# APPLICATION OF TERRESTRIAL LASER SCANNING TECHNOLOGY IN THE ANALYSIS OF THE COLUMNS VERTICALITY AND THE CREATION OF A 3D MODEL OF THE SPORTS HALL

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## ABSTRACT

The research presented in this paper focuses on the application of Terrestrial Laser Scanning (TLS) technology to analyse the verticality of columns and create a 3D model of the sports hall in the suburban settlement Futog, city of Novi Sad, Serbia. The examination of the verticality of the columns was performed by generating horizontal sections and extracting the cross-sectional profile of each column from the point cloud. These analyses enabled the determination of the columns' deviations from the verticality by comparing the coordinates of the centroids of the cross-sections. The 3D model of the object's exterior and interior was generated using the point cloud in the Revit software package. All surveying works, including Terrestrial Laser Scanning, establishment of geodetic network, registration and georeferencing of point clouds, analysis of column verticality, and the creation of 3D model, were performed according to relevant standards and regulations for this type of surveying work. The research results indicate the high efficiency and precision of TLS technology in identifying verticality deviations of columns and creating precise 3D model, which significantly contribute to the digitalization of construction objects.

KEYWORDS:

Verticality of columns, 3D Model Creation, Terrestrial Laser Scanning

# 1 INTRODUCTION

In the last few decades, TLS technology has undergone significant development, representing a key role in geodetic engineering, architecture, and construction. This technology provides high precision, efficiency, and flexibility in data collection, enabling digitization of physical objects in three dimensions. The application of TLS in analysing the verticality of columns and creating a 3D model of a sports hall in Futog, a suburb of Novi Sad, is a practical example of project implementation using this technology.

Testing the verticality of structural elements is a key parameter that indicates the assessment of the functionality and stability of structures. In recent decades, traditional approaches to determining the verticality of structural elements relied on optical theodolites, later total stations, whose main drawback was the inaccessibility of points on structural elements and the need to measure a large number of points on their surface [1]. Today's advances in engineering techniques, including terrestrial laser scanners, allow for precise, non-contact, high-resolution scanning of objects. This advanced approach allows for fast and accurate slope tracking and continuous monitoring of changes over time. TLSs, using the principle of emitting a light beam and collecting reflected light, scan the surface of an object, creating a dense point cloud of high precision. TLS technology enables data collection from a certain distance, eliminating the need for physical contact with the structure while ensuring high precision and a high level of detail. Laser scanning is the optimal choice for assessment the stability of many structures [2-4].

Integrating TLS in the modelling process represents a revolutionary step in creating precise 3D model of building objects. By using TLS technology, it is possible to achieve exceptional level of detail in the digital representation of objects, which is of key importance in the renovation and preservation of objects [5-7]. Building Information Modelling (BIM) is the digital representation of buildings' physical and functional characteristics, enabling the integral management of information throughout their life cycle. Using the Revit software package for processing the collected data enables the creation of 3D models that facilitate the realization of BIM projects. TLS technology advances this process by providing a precise foundation for BIM projects [8]. BIM projects enable comprehensive monitoring and management of construction projects, from idea to realization [9, 10]. The combination of TLS technology and advanced software solutions enables achieving high precision and efficiency in creating 3D model, which represents a key step towards digitization and optimization of construction processes.

This paper investigates the application of TLS technology in the analysis of column verticality and the creation of 3D model, demonstrating the high efficiency and precision of the technology in the identification of column vertical deviations and the creation of 3D model. The research results provide a significant contribution to the digitization of construction objects, highlighting the potential of TLS technology in engineering fields.

# 2 MATERIALS AND METHODS

## 2.1 TERRESTRIAL LASER SCANNING

TLS has revolutionized the process of detailed and precise measurement of objects. The scanners work on the LiDAR (Light Detection And Ranging) principle, using laser light to measure the distance between the scanner and a target object or surface. Lasers are reflected from the surface towards the device, generating return signals. The distance *s'*, vertical angle $w_1$ and horizontal angle $w_2$ are measured for each reflection point (Figure 1). Based on these parameters and the intensity of the reflected signal, it is possible to precisely locate each point within the 3D coordinate system [11]. This technology allows users to rapidly collect millions of points per second, creating a dense point cloud that accurately represents the shape, size and surface features of the scanned structure. Modern terrestrial laser scanners have shown significant improvements in performance and overall system functionality [12]. The application of TLS technologies has a wide application in other branches of industry as well, focusing on quick and easy data collection about objects, machines, etc.

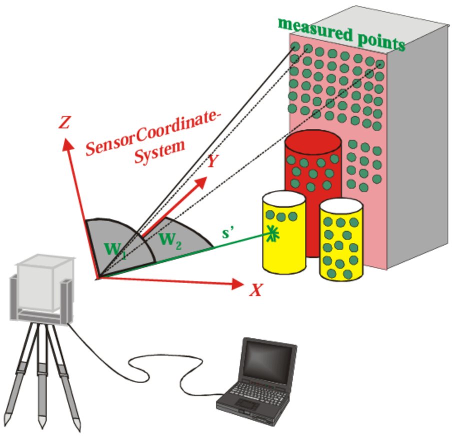


Figure 1: The principle of tachymetric Laser Scanning [11]

Objects to be scanned are usually larger areas to scan from one position, so scanning is done from multiple positions. The number of positions is determined, among other things, by the geometry of the object being scanned and the conditions on the location. A comprehensive point cloud is formed by collecting multiple scans from different positions. A point cloud is a collection of points in three-dimensional (3D) space, where each point represents a specific location. The terrestrial laser scanning method is an iterative process that must ensure the coverage of objects of interest and the percentage of overlap between adjacent scans.

When the scan is complete, the raw point cloud from the instrument is transferred to the processing software. The problem with the TLS method is that it collects a large amount of data; therefore, it is necessary to remove data that is not part of the scanned object. The first step in the phase of processing the collected data is the registration of the point clouds. Registration represents the connection of individual point clouds associated with each scanner position into a unique point cloud of the entire object. Accordingly, during field scanning, connection points (markers) were materialized, which made it possible to register point clouds during the processing process. The registered point cloud is used for further analysis and modelling. In the next step, the point cloud is georeferenced based on the points of the geodetic network, i.e., the point cloud is transformed from the local coordinate system to the national coordinate system.

## 3 RESULTS AND DISCUSSION

The object of terrestrial laser scanning is the sports hall in Futog. Terrestrial laser scanning was performed on September 4, 2023, to test the structure's supporting columns' verticality and create a 3D model. A *Trimble TX-8* scanner was used in the terrestrial laser scanning process (Table 3). To georeference the point cloud, a three-dimensional (3D) geodetic network was established.

Table 3: Specification of *Trimble TX-8*

| | |
|---|---|
| Range | 0,6 – 100 m |
| Extended range | 340 m |
| Range systematic error | < 2 mm |
| Angular Accuracy | 80 μrad |
| Field of view | 360°x317° |
| Weight (with battery) | 11,0 kg |
| Operating temperature range | –0°C to +40°C |
| Scan time per battery | >2 h |
| Resolution | 0,3" |

### 3.1 STAGES OF FIELDWORK

The first phase of fieldwork began with the reconnaissance of the terrain in the immediate vicinity of the sports hall. Before starting the acquisition of geospatial data using terrestrial laser scanning technology, the 3D geodetic network of the object was established. Measurements in the 3D geodetic network were realized by the relative kinematic method of satellite positioning in real-time (*Real-Time Kinematic*) using the *Trimble R10 Global Navigation Satellite System* (GNSS) receiver. The measurements were realized with an observation interval of *3x5* s, taking care that there were no obstacles that would affect multiple reflections and degrade the accuracy of the measurements.

The second phase of fieldwork included terrestrial laser scanning of the exterior and interior of the sports hall in Futog. The exterior of the sports hall was scanned from 23 positions, while the interior was scanned from 68 different positions. Figure 2 shows the scanner from different positions during scanning.

Figure 2: *The Trimble TX-8* scanner in front of the entrance to the sports hall (left) and during the scanning of the interior of the hall (right)

The product of the laser scan of the sports hall is a high spatial resolution point cloud consisting of 6.526.413.730 3D points. Therefore, it is about billions of points, which represent a rich digital archive from which it is possible to generate a 3D model, vertical and horizontal sections and other data.

### 3.2 DATA PROCESSING

The first step in the phase of processing the collected data is the registration of the point clouds. Point clouds registration was performed in the *Trimble Business Center* software package using a combination of two methods, manual, which involves the use of connection points, and the automatic cloud-to-cloud. Point cloud registration was realized with very high accuracy. The total error of point cloud registration is 2.8 mm.

In the next step, georeferencing of the point cloud based on the points of the 3D geodetic network was performed, that is, the transformation of the point cloud from the local coordinate system to the national coordinate system (*Gauss-Krüger projection*, 7 zone). Seven points were used in the georeferencing procedure. Table 2 shows the residuals along all three coordinate axes for each point used in the georeferencing of the point cloud.

Table 4: Residuals of points in the process of point cloud georeferencing

| Points | $v_Y$[m] | $v_X$[m] | $v_H$[m] | $v$ [m] |
|---|---|---|---|---|
| 1 | 0,025 | 0,013 | 0,017 | 0,033 |
| 6 | 0,017 | 0,010 | 0,025 | 0,032 |
| 10 | 0,012 | 0,018 | 0,002 | 0,022 |
| 11 | 0,000 | 0,004 | 0,005 | 0,006 |
| 13 | 0,022 | 0,008 | 0,011 | 0,026 |
| 14 | 0,024 | 0,009 | 0,036 | 0,044 |
| 15 | 0,009 | 0,016 | 0,019 | 0,026 |

Georeferencing was performed with an accuracy of several centimetres, which is quite satisfactory for this type of geodetic work. It is important to point out that the relative accuracy of the obtained point cloud is at the level of several millimetres, which is confirmed by the registration results.

Figures 3 and 4 show the point cloud of the interior of the sports hall in Futog.

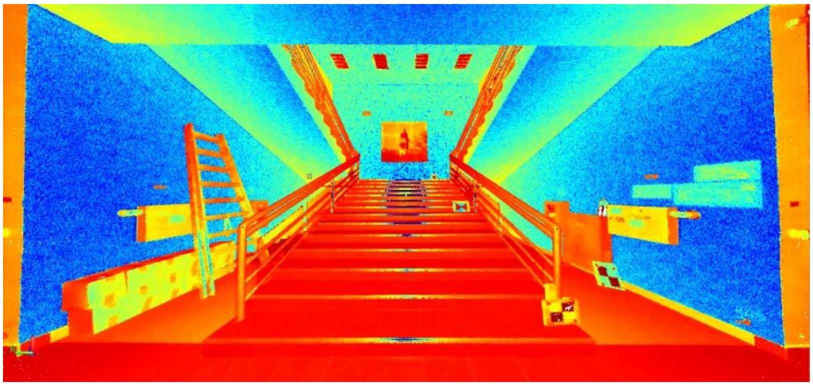

Figure 3: Point cloud of the interior part of the sports hall

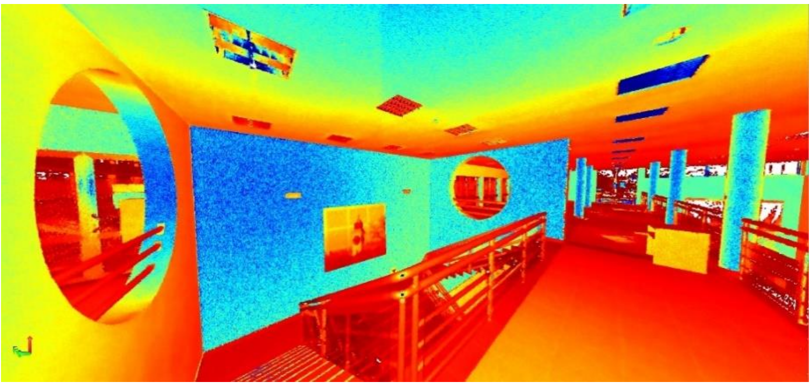

Figure 4: The point cloud of the gallery section

### 3.3 EXAMINATION OF THE VERTICALITY OF COLUMNS

Based on the point cloud, the verticality of the supporting columns of the sports hall in Futog was examined. The analysis included 20 circular columns (SO1, ..., SO20) and 12 rectangular columns (SP1, ..., SP12). The locations of the columns are shown in Figure 5. Due to the size of the object and clarity of the sketch, only the part where the columns are located is depicted. For each column, two horizontal sections were created in the point cloud:

HP1 – the bottom of the column;

HP2 – the top of the column.

At columns SO11, ..., SO16, one more characteristic horizontal section was created in the point cloud:

HP3 – the middle of the column (the bottom of the column in the gallery).

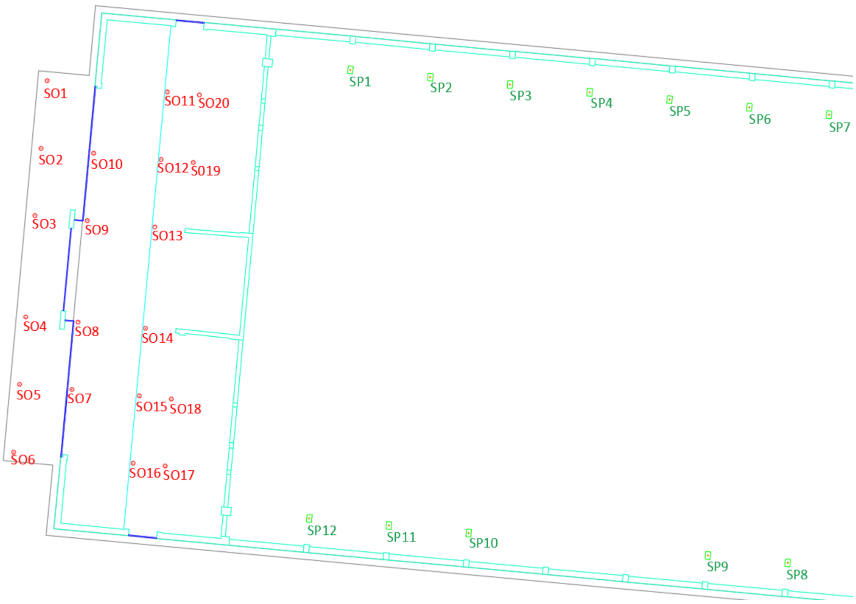


Figure 5: Identification of circular (red) and rectangular (green) columns from the object's top view

Figure 6 shows the positions of the horizontal sections of the columns. The cross-section of each individual column was extracted from the point cloud in the specified horizontal sections. The columns' deviations from the vertical are determined by comparing the centroid coordinates of the columns cross-sections - HP1 relative to HP2 and HP3; and HP3 relative to HP2. Figure 7 shows an example of cross-sections of circular and rectangular shapes.

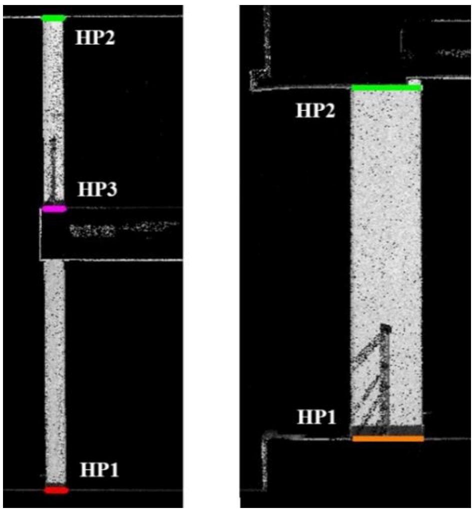


Figure 6: Positions of cross-sections on a circular (left) and rectangular (right) column

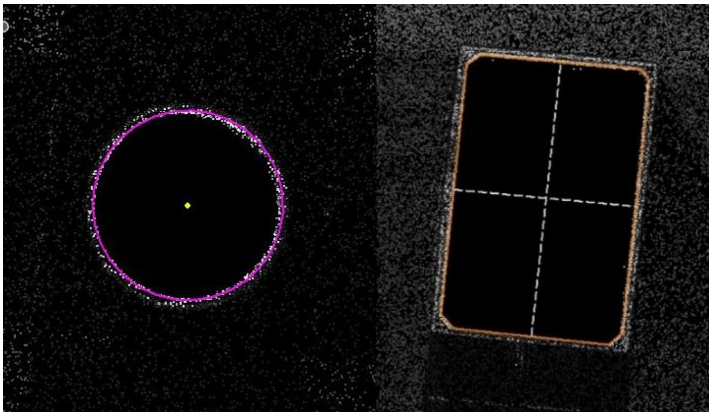

Figure 7: Extraction of cross-sections of columns from the point cloud

Tables 3 and 4 show the deviations from the vertical of the tops of the rectangular and circular columns in relation to the sections HP1, which represent the bottoms of the columns.

Table 5: Values of deviations from the vertical of the tops from the bottoms of rectangular columns

| Column | | $dY$ [cm] | $dX$ [cm] | $d$ [cm] |
|---|---|---|---|---|
| SP1 | HP2 – HP1 | 0,17 | 2,07 | 2,08 |
| SP2 | HP2 – HP1 | 1,37 | 0,49 | 1,46 |
| SP3 | HP2 – HP1 | 0,46 | 1,07 | 1,16 |
| SP4 | HP2 – HP1 | 0,09 | -0,48 | 0,49 |
| SP5 | HP2 – HP1 | -1,01 | -0,84 | 1,31 |
| SP6 | HP2 – HP1 | 0,37 | 0,94 | 1,02 |
| SP7 | HP2 – HP1 | -0,30 | 1,03 | 1,07 |
| SP8 | HP2 – HP1 | -0,98 | -0,61 | 1,15 |
| SP9 | HP2 – HP1 | -0,70 | -1,16 | 1,36 |
| SP10 | HP2 – HP1 | -0,54 | -0,79 | 0,96 |
| SP11 | HP2 – HP1 | 0,61 | 0,60 | 0,86 |
| SP12 | HP2 – HP1 | 0,84 | -1,42 | 1,65 |

The deviation values from the vertical of the HP3 section of circular columns SO11, ..., SO16 in relation to the bottom of the columns (HP1 sections) are shown in Table 5. Table 6 shows the deviation values from the vertical tops of these columns (sections HP2) in relation to sections HP3.

Table 6: Values of deviations from the vertical of the tops from the bottoms of circular columns

| Column | | $dY$ [cm] | $dX$ [cm] | $d$ [cm] |
|---|---|---|---|---|
| SO1 | HP2 – HP1 | 0,33 | 0,06 | 0,33 |
| SO2 | HP2 – HP1 | -2,37 | 0,83 | 2,51 |
| SO3 | HP2 – HP1 | -0,49 | -0,02 | 0,49 |
| SO4 | HP2 – HP1 | -0,08 | 1,98 | 1,98 |
| SO5 | HP2 – HP1 | -0,38 | -0,19 | 0,43 |
| SO6 | HP2 – HP1 | -0,75 | -0,59 | 0,95 |
| SO7 | HP2 – HP1 | -0,93 | 1,36 | 1,64 |
| SO8 | HP2 – HP1 | -0,74 | 0,06 | 0,74 |
| SO9 | HP2 – HP1 | 2,13 | 0,30 | 2,15 |
| SO10 | HP2 – HP1 | 0,42 | 0,19 | 0,46 |
| SO11 | HP2 – HP1 | -2,36 | 0,50 | 2,41 |
| SO12 | HP2 – HP1 | -3,51 | 0,12 | 3,51 |
| SO13 | HP2 – HP1 | 0,20 | -0,42 | 0,46 |
| SO14 | HP2 – HP1 | 0,89 | 3,35 | 3,47 |
| SO15 | HP2 – HP1 | -4,91 | 0,17 | 4,91 |
| SO16 | HP2 – HP1 | -5,15 | 2,60 | 5,77 |
| SO17 | HP2 – HP1 | -0,31 | 0,59 | 0,66 |
| SO18 | HP2 – HP1 | -0,33 | -0,54 | 0,63 |
| SO19 | HP2 – HP1 | -0,32 | -0,19 | 0,37 |
| SO20 | HP2 – HP1 | 0,39 | -0,79 | 0,88 |

Table 7: Values of the deviation from the vertical of the centre from the bottom of the circular columns

| Column | | $dY$ [cm] | $dX$ [cm] | $d$ [cm] |
|---|---|---|---|---|
| SO11 | HP3 – HP1 | -2.43 | -0.14 | 2.44 |
| SO12 | HP3 – HP1 | -2.22 | 0.32 | 2.24 |
| SO13 | HP3 – HP1 | 1.08 | -0.58 | 1.23 |
| SO14 | HP3 – HP1 | 1.24 | 1.81 | 2.19 |
| SO15 | HP3 – HP1 | -3.31 | 0.45 | 3.34 |
| SO16 | HP3 – HP1 | -4.28 | 2.36 | 4.88 |

## 3.4 CREATION OF A 3D MODEL

The 3D model of the exterior and interior of the sports hall in Futog was created using point cloud within the Revit software package. Figures 8 and 9 show a 3D model of the exterior and interior of the sports hall in Futog.

Table 8: Values of deviations from the vertical of the tops from the centre of circular columns

| Column | | $dY$ [cm] | $dX$ [cm] | $d$ [cm] |
|---|---|---|---|---|
| SO11 | HP2 – HP3 | -0.07 | -0.64 | 0.65 |
| SO12 | HP2 – HP3 | 1.29 | 0.19 | 1.30 |
| SO13 | HP2 – HP3 | 0.88 | -0.17 | 0.89 |
| SO14 | HP2 – HP3 | 0.35 | -1.55 | 1.58 |
| SO15 | HP2 – HP3 | 1.59 | 0.28 | 1.62 |
| SO16 | HP2 – HP3 | 0.88 | -0.24 | 0.91 |

Figure 8: 3D model of the exterior of the sports hall in Futog

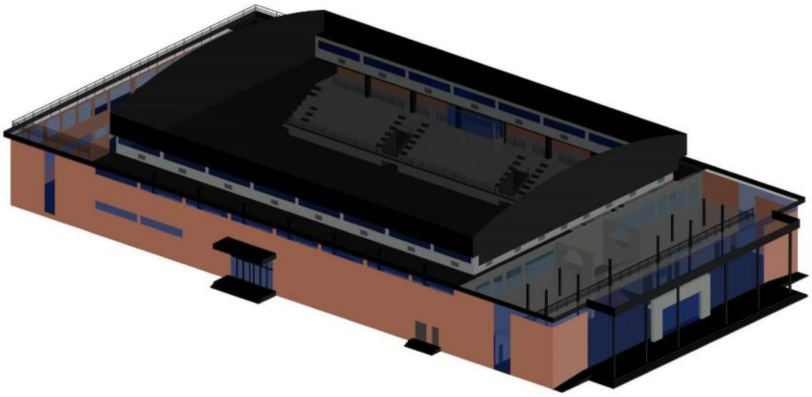

Figure 9: 3D model of the exterior and interior of the sports hall in Futog

## 4 CONCLUSIONS

Through the application of terrestrial laser scanning technology, it is possible to collect high-precision spatial data efficiently and thereby significantly improve the restoration and renovation processes of buildings. TLS technology represents an advance in the creation of detailed 3D model and analysis of verticality. The application of TLS lays the foundation for integration with BIM technology, which represents the future of planning, design and maintenance of construction facilities. The use of BIM in combination with TLS enables better project management through all phases of the building life cycle while increasing efficiency and reducing the possibility of errors.

Future development directions explore how TLS data can be effectively integrated into BIM systems to monitor better and manage construction resources. The application of TLS in BIM systems would further reduce the costs and time required for construction and renovation. Integrating artificial intelligence (AI) with data obtained through TLS technology and their application in BIM systems opens new directions for process optimization in construction. AI can significantly contribute to automating data processing, object recognition, and classification in point clouds. In addition, the application of AI can improve the ability of BIM systems to predict maintenance needs and renovation costs, enabling proactive management of facilities and infrastructure.

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