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ADVANCED GEODETIC TECHNIQUES FOR URBAN DIGITAL TWIN CREATION

Abstract: The concept of a digital twin of a city requires accurate, high-resolution, and up-to-date geospatial data describing the urban environment. This paper focuses on the selection, description, and comparison of modern geodetic methods used for data acquisition to support the development of urban digital twins. The study reviews key technologies, including terrestrial laser scanning (TLS), mobile laser scanning (MLS) and SLAM-based mapping systems. Each method is evaluated in terms of data quality, spatial resolution, acquisition efficiency, operational limitations, and suitability for different urban scenarios. Particular attention is given to the integration of heterogeneous datasets into unified 3D city models and point cloud environments. The paper discusses workflows for combining multi-source data, addressing challenges such as data fusion, georeferencing consistency, and temporal updating. The advantages of each method are analyzed with respect to specific urban features, including buildings, infrastructure, and public spaces. The results highlight that no single method is sufficient for comprehensive digital twin creation. Instead, a hybrid approach combining multiple geodetic techniques provides the most robust solution. The proposed framework supports efficient data acquisition and contributes to the development of accurate and scalable urban digital twins for planning, management, and smart city applications.

Keywords: Geodetic Techniques, Digital Twin, TLS, MLS, SLAM

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Introduction

The rapid development of geospatial technologies in recent years has significantly transformed the acquisition of spatial data for urban environments. High-resolution spatial data have become an essential prerequisite for the creation of reliable 3D city models, which are widely applied in engineering, environmental analyses, infrastructure management, and the development of Smart City concepts (Salih et al., 2025; Zaman et al., 2024). Among the most important technologies for acquiring detailed spatial information are TLS and MLS, which enable the generation of accurate and dense point clouds suitable for modelling complex urban environments. TLS is characterized by its high geometric accuracy and dense point clouds, making it particularly suitable for the documentation of buildings (Bariczová et al., 2021), engineering structures (Erdélyi et al., 2020), historical monuments (Casula et al., 2026), and other objects requiring highly detailed spatial representation. MLS, implemented using vehicle-mounted, backpack, handheld, or smartphone-based systems employing simultaneous localization and mapping (SLAM) technology (Macario Barros et al., 2022; Tang et al., 2015), enables significantly more efficient data acquisition while maintaining sufficient accuracy for most urban mapping applications. MLS technologies allow the acquisition of large-scale datasets of urban features, while the resulting dense and accurate point clouds provide a reliable basis for a wide range of surveying and analytical tasks. MLS has been successfully applied to the reconstruction of outdoor scenes and cultural heritage objects (Zlot et al., 2014; Štroner et al., 2022). Furthermore, it has found extensive applications in civil engineering (Erdélyi et al., 2022), as well as in the detection and inventory of utility poles, traffic signs, road infrastructure (Ma et al., 2018; Weiss and Dietmayer, 2007), and street lamps, making it an important technology for the maintenance and management of urban infrastructure (Lehtomäki et al., 2010; Wang et al., 2019).

The rapid advancement of these technologies has significantly contributed to the development of Digital Twins (Hananto et al., 2024; Wagg et al., 2020), which represent dynamic virtual models of real-world environments by integrating accurate geospatial data with semantic information. Digital Twins enable efficient urban infrastructure management, spatial planning, change monitoring, scenario simulation, and decision support within Smart City frameworks. The quality, accuracy, and timeliness of the input spatial data are therefore crucial factors determining the reliability and practical usability of a Digital Twin (Nocerino et al., 2017).

The aim of this study is the comprehensive documentation of the city centre of Žiar nad Hronom using advanced laser scanning technologies, namely TLS and MLS. The primary objective is to compare the advantages and limitations of the individual data acquisition methods and to assess their suitability for creating accurate and scalable geospatial databases intended for the development of urban Digital Twins. For both surveying methods, the acquired point clouds were georeferenced using ground control points (GCPs), whose coordinates were determined by Global Navigation Satellite System (GNSS) technology. The field survey was carried out according to the following workflow:

– Terrain reconnaissance and determination of the study area.

- Location and determination of the coordinates of the GCPs and CPs for TLS and MLS.
- Measurement using the TLS method.
- Measurement using the MLS method.

To achieve the goal of this study, several surveying instruments and mapping systems were employed. Prior to field measurements, all instruments were configured and their functionality was verified. The TLS survey was performed using a Leica RTC360 terrestrial laser scanner. MLS data acquisition was carried out using the Lidaretto system mounted on both a vehicle and a backpack platform. Additional MLS datasets were collected using the Stonex X120GO handheld mobile laser scanner, which was carried throughout the entire study area. The coordinates for the GCPs used for TLS and MLS and check points (CPs) for MLS were determined using a dual-frequency GNSS set Leica GS07.

Material and methods

This chapter describes the study area, surveying equipment, fieldwork procedures, and data processing workflow used to acquire and evaluate high-resolution spatial data for urban digital twin development. The experimental methodology was designed to enable a comprehensive comparison of TLS and MLS technologies under identical field conditions. Particular attention was devoted to the selection of suitable surveying instruments, the establishment of GCPs and CPs, the acquisition of point cloud data, and the subsequent processing and georeferencing of the datasets. The adopted workflow ensures consistent data quality and provides a reliable basis for the comparative analyses presented in the following sections.

Study area. The selected area for data acquisition, comparison, and evaluation of spatial information is a section of urban area located in the city center of Žiar nad Hronom. Such a site represents an ideal test environment for assessing the capabilities and limitations of different technologies, such as TLS and MLS. Žiar nad Hronom is a district town in the Banská Bystrica Region in central Slovakia. The total area of the selected site is 2.8 ha, within which 12 buildings are located. The city center contains a wide variety of objects, including historical and modern buildings, roads, vegetation, and public spaces. This diversity enables the creation of detailed 3D models of different types of objects and their subsequent analysis in terms of accuracy, level of detail, and usability. The city of Žiar nad Hronom (Fig. 1) is located in central Slovakia (Žiar nad Hronom, 2026; Slovensko v kocke, 2026).

Surveying equipment. GNSS set Leica GS07. Modern GNSS instruments represent a key technology that uses satellite signals to determine precise positions on the earth's surface with high accuracy. The GNSS set Leica GS07 (Fig. 2) consists of a Smart Antenna, the Leica CS20 controller, and a telescopic range pole. All further specifications of the GNSS set are provided in the table (Table 1). The main advantages of this device include accuracy, measurement speed, durability, and stable satellite connection. Accurate position determination is not possible in cases where the signal is weak or when loss of fixed solutions occurs under obstructed environments. These represent the main limitations of GNSS instruments, which can significantly affect the accuracy and reliability of measurements (Trimble R12i, 2026).

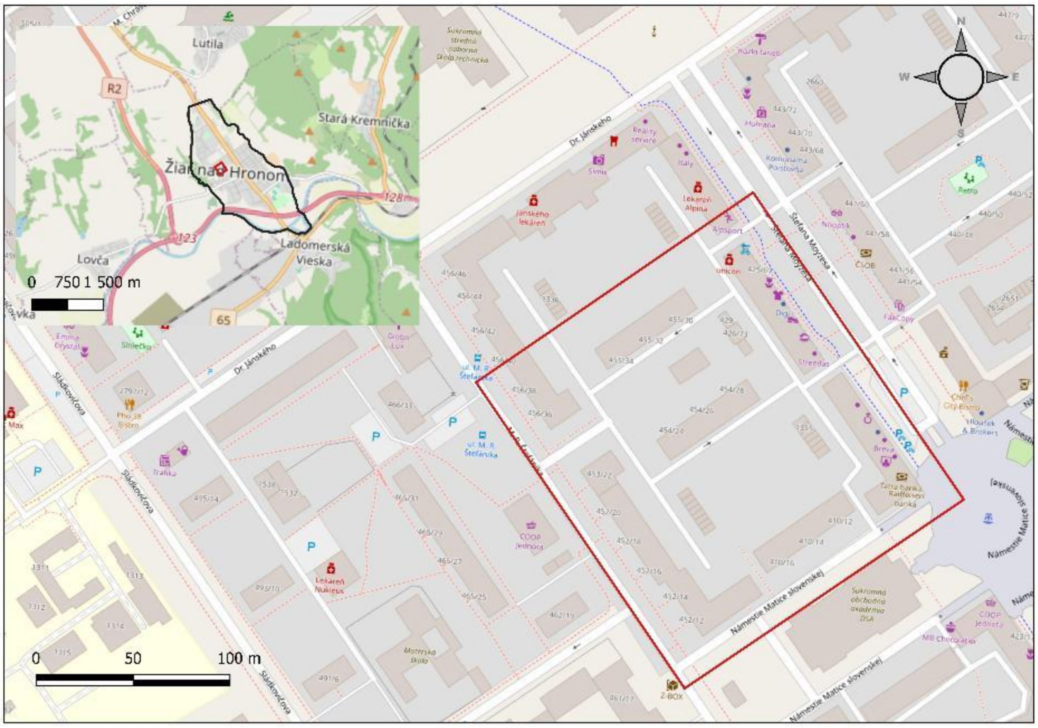


Fig. 1. Location of the urban area in the city center of Žiar nad Hronom
Source: Own elaboration

Fig. 2. GNSS set Leica GS07
Source: Own elaboration

Table 1. Specification of GNSS set Leica GS07

<table>
<tr><th>Technology</th><th colspan="2">Leica RTKplus</th></tr>
<tr><td>Weight</td><td colspan="2">2.85 kg</td></tr>
<tr><td>Channels</td><td colspan="2">320</td></tr>
<tr><td>SmartCheck</td><td colspan="2">Continuous check of RTK solution</td></tr>
<tr><td>Initialisation</td><td colspan="2">6 s</td></tr>
<tr><td rowspan="4">RTK surveying</td><td rowspan="2">Single baseline</td><td>Horizontal: 10 mm + 1 ppm</td></tr>
<tr><td>Vertical: 20 mm + 1 ppm</td></tr>
<tr><td rowspan="2">Network RTK</td><td>Horizontal: 10 mm + 0.5 ppm</td></tr>
<tr><td>Vertical: 20 mm + 0.5 ppm</td></tr>
<tr><td rowspan="4">Static GNSS surveying</td><td rowspan="2">High-Precision Static</td><td>Horizontal: 3 mm + 0.5 ppm</td></tr>
<tr><td>Vertical: 6 mm + 0.5 ppm</td></tr>
<tr><td rowspan="2">Static and fast static</td><td>Horizontal: 5 mm + 0.5 ppm</td></tr>
<tr><td>Vertical: 10 mm + 0.5 ppm</td></tr>
</table>

Source: Own elaboration based on Leica GS07, 2026

Surveying equipment. Terrestrial laser scanner Leica RTC 360. Laser scanners are currently considered among the most advanced and high-performance geodetic instruments, capable of high-accuracy scanning. Due to their speed and level of detail, they are indispensable for acquiring dense spatial data. One of these high-performance laser scanners is the Leica RTC360 (Fig. 3), which represents an advanced device for capturing detailed 3D scenes in a short time. The scanner is equipped with a VIS system that enables automatic registration of individual scans during data acquisition. During scanning, the device can also capture HDR panoramic images using integrated cameras. Another feature is dual scanning, which allows moving objects to be automatically removed. The device can be operated via a large integrated color touchscreen or through a mobile phone or tablet. The main disadvantages of this instrument include its high cost, the need for specialized expertise, and high hardware requirements. Table 2 presents the technical parameters of the Leica RTC360 terrestrial laser scanner manufactured by Leica Geosystems (Leica RTC360, 2026).

Surveying equipment. Mobile laser scanners Lidaretto with H32X and Stonex X120GO. Modern geodetic instruments, such as mobile laser scanners, enable efficient and accurate acquisition of spatial data in real time during sensor movement. These devices represent a technologically advanced solution that is widely used in mapping, monitoring, and analyzing complex terrain surfaces. The systems use Light Detection And Ranging (LiDAR) technology, which emits laser beams toward the scanned object or surface. After reflection back to the sensor, the return time and intensity are analyzed, resulting in a precise three-dimensional model. They are notable for their mobility, as they can be mounted on various platforms such as vehicles, boats, Unmanned Aircraft System (UAS), or used as handheld devices. This allows large amounts of data to be captured in a short time over extensive areas. For proper operation, these systems require additional components such as an Inertial Measurement Unit (IMU), a GNSS antenna, and cameras. SLAM is a technology that enables a mobile scanning system to simultaneously determine its position and orientation while constructing a map of the surrounding environment. The system continuously processes measurements from LiDAR sensors together with data from the Inertial Measurement Unit (IMU) and, depending on the system configuration, cameras or other sensors. By identifying and matching common features between consecutive measurements, SLAM estimates the movement of the scanner and continuously updates the spatial representation of the surveyed environment. This approach allows mobile laser scanners to acquire georeferenced three-dimensional point clouds while the sensor is moving, without requiring a permanently fixed position during data acquisition. The advantages of mobile laser scanners include accuracy, high level of detail, and fast data acquisition. Additional benefits include ease of data collection and device compactness. Mobile laser scanners are a key technology in modern geodesy and offer a wide range of applications for rapid and precise environmental mapping (Riveiro and Lindenbergh, 2019; Rodríguez-Gonzálvez et al., 2019).

Fig. 3. Terrestrial laser scanner Leica RTC 360
Source: Own elaboration

Table 2. Specifications and technical parameters of Terrestrial laser scanner Leica RTC360

<table>
<tr><td>Technology</td><td colspan="3">3D laser scanner with integrated system for capturing HDR panoramic images and VIS (Visual Inertial System) for real-time cloud data registration</td></tr>
<tr><td>Data acquisition</td><td colspan="3">< 2 minutes for full scan and HDR panoramic image at 6 mm @ 10m scan resolution</td></tr>
<tr><td>Weight</td><td colspan="3">5.35 kg (without batteries)</td></tr>
<tr><td rowspan="2">Scanning</td><td colspan="2">Double scanning</td><td>Automatic removal of moving objects</td></tr>
<tr><td colspan="2">Scanning speed</td><td>2,000,000 points/sec</td></tr>
<tr><td rowspan="5">Accuracy</td><td>Angle</td><td colspan="2">18"</td></tr>
<tr><td>Distance</td><td colspan="2">1.0 mm + 10 ppm</td></tr>
<tr><td rowspan="3">3D point</td><td colspan="2">1.9 mm @ 10 m</td></tr>
<tr><td colspan="2">2.9 mm @ 20 m</td></tr>
<tr><td colspan="2">5.3 mm @ 40 m</td></tr>
<tr><td rowspan="3">Camera</td><td rowspan="2">Quality</td><td>36 MPx</td><td>3-camera systém</td></tr>
<tr><td>432 MPx</td><td>Raw data for calibrated 360° x 300° panoramic image</td></tr>
<tr><td>Capturing speed</td><td colspan="2">1 minute for 360° HDR panoramic image in any lighting conditions</td></tr>
<tr><td>Range</td><td colspan="3">0.5 m – 130 m</td></tr>
<tr><td>Resilience</td><td colspan="3">IP54</td></tr>
<tr><td>Working temperature</td><td colspan="3">- 5°C to + 40°C</td></tr>
<tr><td>Storage temperature</td><td colspan="3">- 40°C to + 70°C</td></tr>
</table>

Source: Own elaboration based on Leica RTC360, 2026

One of the mobile sensors is the Lidaretto (Fig. 4a), which represents a fast and simple mapping system for reality capture from various platforms. The application of this system is possible across different sectors due to its ability to generate accurate 3D point clouds. Within a few seconds, it can scan millions of points at high density. During scanning, it uses SLAM technology, which, together with GNSS and IMU data, ensures an accurate trajectory. Lidaretto can be used for monitoring hazardous sites, mapping urban areas, or other important applications (Lidaretto, 2026; Hesai, 2026).

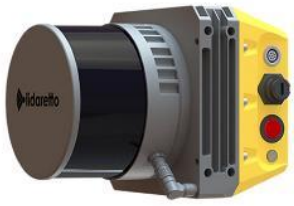
An advanced and frequently used mobile laser scanner is the Stonex X120GO (Fig. 4b), which enables efficient and accurate spatial data acquisition. This scanner is suitable for a wide range of applications due to its mobility and advanced features. The device has a durable and lightweight design with three integrated RGB cameras. A mobile application, GOapp, is used for control, visualization, and operation. A Real-Time Kinematic (RTK) module can also be connected to the device, allowing improved georeferencing accuracy directly in the field. It is used for capturing various environments, including complex or hard-to-access locations (Stonex X120GO, 2026). A comparison of the technical parameters of mobile laser scanners is presented in Table 3.

(a) (b)

Fig. 4. Mobile laser scanners – Lidaretto with H32X (a) and Stonex X120GO (b) Source: Own elaboration

Fieldwork. GCP and CP for TLS and MLS surveying. GCPs for TLS measurements in the city centre of Žiar nad Hronom were temporarily stabilized using black-and-white circular targets with dimensions of 20 × 30 cm. At every second scanner setup, three GCPs were placed in the vicinity of the scanner. These points were subsequently scanned and used to georeference the TLS dataset into the transformed into the national positional coordinate system Datum of Uniform Trigonometric Cadastral Network (S-JTSK) and the height system Baltic Vertical Datum after adjustment using the digital height reference model DVRM. In total, 44 GCPs and CPs were used during the TLS survey of the city centre of Žiar nad Hronom.

Table 3. Technical parameters of mobile laser scanners Lidaretto with H32X and Stonex X120GO

	 **Lidaretto with H32X**	 **Stonex X120GO**
Technology	3D laser scanner with SLAM technology with GNSS and IMU system that ensures real-time registration of data clouds	3D handheld laser scanner with SLAM technology, integrated IMU and RTK module, thanks to which it is possible to georeference point clouds during measurement
Mobility	Mobile (placed on a carrier: car, backpack)	Mobile (handheld measurement)
Weight	1.2 kg	1.6 kg (without batteries)
Range	0.05 m – 300 m	0.05 m - 120 m
Waterproof/dustproof	IP67	IP54
Operating	- 5°C to + 50°C	- 10°C to + 45°C
Dimensions	125 mm × 125 mm × 150 mm	372 mm × 163 mm × 106
GNSS	External GNSS set with RTK module	External GNSS set with RTK module
Scanning point frequency	640,000 pts/s	320,000 pts/s
Accuracy	+/- 10 mm GNSS: 10 – 20 mm IMU: 0.010/0.005/0.005 (°)	Up to 6 mm
Field of view	360° x 40.3°	360° x 270°
Price	60,000 €	40,000 €
Camera	External camera	3x 5MPx RGB camera with FOV 200° x 100°

Source: Own elaboration based on: Lidaretto, 2026; Hesai, 2026

For the mobile laser scanner Lidaretto, CPs were selected from natural signalized features such as manholes, utility covers, and curbstones. A total of 75 CPs were used. For the Stonex X120GO laser scanner, five GCPs were used, evenly distributed across the study area. These consisted of black-and-white circular targets with dimensions of 0.3 × 0.3 m. The targets were temporarily stabilized using ground nails to prevent displacement. During the Stonex X120GO survey, CPs were also used, represented by curbstones and manholes. All GCPs and CPs for both TLS and MLS datasets were determined using a GNSS set Leica GS07 operating in RTK method, connected to the Slovak Real-time Positioning Service (SKPOS) – national active geodetic reference network.. The achieved positional accuracy of the GCPs and CPs was 0.02 m in position and 0.04 m in height.

Fieldwork. TLS surveying. The first method used for mapping the city center of Žiar nad Hronom was TLS. A Leica RTC360 laser scanner was used for the TLS survey. The TLS measurements were carried out at 40 setups (Fig. 5) over approximately 5 hours. At every second station, three temporary black-and-white circular scanning targets were captured, serving as GCPs or CPs. The scanning resolution was set to 6 mm/10 m with a range of 130 meters.

Fig. 5. Distribution of setups in surveying by TLS method
Source: Own elaboration

Fieldwork. MLS surveying. The mapping of the city center of Žiar nad Hronom was also carried out using the mobile laser scanner Lidaretto. The Lidaretto mobile laser scanner was first mounted on the roof of a car. Before the actual scanning, a one-minute device calibration and connection to the GNSS antenna were performed. The scanning operation from the car roof within the study area lasted approximately 15 minutes. Subsequently, the Lidaretto was mounted on the surveyor's backpack, and data acquisition continued while the operator moved through the study area using an electric scooter. The total duration of scanning with the Lidaretto was 40 minutes.

The MLS method was also carried out using the Stonex X120GO mobile scanner. This device is equipped with an RTK module, including an external antenna used during scanning. Before data acquisition, a 60-second calibration is required via the GOapp application. During calibration, the scanner was placed on a stable surface. The scanning itself was controlled through the GOapp application, and during data acquisition the device was carried by hand throughout the study area. During scanning, 5 GCPs were surveyed by placing the scanner directly on the respective points. The resulting point cloud for the study area was obtained from four separate scans with a total duration of approximately 1 hour. A single scan session can last a maximum of 20 minutes. The study area was progressively mapped over four scan sessions. During the first scan, which lasted 17 minutes, 3 GCPs and 3 CPs were captured. During the second 17-minute scan, 1 GCP and 3 CPs were captured, and the remaining part of the study area was completed during the third scan. The third scan lasted 7 minutes and included 1 GCP and 2 CPs. A fourth scan, lasting 14 minutes, was performed to re-scan the entire area, during which 5 GCPs and 8 CPs were captured. The trajectory of measurements using both mobile laser scanners is shown in Fig. 6.

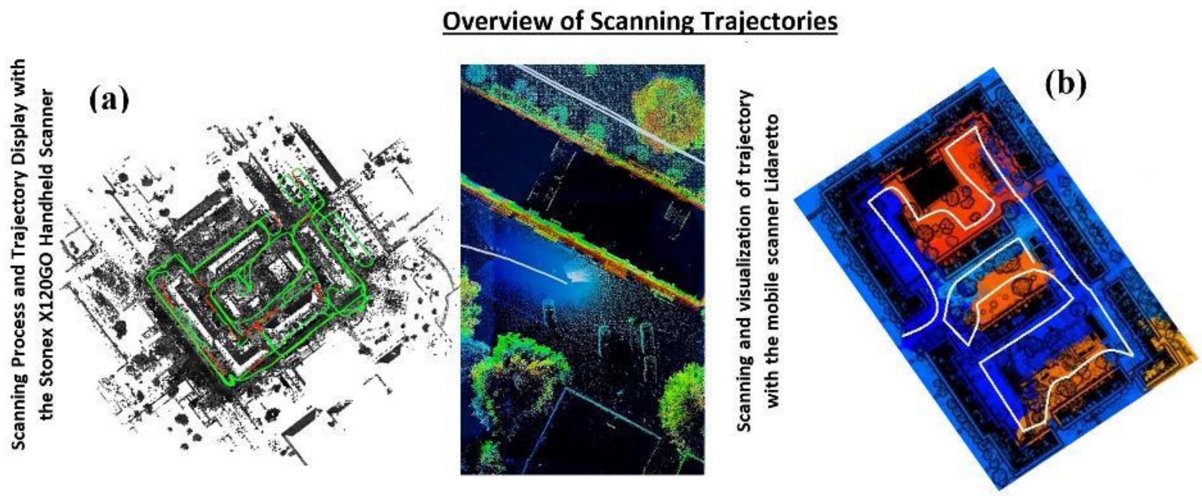


Fig. 6. Measurement trajectory using mobile laser scanners Lidaretto and Stonex X120GO
Source: Own elaboration

Data processing. TLS data processing. For data acquisition using the TLS method, a Leica RTC360 laser scanner was used, with which the city centre within the study area of Žiar nad Hronom was scanned from 40 setups. The acquired data were subsequently processed in Leica Cyclone Register 360 software, where individual point clouds were registered and georeferenced based on 44 GCPs and CPs. Of these, 7 points were used as GCPs and 37 points as CPs. The resulting dense point cloud contained 916,014,221 points. The mean RMSE value reached 0.010 m, the Bundle Error was 0.005 m, and the Cloud-to-Cloud error was also 0.005 m. The overall overlap between individual point clouds reached 37%, while the final point cloud strength was evaluated at 78%. Detailed parameters of the resulting TLS point cloud are provided in Table 4.

Data processing. MLS data processing. Processing of data acquired by the mobile laser scanner Lidaretto was performed using Inertial Explorer software for trajectory computation. Subsequently, individual point clouds were merged and aligned into a single dataset in LiDAR360 software. The final point cloud was generated by integrating data from the vehicle-mounted and backpack-mounted scanner configurations and contained 119,383,840 points. Quality control of the final dataset was carried out in Lidaretto Creator software, which also served for data export. The accuracy of the resulting point cloud was improved using CPs, with the RMSE reaching 0.034 m. Further characteristics of the MLS point cloud acquired using the Lidaretto system are presented in Table. 4.

Data acquired using the Stonex X120GO mobile laser scanner were processed in the GOpost software environment. During processing, the trajectory was computed and registration and assignment of GCPs were performed, resulting in an RMSE value of 0.021 m. The software was also used for point cloud registration and for adding color information to individual points. Based on GCPs and CPs, the resulting point cloud was transformed into the national positional coordinate system Datum of Uniform Trigonometric Cadastral Network (S-JTSK) and the height system Baltic Vertical Datum after adjustment using the digital height reference model DVRM. The final dataset consisted of 199,096,585 points. Other parameters of the MLS point cloud acquired using the Stonex X120GO scanner are presented in Table 4.

Results

The final datasets acquired using TLS and MLS were subsequently used for a series of analyses involving the comparison of point clouds for individual object. Prior to the comparison, the datasets were preprocessed to remove unwanted and redundant points from each point cloud. Point cloud segmentation was performed in Trimble RealWorks software, while Leica Cyclone 3DR, Trimble RealWorks, and CloudCompare software were used for further processing, filtering, visualization, and comparison. Following data processing, dense point clouds (Fig. 7) were generated from both TLS and MLS datasets, serving as the input for subsequent analyses and comparisons. The spatial data acquired from the Žiar nad Hronom study area were analyzed and compared using several approaches. The performed analyses highlight the accuracy, differences, and limitations of the individual spatial data acquisition methods. The results are presented through both quantitative indicators and graphical outputs, enabling a clear and comprehensive interpretation. The resulting dense point clouds also constitute the fundamental building blocks for the creation of a digital twin. Their high spatial accuracy and level of detail enable the development of a faithful digital representation of the real-world environment, which can support urban infrastructure management, change detection, Smart City planning, and decision-making processes through the regular updating of spatial data.

Table 4. Parameters of the resulting point clouds obtained by surveying methods

Results	**TLS**	**MLS**	
	Leica RTC360	**Lidaretto**	**Stonex X120GO**
Nr. of setups/scans	40/0	0/2	0/4
GCP/CP	7/37	0/75	5/8
Resulting point cloud	916,014,221	119,383,840	199,096,585
Area [m^2]	28,000	28,000	28,000
Point density [points/m^2]	54,798	2 802	10,652
RMSE on GCP [m]	0.010	-	0.021
RMSE on CP [m]	0.029	0.034	0.036
Measurement time [h]	5	0.66	1

Source: Own elaboration

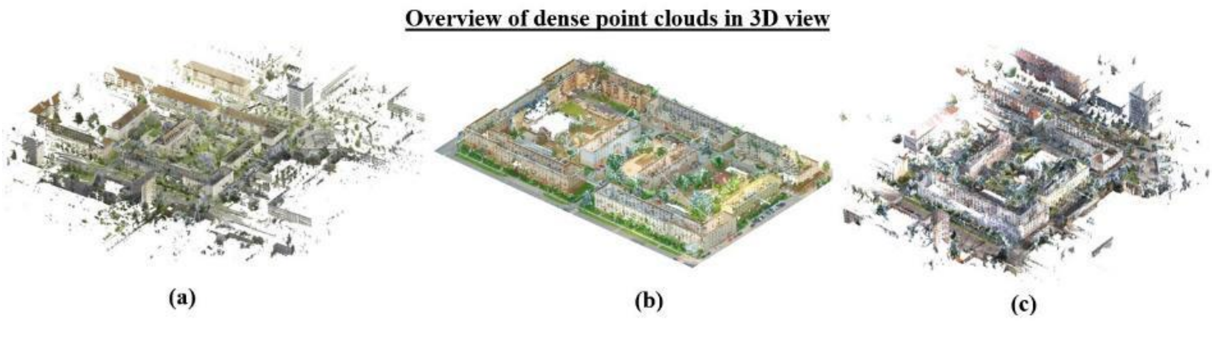


Fig. 7. The resulting point clouds of the Leica RTC360 (a), Lidaretto (b) and Stonex X120GO (c)
Source: Own elaboration

In this chapter, we focus on the analysis of accuracy and reliability of TLS and MLS methods and evaluate differences on selected objects in an urban environment. For the purposes of this analysis, an object type characterized by its structural simplicity and stability was selected: a street lamp. The aim is to quantify differences between TLS and MLS methods based on the accuracy of measurements of this object and to identify potential discrepancies that may influence the resulting point clouds. The analysis of this object was carried out in the Leica Cyclone 3DR software environment. The object used for assessing differences between individual point clouds is the street lamp. Differences were evaluated and compared on ten street lamp evenly distributed across the study area (Fig. 8). Each of these street lamps was captured using three scanning technologies: TLS Leica RTC360 (reference method), the mobile laser scanner Lidaretto, and the mobile laser scanner Stonex X120GO.

Fig. 8. Visualization of the location of selected tested street lamp
Source: Own elaboration

Based on Table 5, it can be observed that the reference method TLS (Leica RTC360) captured between 16 and 46 points on individual street lamps. The lowest number of points was recorded for street lamp No. 3, while the highest values were observed for street lamps No. 5 and 6. The radius values ranged from 0.046 m to 0.055 m.

In the case of the MLS method using the mobile laser scanner Lidaretto, the point density was significantly lower. The lowest number of points was recorded for street lamp No. 1 with 6 points, which is 18 points fewer compared to the reference method. The largest difference occurred for street lamp No. 5, with 33 fewer points. The radius values in this case ranged from 0.045 m to 0.069 m. The average RMSE of the radius was 0.008 m. Overall, the radius increased for street lamps No. 1, 2, 3, 4, and 10 compared to the reference method. The differences ranged from 0.019 m (street lamp No. 5) to 0.104 m (street lamp No. 3), and the average RMSE of the differences reached 0.079 m, indicating that the accuracy of this method is highly dependent on specific field conditions.

Table 5. Analysis of individual street lamp based on point count, radius, and difference from the reference method

Analysis of individual street lamp		Street lamp No. 1	Street lamp No. 2	Street lamp No. 3	Street lamp No. 4	Street lamp No. 5	Street lamp No. 6	Street lamp No. 7	Street lamp No. 8	Street lamp No. 9	Street lamp No. 10	RMSE
TLS – Leica RTC360	Number of points [b]	24	40	16	22	46	46	41	37	39	27	-
	Radius [m]	0.050	0.046	0.047	0.047	0.055	0.055	0.053	0.052	0.053	0.054	-
	Reference method											
MLS – Lidaretto	Number of points [b]	6 -18	10 -30	10 -6	10 -12	13 -33	16 -30	13 -28	12 -25	17 -22	16 -11	-
	Radius [m]	0.058 +0.008	0.059 +0.013	0.066 +0.019	0.049 +0.002	0.053 -0.002	0.048 -0.007	0.045 -0.008	0.047 -0.005	0.050 -0.003	0.069 +0.015	- **0.008**
	Differenc e [m]	0.033	0.053	0.104	0.091	0.019	0.029	0.053	0.074	0.090	0.055	**0.079**
MLS – Stonex X120GO	Number of points [b]	74 +50	92 +52	64 +48	86 +64	116 +70	97 +51	76 +35	145 +108	104 +65	84 +57	-
	Radius [m]	0.056 +0.006	0.053 +0.007	0.059 +0.012	0.058 +0.011	0.062 +0.007	0.062 +0.007	0.061 +0.008	0.065 +0.013	0.064 +0.011	0.076 +0.022	- **0.010**
	Differenc e [m]	0.039	0.022	0.018	0.021	0.021	0.018	0.028	0.022	0.028	0.033	**0.025**

Source: Own elaboration

The results of the MLS method using the mobile laser scanner Stonex X120GO showed higher consistency in the number of captured points compared to the previous methods. The lowest number of points was 64 (street lamp No. 3), while the highest was 145 (street lamp No. 8). The largest difference in point count compared to the reference method occurred at street lamp No. 8, with 108 fewer points. Compared to the reference method, the radius were slightly larger, ranging from 0.006 m to 0.022 m, with an average RMSE of 0.010 m. The differences ranged from 0.018 m to 0.039 m. The average RMSE of the differences between TLS and MLS using the Stonex X120GO reached 0.025 m. The smallest differences were observed at street lamps No. 3 and No. 6 (0.018 m), which is lower than in the MLS–Lidaretto method, where the smallest difference was observed at street lamp No. 5 with 0.019 m. These results are also confirmed by the average RMSE values of the differences.

The methods used in the study area were also tested based on noise analysis. One of the key parameters in the analysis of laser scanning data is noise, which represents an unwanted factor affecting the accuracy and quality of point clouds. Noise was evaluated on three selected areas (Fig. 9), which represent ideal smooth surfaces for research purposes. The first tested area was the lower part of an entrance door with an area of 0.585 m^2. The other two areas were sections of an asphalt sidewalk at different locations, with areas of 5.527 m^2 (test area No. 1) and 5.604 m^2 (test area No. 2). All steps of the noise analysis were carried out in CloudCompare software, which provides a suitable environment for processing and evaluating spatial data through its built-in tools. After selecting the areas, the data processing was performed using the tool Tools → Other → Compute geometric features, which allows the computation of geometric properties of spatial data. Subsequently, a local neighborhood radius was defined, set to 0.10 for photogrammetric data and 0.25 for laser scanning data. The processing continued by selecting the 3rd eigenvalue function. After completing this step, the results were further processed using the Scalar Fields Arithmetic function, where in SF1 the 3rd eigenvalue and square root options were selected. This operation enabled recalculation of the values, after which it was only necessary to perform Distribution Fitting using a Gaussian model. These steps resulted in graphical outputs representing the average noise level as well as the interval of highest point density at a given distance. The results of this processing provide valuable information about the quality and accuracy of the processed datasets.

Noise analysis of spatial data can demonstrate the suitability and quality of new technologies. This analysis represents random variations in measurements that arise during the acquisition of spatial data and are influenced by several factors (surface properties of scanned objects). The obtained statistical results presented in Table 6 serve for comparison and overall evaluation. Results from three different scanning technologies were compared, while for each tested technology three independent test areas were analyzed. For each area, the number of points, size area, average value, standard deviation, and interval of highest point density were recorded. The accuracy of each applied method is expressed using RMSD.

For the TLS device – Leica RTC360, all measurements showed very low noise levels. The average value across all areas was 0.0017 m, and the standard deviation was practically negligible at 0.0003 m. The highest point density was recorded on test area No. 1 with 142,435 points. The interval of highest point density was very narrow, ranging within a few thousandths of a meter for the first two areas. For the third area, the interval ranged from 0.002 to 0.0032 m. The RMSD value for the TLS method was 0.0017 m. These results confirm that static laser scanning provides highly accurate data with minimal noise, while measurements remained very stable across all tested areas.

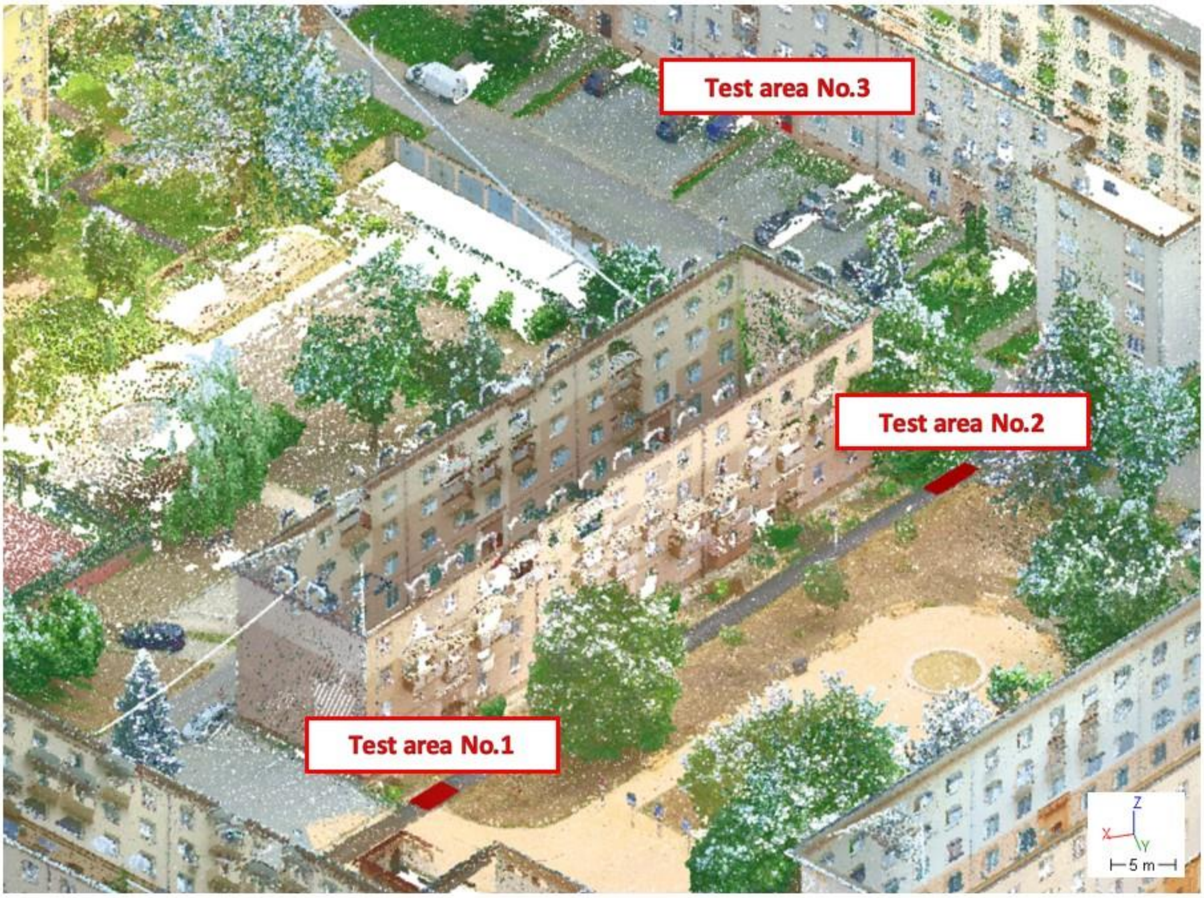


Fig. 9. Visualization of the test areas used for noise analysis
Source: Own elaboration

The second technology, MLS – Lidaretto, shows an average value across all tested areas of 0.0013 m and a standard deviation of 0.0007 m, indicating higher point dispersion compared to the TLS device. Point density ranged from 863 to 21,331 points. The interval of highest point density was slightly wider, which is a natural consequence of movement during scanning. The highest values of 0.0017–0.0028 m were observed for test area No. 3. The RMSD for the Lidaretto mobile laser scanner was 0.0015 m, suggesting lower noise than the TLS method. However, the MLS data were filtered for noise prior to analysis, which significantly biases the results. Under identical processing conditions for TLS (Leica RTC360) and MLS (Lidaretto) point clouds, lower noise would be expected for the TLS method.

Significantly higher noise was observed for MLS – Stonex X120GO. The average value across all areas reached 0.007 m, the standard deviation was 0.001 m, and the RMSD also reached 0.007 m. This result indicates higher variability in measured points and lower accuracy compared to the previous two methods. On the other hand, point density reached the highest values, ranging from 1 260 to 191,790 points. The interval of highest point density was substantially wider, indicating lower data quality. The lowest and best values were observed for test area No. 2, ranging from 0.0055 to 0.007 m.

Table 6. Statistical noise analysis of the applied methods

Statistical parameters		Area [m²]	Number of points [b]	Average value [m]	Standard deviation	Interval of highest point density [m]
TLS – Leica RTC360	Test area No.1	5.527	142,435	0.001	0.000	0.0005 – 0.0008
	Test area No.2	5.604	51,003	0.001	0.000	0.0000 – 0.0012
	Test area No.3	0.585	5 457	0.003	0.001	0.002 – 0.0032
	Resulting average	-	-	0.0017	0.0003	-
	RMSD [m]	-	-	**0.0017**		-
MLS – Lidaretto	Test area No.1	5.527	21,331	0.001	0.000	0.0008 – 0.0013
	Test area No.2	5.604	13,101	0.001	0.001	0.0007 – 0.0015
	Test area No.3	0.585	863	0.002	0.001	0.0017 – 0.0028
	Resulting average	-	-	0.0013	0.0007	-
	RMSD [m]	-	-	**0.0015**		-
MLS – Stonex X120GO	Test area No.1	5.527	191,790	0.008	0.001	0.007 – 0.009
	Test area No.2	5.604	176,081	0.006	0.001	0.0055 – 0.007
	Test area No.3	0.585	1 260	0.007	0.001	0.0065 – 0.0083
	Resulting average	-	-	0.007	0.001	-
	RMSD [m]	-	-	**0.007**		-

Source: Own elaboration

Discussion and future work

The presented results demonstrate that the selection of an appropriate laser scanning technology for urban digital twin creation depends primarily on the balance between geometric accuracy, acquisition efficiency, and the intended application. The performed experiments confirmed that TLS remains the most accurate method for capturing detailed urban environments, producing the highest point density, the lowest geometric deviations, and the smallest noise values. These characteristics make TLS particularly suitable for the documentation of buildings, engineering structures, cultural heritage

objects, and other applications where centimetre or millimetre-level accuracy is required. However, the significantly longer field acquisition time and the necessity of multiple scanner positions reduce its operational efficiency when surveying larger urban areas.
In contrast, MLS substantially improves the efficiency of spatial data acquisition while maintaining an accuracy level that is sufficient for most urban mapping tasks. The comparison of the two evaluated MLS systems revealed notable differences in their performance. The Lidaretto system proved to be highly efficient for rapid large-scale mapping and demonstrated relatively low noise after post-processing, although its lower point density resulted in less detailed representation of small urban features. Conversely, the mobile laser scanner Stonex X120GO generated considerably denser point clouds and showed better geometric consistency when analysing street lamps, making it more suitable for applications requiring higher object detail. Nevertheless, the increased point density was accompanied by a higher level of measurement noise, highlighting the importance of appropriate filtering and post-processing procedures before further analyses.

The comparison performed on selected street lamps illustrates the influence of point density and scanning geometry on the representation of relatively small cylindrical objects. Although TLS provided the reference dataset, both MLS systems were able to reproduce the geometry with acceptable accuracy for practical urban applications. The larger deviations observed for the Lidaretto system indicate that scanning speed, trajectory stability, and sensor configuration have a considerable influence on the resulting point cloud quality. Similarly, the noise analysis confirmed that different technologies exhibit different characteristics depending not only on the hardware itself but also on the applied processing workflow. Therefore, direct comparison of different systems should always consider both acquisition methodology and post-processing strategies. An important outcome of this study is the confirmation that no single surveying technology can satisfy all requirements associated with urban digital twin development. Digital twins require not only highly accurate geometry but also frequent updating, scalability, and efficient data acquisition. While TLS provides an excellent reference dataset for detailed modelling, MLS enables rapid updates of extensive urban environments with significantly lower field time. Consequently, integrating datasets acquired from multiple platforms appears to be the most effective strategy. Such hybrid datasets combine the strengths of individual technologies while minimizing their respective limitations, providing a comprehensive representation of urban infrastructure suitable for asset management, change detection, maintenance planning, and Smart City applications.

Despite the promising results, several limitations should be acknowledged. The study was conducted within a single urban environment covering approximately 2.8 ha under favorable weather and GNSS conditions. Consequently, the presented results may not fully represent the behavior of the evaluated technologies in more challenging environments, such as dense historical city centers, narrow streets with severe GNSS obstruction, heavily vegetated areas, or large metropolitan regions. Furthermore, the evaluation focused primarily on geometric accuracy, point density, and noise characteristics, while other important aspects, including radiometric quality, semantic segmentation performance, long-term repeatability, and economic efficiency, were not investigated in detail.

Future research should therefore concentrate on expanding the experimental framework to include more diverse urban scenarios and additional mobile mapping technologies. Particular attention should be devoted to evaluating the long-term stability of repeated surveys for continuous digital twin updating and change detection. Another promising direction is the integration of laser scanning data with complementary sources, such as UAS photogrammetry, airborne LiDAR, multispectral imagery, and Building Information Modelling (BIM), enabling richer semantic and geometric digital twin models. Future work should also investigate the application of artificial intelligence and deep learning techniques for automatic point cloud classification, object recognition, and semantic enrichment. These approaches have the potential to significantly reduce manual processing while increasing the automation and scalability of digital twin generation. Finally, further research should address standardized workflows for multi-source data fusion and quality assessment, contributing to the wider adoption of geodetic technologies in operational Smart City and urban infrastructure management systems.

Conclusions

This article presents a comprehensive comparison of terrestrial and mobile laser scanning from the perspective of acquiring high-precision spatial data in an urban environment, with a focus on their application in the creation of digital twin. Experimental measurements were carried out in the city center of Žiar nad Hronom, where TLS technology and multiple mobile laser scanning platforms were applied under identical conditions. The results confirmed that the terrestrial laser scanner Leica RTC360 provides the highest geometric accuracy, the highest point cloud density, and the lowest noise level. These characteristics make TLS particularly suitable for generating reference datasets, detailed documentation of building objects and engineering structures, as well as for applications requiring maximum precision. Its main disadvantage is longer acquisition time and lower efficiency when mapping large areas. Mobile laser scanning demonstrated significantly higher data acquisition productivity while maintaining accuracy sufficient for most urban mapping tasks. Among the evaluated systems, the Stonex X120GO mobile laser scanner achieved higher point density and better geometric consistency than the Lidaretto system, but at the cost of a higher noise level. In contrast, the Lidaretto system enabled the fastest data collection over large areas, making it suitable for applications where mapping speed is critical. The conducted analyses of geometric differences and noise clearly showed that none of the evaluated technologies alone can ensure optimal performance across all required parameters. Therefore, the most suitable approach appears to be a combination of terrestrial and mobile laser scanning, which integrates the high accuracy of TLS with the efficiency and flexibility of MLS. Such a hybrid approach enables the creation of comprehensive, detailed, and regularly updated spatial databases. The resulting point clouds form a high-quality basis for the creation of a digital twin, which can support urban infrastructure management, change monitoring, spatial planning, decision-making processes, and Smart City implementations. However, the analysis was focused primarily on street lamps and selected test areas for noise evaluation. Future research should therefore extend the assessment to a wider range of representative urban features, such as building façades, curbstones, road markings, and vegetation, in order to provide a more comprehensive evaluation of the capabilities and limitations of the investigated scanning technologies in urban digital twin creation.

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Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Use of generative AI and AI-assisted technologies

Generative AI tools were used only for language editing and grammar improvement. The authors reviewed and approved all final content.

References

Bariczová G., Erdélyi J., Honti R., Tomek L. (2021). Wall Structure Geometry Verification Using TLS Data and BIM Model. Applied Sciences, 11, 11804. https://doi.org/10.3390/app112411804.

Casula G., Fais S., Bianchi M.G., Ligas P. (2026). A Multi-Disciplinary Approach to the Identification and Characterization of Areas of Potential Damage in the Building Materials of Ancient Monuments. Sensors, 26, 1648. https://doi.org/10.3390/s26051648.

Erdélyi J., Honti R., Funtík T., Mayer P., Madiev A. (2022). Verification of Building Structures Using Point Clouds and Building Information Models. Buildings, 12, 2218. https://doi.org/10.3390/buildings12122218.

Erdélyi J., Kopáčik A., Kyrinovič P. (2020). Spatial Data Analysis for Deformation Monitoring of Bridge Structures. Applied Sciences, 10, 8731, https://doi.org/10.3390/app10238731.

Geotech s.r.o. 2026. Leica GS07. https://www.geotech.sk/downloads/GPS/GS07/Leica%20GS07%20prospekt%20SK.pdf [access: 27.06.2026].

Geotech s.r.o. 2026. Leica GS07. https://www.geotech.sk/Produkty/GPS-GNSS/Leica-GS07.html [access: 27.06.2026].

Geotech s.r.o. 2026. Leica RTC360. https://www.geotech.sk/Produkty/Laserove-skenery-HDS/Leica-RTC360.html [access: 27.06.2026].

Geotech s.r.o. 2026. Leica RTC360. https://www.geotech.sk/downloads/Laserove-skenery-HDS/Leica_RTC360_sk2.pdf [access: 27.06.2026].

Geotech s.r.o. 2026. Lidaretto. https://www.lidaretto.com/app/uploads/2023/03/Lidaretto_with_Hesai.pdf [access: 27.06.2026].

Hananto A.L., Tirta A., Herawan S.G., Idris M., Soudagar M.E.M., Djamari D.W., Veza I. (2024). Digital Twin and 3D Digital Twin: Concepts, Applications, and Challenges in Industry 4.0 for Digital Twin. Computers, 13, 100. https://doi.org/10.3390/computers13040100.

Hesai. 2026. XT32. https://www.hesaitech.com/product/xt32/#specs [access: 27.06.2026].

Lehtomäki M., Jaakkola A., Hyyppä J., Kukko A., Kaartinen H. (2010). Detection of Vertical Pole-Like Objects in a Road Environment Using Vehicle-Based Laser Scanning Data. Remote Sensing, 2, 641-664. https://doi.org/10.3390/rs2030641.

Ma L., Li Y., Li J., Wang C., Wang R., Chapman M.A. (2018). Mobile Laser Scanned Point-Clouds for Road Object Detection and Extraction: A Review. Remote Sensing, 10, 1531. https://doi.org/10.3390/rs10101531.

Macario Barros A., Michel M., Moline Y., Corre G., Carrel F. (2022). A Comprehensive Survey of Visual SLAM Algorithms. Robotics, 11, 24. https://doi.org/10.3390/robotics11010024.

Nocerino E., Menna F., Remondino F., Toschi I., Rodríguez-Gonzálvez P. (2017). Investigation of indoor and outdoor performance of two portable mobile mapping systems. Proceedings. SPIE 2017, 10332. https://doi.org/10.1117/12.2270761.

Riveiro B., Lindenbergh R. (2019). Laser Scanning: An Emerging Technology in Structural Engineering. Netherlands: CRC Press.

Rodríguez-Gonzálvez P., Nocerino E., Toschi I. (2019). Mobile Mapping Technologies. Switzerland: MDPI.

Salih S., Abdelmaboud A., Husain O., Motwakel A., Elshafie H., Sharif M., Hamdan M. (2025). IoT in urban development: insight into smart city applications, case studies, challenges, and future prospects. PeerJ Computer Science 11:e2816 https://doi.org/10.7717/peerj-cs.2816.

SGS Geosolutions s.r.o. 2026. Stonex X120GO. https://www.geopriestor.sk/produkt/rucny-laserovy-skener-stonex-x120go-slam/ [access: 27.06.2026].

Slovensko v Kocke.sk. 2026. Žiar nad Hronom. https://slovenskovkocke.sk/ziar-nad-hronom [access: 27.06.2026].

Štroner M., Křemen T., Urban R. (2022). Progressive Dilution of Point Clouds Considering the Local Relief for Creation and Storage of Digital Twins of Cultural Heritage. Applied Sciences, 12, 11540. https://doi.org/10.3390/app122211540.

Tang J., Chen Y., Chen L., Liu J., Hyyppä J., Kukko A., Kaartinen H., Hyyppä H., Chen R. (2015). Fast Fingerprint Database Maintenance for Indoor Positioning Based on UGV SLAM. Sensors, 15, 5311-5330. https://doi.org/10.3390/s150305311.

Wagg D.J., Worden K., Barthorpe R.J., Gardner P. (2020). Digital Twins: State-of-the-Art and Future Directions for Modeling and Simulation in Engineering Dynamics Applications. ASME. ASME Journal Risk Uncertainty Part B. September 2020, 6(3): 030901. https://doi.org/10.1115/1.4046739.

Wang Y., Chen Q., Zhu Q., Liu L., Li C., Zheng D. (2019). A Survey of Mobile Laser Scanning Applications and Key Techniques over Urban Areas. Remote Sensing, 11, 1540. https://doi.org/10.3390/rs11131540.

Weiss T., Dietmayer K. (2007). Automatic Detection of Traffic Infrastructure Objects for the Rapid Generation of Detailed Digital Maps using Laser Scanners, 2007 IEEE Intelligent Vehicles Symposium, Istanbul, Turkey, 2007, pp. 1271–1277. https://doi.org/10.1109/IVS.2007.4290293.

Zaman M., Puryear N., Abdelwahed S., Zohrabi N. (2024). A Review of IoT-Based Smart City Development and Management. Smart Cities, 7, 1462-1501. https://doi.org/10.3390/smartcities7030061.

Žiar nad Hronom. 2026. https://www.ziar.sk/ [access: 27.06.2026].

Zlot R., Bosse M., Greenop K., Jarzab Z., Juckes E., Robert J. (2014). Efficiently capturing of large, complex Cultural Heritage sites with a handheld 3D mobile laser mapping system. Culture Heritage, 15, 670–678. https://doi.org/10.1016/j.culher.2013.11.009.