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Research Article

3D MODELING OF CULTURAL HERITAGES WITH UAV AND TLS SYSTEMS: A CASE STUDY ON THE SOMUNCU BABA MOSQUE

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Abstract

With rapidly developing technology, Terrestrial Laser Scanners (TLS) and Unmanned Aerial Vehicle (UAV) have taken the place of traditional measurement and modeling techniques. The overall aim of this study is to create 3D model of Somuncu Baba Mosque with data obtained from TLS and UAV systems. More specific goals include: (1) create ground plans of Somuncu Baba Mosque, one from TLS and one from UAV systems, and compare the positioning accuracy of these two ground plans using a base map, as reference data; (2) create 3D mesh models of Somuncu Baba Mosque using point clouds obtained from TLS and UAV systems and compare the measurements of building features (e.g., length/width of doors and windows) of final 3D models; and (3) generate 3D CAD model of the selected facade of the Somuncu Baba Mosque to evaluate the accuracies of two modeling systems. Results of this study showed that length measurements (over ground plans) obtained from these two systems were very close to each other and only milimetric errors were found. Therefore, both systems can be used to create ground plans with high accuracies. Also, successful 3D CAD models were obtained from these systems with high accuracy.

Keywords: UAV; TLS; 3D Building Model; Positioning Accuracy; Somuncu Baba Mosque.

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Arastirma Makalesi

İHA VE TLS SİSTEMLERİ İLE KÜLTÜREL MİRASLARIN 3B MODELLENMESİ: SOMUNCU BABA CAMİİ ÖRNEĞİ

Özet

Hızla gelişen teknoloji ile Yersel Lazer Tarayıcılar (YLS) ve İnsansız Hava Aracı (İHA) geleneksel ölçüm ve modelleme tekniklerinin yerini almıştır. Bu çalışmanın genel amacı, TLS ve İHA sistemlerinden elde edilen veriler ile Somuncu Baba camisinin 3 boyutlu modelini oluşturmaktır. Daha spesifik hedefler şunlardır: (1) Somuncu Baba Camii'nin zemin planlarını YLS ve İHA sistemlerinden oluşturmak ve bu iki zemin planının konum doğruluğunu alana ait halihazır harita ile karşılaştırmak; (2) YLS ve İHA sistemlerinden elde edilen nokta bulutlarını kullanarak Somuncu Baba Camii'nin 3B mesh modellerini oluşturmak ve nihai 3B modellerin yapı özelliklerinin ölçümlerini (ör. Kapı ve pencerelerin uzunluğu / genişliği) karşılaştırmak; ve (3) iki modelleme sisteminin doğruluklarını değerlendirmek için Somuncu Baba Camii'nin seçilen cephesinin 3D CAD modelini oluşturmaktır. Çalışmanın sonuçlarına göre, bu iki sistemden elde edilen uzunluk ölçümlerinin (yer planları üzerinde) birbirine çok yakın olduğunu ve sadece milimetrik hataların bulunduğunu görülmektedir. Bu nedenle, her iki sistem de yüksek doğruluklu zemin planları oluşturmak için kullanılabilir. Ayrıca bu sistemlerden yüksek doğrulukta başarılı 3D CAD modelleri elde edilmiştir.

Anahtar Kelimeler: İHA; YLS; 3B Bina Modelleme; Konum Hassasiyeti, Somuncu Baba Camii.

1. INTRODUCTION

Three-Dimensional (3D) building modeling is one of the important components among geospatial information, especially in urban areas. 3D building models are requested as an input source for a variety of applications, such as city planning, shadow modeling, flood modeling, and analyzing solar potential from roof directions. Due to the complexity of buildings, many researchers pay attention to the data model and structure. Building modeling is a digital representation of the physical and functional characteristics of a facility (Styliadis, A., 2007; Fan et al., 2009;). Its purpose is to serve as a shared knowledge resource for information about a facility. Accurate documentation of buildings is essential for potential damage assessment and restoration work. However, positioning accuracy of 3D modeled buildings is also important for city modeling and mapping, land use management and planning, and surveying applications (Grün et al., 2012; Karantzalos and Paragis, 2010; Guo et al., 2008). Positioning accuracy is essential for integrating these models with google maps, remote sensing data, and GIS datasets as well. Accuracy of such data will affect the accuracy of subsequent analysis. 3D CAD models are 3D computational representations of objects drawn in the x, y, and z axes and illustrated in isometric, perspective, or axonometric views.

Advances in photogrammetry and remote sensing technologies provide very powerful tools for building modelings such as terrestrial laser scanners (TLS) and Unmanned Aerial Vehicles (UAVs). The TLS system is widely being used in the generation of 3D models of historical structures (Georgeta et al., 2008; El-Hakim, et al., 2004), cultural heritage objects (Kulur and Sahin, 2008; Remondino F., 2011), and sites. It has become popular due to the rapid data acquisition, the high point precision, and the ease of use, which has resulted in the technique being adopted by domain experts outside the geomatics field. Laser scanning is an active remote sensing technique that emits a series of laser pulses and measures the distance to targets based on the speed of light and travel time of the laser pulses to and from a system (Kedzierski and Fryskowska, 2014). The principle of the TLS system is based on the emission reception of a laser beam. The emitted laser beam is deflected by a mirror and automatically scans a scene, the laser is reflected by the first object encountered. The data acquired with TLS are dense laser point clouds composed of millions of points with accurate 3D coordinates, which can be used to reconstruct very detailed models of the targets. Unlike passive optical remote sensing, TLS real-time measurement system provides abundant spatial information and detailed information on both horizontal and vertical distribution of a scanned target (Bosche, F., 2010; Kedzierski and Fryskowska, 2015). UAVs are also showing great potential for modeling the buildings since they provide a faster and easier solution for 3D building modeling. The name UAV covers all vehicles, which are flying in the air with no person onboard controlling the aircraft. These systems are small, flexible, light, remotely-controlled helicopters, and aircraft. They are equipped with precision sensors, for instance, Global Positioning System (GPS), Inertial Motion Units (IMU), gyroscopes, and consumer cameras. These systems can obtain information about an object from low altitude; therefore, they provide high-resolution images of an object. Also, these systems provide additional exploitation of higher accuracy sensors that allow for the estimation of the orientation elements of the camera, thus decreasing the time of the photogrammetric procession of data (Tong et al., 2015; Manyoky et al., 2011; Rehak et al., 2013; Zhou and Neumann, 2010).

This paper will focus on positioning and measurement accuracies of 3D building models obtained from UAV and TLS. Position accuracy is an important issue when modeling anything on Earth. UAV and TLS systems are the most popular and widely used in 3D structure modeling. Measuring accuracy is also important especially for reconstruction and restoration of the building (Yang et al., 2014). For an absolute accuracy measurement, an independent reference dataset is needed to check for differences between the 3D modeled data and the reference dataset (Küng et al., 2011; Becerik-Gerber et al., 2011; Baumker and Przybilla, 2011). In this study, a base map of the study area was used to check position accuracy (X and Y coordinates) of the Somuncu Baba Mosque. To check the measurement accuracy of the 3D CAD model of the building, fieldwork measurements gathered using a total station were used in the study study. The results of this study will play a major role in the selection of modeling technologies for the above mentioned studies.

2. MATERIALS AND METHODS

The flowchart presented in Figure 1 provides the general methodology followed to accomplish the objectives of this study.

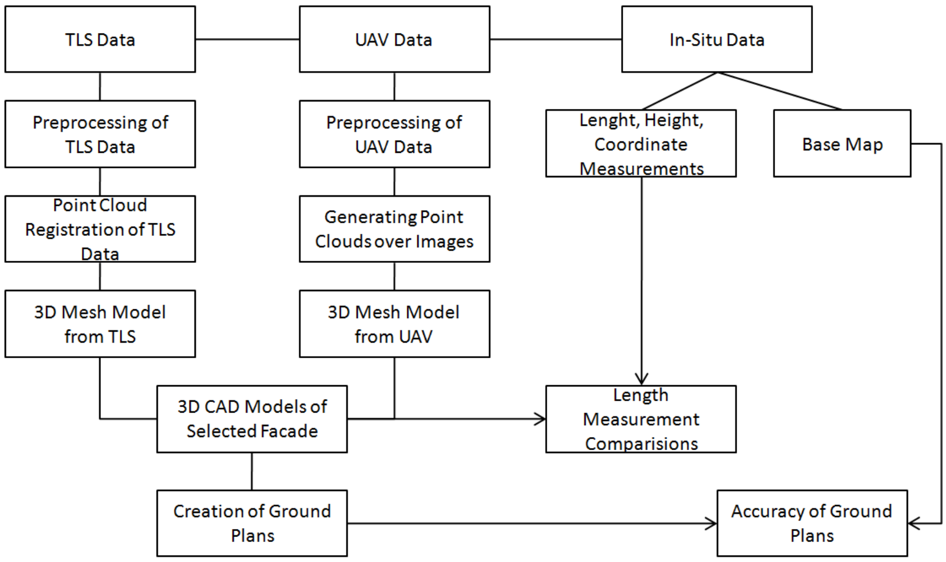

Figure 1. The general methodology followed to accomplish the objectives of this study.

2.1. Study Area

Somuncu Baba Mosque in Aksaray was selected as the study area (Figure 2). Somuncu Baba trained many students and, entered into the hearts of millions after he took the province flag from the Persian tower and brought it to Anatolian country. He is a great ancestor of Ottoman intellectuals and a master of humility. Therefore, Somuncu Baba Mosque is an important place of worship for the local people of Aksaray. Somuncu Baba Mosque covers an area of approximately 900 square meters and it is surrounded by a restaurant and Aksaray Municipality Directorate of Cemeteries building.

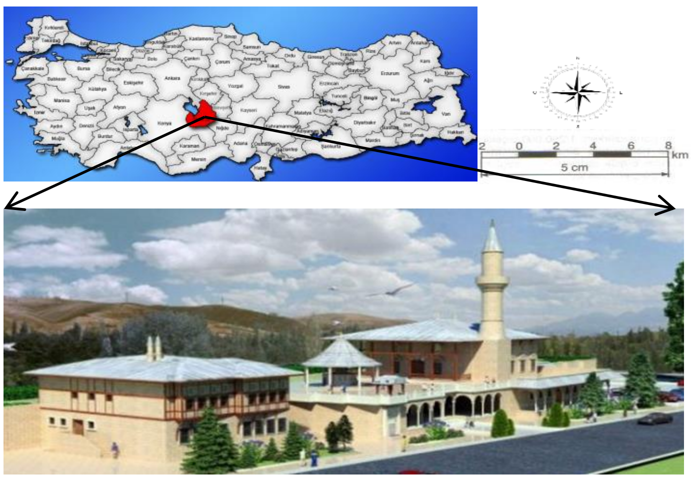

Figure 2. Study site

2.2. Data Processing and 3D Modeling

Three types of data were used in this study: In-situ data, Terrestrial Laser Scanner (TLS) data, and Unmanned Aerial Vehicle (UAV) data.

2.2.1. In-situ Data

In this study, TOPCON GTS-250 Total Station was used to collect in situ data for accuracy assessment of measurements of building features. A total of 46 measurements were taken from the corners of the windows and doors of the Somuncu Baba mosque. Also, digital pictures of in situ data locations were taken and these measurements were used as reference data. Also, a base map of the Somuncu Baba Mosque area obtained from the Aksaray Municipality was used as reference data to compare the positioning accuracy of the ground plans obtained from TLS and UAV systems.

2.2.2. Terrestrial Laser Scanner (TLS) Data Processing and 3D Modeling

The scans were conducted using Topcon GLS-1000. The field experiment was carried out on June 26-30, 2015. This system sends out a laser beam that measures 3000 pulses per second. It measures distances up to 330m away. A sophisticated lens mechanism ensures consistent 4mm accuracy through the scanner’s range up to 150m. The maximum field-of-view (per scan) is 360° horizontal and 70° vertical. This device can operate in temperatures from -10 °C to 40 °C. The laser scanner has a near-infrared laser beam (1535 nm) with a beam divergence of 0.3 mrad. This system also takes several photos at each scan station to provide a panorama view of the surrounding. The laser point density varies with distance – i.e. the further away from the scanner, the less dense is the point cloud, and vice versa. The closest range is achieved when the scanner is located on the ground to obtain a high laser point cloud. The TLS system is needed to be set in a position that could be seen and corresponded between two scan stations which require a minimum of 3 corresponding targets. Laser scanning measurements have been performed at 17 stations with an average distance of 8 meters from the target. The single scan time for each scanning session was approximately 40 min. Fieldwork took almost 4 working days. The point cloud of the Somuncu Baba Mosque contains approximately 449.733.56 laser points.

In this study, a total of 18 scans were made around the Somuncu Baba Mosque. The point clouds obtained from all scans were registered into one coordinate system to achieve a 3D model of the Somuncu Baba Mosque. The local coordinate system was chosen for the surveying of the required control points for each determined scanning site. A TOPCON GTS-250 Total Station was used to collect ground control points to adjust all acceptable data into X, Y, and Z values. A total of 17 ground control points was collected from places that are easy to determine, such as corners and top of buildings, corners of windows and doors, and stairs, in point cloud data in ASCII file format.

Polyworks software was used to register the range data and produce a 3D visualization model based on registered colorized point clouds (Figure 3). First, all scanned data obtained from each station were in .clr format. Scanned data were transformed to .ptx file format using ScanMaster software to be able to process them in Polyworks software. Then, each scan station data was opened in Polyworks. The registration of all scans was performed pair by pair using 6 control points (min. 3 control points are required) to match two different datasets in one common local coordinate system. To remove noise and errors, a data filtering process was applied to all point clouds to correct and/or remove the selected scan point from the raw data. This involves the basic checking of data, removal of bad point cloud caused by a blocking object or false returns.

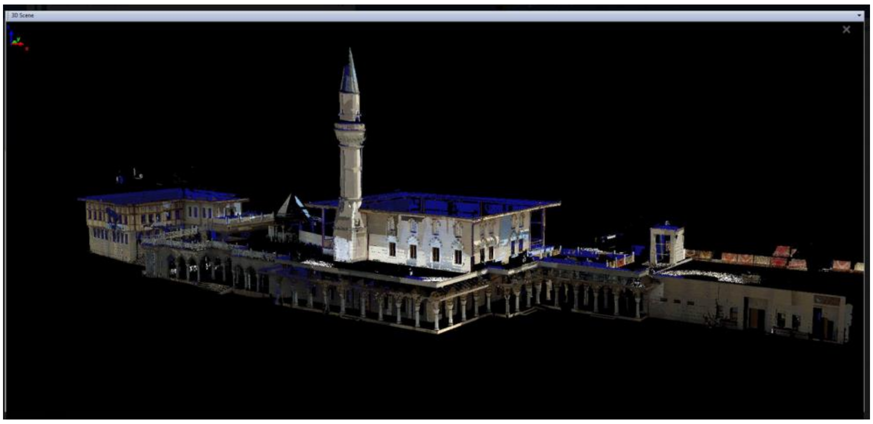

Figure 3. Generated point cloud model of the study site

Using ground control points obtained from the total station, all point cloud data were converted from the local coordinate system to a global coordinate system (WGS-84). Then, a triangulated Irregular Network (TIN) surface of the point cloud was created (Figure 4). After preprocessing of point cloud data, a 3D mesh model of Somuncu Baba Mosque was created using IMMerge tool in Polyworks software. Finally, the 3D CAD model of the selected facade of the Somuncu Baba mosque was generated to evaluate the mesh model effects on 3D CAD modeling. The AutoCAD program was used to create a 3D CAD model. With polygon surface tool in Polyworks software, cross-sections were generated on point clouds and ground plan of Somuncu Baba mosque was created.

2.2.3. Unmanned Aerial Vehicle (UAV) Data Processing and 3D Modeling

UAV data was collected on June 14, 2015. The aircraft used in this study was a hand-launched MULTIROTOR G4 Surveying-Robot. It weighs 6.5 kg and can fly up to 20 min and up to max 10m/s with one battery charge even in strong winds. Ground resolution is up to max 1mm per pixel with a positional accuracy of 1cm. This system carries a consumer Olympus PEN E-PL5 camera with GeoModul, 14mm fixed focal length, and standard zoom lens 14 – 42mm. It has a radio control transmitter, Jeti DS14 with 2,4 GHz. Also, this radio control system provides voice supported data telemetry between the UAV and the transmitter. Weather conditions during the data collection were ideal. There was no cloud cover and no wind, and the air temperature was 20 °C. Therefore, these conditions ensured that the aircraft was relatively stable during flight and that lighting conditions were consistent for all images.

The MULTIROTOR G4 system provides georeferenced image data. A satellite map from Google Earth was imported to find the coordinates of the study area. Then, the boundaries of the study area were determined. The flight route was calculated with three waypoints using GeoMap Win Software, It took about 45 minutes to collect UAV data over the Somuncu Baba Mosque. The study area was flown overusing a grid of parallel and side flight lines to ensure that every detail on Somuncu Baba Mosque was imaged. A total of 16 overlapping flights (longitudinal and traversal coverage of 80% each) were carried out while collecting UAV data with a 30 m flying height. A total of 145 images of the Somuncu Baba Mosque were taken during the flight. Photogrammetric data processing was carried out to generate a georeferenced 3D point cloud from the unordered, overlapping, and airborne image collection of the Somuncu Baba mosque. The images must have an adequate overlap between each other. All the images were aligned and geometry and texture of them were built. The projection was defined in WGS 84 format using Pix4Dmapper software. Finally, high density coordinated point clouds (in

LAS file format) and 3D mesh model (in OBJ file format) of Somuncu Baba mosque was generated with 1.000.000 max number of triangles and a texture size of 8192 x 8192 using Pix4Dmapper software (Figure 4). The AutoCAD program was used to create a 3D CAD model of the selected facade of the Somuncu Baba Mosque. Also, the ground plan was generated using all point clouds (Figure 5).

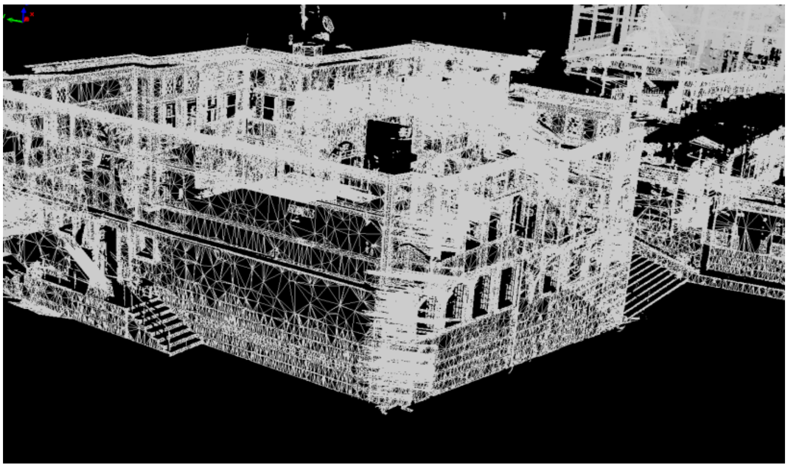

Figure 4. Triangulated point cloud model

3. RESULTS AND DISCUSSION

The results of the two modeling and measurement systems were assessed. First, the two ground plans of the Somuncu Baba mosque were created using TLS and UAV data, respectively. Then, all three ground plans (TLS-ground plan, UAV-ground plan, and base map) were overlaid on top of each other to assess the accuracies of these two plans (Figure 5).

Figure 5. MULTIROTOR G4 Surveying-Robot System used in this study

First, 20 points were selected on all ground plans. Then, the lengths between the two selected points were compared (Table 1). For instance, the length between the Point-34 and Point-35 was measured on the base map (10m), TLS-ground plan (9,999m), and UAV-ground plan (10,001m), respectively. As shown in Table 1, more accurate measurements were obtained from the TLS system compared to measurements taken from the UAV system. However, the results of the length measurements obtained from TLS and UAV systems were very close to each other and only millimetric errors were found. These measurement differences were not surprising since measurements were taken from a closer distance with the TLS system. Based on the results, it appears that both systems can be used to create ground plans. However, time spent during field measurements is of great importance in this kind of study. Therefore, the use of UAV systems in such studies may be more advantageous since data collection is time-consuming with the TLS system.

Table 1. Comparison of length measurements on ground plans.

Building Name	Point Name	Comparison of Length Measurements				
		BASEMAP (m)	TLS (m)	UAV (m)	Basemap-TLS (mm)	Basemap-UAV (mm)
1	34-35	10,000	9,999	10,001	1	-1
	35-36	7,750	7,757	7,752	-7	-2
	36-37	10,000	9,996	9,992	4	8
	37-34	7,750	7,756	7,754	6	-4
2	38-40	13,000	13,001	13,002	-1	-2
	40-43	10,000	10,002	10,003	-2	-3
	43-45	13,000	13,001	13,001	-1	-1
	45-38	10,000	10,002	10,003	-2	-3
3	15-16	6,163	6,161	6,168	2	-5
	16-17	10,285	10,286	10,287	-1	2
	17-18	13,965	13,964	13,962	1	3
	18-19	18,323	18,321	18,329	2	6
	19-20	7,351	7,348	7,343	3	8
	20-21	1,085	1,089	1,084	-4	1
	21-22	5,796	5,795	5,792	1	4
	22-23	3,868	3,870	3,863	-2	5
	23-24	4,586	4,584	4,583	2	3
	24-25	4,104	4,101	4,096	3	8
	25-26	4,527	4,521	4,519	6	8
	26-15	2,836	2,827	2,830	9	6

High-quality 3D CAD models of the selected facade of the Somuncu Baba Mosque were created using 3D mesh models obtained from UAV and TLS systems. Dimensions of the selected window and minaret were measured using laser meter then these measurements were compared with dimensions obtained from the 3D CAD models. Figure 6 illustrates the 3D CAD model and the location of the points where measurements were taken over the building.

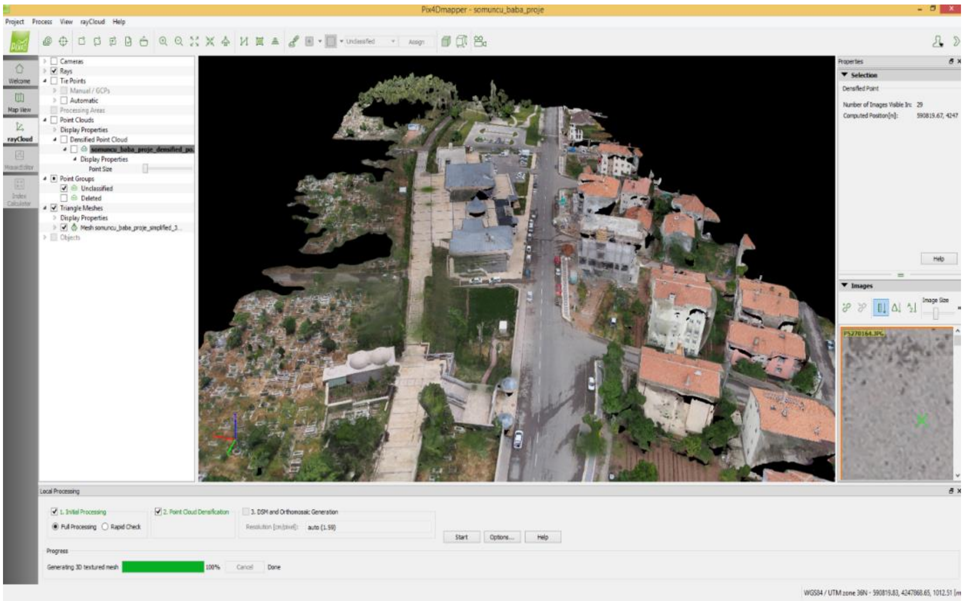

Figure 6. Point cloud model of study site generated from UAV data

Dimensions of the selected facade of the Somuncu Baba Mosque were measured. Table 2 shows a comparison of results for measurements taken over the building. As shown in Table 2, the two modeling techniques results are very close to each other. Compared to the measurements made with the TLS system, more accurate height measurements were obtained from the UAV system when measuring 'Minaret'. It can be expected to obtain more accurate results from the UAV system because measurements are taken from above with this system since measurements are made at a fixed point with the TLS system. Therefore, some height measurements made with UAV may be more accurate than the measurements made with the TLS.

Table 2. Comparision of results for measurements taken over the building.

Selected Features	Length Measurements				Differences	
	Ground Measurement (m)		TLS (m)	UAV (m)	Ground-TLS	Ground-UAV
Window-1	heigth	1.3650	1.3664	1.3662	-0.0014	-0.0012
	width	1.4150	1.4140	1.4136	0.0010	0.0014
Window-2	heigth	2.0400	2.0409	2.0406	-0.0009	-0.0006
	width	1.5500	1.5511	1.5510	-0.0011	-0.0010
Minaret	height	25.6250	25.6268	25.6260	-0.0018	-0.0010

Different modeling and measurement systems were evaluated in this study. TLS and UAV systems are widely used in a way to collect local data. In this study, the accuracy of the collected data over the Somuncu Baba Mosque was analyzed. Both systems have advantages and disadvantages. This is the first study, to my knowledge, to assess the accuracies of UAV and TLS modeling outputs. UAV systems can take true aerial photos and they are capable of flying close to buildings and properties so we can obtain detailed images for modeling and surveying. UAV systems are very quick to set up and deploy. As commonly noted in the literature, the collection of TLS scans is time-consuming. Compared to data obtained from UAV systems, more time and people are needed to process TLS data. However, the accuracies of models obtained from these systems are very close to each other. Therefore, both systems can be used in city modeling, natural disaster planning, restoration, reconstruction, and aftermath evaluation.

4. CONCLUSIONS AND RECOMMENDATIONS

The three-Dimensional building model is an important component in many applications such as urban modeling, natural disaster planning, restoration, reconstruction, and aftermath evaluation. The importance of accurate and up-to-date building models has been discussed by many researchers, and many different approaches for efficient building model generation have been studied. This study focused on assessing accuracies of different modeling systems, UAV and TLS systems, respectively. Using advanced 3D modeling technologies, Somuncu Baba Mosque was modeled and ground plan of the study area was created. The results of this study are promising in selecting the right technology in similar studies. Positioning and measurement accuracy of 3D models is essential because any errors in building models will result in decreasing confidence in the rest of the models, such as city models. Accuracy of 3D building modeling is also particularly important for modeling cultural and/or historical structures for preservation, as-built documentation, planning, and reconstruction. Urban planners have begun to regularly rely on 3D urban maps to support a wide variety of everyday decision-making tasks. When the construction of a new structure is proposed, it is now possible to assess the visibility impacts of the new building on the surrounding area. Especially for applications such as web-based 3D GIS and the presentation of virtual walk-throughs on mobile computing devices, these generated representations of the 3D models are a prerequisite to generate the level of detail structures for real-time rendering. From a coordinated 3D CAD model, individual services layouts can be generated for example ductwork, mechanical pipework, public health, fire protection, and electrical services using relevant layers with text and dimensions.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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