

The geometric features of iPhone LiDAR point clouds: statistical analysis and comparison with TLS reference

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Abstract

This study evaluates the geometric features of point clouds generated by iPhone LiDAR across three different applications: Modelar, 3D Scanner, and SiteScape. While iPhone LiDAR offers a cost-effective alternative to Terrestrial Laser Scanning (TLS), its performance is influenced by internal processing algorithms and environmental factors. We measure the systematic biases and spatial stability of these sensors by examining geometric properties, including roughness, planarity, and linearity. The findings show that although iPhone LiDAR achieves centimetre-level precision appropriate for initial BIM operations, statistical analysis shows constant systematic bias but strong spatial repeatability (95% CI).

Keywords: point cloud, iPhone LiDAR, TLS, geometric features, statistical analysis.

Introduction

A number of technologies for 3D modelling and reconstruction have emerged. Laser scanning is a highly efficient technology for correctly recording structures (Pritchard et al., 2017), producing precise point clouds that are suited for BIM workflows. Jung et al. (2014) describe techniques for as-built BIM modeling with laser-scanned data, focusing on process integration from raw scans to semantic models. TLS datasets provide low noise and great geometric integrity, with surface roughness often less than 0.002 m, ensuring a true representation of reality (Conti et al., 2024). Alternative technologies, such as Mobile Mapping Systems (MMS), provide quick 3D data capture during construction. Petrie (2023) exhibits MMS performance in large-scale surveys, Sgrenzaroli et al. (2022) show how MMS improves BIM by lowering scanning time, and Previtali et al. (2020) emphasize its cost-effectiveness in keeping accurate asset documentation. Recent advances in consumer-grade LiDAR sensors, particularly in iPhones from 12 Pro onward, allow affordable 3D point cloud acquisition with RGB registration and an operational range of 5 m (Vacca, 2023). In a study conducted by Teppati et al. (2022), the metric quality of iPhone LiDAR data was assessed, and the results confirmed centimeter-level precision under controlled conditions. Co-registration by point-pair selecting is further examined in (Luetzenburg et al., 2021), which also focuses on improving alignment with reference geometries during the process.

Comparison studies on iPhone LiDAR for Building Information Modeling (BIM), such as the one conducted by (Askar et al., 2023), evaluated four applications: 3D Scanner, PolyCam, SiteScape, and Scaniverse with respect to TLS reference data. The M3C2 algorithm showed global deviations that were often under 5 centimeters, while the local positional errors reported as root mean square error (RMSE) reached 10 centimeters for the majority of applications, with Scaniverse exhibiting larger local errors of up to 55 centimeters. Apps such as 3D Scanner and Clirio Scan were analyzed and shown to have a strong linear relationship ($R^2 > 99\%$). Those are based on actual values, with some variations. There were notable discrepancies, as shown by statistical testing ($p = 0.034$). SLAM trajectory errors can generate linear measurement gaps as large as 5.15 cm. Günen et al. (2023) noted that the 5 m sensor range frequently results in

data gaps in vast areas, drawing attention to the unique benefits and drawbacks of iPhone LiDAR for interior mapping. This study investigates whether free iPhone LiDAR apps can provide reliable geometric characteristics necessary for Building Information Modelling (BIM), including planarity, linearity, and roughness. In particular, we test the hypothesis that, despite systematic bias, the geometric consistency of iPhone LiDAR is suitable for structural modeling and semantic segmentation.

Materials and methods

The main facade of the ground floor of the University of Debrecen's GeoMath building, which is 46.5 meters long, was the focus of the area of interest. This façade features thirteen glass windows and a main entrance, providing a complex environment for testing iPhone LiDAR performance. To ensure high-precision alignment and georeferencing, we established a geodetic network by placing surveying points. This network included five permanent survey points distributed in a homogeneous manner surrounding the building (Fig. 1).



Figure 1. Area of interest and geodetic network: (a) the GeoMath building at the University of Debrecen; (b) Network Layout: Spatial distribution of survey points for georeferencing.

A Spectra Precision Focus 8 total station, an optical leveller, and an Emlid Reach RS2 RTK GNSS instrument were used to establish a reliable control network. Datasets were generated using an iPhone 13 Pro Max equipped with a LiDAR sensor and an A15 Bionic chip. Three mobile applications, Modelar, 3D Scanner and SiteScape, were used to scan the main façade and generate 3D point clouds. The resulting data were compared against a high-precision reference dataset captured by a Trimble X7 (TLS).

Official Metashape markers were utilized as control points to align iPhone LiDAR point clouds with the absolute coordinate system. These markers facilitated precise visual detection of marker centres and ensured compatibility (Fig. 2).

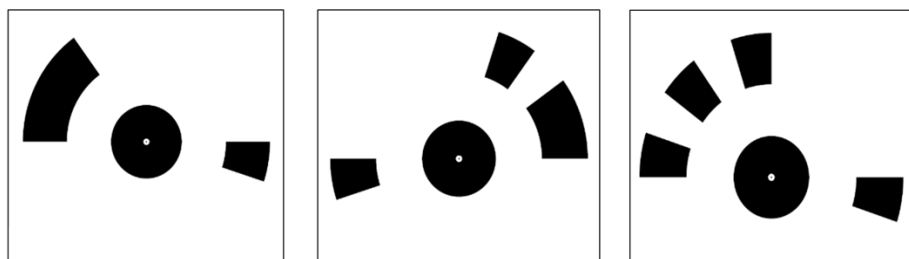


Figure 2. Official Metashape markers.

The research employed a comparative statistical analysis where iPhone point clouds were aligned to the TLS reference via control points and Iterative Closest Point (ICP) registration using CloudCompare software. This software was used to compute geometric features like

roughness, planarity, and linearity, while R programming was employed for geometric features evaluation.

The following metrics were extracted for each point with full original density and a search radius of 0.10 m:

- Roughness: Shows surface irregularities and fine topography.
- Planarity: Measures how similar the point is to a flat geometric plane.
- Linearity: Often used as an indicator for algorithmic smoothing, it evaluates linear alignment.

After feature extraction, subsamples were taken from the point clouds using a random subsampling procedure to a fixed size of 1,000,000 points in order to standardise the datasets for statistical analysis. The resulting datasets were exported as text files. The study employed spatial bootstrapping by generating twenty random spatial subsamples from each point dataset to calculate 95% confidence intervals (CI), ensuring that the results reflect the sensor's performance across the interface, including complex openings, rather than just a general average. Independent t-tests were used to compare each application to the TLS reference, and stars of significance were used to show levels of significance.

Results

Figure 3 shows the 3D point clouds for each application alongside the TLS point cloud. All the applications successfully scanned the entire wall, with some gaps in the window areas and the main entrance due to the presence of glass surfaces that prevented complete coverage.

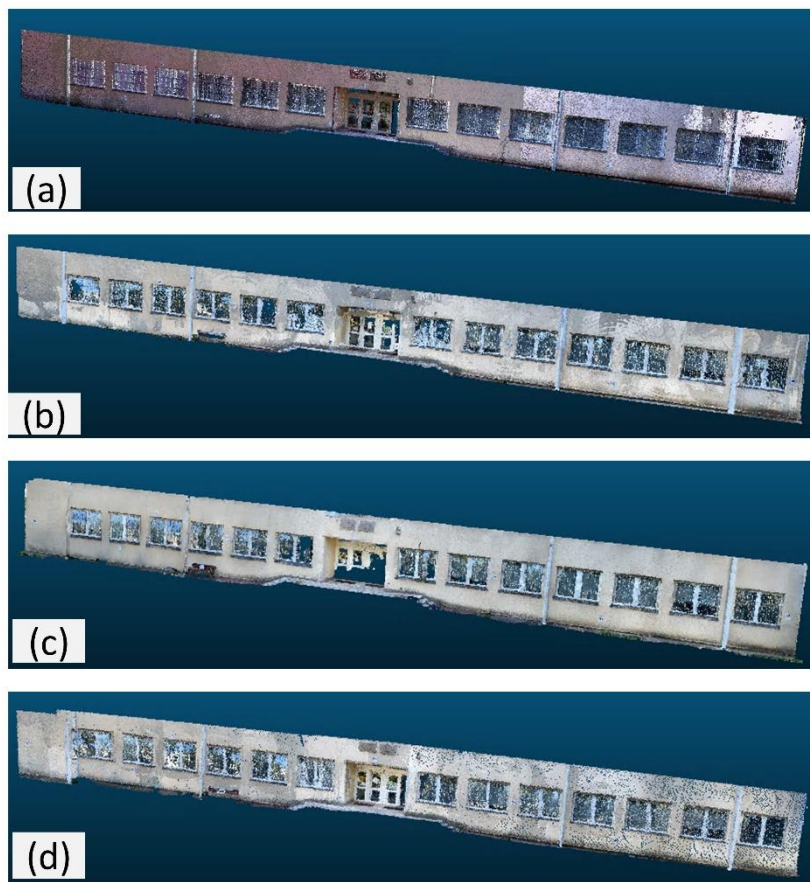


Figure 3. Point cloud registration for comparison between TLS reference and iPhone apps:(a) TLS; (b) Modelar; (c) 3D Scanner;(d) SiteScape.

The figure also shows the split surfaces in the overlap area due to the limited scanning period between two loops, only for the SiteScape application. The Modelar app generated 32.8 million points, 3D Scanner generated 1.8 million points and SiteScape generated 49.931 million points.

Table 1: The RMS error distribution for alignment by control points and fine alignment ICP for every application.

App	RMS - Alignment by Control Points (cm)	RMS - Fine alignment ICP (cm)
Modelar	8.1	4.6
3D scanner	19.6	8.5
SiteScape	28.01	18.4

The ability of each application to produce continuous surfaces and accurately read control points is the main factor influencing the variations in RMS alignment errors. The primary cause of the high error in SiteScape (18.4 cm) is incomplete and fractured surfaces, which make precise registration difficult in SiteScape (18.4 cm) is incomplete and fractured surfaces, which make precise registration more difficult. 3D Scanner had difficulty measuring the control point centers in the point cloud. On the other hand, Modelar produced a continuous and coherent point cloud that made it possible to reliably read control point markers, resulting in the lowest error (4.6 cm). The findings align with earlier research that reported centimeter-level RMSE for mobile LiDAR applications in small-to-medium-scale settings (Teppati et al., 2022; Askar et al., 2023; Treccani et al., 2024). Positional accuracy was verified inside a BIM framework using the Level of accuracy (LOA) criteria by the US Institute of Building Documentation. Allowable deviations vary from ± 5 cm (LOA10) to ± 1 cm (LOA30). In this investigation, the Root Mean Square Error (RMSE) obtained after fine alignment using the Iterative Closest Point technique was the key indication of positional accuracy relative to the reference dataset.

The roughness distribution was treated with a standard threshold of approximately 7 mm in order to establish a benchmark for comparison (Fig. 4). Analysis of the TLS reference revealed that 81.3% of points fell within this 7 mm threshold, confirming the low noise of the sensor with an average roughness of 4.2 mm. Because BIM standards do not clearly establish threshold values for these identifiers, they were evaluated by comparing them to the TLS dataset, which served as the reference geometry. TLS is generally recognized as a high-accuracy technology for three-dimensional documentation, and it is widely employed as ground-truth data to validate other reality-capture techniques in architectural and BIM applications (Fassi et al., 2013; Conti et al., 2024). This approach allows both positional accuracy and surface geometric consistency to be evaluated against recognized scan-to-BIM practices.

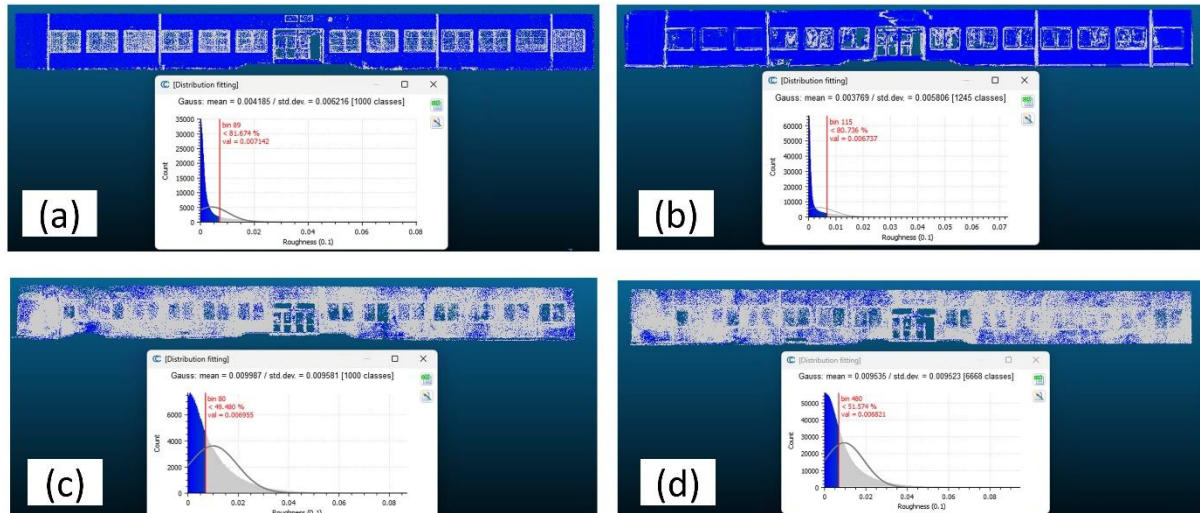


Figure 4. Comparison of roughness distribution comparison between: TLS reference and. iPhone apps: (a) TLS; (b) 3D Scanner; (c) SiteScape; (d) Modelar.

In contrast, the 3D Scanner showed approximately 80.7% of the points below the threshold, with an average roughness of 3.8 mm. Although filtering reduces noise, it carries the risk of losing the fine texture of the construction preserved by TLS. This low roughness indicates artificial surface homogeneity. Conversely, only about 49-52% of the points in SiteScape and Modelar met the minimum threshold of 7 mm, indicating a much higher average roughness (9.5-10 mm). This indicates that high-frequency noise requires more thorough manual cleaning for BIM modelling, especially near depth transitions such as window frames.

Independent t-tests were conducted to compare iPhone LiDAR metrics against the TLS ground truth (Fig. 5). All applications showed extreme statistical significance ($p < 0.0001$, ****) due to the very large sample size, indicating that the geometric deviations are significant differences brought on by internal processing algorithms rather than random noise.

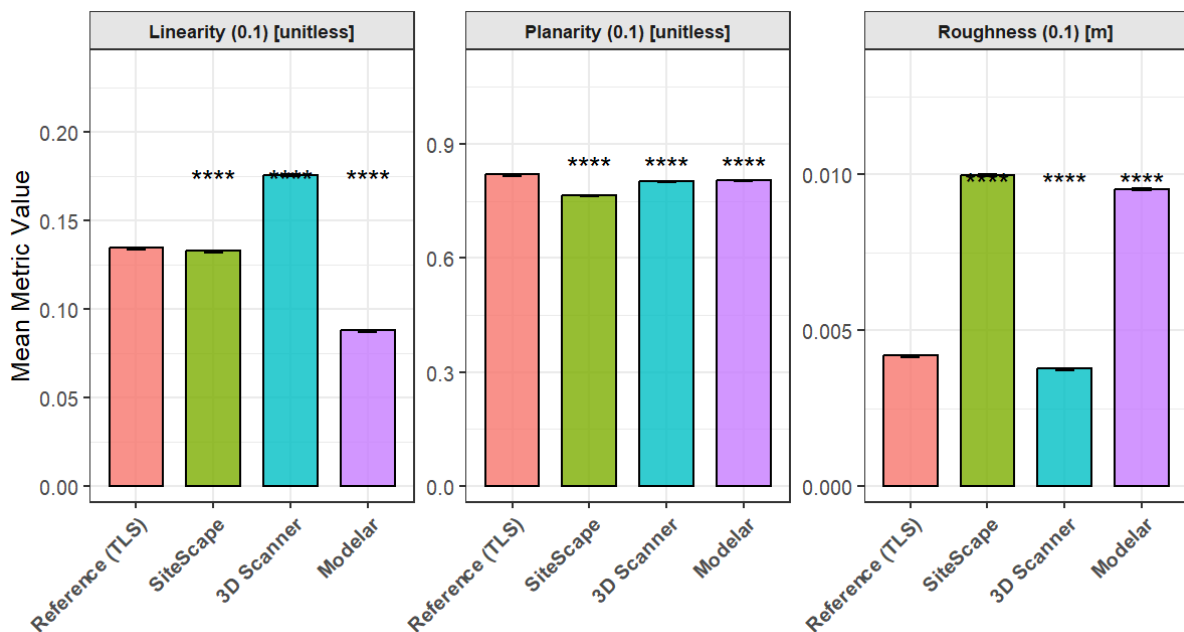


Figure 5. Statistical accuracy and structural stability analysis of LiDAR metrics relative to the TLS reference.

SiteScape was found to be the most accurate application for representing linearity, more closely following the TLS reference than other tested applications, according to the statistical analysis of higher-order geometric features. The aggressive algorithmic edge-smoothing of the 3D Scanner App, which departs from the raw geometric reality of TLS, is responsible for its highest absolute linearity values. When compared to the TLS ground truth, all applications maintained a high relative accuracy of roughly 95% in terms of planarity.

The high operational stability of iPhone LiDAR sensor across the 20 bootstrapping sub-samples is demonstrated by the temporal and spatial consistency comparison (Fig. 6). The near-horizontal trend lines for all metrics, Linearity, Planarity, and Roughness, indicate that the sensor's performance does not fluctuate significantly across different spatial zones of the façade. Notably, while there is a clear vertical offset (systematic bias) between the iPhone apps and the TLS Reference, the parallel nature of these lines confirms that the bias is constant and predictable. This demonstrates that iPhone LiDAR is still a reliable tool for accurate geometric documentation in spite of its inherent computational constraints by validating the high repeatability of the data.

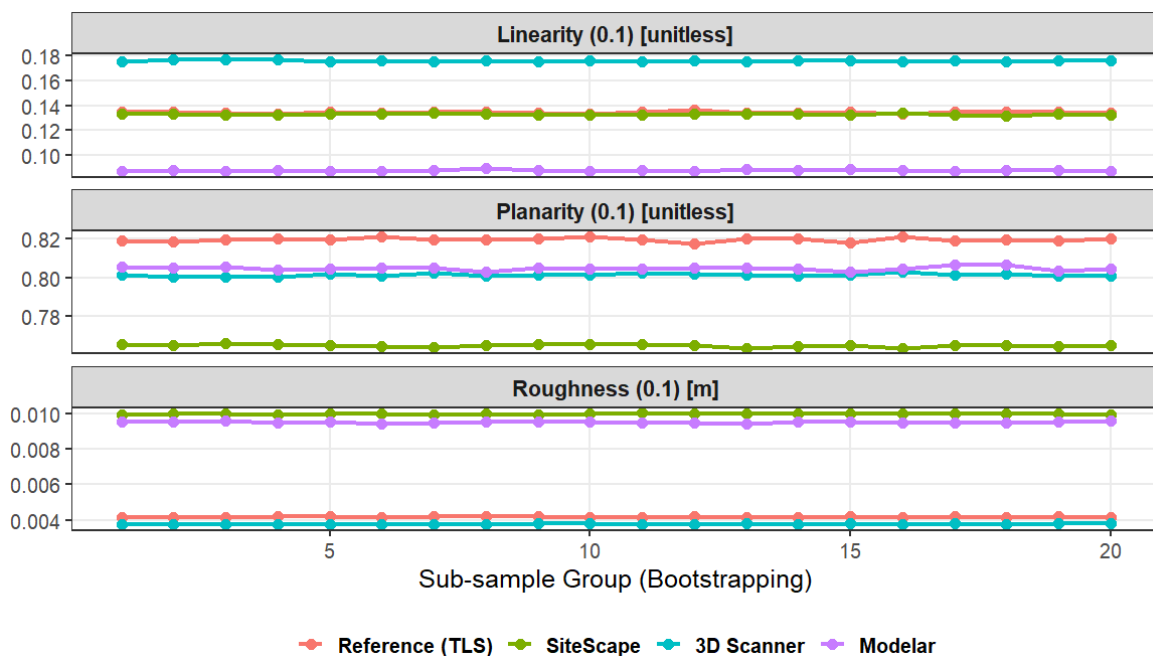


Figure 6. Analysis of 20 subsamples' operational and spatial consistency.

Conclusion

We conclude that iPhone LiDAR applications provide affordable and reliable alternative for 3D documentation at the centimetre scale, as long as their algorithmic limitations are acknowledged. Compared to the TLS reference, our study shows that all applications have systematic bias ($p < 0.0001$), the geometric consistency of the data is still appropriate for semantic segmentation and preliminary BIM workflows. The high spatial homogeneity and repeatability of the geometric metrics, supported by narrow 95% confidence intervals, validate the stability of the sensor's performance.

To ensure complete accuracy, we advise integrating iPhone LiDAR with a well-established geodetic control network for practical implementation. To further increase the effectiveness of mobile mapping solutions, future research should concentrate on creating automated noise-filtering algorithms for transparent surfaces and enhancing automated control point detection.

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