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Documentation of complex structure using Unmanned Aerial Vehicle (UAV) photogrammetry method and Terrestrial Laser Scanner (TLS)

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ABSTRACT

Modeling objects with different size and geometry and extracting metric information of this object is more difficult than ordered geometric structures. Especially, analyses and measurements to be made on similar structures cannot be accurate and precise with conventional methods such as minarets, domes, columns, mausoleums, and statues that have a conical, spherical, or cylindrical shape. Three-dimensional (3D) scanning technologies such as Terrestrial Laser Scanners (TLS) are important tool for modeling to complex structures Clearly, 3D scanners are more suitable than conventional methods for measuring objects with disordered and complex surfaces. It is one of the best methods for applications with similar complex structures. However, the biggest disadvantage of ground-based scans such as TLS are that the data of the upper facades of the building cannot be collected due to the scanning location. The collection of data on the upper facades of the buildings with carrier platforms such as Unmanned Aerial Vehicles (UAV) that make it possible to take images from the air contribute to overcoming this problem. In this study, the data of the columns with complex structures in the archaeological site of Soli-Pompeipolis were collected and modeled using TLS and UAV photogrammetry methods. For modeling, a hybrid method was used by combining the data obtained by TLS and UAV photogrammetry methods. As a result of the study, 0.21 and 2.3 cm precise were obtained for point clouds produced by TLS and UAV photogrammetry, respectively. By combining the point clouds obtained from both data collection methods, 1.7 cm precise was calculated.

1. INTRODUCTION

The analysis of attribute information and integration with information systems is one of the common areas of study of several disciplines (Dereli et al., 2019; Aicardi et al., 2016). Especially, structures exposed to object deformation are the main analysis studies. Structures are deformed due to many natural or unnatural reasons (Yakar et al., 2015; Ulvi et al., 2020). Analysis studies of structures that are subject to deformation cannot be performed as desired using classical methods. Various analyses of these structures can be made with modern methods. At this point, analyses can be made quickly and easily by producing 3D models with various data collection methods (Balletti, et al., 2015; Bolognesi et al., 2014).

Using 3D models to extract metric information of structures with different dimensions and geometries give precise and accurate results (Yılmaz and Yakar, 2006; Ulvi and Yiğit, 2019; Cryderman et al., 2014). Modern methods should be used for analysis and measurements on similar structures such as minarets, domes, columns and sculptures, especially, those with conical, spherical or cylindrical shapes (Harshit et al., 2020; Dayal et al., 2017;). These methods used in the creation of 3D models have a significant effect on the accuracy of the model and analysis (Uysal, M., et al., 2018; Makineci et al., 2020). With the developing technology, UAV photogrammetry and laser scanning technology are used more and more effectively in 3D model studies (Remondino, et al., 2014; Martínez-Carricondo et al., 2020; Sanz-Ablanedo et al., 2018; Pepe et al., 2016; Ulukavak et al., 2019). These systems, which are complementary to each other, in the collection and evaluation of data; It is fast, efficient, economical and reliable (Yakar and Yılmaz, 2008; Güvenlikaz et al., 2011; Şanlıoğlu et al., 2013; Comert. et al., 2019). These systems allow the creation of high-precision 3D models, a clearer view of the details on the object, the examination of the changes on the object, and the digital presentation and storage of the documents belonging to the object (Ulvi et al., 2019). Therefore, these systems are used in different

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disciplines (Karabörk et al., 2009, Alptekin et al., 2019a, Şenol et al., 2017).

Studies in the literature show that the TLS data, such as buildings that make up the 3D city model can be quickly collected and extracted from the land (Yakar et al., 2006; Çelik et al., 2020; Şenol et al., 2019; Şenol et al., 2020). In addition, with the integration of UAVs in this area, the collection of data on the missing fronts has been ensured (Mırdan & Yakar, 2017).

In this study, accuracy analysis was performed on the 3D model of the cylindrical columns considering the advantages of UAV photogrammetry and the TLS system. The combined utilization of UAV and TLS technologies contribute to obtaining highly sensitive products (Chen et al., 2020). In addition, the use of the UAV-TLS hybrid method allows the entire object to be modeled since data on all surfaces of the object that cannot be collected with a single system (Valenti et al., 2019; Alptekin et al., 2019b; Hamal et al., 2020). Getting both visual and metric information of the result obtained with these systems allow it to be used as a base in different studies (Ağca et al., 2020). As a result of the study, 0.21-2.3 cm accuracy was obtained for point clouds produced by TLS and UAV photogrammetry, respectively. By combining the point clouds obtained from both data collection methods, 1.7 cm was calculated.

2. METHODOLOGY

In this study, 3D models of complex structures were produced using TLS and UAV photogrammetry methods and accuracy analysis was evaluated.

2.1. Study Area

The study area is the *Sütunlu Cadde* of the ancient city of Soli-Pompeiopolis in Mersin province (Figure 1). There are 49 columns in the study area. That's why the study area is divided into three blocks. Blocks A, B and C include 14, 8 and 27 columns, respectively. (Figure 2).

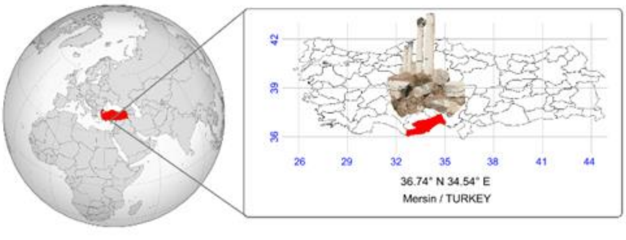

Figure 1. Study area (36.74°N 34.54°E)

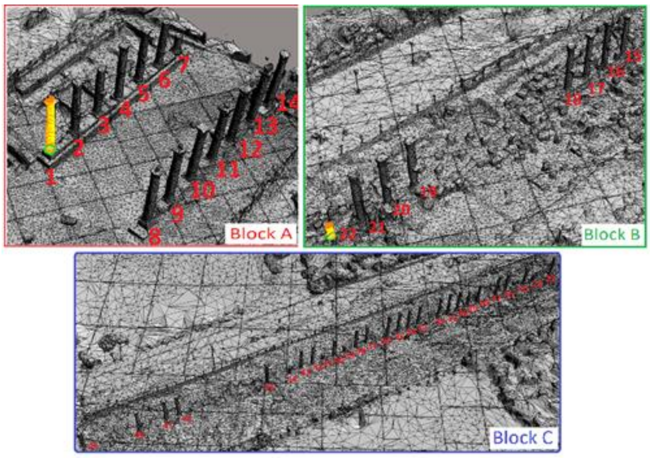

Figure 2. The study area is divided into A-B-C blocks

2.2. 3D Modeling and Analysis

TLS method; LIDAR (Light Detection and Ranging) technology is a system that is used to obtain a point cloud with X, Y, Z coordinates belonging to the targeted object. It can measure with high accuracy and speed with TLS. In addition, it is used in the documentation, restoration, restitution, reverse engineering, 3D modeling, and analysis studies, as it enables printing in digital form and creating a base for different studies.

The UAV photogrammetry method is basically a method of taking pictures with overlays and obtaining 3D models using the photogrammetry method (Yiğit & Uysal, 2020).

Within the context of the study, a 3D model was created using Soli's UAV and TLS methods (Figure 3).

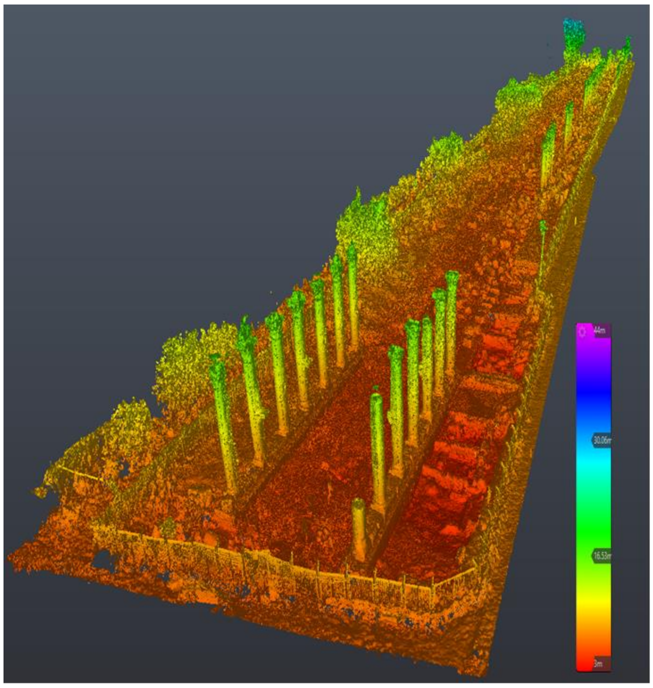

Figure 3. 3D model created using UAV and TLS methods

The 3D model workflow used in the study is shown in Figure 4.

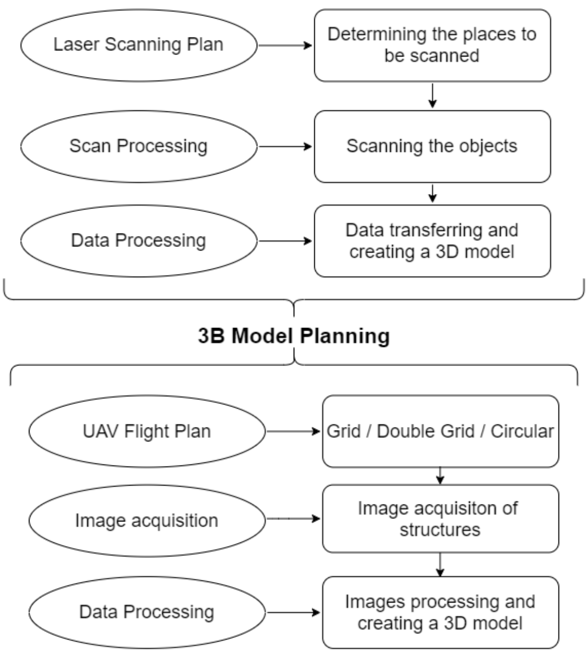

Figure 4. 3D model planning

The data collection methods and workflow used in the study are shown in Figure 5.

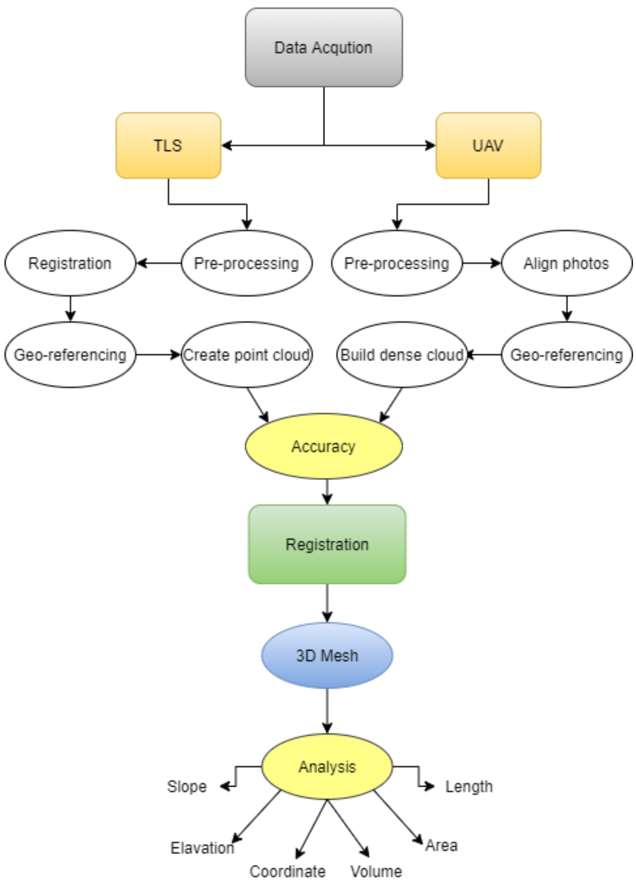

Figure 5. Workflow diagram

In this study, 37 control points were measured homogeneously over the columns with the Total-station to measure coordinate the 3D model and determine the position accuracy. 20 of the control points were used in coordinating the model, and 17 of them were used as check-points for accuracy analysis.

Considering the physical properties of the columns, sharp details have been chosen for the control points. The selection of control points from sharp details is important in terms of distinguishing and marking on the model.

3. RESULTS

Firstly, generate point clouds were used by TLS and UAV photogrammetry techniques in the study. Scanning was performed from 49 different station points using the TLS method. The 3D point cloud was created with the obtained data with JRC 3D Reconstructor software. Point cloud is combined with a precision of 0.21 cm. 386 images were obtained with UAV. 3D point cloud with an accuracy of 2.3 cm was created with Contex Capture software.

Combining TLS and UAV point cloud was created in JRC 3D Reconstructor software with the hybrid method and 1.7 cm precision was obtained. Later, 20 of the 37 points that collected by the Total-station were accepted as actual coordinates and 17 points were accepted as check-points. Control points were used in the accuracy analysis.

3.1. Accuracy Analysis of 3D Models Obtained TLS and UAV

On the model created by TLS and UAV photogrammetry techniques, the accuracy of 17 Check-point positions measured by Total-station were examined. mXYZ values for TLS and UAV photogrammetry methods are shown in Table 1.

Table 1. mXYZ accuracy analysis of control points

	Total-Station (m)			TLS(cm)			UAV (cm)		
NN	x	y	z	x	y	z	x	y	z
1	1002.31	1000.83	999.51	2.3	0.8	-0.5	2.6	1.8	-0.8
2	1000.82	999.91	999.59	0.8	-0.1	-0.4	-0.2	1.5	-0.4
3	996.10	996.97	999.97	-3.9	-3.0	0.0	-8.9	-11.5	-0.2
4	1000.83	998.11	997.72	0.8	-1.9	-2.3	1.4	-0.2	-2.3
5	1001.34	1002.55	998.53	1.3	2.5	-1.5	2.2	3.6	-1.8
6	1000.88	1002.60	999.80	0.9	2.6	-0.2	2.3	3.7	0.0
7	1001.56	1001.70	1000.09	1.6	1.7	0.1	2.9	3.5	0.4
8	1001.29	1001.52	1001.40	1.3	1.5	1.4	1.9	1.4	1.8
9	1001.14	1000.81	1001.42	1.1	0.8	1.4	1.3	0.8	1.5
10	1003.13	1001.06	1000.98	3.1	1.1	1.0	4.1	0.4	1.6
11	1001.31	1000.93	999.49	1.3	0.9	-0.5	2.3	1.1	-0.1
12	1000.70	1001.56	998.71	0.7	1.6	-1.3	2.2	2.2	-1.2
13	999.84	1000.93	998.98	-0.2	0.9	-1.0	-0.2	-0.3	-0.1
14	1002.93	1000.76	1001.16	2.9	0.8	1.2	3.0	1.9	1.7
15	993.84	996.33	997.53	-6.2	-3.7	-2.5	-5.2	-6.7	-2.9
16	999.41	998.25	997.79	-0.6	-1.7	-2.2	-1.8	-1.9	-1.2
17	1000.50	1003.32	1001.30	0.5	3.3	1.3	1.2	4.6	1.7

As seen in Figure 6, the mX mY mZ position accuracies for TLS and UAV photogrammetry techniques are consistent with each other.

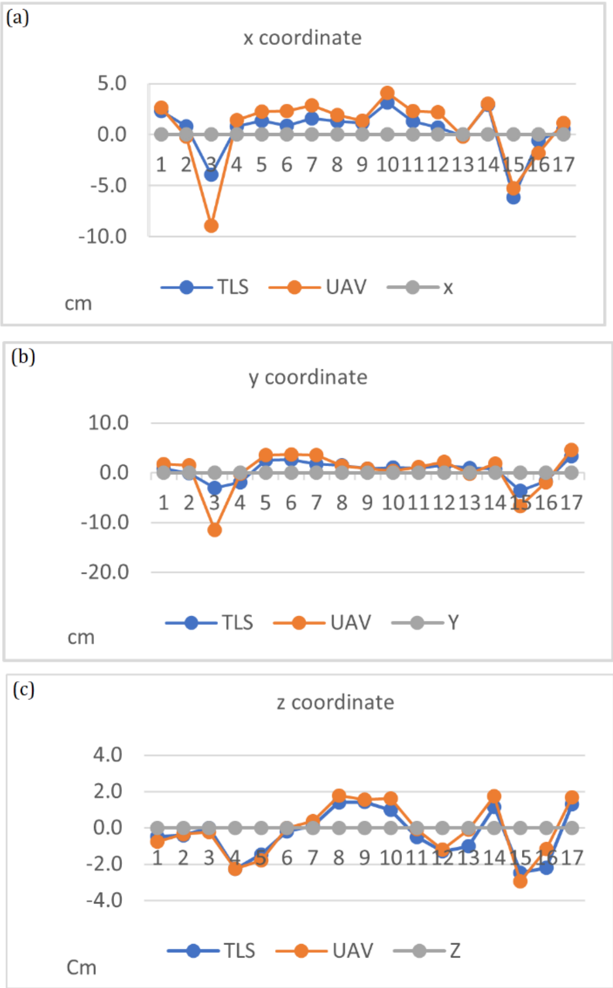

Figure 6. TLS and UAV Photogrammetry mXYZ position accuracy : (a) mX , (b) mY , (c) mZ

However, there is an inconsistency in the checkpoint of TLS and UAV data of number 3 shown in Figure 7. The reason for the error value of the point is deformation and error caused by the operator. In brief, the sharpness and location of the selected detail points are important in the georeferencing of 3D models.

Figure 7. Check-point of the number 3

3.2. Accuracy Analysis of the Model's Base Area and Volume

The area (A) and volume (V) of a flat cylindrical object are calculated with (1) and (2) equations, respectively. In the equation, r and h refer Radius and height.

$$A = 2\pi r(r + h) \quad (1)$$

$$V = \pi r^2 h \quad (2)$$

Hand Survey and Total-station measurement and Advanced Model (3D) calculations of the columns are compared and shown in Table 2.

Table 2. Base Area and Volume Accuracy Analysis

			HAND SURVEY and TOTAL-STATİON MEASUREMENT		ADVANCED MODEL (3D MODEL)	
NN	R(m)	Height (m)	Base Area (m²)	Volume (m³)	Base Area (m²)	Volume (m³)
1	0.93	7.30	0.68	4.95	1.03	4.45
2	0.85	6.84	0.56	3.84	0.91	3.12
3	0.83	6.52	0.54	3.53	1.21	4.12
4	0.84	7.76	0.55	4.30	1.03	3.86
5	0.85	6.65	0.57	3.77	0.96	3.45
6	0.87	2.97	0.59	1.75	0.98	2.94
7	0.88	1.91	0.61	1.16	0.60	1.17
8	0.86	7.90	0.58	4.55	1.03	5.15
9	0.86	7.85	0.58	4.52	0.98	5.88
10	0.87	7.99	0.60	4.79	1.02	5.10
11	0.87	7.95	0.59	4.71	0.95	4.75
12	0.89	7.78	0.62	4.79	1.20	5.04
13	0.88	7.69	0.60	4.63	1.04	5.20
14	0.89	7.59	0.62	4.69	0.98	5.88
15	0.85	7.51	0.57	4.28	0.94	5.64
16	0.86	7.63	0.58	4.41	0.94	6.58
17	0.86	7.73	0.59	4.54	1.31	5.90
18	0.85	7.97	0.57	4.57	1.36	5.54
19	0.88	7.66	0.61	4.65	1.06	5.96
20	0.89	7.12	0.62	4.38	1.07	4.81
21	0.87	7.41	0.60	4.45	1.06	5.28
22	0.87	3.55	0.59	2.09	0.55	2.44
23	0.90	7.75	0.63	4.88	1.08	5.06
24	0.85	3.27	0.57	1.86	0.60	2.36
25	0.88	7.88	0.61	4.79	1.06	5.61
26	0.90	7.94	0.63	5.04	1.09	6.45
27	0.87	7.67	0.59	4.54	1.05	5.35
28	0.89	7.70	0.62	4.74	1.07	5.66
29	0.88	5.41	0.60	3.26	1.06	5.29
30	0.87	6.75	0.59	3.98	1.04	5.22
31	0.88	7.37	0.61	4.48	1.06	5.31
32	0.87	7.61	0.60	4.55	1.05	5.26
33	0.90	7.44	0.63	4.69	1.09	5.43
34	0.87	7.85	0.59	4.62	1.04	5.22
35	0.90	6.78	0.63	4.28	1.09	5.43
36	0.85	7.29	0.57	4.18	1.03	5.56
37	0.88	6.86	0.60	4.13	1.06	5.71
38	0.91	6.84	0.65	4.46	1.11	5.98
39	0.89	2.61	0.62	1.63	0.58	1.72
40	0.91	5.47	0.66	3.59	1.11	4.22
41	0.90	2.09	0.63	1.32	0.52	1.48
42	0.88	5.59	0.60	3.36	1.06	4.23
43	0.90	5.76	0.63	3.63	1.08	4.34
44	0.86	2.39	0.58	1.39	1.04	1.52
45	0.87	6.24	0.59	3.68	1.04	4.80
46	0.90	7.24	0.64	4.62	1.09	5.03
47	0.89	7.45	0.62	4.60	1.07	4.93
48	0.88	7.34	0.60	4.42	1.06	5.29
49	0.79	7.61	0.49	3.72	1.18	4.48

Only 6 colums of the 49 cylindrical columns in the study area are flat cylindrical objects. As an example, the height (h) and diameter(R) measurement of column number 7 shown in Figure 8 with the classical measurement method was measured as 1.19 m and 0.88 m, respectively. The base area of the cylindrical structure is 0.652 m^2 with equation (1) and the volume is calculated as 1.169 m^3 with equation (2). The base area and volume of the same column from the solid model created by the photogrammetry technique were calculated as 0.60 m^2 and 1.17 m^3, respectively.

Figure 8. Check-point of the number 7

However, there are 6 flat cylindrical-shaped columns in the study area and there are indentations and protrusions in other structures. Measuring indentations and protrusions on columns are difficult and time-consuming. The diameters and heights of the complex columns were measured in the study.

For example, the height and diameter of column number 3 were measured as 6.52 m and 0.829 m, respectively, using the classical method. The base area of column 3 was calculated as 0.54 m^2 with the equation (1) and the volume was calculated as 3.53 m^3 with equation (2). The base area of the same column is calculated from the model as 1.21 m^2 and its volume as 4.12 m^3 (Figure 9).

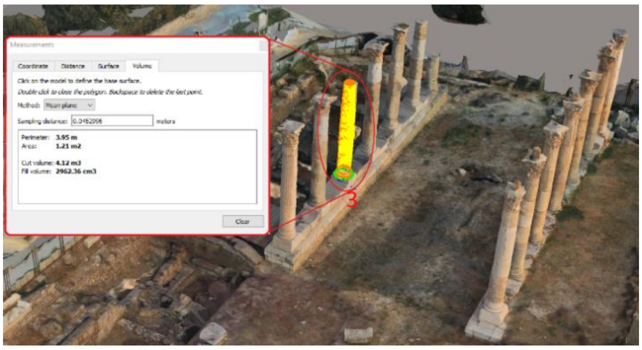

Figure 9. Check-point of the number 3

4. CONCLUSION and DISCUSSION

For the analysis of structures with different geometric shapes, their physical properties should be considered and appropriate evaluation tools should be selected. Rather than using a single method in the spatial recording of buildings, the use of hybrid methods contributes significantly to an accurate analysis. For this purpose, firstly geodesic measurement techniques, laser scanning data collection methods such as UAV photogrammetry and TLS were used for the analysis of complex structures. However, field studies made with geodesic or classical measurements cause excessive time, manpower, and increase the cost. TLS and UAV photogrammetry use because of faster and more accurate data collection, especially with time and cost savings.

The distance between TLS and the scanned surface directly affects the resolution of the point cloud data, and the rays coming from the laser scanner to the surface to be scanned also affect the quality of the point cloud data. The TLS system also allows an object, structure, or object to be scanned from horizontal and vertical directions to obtain a point cloud image. Therefore, it is the most preferred system in the 3D modeling of buildings. However, with such ground-centered systems, the data of the upper facades of the buildings are missing. This problem has been resolved by using carrier platforms such as UAVs. By taking pictures from the air, the UAV photogrammetry method was used and a 3D point cloud of the building was produced. In this way, the data of the lateral facades of the building were collected with TLS, and the data of the upper facades were collected by UAV. Complete 3D data of the building was obtained with hybrid data collection methods and various analyses were made.

In this study, the merging process of point cloud is 0.21 cm with TLS and 2.3 cm accuracy with UAV. The precision of combining UAV and TLS data is 1.7 cm. More sensitive results were obtained with the TLS method. However, data on the superstructures of the columns cannot be obtained with TLS. This problem has been solved with the UAV photogrammetry technique and the missing areas have been completed.

As a result of the Check-point mXYZ location analysis shown in Figure 6, TLS and UAV methods have obtained values close to each other. In Figure 7, although mZ is consistent in both methods, the error value of mX and mY is higher than mZ. Therefore the location of the points are not chosen clearly and sharply. In brief, the clarity and location of the detailed points to be selected are important in geographical referencing.

The volumes of cylindrical structures with smooth geometries are not difficult to calculate in a classical way. However, only 6 out of the 49 cylinders in our study area have a smooth geometric structure. The volume of cylindrical objects with disordered geometry is difficult to calculate with classical methods. This study investigated the use of TLS and UAV photogrammetry methods in modeling complex structures, extracting metric information of the structure, and performing analysis.

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