Terrestrial Laser Scanning – Challenges and Opportunities in 3D Building Model Creation

Gergana Antova[1*], Gabriela Simeonova [2], Christina Mickrenska[3]

[1*] University of Architecture, Civil Engineering and Geodesy (UACEG), 1 H. Smirnenski Blvd., Sofia 1046, Bulgaria; email: antova_fgs@uacg.bg; https://orcid.org/0000-0002-0926-8033

[2] University of Architecture, Civil Engineering and Geodesy (UACEG), 1 H. Smirnenski Blvd., Sofia 1046, Bulgaria

[3] University of Architecture, Civil Engineering and Geodesy (UACEG), 1 H. Smirnenski Blvd., Sofia 1046, Bulgaria; kmikrenska_fgs@uacg.bg; https://orcid.org/0000-0002-7054-1799

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Abstract

The technology of terrestrial laser scanning and its possibilities are subject of scientific research in the area of geodesy, construction, architecture and even more over the last decades. This method provides point clouds data, which contains full and accurate representation of the geometrical parameters of the examined subject. This publication discusses in short the principles and possibilities for creating a three-dimensional data model using the advantages of terrestrial laser scanning. The building of University of Architecture, civil engineering and geodesy, situated in Semkovo resort, Blagoevgrad district is selected for the purpose of the task. Classical land surveying measurements with a total station and terrestrial laser scanning are used for the creation of the three-dimensional models. A comparison and evaluation of the obtained model is made. The result of this evaluation indicates that the technology of terrestrial laser scanning is efficient for representation of high quality data with a wide scope of advantages such as high range, fast data processing, high precision and accurate details.

Keywords: laser scanning, 3D digital model, point cloud processing, accuracy

Introduction

Three-dimensional modeling of buildings is a complex process that consists of collecting spatial data and post-processing to recreate an accurate geometric model of the studied object.

Terrestrial laser scanning technology has been the subject of scientific research in recent decades in numerous scientific and applied fields such as surveying, construction, architecture and others. This method uses laser beams to measure distances from the instrument to objects in its surroundings.

For development purposes, classic geodetic measurements with a total station and terrestrial laser scanning were performed to create a three-dimensional model of a building in a forest area. Measurements of distances were made with a tape measure in order to control the quality of the created model. The result of this evaluation shows that terrestrial laser scanning technology is effective in presenting high-quality data with a wide range of advantages such as large range, fast data processing, high precision and accurate details.

Laser Scanning Technology

Three-dimensional laser scanning is an electro-optical remote sensing technology for determining distances to objects using a directed beam of light, without the need for direct access to the object under study [1].

Laser scanners have a great advantage over other instruments because it record high-density spatial data. The disadvantage of a laser scan is that no fixed point from the deformable surface can be measured unless these points are specifically marked and their recognition is ensured [2].

There are two types of laser scanning: Terrestrial Laser Scanning (TLS) and Airborne Laser Scanning (ALS).

Terrestrial Laser Scanning

Terrestrial Laser Scanning technology is a measurement of distances using laser beams. The result of the scan is a cloud of point that have X, Y and Z spatial coordinates and reflected signal intensity that depends on the reflectivity of the surface of the object.

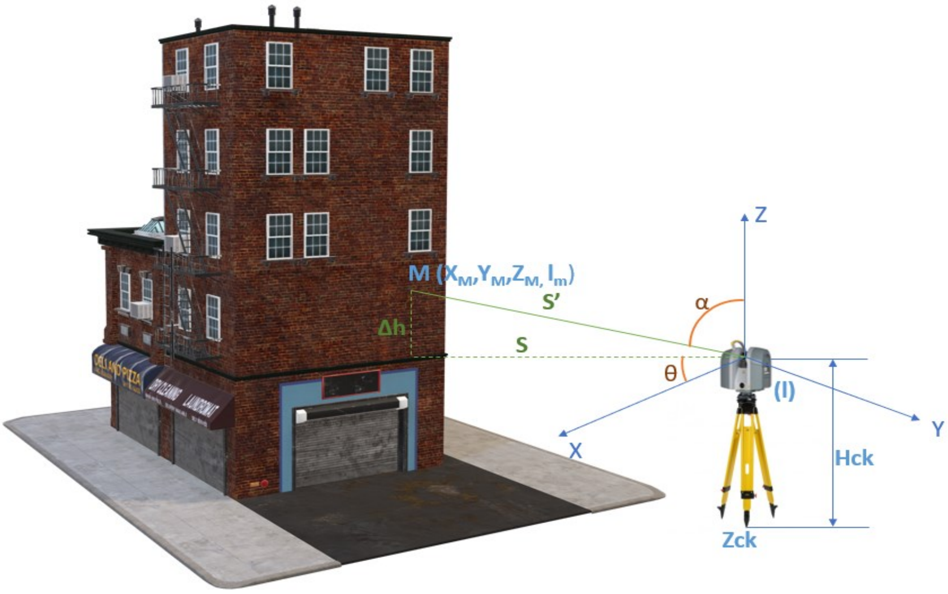

Fig. 1. Measurement with TLS

Fig. 1 shows the principle of the laser scanner for the coordinates of each scanned point M (X_M, Y_M, Z_M) is:

$$
\begin{aligned}
X_M &= X_{CK} + S'\cos\theta\cos\alpha \\
Y_M &= Y_{CK} + S'\cos\theta\sin\alpha \\
Z_M &= Z_{CK} + H_{CK} + S'\mathrm{c}tg\alpha
\end{aligned}
\qquad (1)
$$

where: X_{CK}, Y_{CK}, Z_{CK} are the coordinates of the scanner position, H_{CK} is the height of the scanner head from the ground, S` is slope distance from scanner to scan point, α and θ – polar angles determining the position of the scanning beam and l – the intensity of the reflected signal from point M.

For object with complex spatial geometry, it is necessary to capture from several stations in order to obtain a complete scan to create a complete 3D model of the object under study. This necessitates the attachment of the individual point clouds in a common coordinate system (point cloud registration). When integrating the final product into a GIS system, the registered point clouds must be transformed into a desired coordinate system. This process is called georeferencing. Depending on whether the scanner is static during the scan or mobile, two types of terrestrial laser scanning are distinguished: ground-based and mobile laser scanning.

In ground-based laser scanning, the scanner is fixed during the measurement. In mobile laser scanning, the instrument is mounted on a mobile platform, which can be some type of vehicle such as a car, ship, or railcar. Scanner mobility provides greater scanning range. Spatial positioning of the mobile scanner is achieved by integrating GNSS technology and an inertial measurement unit (IMU) (Fig. 2).

Fig. 2. Mobile laser scanning system using GNSS-IMU positioning for direct georeferencing of received data

In highly urbanized areas, GNSS technologies are not always the best method of positioning, due to erroneous results due to lack of direct "sight" to satellites. For this reason, IMU equipment is also integrated into mobile laser scanners. It is inertial navigation that provides high-frequency data by tracking changes along and around the three axes of linear acceleration and angular velocity.

Airborne Laser Scanning

Airborne laser scanning (ALS) is a scanning system that is mounted on an aircraft (Fig. 3). ALS can be used to collect spatial data over large areas due to its volumetric operating range. This technology again features GNSS technology and an IMU for accurate positioning at all times.

The data acquired by airborne laser scanners are collected by sending out laser beams to the ground using pulsed or continuous wave techniques. Therefore, the distance is derived by measuring travel time or phase shift of the emitted signal. To improve coverage of the sampled area system manufacturers use varying techniques to deflect the laser beam during flight time. The result is called a digital surface model (DSM) because it contains both points from the ground surface and points from objects on top of the surface, like buildings and trees. [3].

Fig. 3. Working principle of ALS

A case study of 3d modelling in forest area

The Range Of Case Study

The object of the research is the buildings of University of Architecture, civil engineering and geodesy, situated in Semkovo resort, Blagoevgrad (Fig. 4-a). They are located at 1620 meters above sea level in southern Rila mountain, 17 km north of the town of Belitsa, region Blagoevgrad. The complex consists of 8 buildings (Fig. 4-b). The buildings are of interest because they are located in a mountainous area and are surrounded by high vegetation (spruce and pine forests) and thus the advantages and disadvantages of the methods used can be indicated, which is also the purpose of the present study.

(a)

(b)

Fig. 4. The range of case study

Terrestrial Laser Scanning

Before starting the scanning, paper marks (Fig. 5) were pasted on the facades of the object to be used for the registration of the individual stations and the georeferencing of the model in a desired coordinate system.

Fig. 5. Placed paper marks on the facades of the object

To determine the coordinates of the marks, classic geodetic measurements were made with a Trimble S3 total station. The measurements were done by 9 points (Fig. 6), 6 of which are known (control) points (points 101, 1, 2, 4, 30, 200 and 400, and 3 additional new points – 1, 3 and 20.

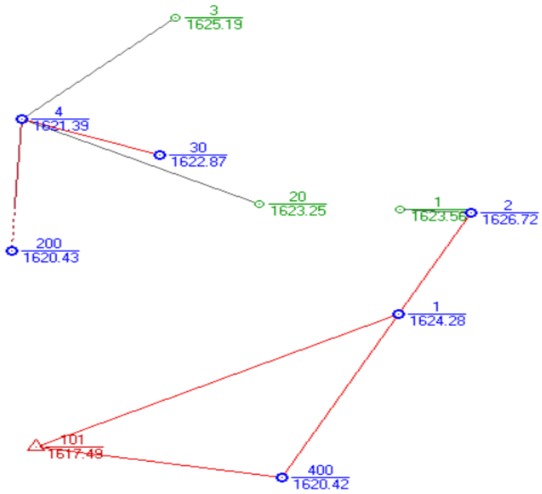

Fig. 6. Location of the control points

Due to the impossibility of placing a large number of marks in the measurement process, natural points of the object, which are clearly distinguishable such as the corner of a building, windows, etc., were determined.

Scanning was performed with a Trimble TX6 laser scanner (Fig. 7-a), and the team consisted of 1 person. The scan was carried out from 11 stations (Fig. 7-b).

(a) (b)

Fig. 7. Position of the scanning stations

Creation of a 3D Model

Laser scanning data were processed with Trimble RealWorks software product.

To be able to connect the individual clouds of points in a single coordinate system, the first step is to identify the common points in the individual stations, which points represent the previously placed flat marks and natural points on the surface of the scanned object (Fig. 8).

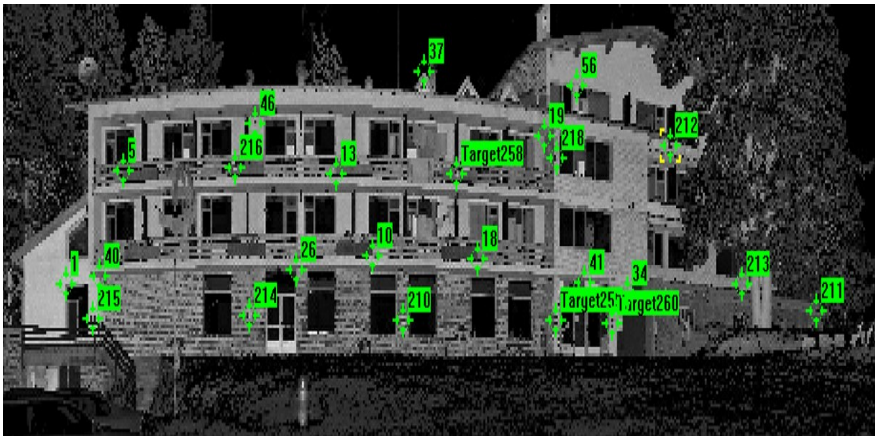

Fig. 8. Marking flat marks and natural points on the surface of the scanned object

Sixty identical points were used to tie the individual stations and the maximum error was 36.8 mm. The merged point cloud (Fig. 9) consists of 5 505 308 million points is georeferenced to the coordinate system of the total station measurements using the already determined point coordinates. Point clouds give a full and exact representation of the building geometry [4].


Fig. 9. Point cloud obtained by terrestrial laser scanning

To create a 3D model, the point cloud must be cleaned of noise. To facilitate this process, automatic classification of cloud points into three classes was made: buildings, ground surface and high vegetation. The total number of points has been reduced to 3 479 705.

The final product of the terrestrial laser scan is a 3D model based on surfaces (Fig. 10), which for better visualization is textured (Fig. 11).

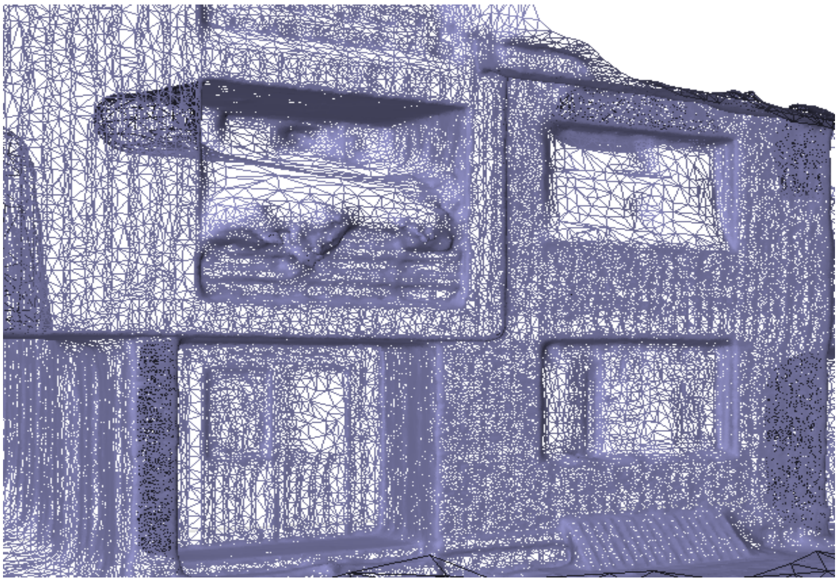

Fig. 10. 3D model based on surfaces

Fig. 11. Textured 3D model

Quality control

During the field work, control distances were measured on the buildings. After obtaining the 3D model, control distances were also measured. A total of 38 control distances were measured to evaluate the models. The differences between the control distances and their corresponding measured distances from the 3D model were formed, where possible:

$$\partial S = S - S^o \tag{2}$$

where S^o is the distance between 2 points from the model, S – the same control distance.

The mathematical expectation and the root mean square error is calculated and a check for gross errors was made:

$$M_x = \frac{1}{n}\sum_{1}^{n}\partial S_i \tag{3}$$

$$m_x = \sqrt{\frac{\sum_{1}^{n}\partial S_i^2}{n}} \tag{4}$$

The maximum difference obtained for the directly measured distances and the 3D model created by TLS is 2.7 cm, and the minimum is 0.0 cm. The results are given at table 1.

Tab. 1. Quality control.

№	Directly measured distances, [m] (1)	3D model - TLS [m] (2)	Diference, [cm] (1)-(2)
1	1.62	1.616	0.4
2	0.32	0.307	1.3
3	0.89	0.88	0.5
4	0.24	0.226	1.4
5	0.12	0.119	0.1
6	0.88	0.88	**0.0**
7	2.26	2.261	-0.1
8	0.99	1.003	-1.3
9	0.29	0.281	0.9
10	1.8	1.827	**-2.7**
11	2.07	-	-
12	1.45	1.423	2.5
13	0.38	0.365	1.7
14	1.36	1.344	1.6
15	3.8	-	-
16	1.5	1.497	0.3
17	3.35	3.348	-0.3
18	1.53	1.533	-0.3
19	0.39	0.394	-0.9
20	1.46	1.473	-1.3
21	1.56	1.569	-0.5
22	1.56	1.575	-1.5
23	4.91	4.904	0.6
24	1.51	1.509	-0.3
25	3.56	3.562	-0.2
26	0.56	0.553	0.7
27	2.15	2.15	0.2
28	1.61	1.585	2.5
29	2.09	-	-
30	3.8	3.814	-1.4
31	6.25	6.262	-1.2
32	2.06	-	-
33	7.15	7.159	-0.9
34	1.23	1.238	-1.1
35	3.71	-	-
36	2.23	-	-
37	2	-	-
38	2.74	-	-
		M_x=	**-0.1**
		m_x=	**1.1**
		$3m_x$=	**3.4**

Conclusion

Collecting spatial information with ground laser scanning took 4 hours and determining the coordinates of the marks – 2.5 hours. The office work that was needed to create the 3D model is 5 hours. The model was created based on the cloud, which contains 3 479 705 points.

The data obtained by a terrestrial laser scanner represents a large volume that has been obtained in a short time. The laser scanner can provide us with up to 500,000 points per second. The process of creating the 3D model with the laser scanner is automated and involves minimal human resources. It can be said that laser scanning has many advantages such as large range, high accuracy, high degree of detail of the captured objects.

Of course, the investment in such a scanner is many times greater than that of a total station or a drone, and a large amount of work is required to justify it. However, TLS also have their disadvantages, such as the impossibility of a complete scan of the roof structures (Fig. 12).

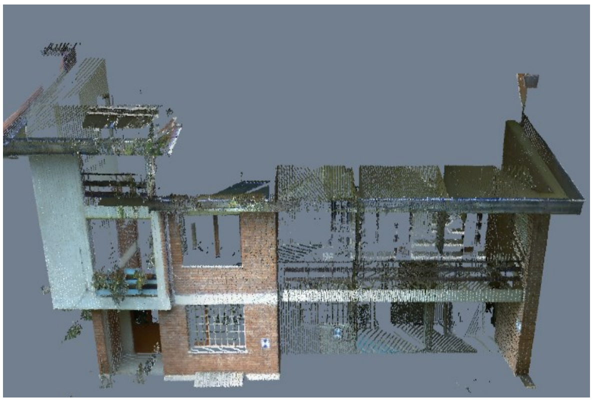

Fig. 12. Impossibility of complete scanning of the roof structures with TLS

In conclusion, a high-quality and complete 3D model of a building can be produced by a combination of TLS and aerial surveying using an unmanned aerial vehicle for roof structures.

At a later stage, the data from the created models can be entered into a GIS environment. GIS are used very often for data presentation and analysis, to support decision-making in management, to monitor development and identify changes in the urban environment [5]. The use of GIS for such research is to represent the change of the urban environment through the use of two-dimensional and three-dimensional modeling, as well as spatio-temporal analyzes [6].

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References

1. M. Blagoev, "3D lazerno skanirane v gradska sreda", http://geocradle.eu/wp-content/uploads/2017/03/Geocad93-3DLaserScan-Blagoev.pdf , visited 12.2022.
2. R. Ivanov, "Engineering Surveying And Deformation Surveys", ISBN 978-954-12-0272-2, Monograph, Sofia, 2020.
3. G. Antova, "Rapid precise mapping with 3D laser scanning", Annual of UACEG, Sofia, Bulgaria, 2006, vol. XLII, pp 81-87.
4. G. Antova, Iv. Kunchev and C. Mickrenska-Cherneva, "Point clouds in BIM", Multidisciplinary Earth Sciences Symposium (WMESS 2016), IOP Conference Series: Earth and Environmental Science, 44 (2016) 042034, https://doi.org/10.1088/1755-1315/44/4/042034\.
5. P. Pavlov, "GIS – application in the development and management of large settlements", ISSN 0324-1610 – XXXIX, Geodesy, cartography and land management journal., Vol. 4, 1999, pp. 16-20.
6. T. Ilieva, "Analysis and GIS-based modeling of free and open data for tracking the dynamics of the urban environment: Case study for Sofia, Bulgaria", Proceedings of 22nd International Multidisciplinary Scientific GeoConference SGEM, 8. Geoinformatics, 2022 (in print).