4d software.

	Vi Differences (mm)			ViVi Differences (mm)2		
	Vx	**Vy**	**Vz**	**VxVx**	**VyVy**	**VzVz**
1	2	2	-1	4	4	1
2	4	4	3	16	16	9
3	-2	-1	2	4	1	4
4	2	2	-2	4	4	4
5	5	-2	1	25	4	1
6	-3	1	1	9	1	1
7	2	4	-4	4	16	16
8	3	-2	3	9	4	9
9	-4	-3	4	16	9	16
10	3	4	3	9	16	9
11	-3	-3	3	9	9	9
12	4	-3	1	16	9	1

Table 11. Accuracy analysis results of the sarcophagus 3D model for Pix4d software

	Vi Farklar (mm)		
	Vx	**Vy**	**Vz**
Vmin	2	1	1
Vmax	4	4	4
Vort	3.1	2.6	2.3
m	3.37	2.91	2.70
mxyz	±5.21		

The error amounts calculated in Agisoft and Pix4d software for both the sarcophagus and the tomb stele are given in Table 12.

Table 12. Error amounts measured in Agisoft and Pix4D softwares (mm)

	Lahit	Mezar steli
Agisoft	±2.66	±5.03
Pix4d	±5.21	±8.05

For both works, the number of point clouds obtained from the two software, the number of photographs used and the amount of errors are also compared in Table 13.

4. Conclusion

It is our duty to preserve our historical artifacts and pass them on to future generations. An important step for this is achieved with documentation. There are many methods for documentation work. One of the most widely used of these methods is terrestrial photogrammetry. It is a frequently preferred method especially for modeling medium-sized works.

Table 13. The number of tomb stele and sarcophagus point clouds found in Agisoft and Pix4d software, the number of photographs used and the amount of error.

		Tomb Stele	Sarcophagus
Number of point clouds	Agisoft	952 233	2637 960
	Pix4d	2613 369	8 136 240
Number of used photos	Agisoft	35	35
	Pix4d	127	127
Amount of error (mm)	Agisoft	±5.03	±2.66
	Pix4d	±8.05	±5.21

In this study, 3-dimensional modeling of the sarcophagus and tomb stele from the Roman period in the Aksaray museum in Aksaray province was carried out with the terrestrial photogrammetry method. Agisoft and Pix4d software were used for the modeling process. As a result of the evaluation studies, the number of point clouds, the accuracy of the coordinates and the usability of the software were compared. For this comparison, the mean square error method was preferred. The position accuracy of both objects was calculated at the mm level. It was determined that the position error of the tomb stele was ±5.03 mm when modeled using Agisoft software, and ±8.03 mm when modeled with Pix4d software. The position error of the sarcophagus was ±2.66 mm when evaluated with Agisoft software, and ±5.21 mm when evaluated with Pix4d software.

Looking at the results obtained, it was seen that the position error obtained from the Agisoft software was lower than the Pix4d software and more point clouds were obtained in the Pix4d software compared to the Agisoft software.

As a result, it has been seen that while Agisoft software stands out in precision for 3D documentation studies, Pix4d software's point cloud production feature is at the forefront.

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