

From Old-School to High-tech: 3D Scanning a Multi-storey Building with Everything We've Got

Ondřej Grešla

Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 16629, Prague 6, ondrej.gresla@fsv.cvut.cz

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Abstract

Modern trends in geospatial data acquisition are increasingly focused on efficiency, automation, and cost-effectiveness while maintaining sufficient accuracy for a wide range of applications. This paper evaluates the performance of several modern scanning devices, including terrestrial laser scanning (TLS) systems and SLAM-based or photogrammetry-LiDAR based solutions. Measurements were carried out in interior and exterior environments to assess not only positional accuracy but also practical aspects such as acquisition time, post-processing requirements, and overall costs. Results show that while SLAM-based scanners significantly reduce acquisition time and required manpower, their accuracy is lower compared to static TLS methods. Hybrid approaches offer a compromise, balancing speed with improved precision. Cloud-based solutions, such as the Matterport Pro3, provide user-friendly workflows but exhibit significant noise and registration errors, making them unsuitable for high-accuracy surveying tasks.

This study confirms that no single scanning technology is universally optimal; instead, the balance between accuracy, efficiency, cost, and operator expertise must guide the choice of device for each specific application.

1. Introduction

In recent years, the development of geospatial data acquisition technologies has been accelerating significantly. Traditional terrestrial laser scanning (TLS) methods are being complemented and, in certain applications, even replaced by mobile scanning systems, simultaneous localization and mapping (SLAM) techniques, and cloud-based platforms. These innovations respond to the growing demand for faster, more cost-effective, and user-friendly solutions while still providing an acceptable level of accuracy for practical use (Běloch, 2023; Pavelka et al., 2023).

Despite the progress in hardware and software development, challenges remain in balancing three key aspects: accuracy, acquisition speed, and overall costs. Each technology has its strengths and limitations, which determine its suitability for specific application fields, ranging from construction and architecture to cultural heritage documentation and facility management.

Recent research has addressed many of these issues, particularly focusing on comparing static TLS with SLAM-based systems in terms of both accuracy and efficiency (Bouček et al., 2024). Cloud-based solutions, such as Matterport Pro3, are widely adopted in real estate and facility visualization, but their potential for precise surveying tasks is still debated due to inherent limitations in registration quality (Vynikal, 2023).

The aim of this paper is to provide a comprehensive evaluation of selected scanning devices, tested under both indoor and outdoor conditions. The study focuses not only on geometric accuracy but also on acquisition and processing times, manpower requirements, and financial costs. By providing this comparison, the paper seeks to support decision-making in selecting the most suitable scanning technology for different practical applications.

2. Methods

This case study involves several different scanning technologies applied to the same multi-story building. The structure consists of three main floors and a basement, with 4–5 rooms on each level. The vertical connection between floors is mostly via staircases, with limited possibilities for open vertical scanning. However, strategic use of open windows and multiple overlap zones significantly improved registration, especially in SLAM-based systems.

First, a network of control points was established and measured using a total station. After adjustment, the estimated accuracy of this network is within 5 mm.

2.1 Tested Devices

The evaluation was carried out on a set of scanning devices representing different acquisition approaches.

2.1.1 SLAM Scanning: FARO Orbis, a scanner developed through years of improving GeoSLAM technology, was used as a representative of SLAM-based scanners. The area of interest was scanned multiple times using both versions – Orbis 1.0 and Orbis Premium. Generally, no significant discrepancies were observed between the individual point clouds.

SLAM scanners are unmatched in terms of acquisition speed. The entire building and its surroundings were scanned in under 30 minutes. During data collection, control points can be captured directly along the trajectory, simplifying post-processing. From raw data to the final point cloud (filtered, georeferenced, and coloured), the process took approximately 90 minutes on a high-performance computer. With the manufacturer's AI filters applied, the resulting level of detail was around 3–4 mm, and the expected accuracy was approximately 10 mm.

2.1.2 Static Scanning: FARO Focus Premium was used as an example of a high-resolution static laser scanner. Among all methods, this one had the longest acquisition time due to the chosen high scanning resolution. The area was captured from approximately 70 scan positions using an accelerated profile with non-HDR panoramic images, averaging 3 minutes per position. The entire acquisition took about 4.5 hours. However, post-processing was faster thanks to on-site pre-registration; precise alignment and georeferencing took less than one hour. This point cloud served as the reference for comparison with all other methods.



Figure 1. Pointcloud from static scanner - area of interest

The level of detail depends on the scanning profile used, but generally reaches around 1 mm.

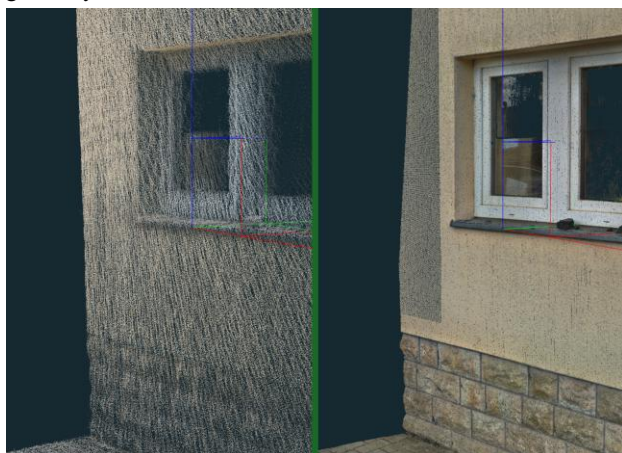


Figure 2. Difference in level of detail in pointcloud from SLAM (left) and static scanner (right)

2.1.3 Hybrid Scanning: FARO BLINK, a static scanner that combines SLAM and traditional static methods, was used as an example of a simple and fast scanning solution. A single scan position took less than 30 seconds, including an HDR panoramic image. The entire acquisition took 90 minutes, and post-processing was similar to that of the Focus – under one hour. The level of detail is comparable to the Orbis data, although the point cloud includes more blind spots due to the static nature of the device.

2.1.4 Photogrammetry + LiDAR: The Matterport Pro3 camera was used as an example of the most affordable and user-friendly solution on the market. This device is commonly used by real estate agencies for virtual tours and property documentation. It includes a built-in LiDAR sensor and combines LiDAR scanning with photogrammetry to generate the final point cloud. Acquisition time was like the BLINK solution. Post-processing is cloud-based and typically takes several hours, depending on server load. Accuracy is around 2 cm at a 10-meter distance, making it the least precise method in this comparison. The level of detail is similar to unfiltered SLAM data.

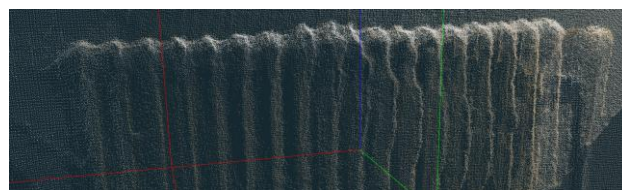


Figure 3. Radiator captured by Matterport Pro3 from multiple scans

These devices were tested in both interior and exterior environments. For each device, acquisition times, post-processing requirements, manpower demands, and geometric accuracy were recorded.

2.2 Experimental Setup

Measurements were conducted in two types of environments:

- Interior part: a controlled indoor environment with stable lighting and limited GNSS signal.
- Exterior part: an outdoor area with complex geometry, enabling evaluation of range accuracy and robustness under environmental conditions.

The comparison of the two point clouds was carried out in CloudCompare software using the 2.5D triangulation method (CloudCompare.org, 2019). The point cloud acquired by the static TLS was used as the reference (etalon), as it provided the highest expected accuracy and stability. The 2.5D triangulation method works by local modelling selecting the k nearest points from the reference cloud to the evaluated points, generating a Triangulated Irregular Network (TIN), and calculating deviations.

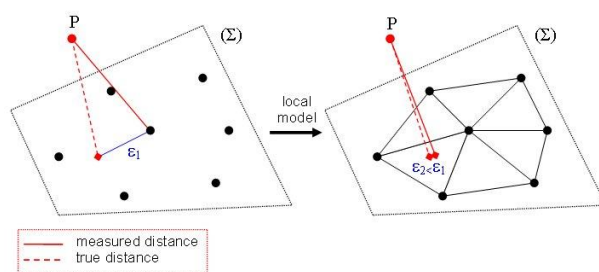


Figure 4. Diagram of Cloud-to-Cloud distance computation with local modelling - 2.5D triangulation (CloudCompare wiki).

Considering the nature of this method and the expected higher deviations for certain devices, especially the Matterport Pro3, the evaluation was not performed on the entire dataset at once. Instead, representative planar areas with sizes ranging from 0.5 to 5 m² were selected across both the interior and

exterior of the building. This approach allowed us to minimise the effect of local irregularities and to focus on surfaces where systematic behaviour could be better observed.

To gain a more detailed understanding of the device performance, the selected patches were further categorised into horizontal and vertical surfaces. The testing was then conducted separately for each group, which enabled us to distinguish between errors occurring predominantly in the XY plane and those manifesting in the Z component. This distinction provided a more comprehensive picture of the error characteristics and helped to identify systematic weaknesses of the tested systems.

2.3 Accuracy Evaluation

The accuracy assessment of the tested scanning devices was based on the comparison of the measured point clouds with reference data obtained from a static terrestrial laser scanner, which served as the benchmark (etalon). For the comparison, the CloudCompare software was used with the Cloud-to-Cloud distances method applying local modeling based on 2.5D triangulation. This approach allowed evaluating the deviations of each point of the tested cloud with respect to the locally interpolated surface of the reference dataset.

The directional deviations along a selected axis u (typically the global Z-axis for vertical differences, or the X/Y-axes for horizontal components) were then computed as:

$$\mu^{(u)} = \frac{1}{n} \sum_{i=1}^n d_i^{(u)} \quad (1)$$

$$s^{(u)} = \sqrt{\frac{1}{n} \sum_{i=1}^n (d_i^{(u)} - \mu^{(u)})^2} \quad (2)$$

where $d_i^{(u)}$ = deviation of point i projected on the axis u (e.g., ΔZ_i)
 N = number of evaluated points
 $\mu^{(u)}$ = mean deviation along axis u

For accuracy in XY-plane and Z axis, the root mean square error (RMSE) was calculated as:

$$RMSE^{(u)} = \sqrt{(\mu^{(u)})^2 + (s^{(u)})^2} \quad (3)$$

For overall 3D accuracy, the root mean square error (RMSE_3D) was calculated as:

$$RMSE_{3D} = \sqrt{(RMSE^{(x)})^2 + (RMSE^{(y)})^2 + (RMSE^{(z)})^2} \quad (4)$$

The manufacturer-provided accuracy values, usually expressed as one standard deviation (1σ), were adjusted for comparison with experimental results. A coefficient of 2.5 was applied to approximate expanded uncertainty:

$$\sigma_{expanded} \approx 2.5 \cdot \sigma_{manufacturer} \quad (5)$$

where $\sigma_{manufacturer}$ = accuracy declared by the manufacturer (1σ)
 $\sigma_{expanded}$ = expanded uncertainty, scaled by factor 2.5 to reflect overall expected accuracy

This allowed for a consistent comparison between declared specifications and experimentally obtained accuracy.

3. Results

3.1 Interior Part

Table 1 summarizes the accuracy results obtained in the interior part of the experiment. For each tested device, mean deviations (equation 1), standard deviations (equation 2), and RMSE values are reported separately for horizontal (XY) and vertical (Z) components (equation 3), as well as for the overall 3D accuracy (equation 4). The results clearly show substantial differences between the technologies.

Static TLS systems provide sub-centimeter accuracy with low variability, confirming their suitability for precise documentation tasks. SLAM-based devices demonstrate larger deviations and increased scatter, especially in the vertical axis, which is a known limitation of trajectory-based positioning methods, but especially in exterior environments, where there are fewer identical planes for SLAM orientation. The Matterport Pro3 exhibits the largest discrepancies across all metrics. This can be explained by its dependency on cloud-based registration and the lack of user control over the alignment process.

Overall, the interior results highlight how different scanning principles cope with confined spaces. SLAM trajectories tend to accumulate errors where the geometry is repetitive, while TLS maintains accuracy through static stations with less noise. Matterport's workflow prioritizes ease of use and speed, but the price is reduced geometric accuracy and greater noise in the data.

Device	Interior - XY			Interior - Z			Interior-3D
	mean [mm]	std.dev. [mm]	RMSE_XY [mm]	mean [mm]	std.dev. [mm]	RMSE_Z [mm]	RMSE_3D [mm]
Orbis 1.0	6,3	4,2	8	12,6	3,7	13	15
Orbis Premium	6,9	5,0	8	14,3	5,9	15	18
Blink	11,0	7,0	13	6,3	1,0	6	14
Matterport Pro3	39,0	12,7	41	-5,9	5,0	8	42

Table 1: Accuracy results for the interior part of the experiment.

3.2 Exterior Part

The exterior measurements, presented in Table 2, extend the analysis by showing how the same devices perform in an open-space environment. The table again lists mean deviations, standard deviations, and RMSE values for XY, Z, and overall 3D components. Compared to the interior conditions, exterior environments can provide better conditions for both SLAM and TLS, since line-of-sight is less restricted and multipath effects are reduced (no mirrors, fewer windows, fewer moving doors, and no small rooms). Static TLS systems maintain their high accuracy and repeatability, confirming their role as the reference method.

SLAM devices require sufficient structural features to support their localization. Without distinct objects to rely on, it is not possible to establish a stable local SLAM solution, and in environments with a limited number of reference surfaces the resulting point cloud is more likely to be affected by errors, typically expressed in the vertical component. In our case, the exterior environment did not include stairs or multi-level structures, which resulted in smaller vertical deviations compared to the interior test, where the trajectory led through a narrow staircase.

Matterport Pro3 shows slightly smaller deviations than indoors, but the overall accuracy remains low for surveying purposes. Its reliance on cloud-based automatic registration continues to introduce errors that grow with project size, making it unsuitable for engineering-grade applications. However, for visualization tasks and quick 3D documentation, the performance remains acceptable.

A specific challenge was observed in the rear part of the building, where a narrow 7 m corridor is bordered on one side by a 5 m wall opening directly to the sky and on the other side by tall thuja trees prone to slight motion. This configuration created a non-ideal environment for all scanning principles. The static TLS, anchored and verified by a total station, ensured that no systematic error was expected in the reference dataset. In this location, the mobile SLAM scanners delivered the most reliable results, maintaining accuracy despite the adverse conditions. In contrast, static methods revealed artefacts in detailed cross-sections, with Matterport Pro3 producing even split or “tripled” point clouds on surfaces. The BLINK device exhibited the highest deviations of the exterior test, yet its point cloud remained only noisy rather than multilayered, which still preserved a usable surface representation.

Device	Exterior - XY			Exterior - Z			Exterior-3D
	mean [mm]	std.dev. [mm]	RMSE_XY [mm]	mean [mm]	std.dev. [mm]	RMSE_Z [mm]	
Orbis 1.0	6,9	3,6	8	5,1	2,4	6	10
Orbis Premium	10,3	7,3	13	-1,9	8,4	9	15
Blink	3,7	2,1	4	4,0	3,2	5	7
Matterport Pro3	16,3	10,5	19	-27,3	9,6	29	35

Table 2. Accuracy results for the exterior part of the experiment.

3.3 Overview of all Devices

A comparison across all devices and parameters is shown in Table 3, which provides an overview of each technology in terms of total data acquisition time, total post-processing time required to produce a complete point cloud with basic automatic filtering, and the manpower needed to obtain the final result (including preparation, acquisition, and computer setup – excluding the actual computation time when no operator input is required).

The table also compares the extended manufacturer-stated accuracy, the observable level of detail in the resulting point cloud, and the average cost. For Matterport, the cost estimation is more complex due to additional charges for cloud processing and data exports on a per-project basis.

Device	Acquisition [min]	Post-processing [min]	Used Manpower [min]	Level of Detail [mm]	Expanded* 3D Accuracy		Average Cost [EUR]
					Accuracy by Manufacturer [mm]	Tested on Experiment [mm]	
Orbis 1.0	25	90	40	4-5	12,5	12	45 000
Orbis Premium	25	90	40	4-5	12,5	16	50 000
Focus Premium	270	45	300	1	5	X	40 000
BLINK	90	50	120	2-4	10	11	27 000
Matterport Pro3	80	180	90	10-15	50	38	7 000 +cloud

Table 3. Overview of all evaluated parameters for tested devices. *As shown on equation 5.

3.4 Time Requirements

Figure 5 shows the acquisition, postprocessing, and manpower times required for each device. SLAM-based systems (Orbis, Blink) demonstrate significant time savings compared to static TLS. As already noted, the reported MANPOWER values represent only the actual time the operator needs to be

physically engaged in the workflow. Periods when the processing runs automatically in the background, without the need for supervision, are not included.

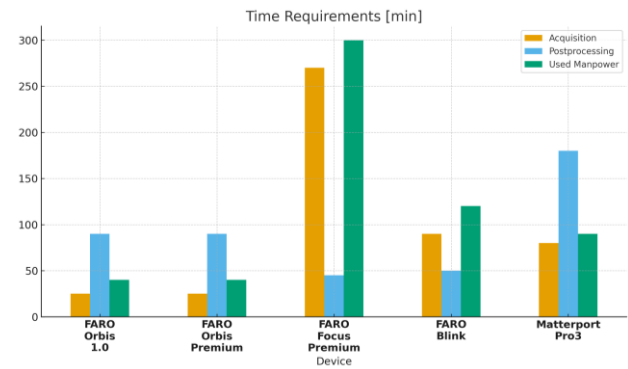


Figure 5. Time requirements for acquisition, postprocessing, and used manpower [min].

It should be emphasized that the time required for static scanning is strongly influenced by the profile settings applied at each station. For the purposes of this study, a higher-quality profile was deliberately selected, since the resulting dataset was intended to serve as the reference point cloud against which all other measurements were compared.

3.5 3D Accuracy

Figure 6 compares manufacturer-declared 3D accuracy (scaled by factor 2.5) with experimentally tested accuracy. It highlights the differences between idealised manufacturer values and practical field performance.

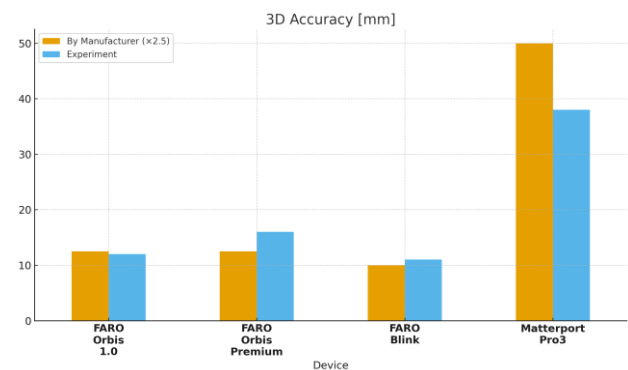


Figure 6. 3D Accuracy – manufacturer vs. tested values [mm].

The results clearly show that while manufacturer-declared accuracies, scaled by the factor 2.5, tend to approximate experimental values, notable deviations remain. The lowest discrepancies were observed for the FARO Orbis 1.0 and Orbis Premium, both staying within a narrow range of a few millimetres. The BLINK device achieved slightly worse accuracy, though still within acceptable limits for rapid documentation. The Matterport Pro3, on the other hand, showed significant divergence between declared and experimental accuracy, with vertical deviations exceeding 35 mm. Despite these differences, it is important to recognise that all results are still influenced by the reference point field used for georeferencing. This introduces an inherent tolerance of 5 mm, which needs to be considered in the overall comparison.

3.6 Average Cost

Figure 7 summarises the average cost of devices. For the Matterport Pro3, additional annual fees for cloud services are shown as a hatched extension of the bar. For the FARO devices, the cost includes a permanent license for processing software and a dedicated workstation for complete data processing.

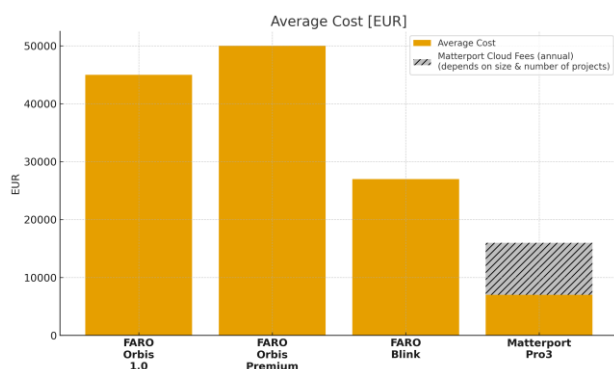


Figure 7. Average cost of devices [EUR], including annual Matterport Cloud fees (depending on size and number of projects).

Beyond the simple acquisition cost, it is important to note the long-term financial implications associated with each technology. While Matterport Pro3 represents the lowest entry price, its cloud-dependent business model requires continuous subscription fees, which may in the long term exceed the price of more expensive instruments. On the other hand, SLAM-based devices such as Orbis or Blink involve a higher initial investment but offer independence from external services and provide full control over the acquired data. This distinction may be crucial for institutions and companies where data security, project scalability, and cost predictability play an essential role in decision-making.

3.7 Example Analyses

Two additional analyses demonstrate device-specific behaviour.

Figure 8 shows the histogram of vertical deviations (Z-axis) for FARO Orbis 1.0 in exterior measurements. The distribution follows a near-normal shape with $\mu = 0.005$ m and $\sigma = 0.002$ m.

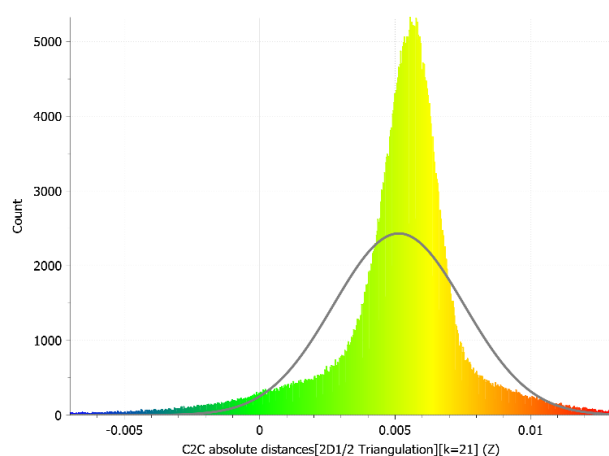


Figure 8. Histogram of vertical deviations (Z-axis) for FARO Orbis 1.0 in exterior conditions.

Figure 9 shows the noise pattern in Matterport Pro3 caused by inaccurate cloud-based registration. Data from three stations demonstrate a spread exceeding 3 cm in XY, which limits the applicability of this device for high-accuracy surveying. The point cloud is colour-coded according to deviations from the static TLS reference dataset, which was used as the benchmark for accuracy evaluation.

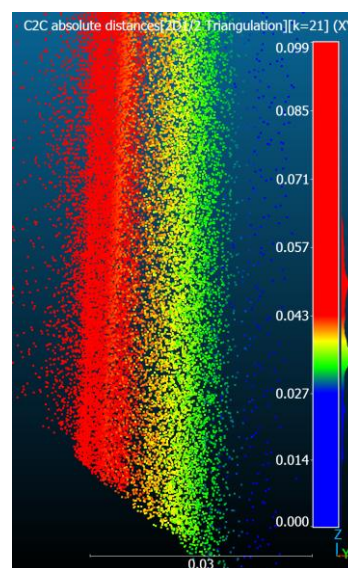


Figure 9. Noise in point cloud data from Matterport Pro3 due to cloud registration errors.

Among the tested devices, the Matterport Pro3 exhibited the highest scatter of measured values. Due to the strong noise present in its point clouds, extreme deviations are often masked, which is why several studies approximate the data and perform comparisons only after additional filtering or noise reduction, as described by Štroner (2016), noise attenuation in point clouds can be achieved through local modeling using neighbouring points to approximate the surface, reinforcing the importance of methodical processing even when automation is involved. In this case study, however, the evaluation focused on the overall user experience, reflecting the results as they would appear to an average operator. It cannot be expected that users of such simplified technologies will engage in complex post-processing steps, and therefore the raw output must be considered as the primary benchmark.

4. Conclusion

This study compared a set of scanning devices representing static TLS, SLAM-based systems, and a cloud-dependent platform under both interior and exterior conditions. The results demonstrate clear trade-offs between acquisition time, postprocessing demands, accuracy, and cost. While static TLS instruments remain the benchmark in terms of precision, they are also the most time-consuming and resource-intensive. SLAM-based devices offer an efficient alternative with rapid data capture and reduced manpower, though at the expense of slightly reduced accuracy. Cloud-based solutions such as Matterport Pro3 stand out for their user-friendliness and low entry cost, but their dependency on external processing and susceptibility to noise make them unsuitable for applications requiring higher precision.

Another important aspect of accuracy is the role of methodology and operator experience. Modern devices are increasingly designed with higher levels of automation and simplification, reducing the demands on the operator. Nevertheless, the way the device is handled in the field remains crucial. In our experiment, the FARO Orbis 1.0 was operated by a specialist with more than five years of SLAM experience, who maintained stable movements and consistent scanning trajectories. By contrast, the newer FARO Orbis Premium was tested by a less experienced operator with only one month of practice. His generally faster walking pace and sharper movements resulted in a noisier trajectory and, consequently, slightly lower accuracy, despite the technological improvements of the device itself. This demonstrates that while automation supports the operator, correct methodology and practical expertise remain key factors in achieving the highest possible accuracy.

Finally, the findings highlight that technology selection cannot be reduced to a single metric such as accuracy or cost. Instead, the decision must consider the specific requirements of the project, including the acceptable error tolerance, available manpower, and financial constraints. For tasks demanding millimetre-level precision, static TLS remains indispensable. For rapid documentation or preliminary surveys, SLAM devices provide a practical balance between speed and accuracy. Cloud-based systems may still play an important role in domains such as real estate or facility management, where ease of use and quick visualization outweigh strict accuracy requirements.

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