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OPTIMIZING BUILDING SCAN DATA: COMPARING LEVELS OF ACCURACY AND CLOUD DETAIL IN THE BUILDING RENOVATION PROCESS

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Abstract

The optimization of point cloud data acquired using LiDAR technology is crucial in the context of building renovation and allows for comparisons of the different levels of detail and accuracy that can be achieved through different scan settings. LiDAR (Light Detection and Ranging) technology produces 360° images where a laser light beam measure precise distances and enables the creation of highly detailed point clouds. The generated point cloud represents a set of data points of the scanned area, which provides a digital image of the structure at different levels of detail. By scanning with different detail settings, the generated point clouds can be compared and analyzed. The work focused on creating point clouds at different scan settings, and different resolution detail levels. The results suggest that a key tool for proper planning and implementation of renovation projects is to make compromises between accuracy, dataset size, and scanning efficiency, as each building type requires an individual approach. In the case of scanning historic buildings, where capturing architectural detail is crucial, it is required to use highly detailed scanning and the point cloud produced should have the smallest possible point spacing. On the other hand, for the renovation of buildings with simpler geometric shapes, it is possible to use lower resolutions, which can significantly save scanning time, data storage size, and make scanning more efficient. Based on the findings, the thesis makes recommendations for selecting the optimal settings according to the type of project.

Keywords: LiDAR, Point Cloud, Terrestrial Laser Scanning, Efficiency, Renovation

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1 INTRODUCTION

LIDAR (Light Detection and Ranging) technology is gaining more and more popularity in the construction industry, especially in the fields of architecture, engineering, but also in building management. The use of Terrestrial Laser Scanning (TLS) in combination with Building Information Modelling (BIM) methods is also becoming more and more popular in the renovation of buildings and the management of historic buildings. This technology allows to significantly improve the accuracy and efficiency of processes, thanks to the ability to scan the space with a laser ray that records data with high precision. TLS technology works on the basis of emitting a laser beam that scans a space by measuring the time the beam is reflected from the surface being scanned. The result is point clouds that can be used directly for measurement and visualization or post-processed to obtain detailed information about the condition and geometry of the building. This data is essential for as-built/as-is modelling and quality control during construction processes, contributing significantly to the efficiency and accuracy of building renovation [1, 2].

LiDAR technology enables the collection of point clouds and the analysis of this data without the need for additional information about the device itself. Several scientific studies are investigating its application, particularly in the identification of surface defects. Although the initial investment in LiDAR scanners may be higher, their long-term time and cost efficiency can offset these costs over time. Compared to models built from image data, LiDAR offers more accurate and higher quality outputs, which is particularly important in difficult conditions such as low contrast or distracting backgrounds. Nevertheless, there are some errors associated with this technology, which include scanner errors (such as incorrect range measurements or scan angle), positioning and orientation system errors (such as GPS or INS errors), errors due to system integration (including incorrect installation or timing variations), and other problems such as platform vibrations, incorrect coordinate transformation, or errors caused by irregular movement of the equipment [3, 4, 5].

The United States of America has been a major leader in LiDAR technology research since the 1980s. During this time, military research institutions have promoted the analysis of three-dimensional LiDAR systems with algorithms capable of automatically recognizing targets, enabling their use in various types of missiles. As an active sensor, LiDAR scans its surroundings by emitting laser pulses, which are then picked up by photodetectors such as avalanche photodiodes (APDs) or single photon photodiodes (SPADs) [5, 6, 7]. These pulses are processed to calculate the range and generate 3D Cartesian coordinates, thus LiDAR offers higher measurement accuracy compared to camera or radar systems. Its high accuracy and data collection efficiency make it an ideal tool for improving management and monitoring approaches. LiDAR technology has the potential to bring about significant changes in the sustainable construction sector, where cost and labour savings of up to 20% are expected, while at the same time contributing to a reduction in environmental impact [8-11].

A point cloud is a three-dimensional geometric representation of objects that is created by scanning and contains millions of measured points with high precision, ranging from a few millimeters to a few centimeters. This technology enables the rapid capture of the geometry of buildings, including historical objects, and is a key part of the process of digitizing and modelling spatial information. During scanning, it is important to consider the appropriate distance, as the density of the point cloud decreases with increasing distance from the scanner, affecting the quality of the acquired data. The accuracy of the point cloud is closely related to the measurement resolution, angular resolution and scanning speed, which also places demands on the proper adjustment of the scanning device parameters. When creating 3D models based on point clouds, it is important to follow standards that include data quality and format requirements.

These standards guarantee the consistency and reliability of the resulting models, which is essential for their efficient use in practice [3, 12-14].

Increasing the accuracy of the resulting point cloud can be achieved by using advanced LiDAR sensors, such as 64- or 128-laser devices, which improve background filtering, classification and data clustering due to higher point density. This leads to better tracking accuracy and a larger detection range. Simpler LiDAR sensors, such as 1- or 8-laser devices, can process data but with lower accuracy and efficiency in detecting and tracking objects. When using point clouds in construction, these data can reveal detailed information about building shapes, opening up possibilities for automatic detection and extraction of building structures. LiDAR, with its high accuracy and speed, can record data for entire medium-sized cities in minutes, making it an ideal tool for collecting and analyzing data from complex urban spaces compared to traditional aerial mapping methods. Automatic extraction of structures from point clouds is possible, but requires the use of multiple filters and the implementation of machine learning algorithms. Such an intelligent and fully automated approach allows the generation of vector outputs with an accuracy comparable to that of the input data and a kappa coefficient of approximately 95%. In the field of intelligent planning of construction equipment, the processing of point clouds into 3D models is crucial, as these models serve as the basis for the operation and simulation of construction machines within automated processes [15-18].

2 METHODOLOGY

The aim of the research paper is to identify the optimal level of point cloud detail that will ensure efficient and accurate building renovation. By focusing on the analysis of different levels of point cloud accuracy and density, it is possible to identify the impact of scanning on the quality and efficiency of renovation processes.

2.1 Scanning method

To compare the different levels of scanning detail, the FARO Focus 3D x 130 was chosen as the ground-based laser scanner, a tool designed to accurately and confidently capture the three-dimensional geometry of objects. This scanner is optimized for a variety of geospatial applications, including topographic surveys, boundary analysis and large infrastructure projects. Its technical design provides a platform suitable for complex scanning environments where maximum accuracy and efficiency are required.

The FARO Focus 3D x 130 has technical parameters that include a scanning range of up to 130 meters. This capability minimizes the need for frequent relocation of equipment in the field while speeding up on-site decision-making processes. The dataset outputs produced are highly accurate and comprehensive ensuring a wide range of applications such as as-built documentation, Building Information Modeling (BIM) implementation, industrial facilities management and infrastructure project implementation. The exceptional versatility of this scanner combined with its high accuracy makes it one of the leading devices in its category.

FARO SCENE software was used to process and analyze the acquired data, which allows efficient generation of 3D point clouds with a high degree of accuracy. This tool supports the integration of scan data into various workflows fluently and is optimized for the creation of datasets that serve as a basis for further analysis and design.

2.2 Description of the scan area

In order to obtain relevant results, it was necessary to make the right choice of the scanning room. Within the selection of the scanned object for the purposes of the scientific work, the attic room of the renovated hallway on the fourth floor of the Faculty of Civil Engineering of the Technical University in Košice was chosen. This hallway has been modernized and transformed into a chill zone for students, giving it a unique combination of traditional and modern architectural elements.

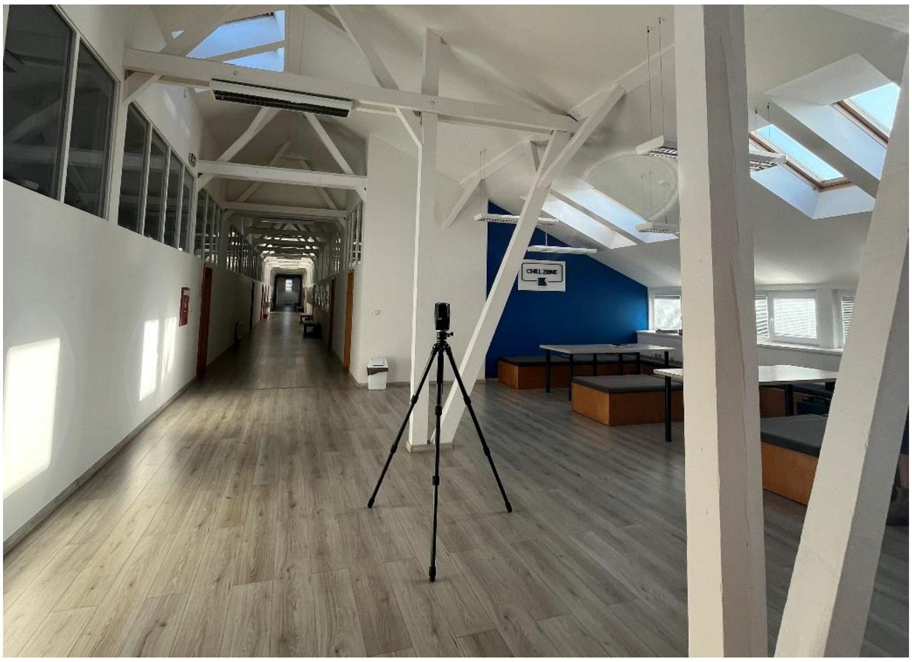

Figure 1: Scan area

The room (Figure 1) has a simple square plan, complemented by the addition of wooden beams and roof rafters, which enhance the structural features of the attic. Several small windows spaced along the walls further complicate the overall geometry and create various scanning challenges. These architectural elements not only contribute to the aesthetic appreciation of the space, but also pose a challenge in accurately digitizing their complex geometries. An additional level of complexity is added by the placement of small windows along the walls, which cause heterogeneity in the surfaces. Access to the room is possible through three entrances: a long open corridor on one side, a glass door leading from the staircase on the other side, and another glass door connecting the room to the respiratory area.

The space was chosen based on a combination of interesting architectural features and availability for scanning purposes. The hallway is a renovated space that incorporates modern finishes and acknowledged structural details such as rafters and beams. This combination presents optimal conditions for a detailed analysis of the geometric complexity of the space on multiple levels. The open and accessible character of space allowed architectural details to be captured while minimizing scanning distortions.

2.3 Creating point clouds

The process of point cloud formation took place in several stages, with the key being choosing the correct resolution setting during scanning. The room was scanned with different levels of resolution in black and white format, allowing the suitability of each setting to be evaluated based on the capture of fine detail and the overall accuracy of the geometric record. Once the scanning was complete, the raw data from the FARO Focus 3dx130 was processed in the specialized FARO Scene software.

In the FARO Scene software, individual scans were manually and automatically registered to ensure accurate integration of the data into a single space. The output of this process was point clouds in .e57 format, which was chosen for its wide compatibility with various design and modelling software used in the construction industry. This format ensures efficient data transfer to the next stages of the analysis, such as the creation of accurate 3D models and digital twins, which serve as the basis for designing renovation works or monitoring the condition of the building.

3 RESULTS

To minimize distractions during the scanning process, the fourth floor chill zone room was scanned at a time when no occupants were present. This arrangement ensured consistent scanning conditions across all settings, minimizing the risk of inaccuracies caused by movement of people or other external influences.

The room scanning process was performed with different resolution settings, which caused significant differences in the time required for scanning. Scanning took from a minimum of 1 minute to a maximum of 15 minutes depending on the resolution chosen. However, these differences in time not only affected the length of the scan, but also had a major impact on the size of the resulting point cloud, which ranged from 8 821 KB to 2 384 543 KB.

An important factor influencing the quality and density of the point cloud was the point distance parameter. Different scan settings affected the point distance and consequently the total number of points in the point cloud. The raw scan data was then processed in the FARO Scene software to register the individual scans and produce the final point cloud.

Scan number	Scan time	Resolution	Quality	Scan size (Pt)	Point distance (mm/10m)	Actual point distance (m)	Number of points in the point cloud	Point cloud size (KB)
1	0:01:06	1/32	4x	1280x534	49,087	0,048565	**599 365**	8 821
2	0:01:17	1/20	4x	2048x854	30,680	0,0033127	**1 597 521**	23 505
3	0:01:26	1/16	4x	2560x1067	24,544	0,026051	**2 507 251**	36 888
4	0:02:08	1/10	4x	4096x177	15,340	0,016481	**6 447 442**	94 853
5	0:02:47	1/8	4x	5120x2134	12,272	0,013131	**10 097 252**	148 546
6	0:05:34	1/5	4x	8192x3414	7,670	0,008185	**25 874 735**	380 653
7	0:05:36	1/4	4x	8192x3414	7,670	0,006587	**40 427 708**	594 745
8	0:15:18	1/2	3x	20480x8534	3,068	0,003288	**162 089 474**	2 384 543

Table 1: Key parameters of individual scans.

The table (Table 1) shows the key parameters of each scan, including the number of points in the cloud, the distance of the points, the time required for the scan, the chosen resolution and the size of the cloud in .e57 format. These parameters show how the chosen settings reflected on the point density and overall size of the resulting data. For the lower resolution scans, the number of points was lower and the distance between them was larger, while the denser, high resolution scans captured more detail and were significantly larger in size.

Differences between point clouds were analyzed through visual and technical comparison methods, focusing on subtle differences in density and accuracy of captured detail. The figure (Figure 2) shows pictures of each point cloud of the room that were taken with different scan settings. Looking at the whole, minimal differences can be seen between the lower and higher resolution scans. However, the denser point clouds that were created with longer scan times and more precise settings provided a fuller and more detailed view of the room. These differences were most pronounced for areas of fine architectural features, with distinct differences particularly evident in areas of subtle architectural features.

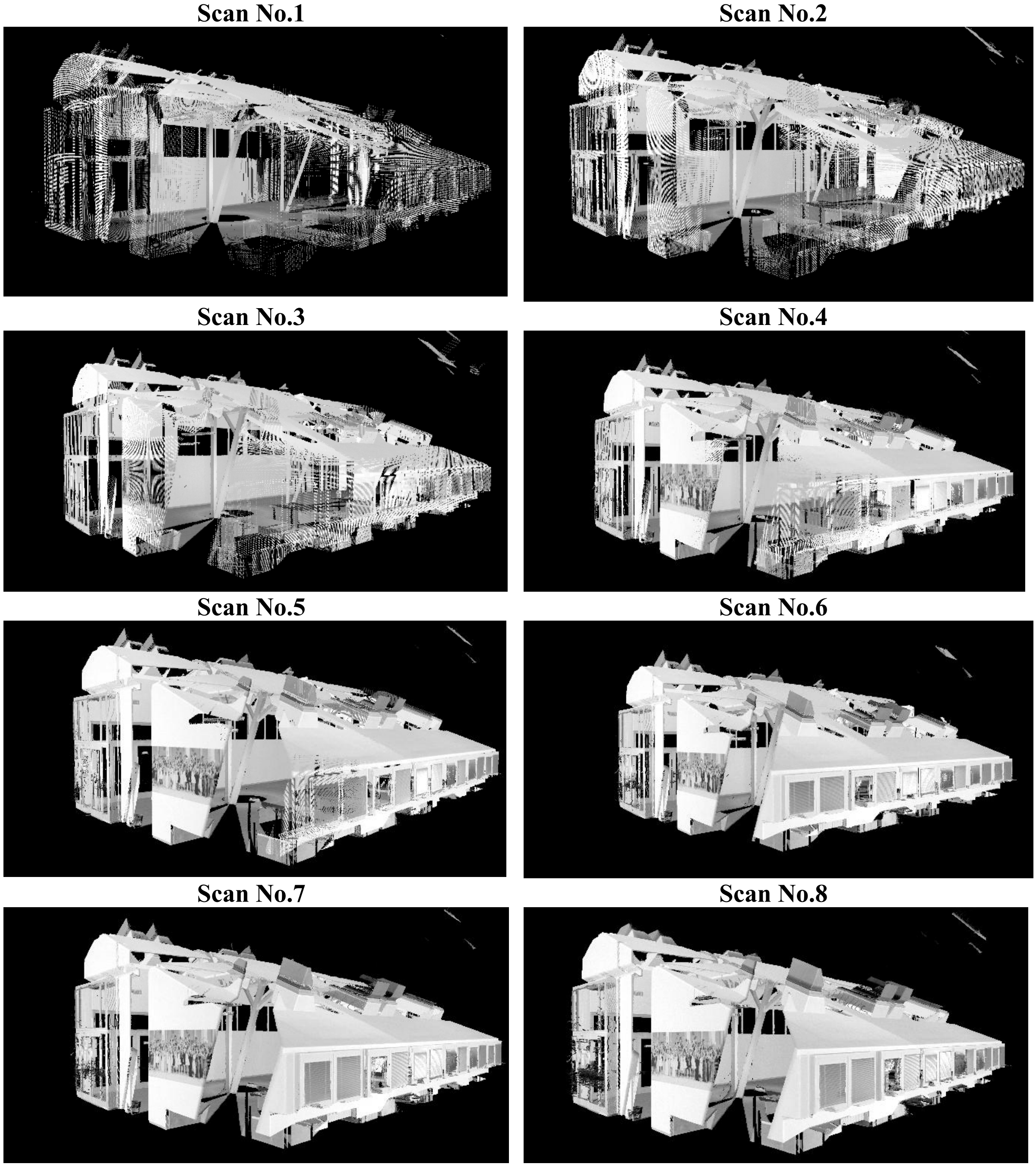

Figure 2: Overall point clouds from individual scans

Detailed analysis showed that working with denser point clouds was limited by the hardware limitations of the computer, especially when processing point clouds with a larger number of points. The second figure (Figure 3) contains point clouds of the wood beam detail, clearly showing increasing point density with finer scan settings.

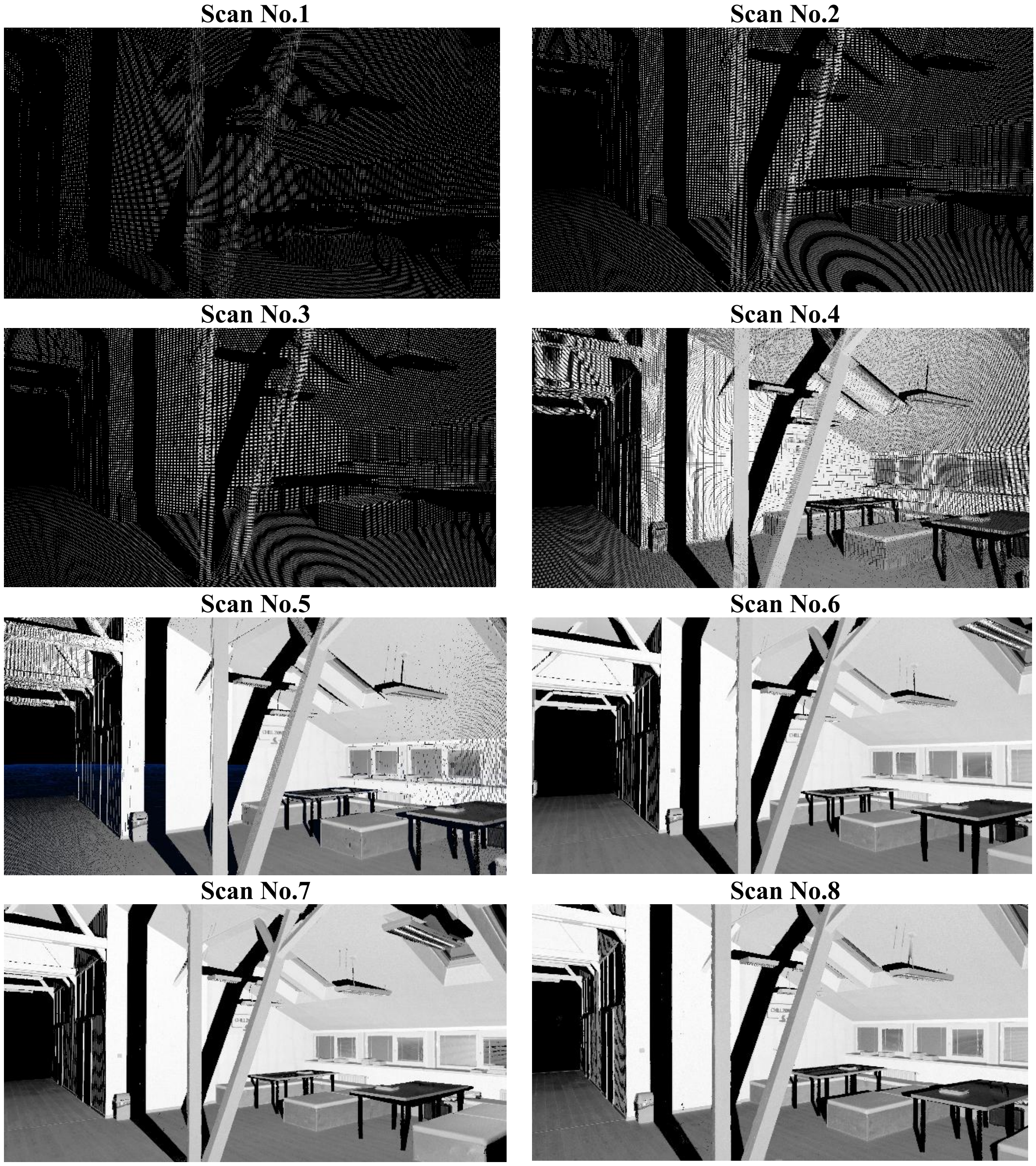

Figure 3: Point clouds of wooden beam detail

From the point clouds, it is clearly visible that denser point clouds provide a higher level of detail. When comparing the text on the backboard with the "CHILL ZONE" inscription, it was found that when scanned with a 4 cm point spacing, the inscription was barely readable, whereas with a 3 mm point spacing, the text was clearly recognizable.

4 DISCUSSION

Based on the analysis of the collected data, recommendations can be formulated for optimum scanning accuracy for different types of construction objects, allowing the key details needed for specific project requirements to be efficiently and reliably captured.

Scanning object		Recommended level of detail (Point Distance, mm/10m)	Reasons and specifications
Type of object	*Characteristics of the object*		
Terrain	Simple plain terrain with little or no vegetation and objects	30-50mm	Capture basic terrain features and major landform irregularities.
	Hilly terrain or terrain with a lot of vegetation or objects	30-50mm	Capture complex terrain formations without the need for high precision.
New Construction	Simple design geometry without significant details	20-30mm	Capturing load-bearing parts and simple construction details.
	Complex design geometry, with architectural elements	5-15mm	Higher level of detail needed to accurately capture complex features.
	HVAC structures, static structures	5-15mm	Detailed capture of wiring and technical systems.
Older/historic structures	Simple geometry, without significant details or architectural elements	10-20mm	Capture the main structural parts and any surface defects.
	Complex geometry, difficult roof trusses, the appearance of details or architectural elements	5-10mm	Accuracy required to document arches, vaults and fine structures
	Historic buildings of cultural value with a large number of complex architectural and artistic elements	3-5mm	Capturing fine ornaments, reliefs and historical details with high precision.

Table 2: Suggested scan levels for individual scan objects.

The table (Table 2) summarizes the recommended levels of detail for different categories of structures and project types, focusing on the optimal choice of point spacing needed to capture the relevant details.

For terrain scanning, higher point distance values in the range of 30 to 50 mm are recommended, ensuring that basic terrain features and major irregularities are captured. Simple flat terrains where vegetation and number of objects are minimal do not require high accuracy, nor do hilly or rugged terrains with high levels of vegetation and objects. In these cases, more detailed scanning is unnecessary as the main priority is to capture the overall topography.

For new buildings, a point distance of 20 to 30 mm is recommended for simple structures without significant details. Such a setting allows the basic geometrical features and load-bearing parts of the building to be efficiently recorded. However, for more complex new buildings with complicated geometry, prominent architectural features or aesthetic details, it is required to increase the level of detail to a range of 5 to 15 mm. These values are particularly important for technical building equipment (HVAC), such as piping systems, air handling systems or other static structures, where detailed capture of piping and technical elements is required.

Older and historic buildings represent a special category where accuracy requirements may be different depending on their complexity. For simple older buildings with minimal architectural detail, a point distance of 10 to 20 mm is adequate. This range allows the main structural parts such as walls, floors or ceilings to be captured, including possible surface defects. However, complex buildings with complex roof structures, arches or vaults require higher accuracy, with suggested values in the range of 5 to 10 mm. Historic buildings with high cultural value and extensive presence of fine architectural details require even more precise scanning with a point distance of 3 to 5 mm to accurately capture ornaments, reliefs and artistic elements.

This division ensures that each building type is scanned with a sufficient level of accuracy according to the project requirements, thus optimizing processing time and the size of the resulting data.

5 CONCLUSION

The results of the analysis show that the optimal choice of scanning accuracy depends on the characteristics of the object to be scanned and the requirements of the specific project. Proper point distance setting is key to achieving the desired level of detail while minimizing redundant data and time requirements. For simple objects, such as flat terrains or structurally simple new buildings, higher point distance values are sufficient to efficiently capture basic geometric data. Conversely, for complex architectural structures or historical objects of high cultural value, considerably finer settings are necessary to accurately capture details.

This distribution of accuracy levels ensures not only technically accurate but also cost-effective scanning, optimizing processing time and the volume of data acquired. Point density directly affects the ability to digitally capture complex features such as curves, reliefs or technical installations, and therefore its selection is a crucial factor in the success of projects, especially in reconstruction and documentation work. The recommendations presented in this paper can serve as a starting point when planning scans of a wide range of objects, from simple field surveys to complex architectural documentation.

Future research should focus on the implementation of artificial intelligence methods for efficient processing of large-scale data generated by high-precision scans of historic buildings. AI can play a key role in the automated filtering and segmentation of point clouds, allowing key architectural features of a building to be identified more quickly and accurately. This approach could significantly reduce the manual work required to pre-clean and organize the data.

REFERENCES

[1] P. Tang, D. huber, B. Akinci, R. Lipman, A. Lytle, Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques, *Automation in Construction, Vol. XIX (7),* 829-843, 2010. https://doi.org/10.1016/j.autcon.2010.06.007.

[2] F. Bosché, E. Guenet, Automating surface flatness control using terrestrial laser scanning and building information models, *Automation in Construction, Vol. XLIV,* 212-226, 2014. https://doi.org/10.1016/j.autcon.2014.03.028.

[3] N. Bolourian, A. Hammad, LiDAR-equipped UAV path planning considering potential locations of defects for bridge inspection, *Automation in Construction, Vol. CXVII,* 103250, 2020. https://doi.org/10.1016/j.autcon.2020.103250.

[4] M. Kim, H. Sohn, Ch. Chang, Localization and Quantification of Concrete Spalling Defects Using Terrestrial Laser Scanning, *Journal of Computing in Civil Engineering, Vol. XXIX (6),* 04014086, 2015. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000415.

[5] M. Li, Y. Hu, N. Zhao, Q. Qian, Modeling and analyzing point cloud generation in missile-borne LiDAR, *Defence Technology, Vol. XVI (1),* 69-76, 2020. https://doi.org/10.1016/j.dt.2019.10.003.

[6] J. Li, Q. Peng, Z. Li, J. Li, Technology of missile-borne laser active imaging guidance, *Infrared and Laser Engineering, Vol. XLIII (4),* 1117-1123, 2014. https://www.scopus.com/record/display.uri?eid=2-s2.0-84901324192&origin=inward&txGid=81d7579ac731637c39313c1b91ea9ddd.

[7] Y. Li, P. Duthon, M. Colomb, J. Ibanez-Guzman, What Happens for a ToF LiDAR in Fog?, *IEEE Transactions on Intelligent Transportation Systems, Vol. XXII (11)*, 6670-6681, 2021. 10.1109/TITS.2020.2998077.

[8] A. Wagar, D. radu, B. T. Alsulami, B. Dordevic, A. Fathi, M. S. Ebrahim, H. R. Almujibah, Functional analysis of LIDAR technology in optimizing efficiency and sustainability in construction sector, *Ain Shams Engineering Journal, Vol. XVI (2)*, 103258, 2025. https://doi.org/10.1016/j.asej.2024.103258.

[9] X. Chen, A. Y. Chang-Richards, A. Pelosi, Y. Jia, X. Shen, M. K. Siddiqui, N. Yang, Implementation of technologies in the construction industry: a systematic review, *Engineering Construction and Architectural Management, Vol. XXIX (8)*, 3181-3209, 2022. https://doi.org/10.1108/ECAM-02-2021-0172.

[10] F.A. Westiing, R. Abbas, C. Skinner, M. Hanus.Smith, A. Harris, N. Kirchner, Applications of LiDAR for productivity improvement on construction projects: Case studies from active sites, *Waterloo: IARC Publications*, *Vol. XXXVII*, 353-361, 2020. https://www.proquest.com/conference-papers-proceedings/applications-lidar-productivity-improvement-on/docview/2526368945/se-2.

[11] P. Meda, D. Calvetti, H. Sousa, Exploring the Potential of iPad-LiDAR Technology for Building Renovation Diagnosis: A Case Study, *Buildings*, *Vol. XIII*, **456**, 2023. https://doi.org/10.3390/buildings13020456.

[12] H. Tran, T. N. Nguyen, P. Christopher, D. Bui, K. Khoshelham, T. D. Ngo, A digital twin approach for geometric quality assessment of as-build prefabricated facades, *Journal of Building Engineering*, *Vol. XXXXI*, 102377, 2021. https://doi.org/10.1016/j.jobe.2021.102377.

[13] K. Khoshelham, Smart Heritage: Challenges in Digitisation and Spatial Information Modelling of Historical Buildings, *2nd Workshop On Computing Techniques For Spatio-Temporal Data in Archaeology And Cultural Heritage*, 2018. https://www.researchgate.net/publication/328543452.

[14] B. Yu, Y. Wang, Q. Chen, X. Chen, Y. Zhand, K. Luan, X. Ren, A review od forad 3D modeling based on light detection and ranging point clouds, *journal of Road Engineering, Vol. IV (4)*, 386-398, 2024. https://doi.org/10.1016/j.jreng.2024.04.009.

[15] J. Zhao, H. Xu, H. Liu, J. Wu, Y. Zheng, D. Wu, Detection and tracking of pedestrians and vehicles using roadside LiDAR sensors, *transportation Research Part C: Emerging Technologies, Vol. C*, 68-87, 2019. https://doi.org/10.1016/j.trc.2019.01.007.

[16] H. M. Jifroudi, S. B. Mansor, B. Pradhan, A. A. Halin N. Ahmad, A. F. B. Abdullah, A new approach to derive buildings footprint from light detection and ranging data using rule-based learning techniques and decision tree, *Measurement*, *Vol. CXCII*, 110781, 2022. https://doi.org/10.1016/j.measurement.2022.110781.

[17] S. L. Ullo, C. Zarro, K. Wojtowicz, G. Meoli, M. Focareta, LiDAR-Based System and Optical VHR Data for Building Detection and Mapping, *Sensors*, *Vol. XX*, 1285, 2020. https://doi.org/10.3390/s20051285.

[18] D. Moon, S. Chung, S. Kwon, J. Seo, J. Shin, Comparison and utilization of point cloud generated from photogrammetry and laser scanning: 3D world model for smart heavy equipment planning, *Automation in Construction*, *Vol. XCVIII*, 322-331, 2019. https://doi.org/10.1016/j.autcon.2018.07.020.