INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

Vol. 16 No. 8 (2024) 1-9
https://publisher.uthm.edu.my/ojs/index.php/ijie

IJIE

The Suitability of Smartphone LiDAR for 3D Building Information Modelling (BIM) Applications

Muhammad Ameer Adam[1], Noraain Mohamed Saraf[1], Lau Chong Luh[1]*, Mohamed Hezri Razali[1], Mukrimo'az Mat Hashim[2]

[1] *School of Geomatics Science and Natural Resources, College of Built Environment, Universiti Teknologi Mara, 40450 Shah Alam, Selangor, MALAYSIA*
[2] *Bandwork GPS Solution Sdn Bhd, 58200 Kuala Lumpur, MALAYSIA*

*Corresponding Author: lauchongluh@uitm.edu.my

DOI: https://doi.org/10.30880/ijie.2024.16.08.001

Article Info

Received: 7 June 2024
Accepted: 12 October 2024
Available online: 21 November 2024

Keywords

LiDAR, building information modelling, iPhone, point clouds, three-dimension

Abstract

An entirely new realm of possibilities for three-dimensional (3D) indoor/outdoor mapping has recently emerged with the incorporation of Light Detection and Ranging (LiDAR) into smartphones. Although these new devices provide unprecedented potential for 3D scanning applications, their data quality is inferior to that of high-end LiDAR sensors. The aim of this study is to determine the capability of smartphone LiDAR in 3D building information modelling (BIM) applications. In this study, the result obtained was compared with the measurements taken using a terrestrial laser scanner (TLS) and distometer. Data acquisition was conducted using a FARO Focus laser scanner, an iPhone 13 Pro, and a distometer. The 3D BIM model was made using Autodesk Revit software. The study found that there was some distortion or drifting in the point cloud data obtained from the iPhone LiDAR. Despite the fact that some parts of the data were distorted, there are some parts of the data that were able to be used for accurate modelling. From the measurements made for BIM (windows, doors, columns, and walls) using the iPhone LiDAR, 27.27% were in the millimetre-level range, whereas 72.73% were in the centimetre-level range. In conclusion, iPhone LiDAR can be applied to 3D BIM applications.

1. Introduction

In the field of geosciences, the methods of terrestrial laser scanning and airborne laser scanning are frequently used for topographic land surveying on a wide range of scales [1]. LiDAR is a widely used technology for determining distances by calculating the time taken for the laser pulse from a laser transmitter to be bound back from the target surface to the receiver [2]. As a result of the rapid proliferation of digital processing techniques and a new generation of remote sensing technology, a revolution in digital elevation modelling and geomorphological terrain analysis is on the horizon [3].

The terrestrial laser scanner (TLS) also offers extra advantages for analysing the scanned data, especially when dealing with complex buildings. The use of 3D models of buildings is now necessary in a wide range of economic sectors, particularly in architecture and engineering for multi-story buildings [4]. In addition, they require correct data in order to perform an as-built analysis, which is crucial for indoor mapping. In order to meet the objectives, it is imperative to gather exact data before starting to produce the strata plan, and using a laser scanner is the ideal method to do so. The laser scanner can provide data with complete accuracy and can speed up the process of obtaining 3D data necessary to create digital as-built models [5].

According to Quattrini et al. [6], the market for laser scanners used for terrestrial applications has developed quite successfully, and these scanners are now acknowledged as one of the surveying tools that can meet the requirements of industrial applications. Laser scanning technology was initially only suitable for usage over a very small area. However, the applications for laser scanning are always growing, which has accelerated technological development to the point where a new and superior laser scanner may now be produced. Due to this development, short, medium, and long-range laser scanners have all been developed [7].

The development of 3D LiDAR scanners that are readily available to customers is made possible by advancements in surveying and mapping technologies. The widespread use of cellphones nowadays, combined with improvements in sensor technology, opens up new scientific options, such as crowd-sourced, low-cost surface change observations and public participation in scientific research [8], [9]. The recent addition of LiDAR sensors to the Apple iPhone and iPad product lines is evidence of this. The addition of scanning capabilities to mobile devices opens the door for the creation of cutting-edge methods for 3D indoor and outdoor mapping, for example, building modelling [10], [11], forest mapping [12], and cultural heritage documentation [13]. The rate at which data is gathered is substantially faster than the TLS, and the time for post-processing is shorter and the cost is cheaper compared to the TLS. However, the manufacturer does not provide a datasheet outlining the LiDAR's technical specifications [14]. Because of this, customers are unaware of how truly useful the technology is in situations where accuracy and precision are crucial [11]. Thus, the purpose of this study is to determine if smartphone LiDAR is suitable for 3D building information modelling (BIM) applications while taking into account the rapid growth of smartphone and LiDAR sensor technologies.

2. Methodology

A well-designed approach was created after a comprehensive review of the literature was completed in order to accomplish the aim of this study. A flowchart of the research methodology followed in this study is shown in Fig. 1. This study was generally separated into four phases: a preliminary study, data collection, data processing, and results and analysis.

In the initial phase of the study, a literature review served as the beginning of the first step of the research. Based on earlier works and studies conducted by reliable researchers, the examination of the literature gave the research a more thorough perspective and new insights. To verify that the methodology and theories employed were true and authentic, all research papers used as references came from reliable and trustworthy sources that were published online. The problem statement, objectives, scopes, and methodology were then decided upon in accordance with the literature review.

2.1 Data Collection

The TLS and smartphone LiDAR were the two different pieces of equipment employed in this study during the phase of data collection. A site reconnaissance or site planning was done before the observation or scanning phase in order to get a quick overview of the data collection workflow.

The TLS measurement was performed using the FARO Focus Premium laser scanner. This laser scanner is frequently used to capture data both indoors and outdoors. The scanner was placed at the station points that have been planned. In order to ensure that the instrument is level, the scanner was mounted on a tripod and levelled. To enhance the coverage of the area, the established stations made use of their full potential. A few scan stations were set up in locations that were either obscured by other scan stations' obstacles or hindered by them. This was done to guarantee complete study area coverage. Black-and-white paper targets were distributed evenly over the case study area before data collection.

The smartphone LiDAR scanner used in this study was an Apple iPhone 13 Pro. The iPhone's LiDAR sensor can detect objects up to 5 metres away, both indoors and outdoors. Before using the iPhone to capture the scan data, an application must be installed. The scanned information was recorded using an iOS application called the 3D Scanner App. The point cloud density and resolutions used for the scans were determined by the sensor's capabilities. The scans were carried out manually by bringing the smartphone to the intended scan area and scanning the entire area using the sweeping scan method in one direction only, as shown in Fig. 2. While taking the scans, it is important to continuously check the surface model that is being created on the smartphone screen. The iPhone was attached to a DJI OSMO 3 gimbal for a steadier and more precise scan. This enables a more thorough overall scan and better-covering point clouds.

At the same time, the dimensions of the room's features were also measured simultaneously using a Leica distometer. The measurements for elements like doors, windows, walls, and columns were acquired. The value from the distometer was used as a reference or the most probable value (MPV) as a comparison to the TLS and iPhone LiDAR for accuracy assessment. The Leica distometer can measure objects up to the millimetre or 0.001 metre level.

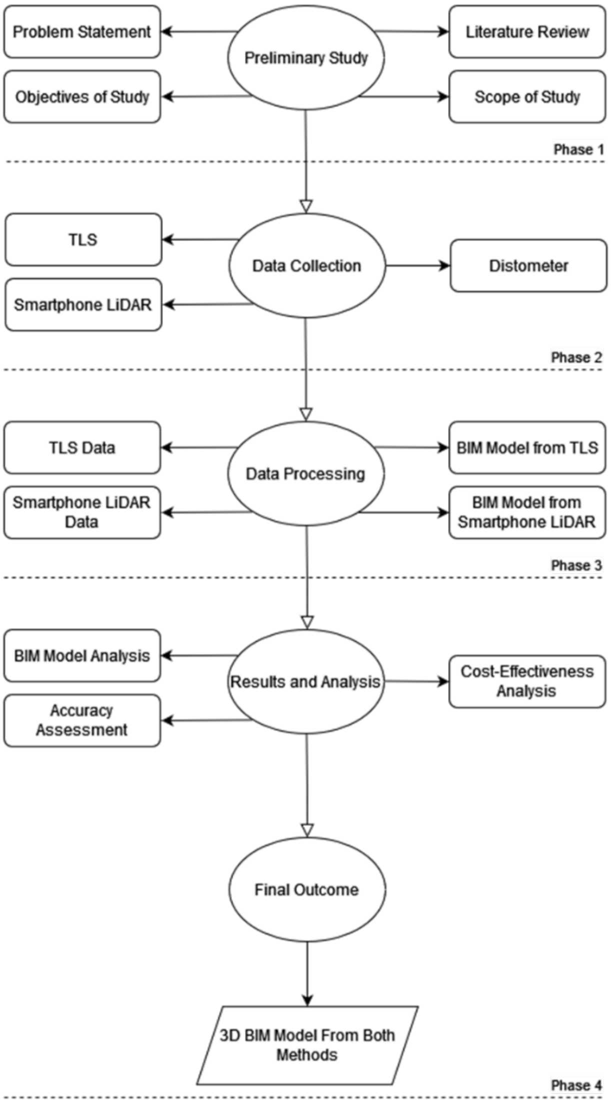


Fig. 1 *Research methodology flowchart*

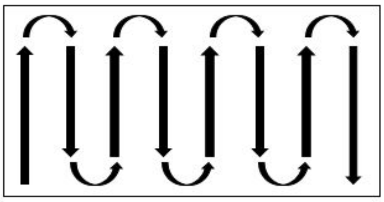


Fig. 2 *Sweeping scan method*

2.2 Data Processing

All of the recorded point clouds were processed using various 3D processing software. The FARO SCENE software, Autodesk Revit, 3D Scanner App, Autodesk AutoCAD, and Autodesk Recap are the software used for processing 3D point clouds and 3D modelling.

First, the data processing phase of the project for the TLS made use of the FARO SCENE software. There were a few phases involved in the processing of the 3D point cloud dataset, which include 3D point cloud filtering, registration, validation, and visualisation. Before the data can be registered, the 3D scan data must be filtered in order to remove any unwanted noise and low-quality point clouds. Errors in certain scan areas can be remedied or completely removed from the scans by using a filter. After all of the scan data had been filtered, it was followed by the data registration process in order to create a complete 3D point cloud of the structure. There must be at least three common reference targets accessible across two different datasets in order to perform the point cloud registration process. The common reference points that these two scan datasets shared were then selected using the black and white target selector. After that, the data can then be sent to CAD software for the creation of a BIM model when the point cloud processing for the TLS point cloud data has been completed. The Autodesk Revit software was used for this study. All of the measurements used in the BIM model were derived from the 3D point clouds, which served as the model's foundation. The conversion of the scan data to BIM is known as Scan-to-BIM. The BIM model produced using the TLS data was then compared to the one produced using iPhone LiDAR as a reference.

On the other hand, data captured on the iPhone using the 3D Scanner App was exported to a software called Autodesk Recap for point cloud processing. The dataset can also be processed within the scanning application before being exported to the desired formats. Several file formats, including the ASCII-based .las and .pts formats, can be exported from the application. The workflow for data processing is the same as it is for TLS. The difference is the processing software. The scan data obtained using the iPhone LiDAR has technically been processed in the 3D Scanner App after scanning was done. The data was then imported into Autodesk Recap after being exported in .pts format. The primary goal of Autodesk Recap is to convert data into the Recap file format (.rcp), which Autodesk Revit can read. Before exporting to Autodesk Revit, further processing or cleaning of the point cloud data was done in Autodesk Recap. Then, the processed point cloud data from the iPhone 13 Pro is exported into the Autodesk Revit software. In order to create an as-built BIM of the room, the building and feature dimensions were extracted. The constructed BIM model was compared to the reference, which was produced using the dataset from the TLS. The accuracy of the BIM model was then analysed using data obtained from an iPhone LiDAR.

2.3 Results and Analysis

A 3D modelling analysis was done to determine whether iPhone LiDAR is appropriate for BIM applications. The model was examined from a BIM perspective to figure out which features needed to be modelled and whether they were modelled correctly. The accuracy of both the iPhone and TLS was then evaluated through measurement analysis by comparing the dimensions to the measurements from the distometer. To evaluate the accuracy of both approaches, the measurements were contrasted. In this study, the Root Mean Square Error (RMSE), as employed by [10], was used to evaluate accuracy. Eq. (1) shows the formula used for the RMSE calculation. The RMSE measures the differences between the values predicted by a model and the values actually observed in order to describe the accuracy and quality of the features. Apart from that, the lower the RMSE value, the better the accuracy. The practicality, efficiency, cost effectiveness, and accuracy of the iPhone LiDAR are then evaluated, with a focus on the BIM application for its cost-effectiveness. The parameters for cost-effectiveness analysis included time taken for data collection, manpower, concept, number of scan stations, registration process, time taken for data processing, and the cost of the instrument.

$$RMSE = \sqrt{\frac{\text{Sum of Square Error, } X^2}{\text{Total Sample Number, } N}} \tag{1}$$

2.4 Final Outcome

The 3D BIM model created utilising both the dataset from TLS and the iPhone LiDAR scanner served as the research's final output. The model's features include the ceiling, floors, walls, columns, doors, and grilled windows.

3. Results and Discussion

By evaluating the accuracy of a 3D BIM model built using a dataset gathered from iPhone LiDAR, the suitability of iPhone LiDAR for BIM applications was examined. The accuracy assessment included comparisons of measurements between the iPhone LiDAR scanner, distometer, and TLS. In contrast, the cost-effectiveness analysis examines the suitability of the iPhone LiDAR in comparison to the TLS and distometer in terms of accuracy, cost, data collection time, processing time, concept, and required manpower.

3.1 BIM Model Analysis

The point cloud from the TLS provided a dense and complete scan of the room with a scanning resolution of 1/8. After that, a 3D model with the features in the room was created. The features could still be distinguished from one another, even though the scan was done without colour. In order to see the 3D model clearly, the visibility of the ceiling has been turned off in Fig. 3, which displays the created 3D model.

When using an iPhone LiDAR, scanning must be done carefully in order to fully cover the entire room. However, the point clouds still showed considerable shifting or drifting, even with the aid of the gimbal stabiliser. This indicates that some parts of the point clouds are disconnected from one another and aren't aligned to the actual position. Nevertheless, a model was finally achieved from the iPhone LiDAR point clouds through several scans to obtain the most satisfactory results. The 3D model created with the iPhone LiDAR scanner is displayed in Fig. 4.

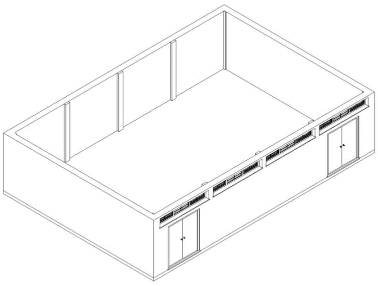


Fig. 3 *BIM from TLS*

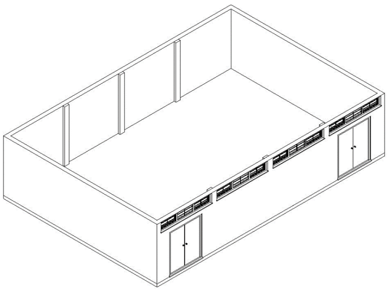


Fig. 4 *BIM from iPhone LiDAR*

Based on the point cloud data from the iPhone LiDAR, all the features were modelled. Due to the iPhone LiDAR scanner's inability to detect the four corner columns, which are small in dimensions, it was not possible to model them in this study. These columns were smaller than the other columns in size. However, TLS has no trouble capturing the 3D point clouds with the smaller dimensions of these corner columns. Fig. 5 shows the point cloud data from the iPhone LiDAR that has some form of distortion.

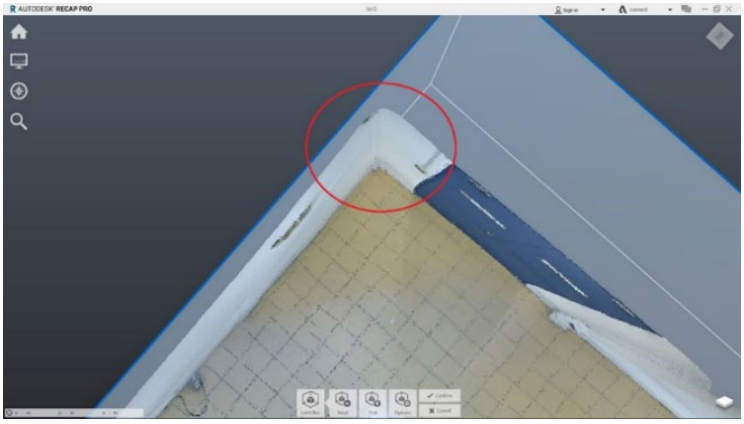


Fig. 5 *Top view of the distortion in the point cloud*

The column should be displayed where the red circle is marked in Fig. 4, but due to the column's small size, it is difficult to discern. As a result, it is challenging to distinguish the columns from the walls, which makes accurate modelling difficult. Due to the iPhone LiDAR's limitations, smaller objects cannot be accurately scanned and are typically combined with an adjacent feature. As a result, using the iPhone LiDAR alone, a 3D model of a room with small features was hard to model.

3.2 Accuracy Assessment

The accuracy assessment was done based on the accuracy of both 3D BIM models created from both methods. Windows, doors, columns, and walls are the four main features whose dimension measurements were used to analyse their accuracy. The accuracy of the point clouds' data was evaluated based on the length of the features. The measurements were compared with those obtained with the distometer, and the latter was taken as the MPV value. RMSE was used in this investigation to evaluate accuracy. Therefore, the RMSE value was then calculated for the TLS and iPhone LiDAR using the discrepancy value of measurements for the features. The lengths at which measurements were obtained for each type of feature are shown in Fig. 6 to Fig. 9.

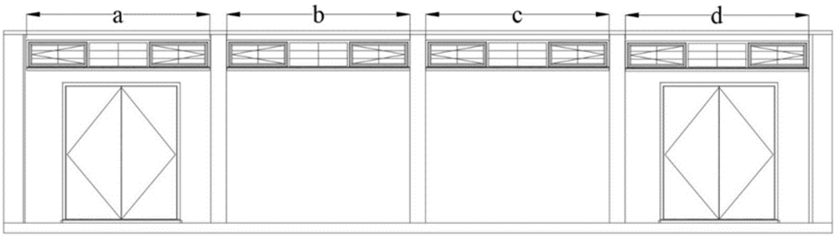


Fig. 6 *Windows with assigned markings*

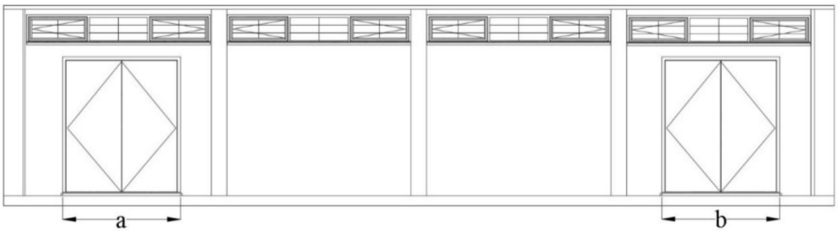
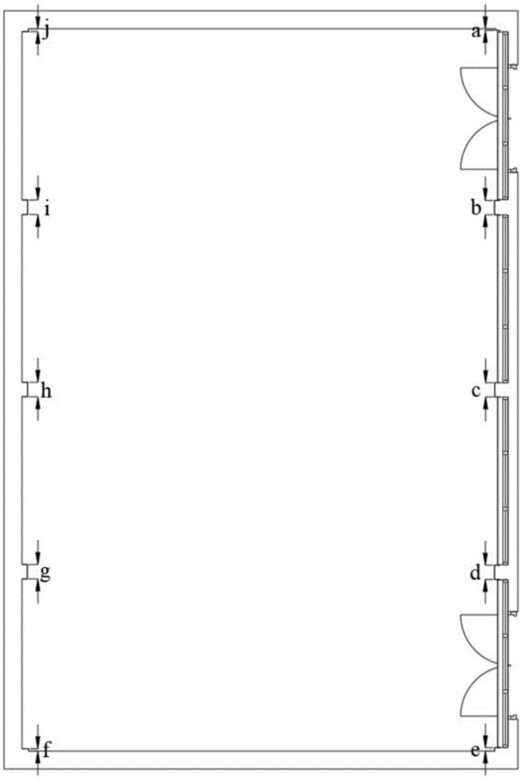


Fig. 7 *Doors with assigned markings*



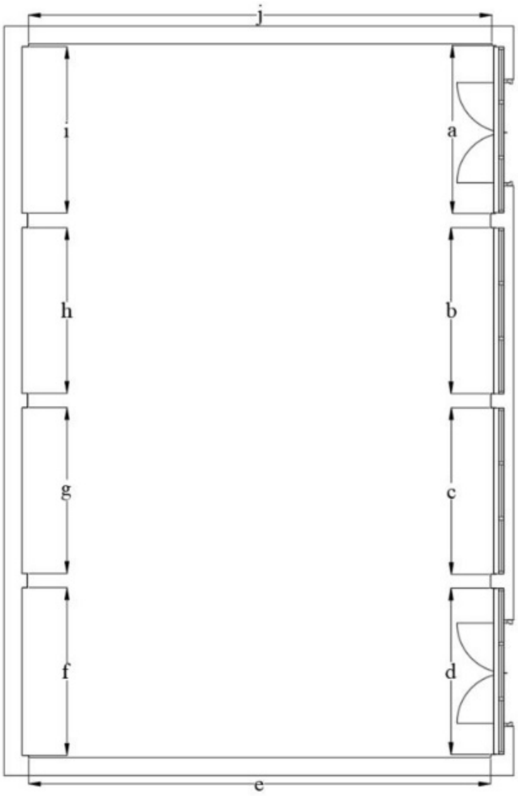


Fig. 8 *Columns with assigned markings*

Fig. 9 *Walls with assigned markings*

The generated RMSE values are used to analyse the accuracy of the datasets. In this case, the dimension measurements from the TLS and iPhone LiDAR datasets were compared to the MPV values obtained using the distometer. The tabulated measurement discrepancy values are shown in Table 1.

The RMSE value obtained for the value between the TLS and distometer is 0.014m. Meanwhile, the RMSE value between the iPhone LiDAR and the distometer is 0.053m. The TLS is more accurate because its RMSE value is lower than that of the iPhone LiDAR. According to the result obtained, the iPhone LiDAR can reach millimetre-level accuracy, but it is not consistent throughout the features. Examples include columns "b", "c", "d", "g" as well as wall "c" and door "a," where the errors were in the millimetre range. Meanwhile, the errors for the other features are in the centimetre range. In the column section, there should be ten columns in total for each method, but for iPhone LiDAR, there are only six columns. This is because the 3D point cloud dataset from the iPhone LiDAR has distortion and is unable to identify these columns. The error for iPhone LiDAR is divided only by 22, as compared to TLS, whereby it is divided by 26. Despite having an RMSE of 0.053m, the dataset produced by iPhone LiDAR is still regarded as inaccurate because four columns could not have been accurately modelled. This happened maybe due to the movement while scanning was not done at an appropriate speed or due to the limitations of the application and hardware.

Table 1 *Calculated RMSE*

Features		Disto – TLS (X) (m)	X^2 (m)	Disto – Smartphone LiDAR (X) (m)	X^2 (m)
Windows	a	0.002	0.000	0.039	0.002
	b	0.008	0.000	0.023	0.001
	c	0.020	0.000	0.050	0.003
	d	-0.026	0.001	0.025	0.001
Doors	a	-0.007	0.000	0.009	0.000
	b	-0.005	0.000	0.017	0.000
Columns	a	-0.001	0.000	-	-
	b	0.000	0.000	0.004	0.000
	c	-0.001	0.000	-0.003	0.000
	d	0.001	0.000	0.007	0.000
	e	-0.005	0.000	-	-
	f	-0.008	0.000	-	-
	g	0.006	0.000	0.004	0.000
	h	0.011	0.000	0.011	0.000
	i	0.005	0.000	0.012	0.000
	j	-0.003	0.000	-	-
Walls	a	-0.025	0.001	-0.024	0.001
	b	-0.013	0.000	-0.056	0.003
	c	-0.001	0.000	0.009	0.000
	d	-0.029	0.001	-0.021	0.000
	e	0.012	0.000	-0.150	0.023
	f	-0.035	0.001	-0.038	0.001
	g	-0.008	0.000	0.025	0.001
	h	-0.021	0.000	-0.024	0.001
	i	-0.016	0.000	-0.067	0.005
	j	-0.012	0.000	-0.150	0.023
	Total	Σ	0.005	Σ	0.062
	RMSE	Σ26	0.014	Σ22	0.053

3.3 Cost-Effectiveness Analysis

There are some broad comparisons to be made between these three techniques: TLS, iPhone LiDAR, and distometer. The general attributes of the iPhone LiDAR as well as the outcomes it produced that were compared with the TLS and distometer were examined in order to determine the cost-effectiveness of it. Table 2 provides a summary of the comparison between the three techniques used in this study.

Table 2 *General comparison of the three techniques used*

Item	TLS	Smartphone LiDAR	Distometer
Time taken for data collection	10 minutes	5 minutes	60 minutes
Manpower	2 persons	1 person	2 persons
Concept	Static	Mobile	Mobile
No. of scan stations	2	None	None
Registration process	Necessary	None	None
Time taken for data processing	5 days	5 days	2 days
Cost of instrument	RM350,000	RM5,000	RM500

The iPhone LiDAR was used together with a gimbal stabiliser in this study. The whole interior of the room was scanned for roughly five minutes by one person. The application used to capture data from the iPhone is the 3D Scanner App, which is free in the App Store. Furthermore, there was no registration process required because there were no scan stations there. Therefore, the 3D point clouds obtained using iPhone LiDAR just need to go through the noise filtering step before moving on to 3D modelling. The time taken for processing the data from the iPhone LiDAR was also around five days, which is shorter compared to the processing time for data from TLS. The iPhone 13 Pro used in this study only costs about RM5,000, which is less than what TLS costs.

From the accuracy assessment of this study, iPhone LiDAR can reach millimetre-level accuracy, but mostly it is at centimetre-level. However, it is unable to accurately portray some of the actual physical features of the study area. This is shown by the output containing some distortions and the inability to scan the columns in the corner of the room. Despite the presence of these distortions, other areas of the study area have accurate scans with measurements ranging from millimetre to centimetre levels.

4. Conclusion

In conclusion, the iPhone LiDAR can be utilised for some BIM applications and to create 3D BIM models. Hence, the objective of this study was achieved, and the findings contribute to the building and facility management industry in BIM. The limitations of the iPhone LiDAR make it possible to generate the 3D BIM model to some extent, as stated in the results and analysis section. This is because certain objects or areas are unable to be modelled due to inaccurate data representation from the iPhone LiDAR's point clouds, while other areas are accurately represented. In conclusion, iPhone LiDAR can produce findings that are satisfactory and accurate within the tolerance level for 3D BIM applications, but this can vary depending on a variety of factors. Future research can focus on sensor integration in order to improve the process of real-time point cloud registration in iPhone LiDAR.

Acknowledgement

The authors would like to acknowledge the assistance of the School of Geomatics Science and Natural Resources, College of Built Environment, Universiti Teknologi Mara (UiTM) throughout the entirety of this study. The authors also express their sincere appreciation to Bandwork GPS Solutions Sdn Bhd for their support and contribution.

Conflict of Interest

The authors declare that there were no conflicts of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Muhammad Ameer Adam, Noraain Mohamed Saraf, Lau Chong Luh;* ***data collection:*** *Muhammad Ameer Adam, Noraain Mohamed Saraf, Mukrimo'az Mat Hashim;* ***analysis and interpretation of results:*** *Muhammad Ameer Adam, Noraain Mohamed Saraf, Lau Chong Luh, Mohamed;* ***draft manuscript preparation:*** *Muhammad Ameer Adam, Noraain Mohamed Saraf, Lau Chong Luh, Mohamed Hezri Razali. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Telling, J., Lyda, A., Hartzell, P., & Glennie, C. (2017). Review of earth science research using terrestrial laser scanning. Earth-Science Reviews, 169, 35–68. https://doi.org/10.1016/j.earscirev.2017.04.007

[2] Lohani, B., & Ghosh, S. (2017). Airborne LiDAR technology: A review of data collection and processing systems. Proceedings of the National Academy of Sciences, India Section A: Physical Sciences, 87, 567–579. https://doi.org/10.1007/s40010-017-0435-9

[3] Meigs, A. (2013). Active tectonics and the LiDAR revolution. Lithosphere, 5, 226–229. https://doi.org/10.1130/RF.L004.1

[4] Ali, M., Mohd Ismail, K., Has-Yun Hashim, K. S., Suhaimi, S., & Mustafa, M. H. (2018). Historic building information modelling (HBIM) for Malaysian construction industry. Planning Malaysia Journal, 16, 332-343. https://doi.org/10.21837/pmjournal.v16.i7.522

[5] Aziz, M. A., Idris, K. M., Majid, Z., Ariff, M. F. M., Yusoff, A. R., Luh, L. C., Abbas, M. A., & Chong, A. K. (2016). A study about terrestrial laser scanning for reconstruction of precast concrete to support QLASSIC assessment. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4/W1, 135–140. https://doi.org/10.5194/isprs-archives-XLII-4-W1-135-2016

[6] Quattrini, R., Malinverni, E. S., Clini, P., Nespeca, R., & Orlietti, E. (2015). From TLS to HBIM. High quality semantically-aware 3D modelling of complex architecture. The International Archives of the

Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5/W4, 367–374. https://doi.org/10.5194/isprsarchives-XL-5-W4-367-2015

[7] Russhakim, N. A. S., Ariff, M. F. M., Majid, Z., Idris, K. M., Darwin, N., Abbas, M. A., Zainuddin, K., & Yusoff, A. R. (2019). The suitability of terrestrial laser scanning for building survey and mapping applications. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W9, 663–670. https://doi.org/10.5194/isprs-archives-XLII-2-W9-663-2019

[8] Desai, J., Liu, J., Hainje, R., Oleksy, R., Habib, A., & Bullock, D. (2021). Assessing Vehicle profiling accuracy of handheld LiDAR compared to terrestrial laser scanning for crash scene reconstruction. Sensors, 21, 8076. https://doi.org/10.3390/s21238076

[9] Heinrichs, B. E., & Yang, M. (2021). Bias and repeatability of measurements from 3D scans made using IOS-Based LiDAR. SAE International Journal of Advances and Current Practices in Mobility, 3, 2219-2226. https://doi.org/10.4271/2021-01-0891

[10] Chase, P., Clarke, K., Hawkes, A., Jabari, S., & Jakus, J. (2022). Apple IPhone 13 Pro LiDAR accuracy assessment for engineering applications. Transforming Construction with Reality Capture Technologies, https://doi.org/10.57922/tcrc.645

[11] Díaz-Vilariño, L., Tran, H., Frías, E., Balado, J., & Khoshelham, K. (2022). 3D mapping of indoor and outdoor environments using apple smart devices. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B4-2022, 303–308. https://doi.org/10.5194/isprs-archives-XLIII-B4-2022-303-2022

[12] Tatsumi, S., Yamaguchi, K., & Furuya, N. (2023). ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. Methods in Ecology and Evolution, 14, 1603-1609. https://doi.org/10.1111/2041-210X.13900

[13] Teppati Losè, L., Spreafico, A., Chiabrando, F., & Giulio Tonolo, F. (2022). Apple LiDAR sensor for 3D surveying: Tests and results in the cultural heritage domain. Remote Sensing, 14, 4157. https://doi.org/10.3390/rs14174157

[14] Apple (2021). IPhone 13 Pro - Technical Specifications. https://support.apple.com/kb/SP852?locale=en_US