

INTEGRATION OF DATA OBTAINED BY PHOTOGRAMMETRIC METHODS SUCH AS A TERRESTRIAL LASER SCANNER AND UAV SYSTEM AND USE IN 3D CITY MODELS: THE CASE OF KÖYCEĞİZ CAMPUS

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ABSTRACT:

The ever-growing and complex structure of cities has increased the need to include advanced information and communication technologies in management processes. In parallel with this, the concept of smart cities has emerged and the creation and use of three-dimensional (3D) city models have become one of the most important components for tracking cities online. Depending on technological advances; Photogrammetric methods come to the fore in surveying because it offers convenience in terms of cost and time. Among the photogrammetric methods, mobile laser scanning and UAV (Unmanned Aerial Vehicle) systems have become very popular. In this study; Necmettin Erbakan University, Faculty of Social Sciences and Humanities (SBIF), located in Köyceğiz Campus, was chosen as the study area and focused on integrating three-dimensional (3D) models produced by terrestrial and aerial photogrammetry under the theme of smart cities.

1. INTRODUCTION

Smart cities are living spaces where practices that increase the quality of life of people living in cities with the help of technology and minimize the negative effects of city life are implemented. In addition, they are urban structures built on an integrated information organization that has an advanced City Information System, where citizens can benefit from all services via fixed or mobile systems and provide information returns in every field. Today, “Smart City” solutions aiming to solve the problems of cities and increase the quality of life of those living in cities gain importance and are rapidly being implemented in many cities around the world. It basically implemented smart city solutions in such a way as to enable decision-making based on real-time information and integrated with the information technologies infrastructure systems of cities such as City Information System (CIS) and Geographic Information System (GIS). With the developing technology, it is seen that CIS has developed into 3D and continues with 3D City Models. The most important data generation method of 3D Urban Models is photogrammetric methods based on LIDAR and UAV technology. In recent years, the use of laser scanning systems (LIDAR systems) has been increasing rapidly in 3D modelling studies, detection of deformation areas, restoration and survey work.

2. 3D CITY MODELING

3D city models, which are the foundation for 3D GIS; It comprises computerized 3D representations of spatial data such as land surface, buildings, roads, trees and other earth objects. The basic components of a 3D city model are digital terrain models, building models, street object models and models of green areas (Döllner et al., 2006). Different names such as “Virtual City”, “Cybertown”, “Cybercity” and “Digital City” are used for 3D city models (Sadek et al., 2002). In 3D city models, especially in recent years, it has been focused on obtaining a view as close to physical reality as possible and creating photorealistic views of urban objects (Döllner et al.,

2006). Many applications, such as urban planning, facility management and personal navigation programs require hosting semantic information about urban objects as well as geometry models (Mao, 2011). During the production of 3D city models, if only presentation-oriented models are produced and modeled in terms of thematic/semantic or topological information is neglected, these models can only be used for visualization, but cannot be used for thematic queries, analyzes and spatial information (Döllner et al., 2006).

The need for different content and detail level representations required for various purposes within the scope of 3D modeling and meeting these needs by using different data types and tools from different sources leads to the need to develop certain standards in 3D modeling over time (Doğru and Şeker, 2009). There are some standards developed to store, manage and integrate 3D city models developed in different data structures and different programs (Mao, 2011). CityGML, proposed by the Open Geospatial Consortium (OGC) in August 2008, is the first international standard to represent 3D city models (Mao, 2011). VDI 3805 and Industrial Foundation Class (IFC), developed in 2011, are among other standards (Mao, 2011). City models can be created in different ways by using developing computer technologies and programs and 3D data structures.

Today, there are many GIS software and many of this software has their own data storage formats. It is inevitable to do additional operations when sharing data from GIS software that stores in its own formats to another GIS software (Emem et al., 2008). When exchanging data between GIS software, formats such as Geographic Markup Language (GML), which can count data in one data structure to be stored directly in another data structure, are used. The data to be shared is converted into a GML document and becomes readable and usable by other software (Emem et al., 2008).

GML was developed by OGC and accepted as 19136 international standards by the International Organization for

Standardization (ISO) in 2007. GML includes basic schema, application schemas and data documents as a concept. It is stated that the GML data structure data contains complementary information, especially the type, geometry and topology information. One of the GML application schemes is given as CityGML. CityGML is a general information model designed for 3D representation of cities. The purpose of CityGML is defined as the storage and exchange of 3D city models data (Emem et al., 2008).

The large amount of data in 3D city models for extensive regions prevents editing and displaying the data quickly. Today, this problem is solved by making modeling at a different level of detail (Level of Detail, LoD) for the purpose (Yücel and Selçuk, 2009). With modeling at different levels of detail, the communication, sharing, presentation and use of complex and large-capacity 3D city models can be provided more efficiently (Özdoğan and Başaraner, 2013).

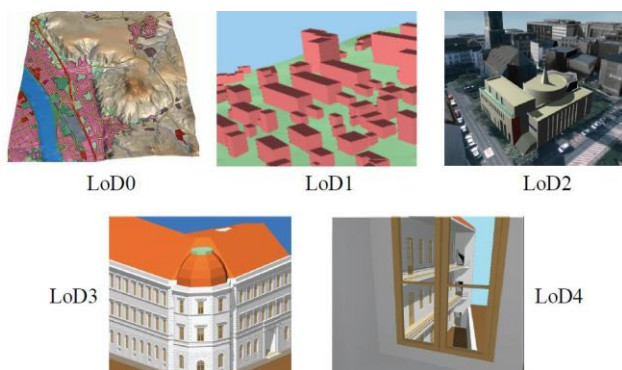


Figure 1. LoD representation defined by CityGML (Kolbe et al., 2005).

CityGML proposes 5 different levels of detail LoD for 3D city models as shown in Figure 1 (Kolbe et al., 2005). These detail levels starting from level zero and how detailed the objects in the city model will be displayed are explained below.

- LoD 0 is a 2.5D digital terrain model.
- LoD 1 is a block model with no roof structure or texture.
- LoD 2 vegetation is represented by models whose roof structure and texture can be separated.
- LoD 3 shows detailed vegetation and transportation objects with detailed wall and ceiling structures and architectural models with balconies.
- LoD 4 can also represent interior structures such as rooms, interior doors, stairs and furniture (Kolbe et al., 2005).

3. UAV PHOTOGRAMMETRY

It is a photogrammetry technique in which different map products such as orthophoto and point cloud are revealed as a result of the evaluation of aerial images taken by UAV with digital photogrammetric techniques, computer vision and image processing techniques (Karlı, 2020).

In this study, the DJI Phantom 4 RTK was used (Figure 2). Remote control operates this system. DJI Phantom 4 RTK is one of the most suitable solutions for 3D model production with the ability to take 1 mm resolution images. Integrated into the Phantom 4 RTK, the internal TRK module provides real-time, centimeter-level positioning data for improved absolute accuracy in image metadata. It enables the production of high-quality orthophoto, digital elevation model, point cloud data with coordinated photo acquisition. High-resolution aerial

photographs of the object are got by flying over the object for which data is to be got. Then, surface elevation models are created from these aerial photographs. On the surface height model got, laser point clouds are produced in the computer environment and the model comprising the positioned 3D point cloud (X, Y, Z) of the object is got. The technical specifications of the system are given in Table 1.



Figure 2. DJI Phantom 4 RTK UAV System.

Drone	Takeoff Weight	1391 gram
	Max Service Ceiling Above Sea Level	19685 ft (6000 m)
	Max Flight Time	Approx. 30 minutes
	Operating Temperature Range	32° - 104° F (0° - 40°C)
	Hover Accuracy Range	RTK enabled and functioning properly: Vertical : ±0.1 m ; Horizontal : ±0.1 m
		RTK disabled: Vertical : ±0.1 m (with vision positioning) ; ±0.5 m (with GNSS positioning) Horizontal : ±0.3 m (with vision positioning) ; ±1.5 m (with GNSS positioning)
	Image Position Offset	The position of the camera center is relative to the phase center of the onboard D-RTK antenna under the aircraft body's axis:(36, 0, and 192 mm) already applied to the image coordinates in Exif data. The positive x, y, and z axes of the aircraft body point to the forward, rightward, and downward of the aircraft, respectively.
GNSS	Single-Frequency, High-Sensitivity GNSS Module	GPS+BeiDou+Galileo (Asia) GPS+GLONASS+Galileo (Other Regions) GNSS Frequency: GPS: L1/L2; GLONASS: L1/L2; BeiDou: B1/B2; Galileo: E1/E5a
		Speed Accuracy: 0.03 m/s
Camera	Sensor	1" CMOS; Effective pixels: 20M
	Lens	FOV 84°; 8.8 mm / 24 mm(35 mm format equivalent:24 mm); f/2.8 - f/11, auto focus at 1 m - ∞
	ISO Range	Video:100-3200(Auto) 100-6400(Manual) ; Photo:100-3200(Auto) 100-12800(Manual)
	Shutter Speed	Electronic Shutter Speed: 8-1/8000 s Mechanical Shutter Speed: 8-1/2000 s
	Max Image Size	3:2: 5472×3648 4:3: 4864×3648

Table 1. DJI Phantom 4 RTK Technical Specification.

4. TERRESTRIAL LAZER SCANNING

LIDAR is a technology that uses laser pulses to measure the distance of an object or a surface. LIDAR systems send millions of laser pulses per second to the object or surface to be measured. The result is a cloud of laser dots with millions of coordinates representing the scanned object. When laser scanning is compared with traditional measurement techniques, it is seen that 3D information is obtained at a very high speed. Laser scanning technology is very effective in identifying irregular objects (Karasaka et al., 2021). Today, many different techniques such as aerial LIDAR (ALS), mobile LIDAR (MLS), terrestrial laser scanning (TLS) or motion-to-structure (SfM) are used for dense point cloud-based mapping purposes. However, these techniques are common and effective in mapping large and large areas. Apart from the mapping of urban areas, different techniques are used in studies such as mapping indoor areas and creating inventory. One of them is the instant positioning and mapping (SLAM) algorithm-based system with LiDAR and Inertial measurement unit (IMU) integrated system (Lagueta et al., 2018). New approaches are required for mapping where the relevant measurement area is small and the field of view very limited. With these approaches, lightweight wearable (WLS) or hand-held (HMLS) devices have been used for mapping purposes (Zeybek, 2019).

In this study, GeoSLAM Zeb-Revo (Geo-SLAM, 2019) handheld LiDAR scanner was tested. The resulting point clouds were reported to be produced in a relatively (RMSE <10 mm) at close range (<10 m) (Geo-SLAM, 2019). According to this experimentally given accuracy criterion, only distance accuracy has been tested. Horizontal and vertical positional evaluations were not made. However, in well-planned measurement networks, it has been stated that the LiDAR system has a relative error rate of 1:10000 without systematic error up to 30 minutes thanks to long loops and blocks (Dewez, Yart, Thuon, Pannet, & Plat, 2017). In this case, it can be said that sufficient accuracy has been achieved in the arrangement of 1/1000 scale maps (<0.08m).


Maximum distance	30 m	
Data collection speed	43200 point/second	
Resolution	0.625° hor	
	1.8° ver	
Laser safety class	1. class	
Laser wavelength	905 nm	
Scanner rotation speed	0.5 Hz	
Total system weight	4.1 kg	
Relative accuracy criterion	2-3 cm	
Absolute accuracy	3-30 cm	

Table 2. GeoSLAM Zeb-Revo System Technical Specification.

Zeb-Revo handheld LiDAR scanner is a time-of-flight measuring device with an IMU integrated positioning system without the need for satellite navigation systems. The scanner determines all the details around it with a simultaneous location and mapping (SLAM) algorithm (Geo-SLAM, 2019). The SLAM algorithm identifies the objects around the scanner as stationary, and according to this assumption, the points are connected and the whole point cloud is obtained (Sammartano & Spanò, 2018). According to the GeoSLAM manufacturer, the accuracy of the measuring points is evaluated as 5 mm + 1 mm/m. Empirically, it is noted that the Zeb-Revo gives a better

result than half a centimeter accuracy in well-constructed indoor studies, as its constant coefficient is noticed to be small here. The features of the product are given in Table 2.

5. METHODOLOGY

As an application, it will be a base for the theme of smart cities; It consists of providing the integration of the 3D Building Model created by integrating the photogrammetric data obtained by Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicle methods. The application consists of field and office studies. For this purpose, Faculty of Social Sciences and Humanities (SBIF) located in Necmettin Erbakan University, Köyceğiz Campus has been selected (Figure 3). The model obtained at the end of the study will be a three-dimensional city model using photogrammetric data in real scale. The aforementioned three-dimensional city model is planned to be a LoD 4 level data containing interior and exterior spaces. If we list the data to be produced and the production methods below:

- LoD 2 Level: Aerial photogrammetry data obtained by Unmanned Aerial Vehicle,
- LoD 3 Level: Aerial photogrammetry data obtained by Unmanned Aerial Vehicle and data obtained by terrestrial photogrammetry method,
- LoD 4 Level: Data obtained by terrestrial photogrammetry method.



Figure 3. Working Area.

6. RESULTS

We can collect Photogrammetric Data Production under two main headings. Air photogrammetry data obtained by UAV for outdoor data and LIDAR data for indoor and outdoor areas.

6.1 Aerial Photogrammetry Data obtained by UAV

The data obtained by the terrestrial photogrammetry method required for LoD 2 and LoD 3 Levels were produced with the DJI Phantom 4 RTK device with approximately 11 million points and used. In addition, the orthophoto of the entire campus to be used as a base was also produced with the same device (Figure 4/a and 4/b). The resulting photos were uploaded to the Pix4D software and the uploaded photos were processed. Condensed point cloud was produced from the conjugate point cloud of the combined photographs. After the ground control points are mapped, the "optimized" point cloud is coordinated and ready for output.



Figure 4/a. SBIF UAV Data. Figure 4/b. Campus Orthophoto.

6.2 LIDAR

Aerial photogrammetry data obtained with the UAV required for LoD 3 and LoD 4 Levels were performed with Zeb-Revo Hand Held Laser Scanner in 5 sessions. The data formed in these sessions are combined and consist of approximately 217 million points as shown in Figure 5/a, 5/b and 5/c. Combining and processing of 5 sessions point cloud data was done with 3DReshaper software.



Figure 5/a. SBIF LIDAR Point Cloud.

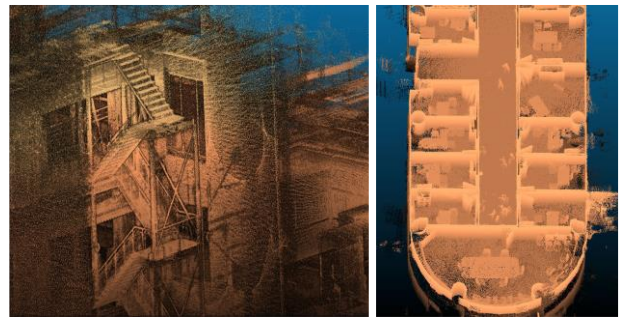


Figure 5/b. SBIF LIDAR Stairs Figure 5/c. SBIF Floor Plan.

In order to make the data more meaningful, it has been seen that it is necessary to continue with one of the options to turn into a 3D drawing (CAD) in mesh or point cloud. However, due to the fact that there are too many gaps for the model in the relevant point cloud data for the mesh operation, there are quite a few gaps in the triangulation process and sufficient quality data could not be produced. In this context, the method of transforming this data into a 3D drawing (CAD) was applied. With the help of AutoCAD software, 2D floor plans were created in CAD environment by taking sections from LIDAR data layer by layer (Figure 6/a and 6/b). In addition, the floor plan of the attic plan was obtained in the CAD environment with the aerial photogrammetry data obtained by the UAV.

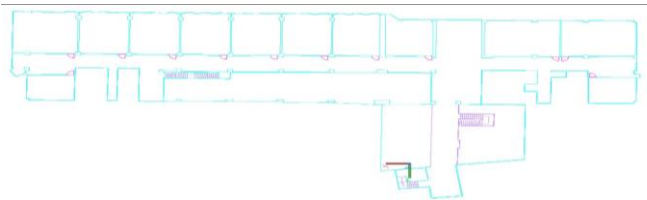


Figure 6/a. SBIF LIDAR Student Building 3. Floor CAD Plan.

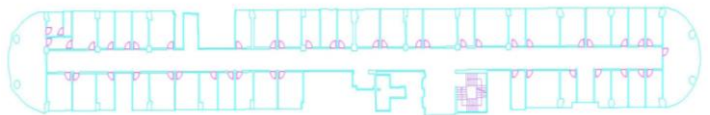


Figure 6/b. SBIF Administrative Building 4. Floor CAD Plan

Later, these floor plans were made 3D with the SketchUp software and a 3D model was created by combining all floor plans and the attic plan (Figure 7/a, 7/b, 7/c and 7/d).

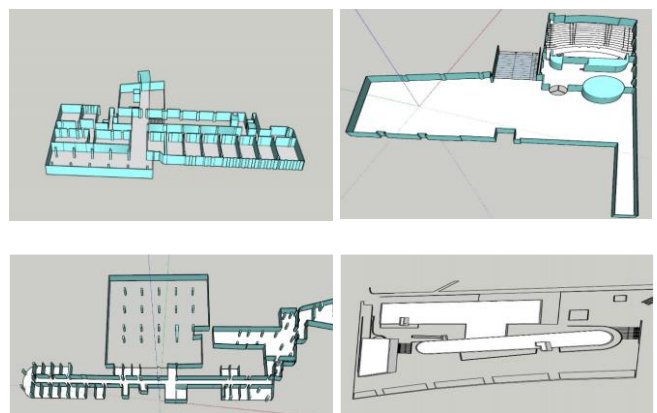


Figure 7/a. SBIF Student Building 2. Floor 3D Model, Figure 7/b. SBIF Middle Garden and Auditorium 3D Model, Figure

7/c. SBIF Administrative Building Ground Floor 3D Model,
Figure 7/d. SBIF Attic Floor Plan.

Finally; All floor plans were combined with the SketchUp software and the whole 3D model is created and shown in figure 8/a and 8/b.



Figure 8/a. SBIF 3D Model with Orthophoto, Figure 8/b. SBIF 3D Model.

As seen in Figure 8/b, a 3D model was produced, and analyses were made in order to comment on the scope of the 3D model produced from LIDAR data. First of all, approximately 91% of the building was scanned with LIDAR and turned into a 3D model. Some private/secret rooms and toilets for privacy reasons were not scanned, other than that almost the entire building was modelled as shown in Table 3.

No	Section	Floor	Total Area	Scanned Area	Unscanned Area	Scan Rate
1	Administrative Building	4	1135,388	1015,196	120,192	89,41%
2	Administrative Building	3	1255,804	1140,731	115,073	90,84%
3	Student Building	3	1921,826	1828,39	93,436	95,14%
4	Administrative Building	2	1238,417	1093,641	144,776	88,31%
5	Student Building	2	2218,249	2068,89	149,359	93,27%
6	Administrative Building	1	801,648	709,464	92,184	88,50%
7	Student Building	1	2733,047	2555,329	177,718	93,50%
8	Administrative Building	Ground	4394,28	4038,475	355,805	91,90%
9	Student Building	Ground	2655,334	2172,494	482,84	81,82%
10	Auditorium	Ground	607,218	572,739	34,479	94,32%
Totally			18961,211	17195,349	1765,862	90,69%

Table 3. Status of the Photogrammetric Model.

7. CONCLUSION

As a result; a study was carried out on a total area of 40,000 m², 20,000 m² of which is indoor and 20,000 m² of which is outside. It has been seen that both data can be integrated with each other and it has been understood that photogrammetric models can be used easily in 3D Urban Models / 3D Cadastre studies, and photogrammetric data is an important data production technique for Building Information Modelling (BIM) and can be easily used in housing stock and quality studies.

In the study, while evaluating the data obtained from both systems (LIDAR and UAV), the advantages and disadvantages of the systems were also examined. Firstly, both systems gave very successful results in outdoor 3D modelling. However, with the UAV system, the data required for 3D modelling can be obtained faster and the data is processed faster. In the scanning process with a hand-held LIDAR scanner, there were some deficiencies in the corners of the buildings, the corners of the roofs, the joints of the columns, due to the measurement principle of the TLS system.

The Zeb-Revo handheld LiDAR system was tested in outdoor conditions for mapping purposes. Outdoors, the scanner's range was a maximum of 20 m (effective distance 15 m). A planar surface was created from a distance of less than 6 m and it was determined that the deviation in the points did not exceed 8 cm according to the square mean error value. The standard deviation value in forming the plane was obtained as 9 mm. It provides sufficient accuracy criteria for plane or line extraction from the point cloud. The mapping performance with the handheld LiDAR Zeb-Revo GeoSLAM is comparable to other systems, demonstrating the feasibility of repositioning by synchronizing with any point cloud. Absolute position accuracies can be increased with indirect coordinating methods. In addition, it has been seen that the known classification and filtering methods form reliable clusters, and the production of topographic and 2D maps for the needs after the classification meets the standards. In the UAV system, the missing places in the TLS lidar systems were successfully measured in this system, provided that the top scan and oblique pictures were taken on the lateral surfaces. This study will benefit studies involving larger areas as this is not a relative study at LoD 4 level.

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