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PRECISE EVALUATION OF 3D BUILDING INTERIOR USING SMARTPHONE LIDAR AND TLS

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ABSTRACT

In 2020, Apple launched the smartphone with innovative build-in LiDAR sensors. The smartphone LiDAR is classified as a Mobile Laser Scanner (MLS) since it has the ability to do scanning activities while on the go. Despite the remarkable development made by Apple, there is still no proof that the smartphone LiDAR can be utilized as a reliable scanner in a land surveying environment. This study is embarked to access the accuracy of the 3D building interior generated from point clouds using two acquisition devices (smartphone LiDAR sensor and TLS). Data acquisition of 3D point cloud datasets only considered the building interior dimension to be measured and processed. The results of 3D building interior model from two acquisition techniques are presented and analysed. Hence, the results of accuracy assessment are compared to investigate the basic technical capabilities of the LiDAR sensors in smartphone. The accuracy of TLS is +0.045m while the accuracy of smartphone LiDAR is +0.136m. The precision of the model is compromised since the point cloud generated by smartphone LiDAR is 5.5mm interval compared to TLS is 1mm interval. Overall, the versatility in handling outweighs the range limitations, making the Apple LiDAR devices cost-effective alternatives to established techniques in survey and mapping application.

1. INTRODUCTION

Light Detection and Ranging (LiDAR) is a remote sensing device that employs a laser beam to gather information about nearby objects. The work of LiDAR, it sends out pulses of light just outside the visible spectrum and time how long each pulse takes to return. Data points concerning an object's direction and separation from LiDAR are collected when the pulse strikes it. LiDAR sensors can be used to determine the shape and orientation of any object in space by measuring the amount of time that passes between the laser signal's emission and its return to the sensor after reflecting off. LiDAR has a high ability to capture spatial data accurately and is not affected by natural light, making it a promising sensor for 3D detection (Wu, Wang, Zhang, & Ogai, 2021).

Utilizing advanced digital mapping tools and 3D laser scanners can facilitate effective electronic planning, consultation, and communication of users' perspectives throughout the entire lifecycle process of built and human environments (Yusuf, 2007). Although the concept of LiDAR was initially proposed in the 1960s, the lasers and detecting devices at the time were bulky and inefficient. Rather than being a technological innovation, LiDAR is more of a methodology. This remote sensing technology employs signals that bounce off objects and return to the scanner to determine spatial connections and shapes, generating 3D models and maps of objects and surroundings. LiDAR can operate in various light ranges, such as ultraviolet, visible, or near-infrared. The majority of today's terrestrial laser scanning technologies are rated to achieve their highest levels of accuracy at ranges of up to 100–130 metres (Son, Bosché, & Kim, 2015).

In the end, the LiDAR data is converted into point cloud data after each reading has been organised and processed. Large groups of 3D elevation points with three coordinates (x, y, and z) and additional data, such as GPS time stamps if they are available, make up an informative point clouds data. Laser scanners gather information in the form of point clouds, which are representations of the shapes and sizes of objects in the physical world. These point clouds are then transformed and depicted as a group of points in a digital 3D

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space (Sepasgozar, Wang, & Shirowzhan, 2016). After analysing the initial LiDAR point cloud, it is feasible to further categorise the unique surface traits that the laser has met. Elevations of the ground, structures, trees, overpasses, and anything else that the laser beam contacts during the survey and gathers data on are included in point cloud data. There has been a recent shift toward gathering information on buildings via the use of terrestrial laser scanning (Bosch, Ahmed, Turkan, Haas, & Haas, 2014). The Terrestrial Laser Scanner has the ability to capture thousands of points per second, each point having its own distinct position coordinates and elevation details (Russhakim, et al., 2018). Conversely, modern smartphones are now equipped with LiDAR sensors. As smartphones already come with geolocation and orientation sensors, they can be used as cameras, making them compact, user-friendly, powerful, and cost-effective tools (Tavani, Granado, Riccardi, Seers, & Corradetti, 2020).

In order to assess the capabilities of the scanner on the iPhone 14 Pro, this research ultimately concentrated on evaluating the quality of smartphone LiDAR in a building inside condition. Due to its portability and ability to perform scanning tasks while on the go, the iPhone 14 Pro is referred to as a Mobile Laser Scanner (MLS). While it shares similar functionality with other MLS devices, the iPhone 14 Pro's compact form factor and built-in system distinguish it from others. The integration of LiDAR technology into a device of this size is considered a significant advancement in the development of the LiDAR industry. For this purpose, terrestrial laser scanners are integrated to ground-based mobile mapping systems, which have been actively researched and developed for a number of years (Wu, Wang, Zhang, & Ogai, 2021).

The launch of the iPhone 12 Pro has shown that technology may become even more user-friendly and small in the future. Despite the remarkable development made by Apple Inc., there is still no proof that the iPhone 14 Pro can be utilised as a reliable scanner in a practical environment. Because of its smaller and more compact form on a smartphone, the goal of this study is to show how LiDAR technology on the iPhone 14 Pro can be beneficial to LiDAR practitioners. An instrument that is small and compact has benefited the operator by increasing its portability and mobility. The ability to move around more freely and quickly while collecting point clouds would result in a better 3D model outcome, which is made possible by using smartphone sensors. Utilizing these sensors for point cloud generation could serve as a quicker, more cost-effective and less complex alternative for local point cloud generation. This could be useful for tasks such as updating 3D archives or for quick damage assessment (Lindenbergh & Sirmacek, 2014).

2. LITERATURE REVIEW

LiDAR technology can be classified into two categories: airborne and terrestrial, with each category consisting of various types. Airborne LiDAR includes topographic and bathymetric LiDAR, whereas terrestrial LiDAR has mobile and static as the two most common types. Regarding to mobile acquisition, the LiDAR system is mounted on a moving vehicle. In the case of static acquisition, the LiDAR system is typically mounted on a tripod or stationary device. Mobile lidar refers to the gathering of lidar point clouds from a platform in motion. Such systems may comprise several lidar sensors attached to a mobile vehicle, train, or even a boat. The mobile systems are usually equipped with a lidar sensor, cameras, GPS, and INS, similar to airborne lidar systems. The data obtained from mobile lidar can be employed for examining road infrastructure and identifying any encroaching overhead wires, road signs, and light poles that may pose a hazard near roadways or rail lines. The static LiDAR system, on the other hand, is stationary and can either scan the entire area or focus on specific areas. The terrestrial laser scanner records thousands of points per second, each with unique position coordinates and elevation information (Russhakim, et al., 2018). The tripod can be placed in a different location after scanning. Static scanning methods, such ground-based LiDAR and fixed camera settings, are frequently used in infrastructure modelling projects to capture information and gather data. This LiDAR can scan up to 180 degrees horizontally and 310 degrees vertically, resulting in comprehensive coverage. As a result, the observed points can be located accurately in space using active optical sensors, often in conjunction with colour data captured by either the device's sensor or an external digital camera.

3. MATERIALS AND METHODS

This study was conducted several phases as described in Figure 1. The phases begin from preliminary study, data acquisition, data processing, data analysis and accuracy assessment.

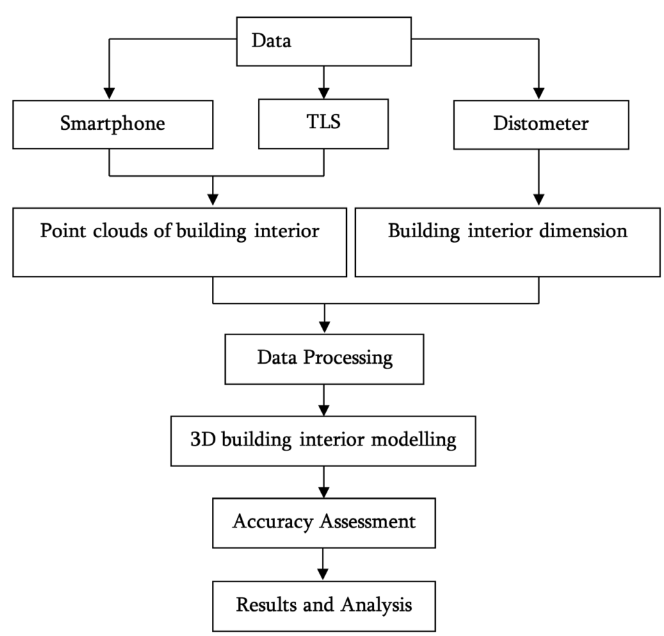


Figure 1: *Flowchart of the methodology*

a. Data Acquisition

The study area of this paper is conducted at Persatuan Jurukur Tanah Bertauliah Malaysia (PEJUTA) which is located in Ulu Klang. Data acquisition of 3D point clouds were collected in the room of the PEJUTA's building. In order to achieve the aim of this study, data collection was conducted using two different devices (smartphone LiDAR and TLS) as well as the evaluation comparison with direct measurement using distometer (Table 1). Meanwhile the data gathering approach will be influenced by the goals and anticipated outcomes, a complete knowledge of both is required for this step. A complete knowledge of how to operate every instrument is also needed for a precise data collecting procedure and the avoiding of potential losses. Since everything went according to plan, a reliable instrument operator is also less likely to repeat this data gathering phase. Using the Polycam programme, the point clouds data was produced using iPhone 14 Pro and transferred to a computer.

Table 1: *Data acquisition form different devices*

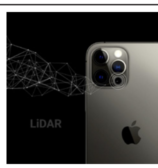
Instrument/ Device	Smartphone LiDAR	Terrestrial Laser Scanner (TLS)	Distometer
Image			
Function	To capture the building interior with LiDAR build-in the smartphone.	To scan the building interior with high accuracy.	To measure the dimension of building interior.

Table 2 shows the model specifications of different devices used for data collection. For the iPhone 14 Pro smartphone, which has a LiDAR scanner, a polycam programme is required in order to continue the data collection process. It will be interesting to see the developments in the use of deep learning for data classification (Kumar, Lohani, & Pandey, 2018). This programme can collect point cloud data to build 3D models. The collected point cloud is very beneficial for quickly verifying data. The point cloud is a universal spatial information acquisition format and plays an important role in indoor and outdoor environment understanding (B, Zhao, Yu, Ikeuchi, & Zhu, 2015).

Table 2: *Model specifications of different devices used for data collection*

Specifications	Device 1	Device 2	Device 3
Model	iphone 14 Pro	Topcon GLS-2000 Laser Scanner	Leica DISTO X4
Camera	48MP Main: 24mm, *f*/1.78 aperture, and 100% Focus Pixels	-	-
TrueDepth Camera	12MP and *f*/1.9 aperture	-	-
Range	-	350m at 90% standard mode	0.05 – 150m
Accuracy	-	3.5mm(1-150nm), 1σ, 6"	1.0mm
Units	-	mm/cm/m	m/ft/in
Size (mm), weight (g)	147 x 71 x 7.85, 206g	-	132 x 56 x 29, 184g
Tilt sensor	-	Liquid 2-axis, +-6'	360

The polycam application lidar scanner can only capture the image within below five meters. Hence, to overcome this problem, it needs to use zigzag scanning method (Figure 2) which can capture all the area in the room. The data result of the image can be converted to LAS format which make it easier to transfer the data to Autodesk recap to clean and filter the point cloud data.

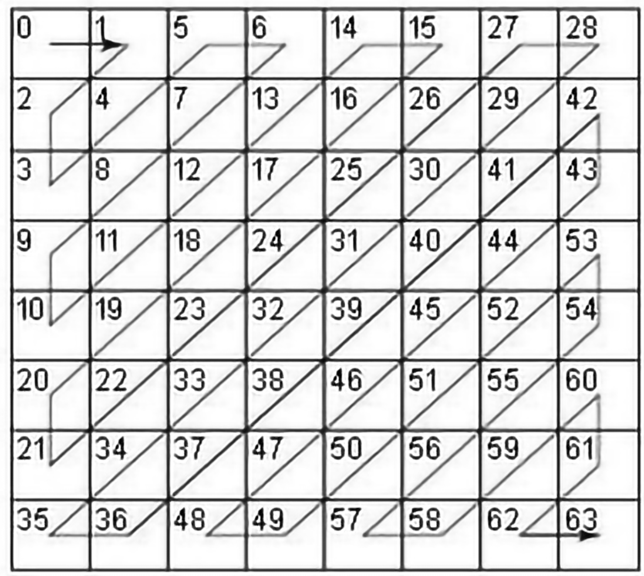


Figure 2*: Zigzag method*

A distometer is a tool for measuring the distance between a spectacle lens's back surface and corner. Generally, the surveyor keeps their eyes closed during the process. While the other end of the tool or measurement sits on the upper eyelid, the other end scrapes against the back of the spectacle lens. In order to measure the dimensions for this study, a distometer was placed at one end of the wall and pointed at the other. This shows the strata title survey. With the advancement of high precision systems, laser scanner can work in real world environments under various conditions (Hadi & Nik, 2011).

b. Data Processing

In modern devices that can identify x, y, and z coordinates and create 3D models, LiDAR is a common attribute. As the system evolved, MLS can currently acquire data on the fly (Fuad, Yusoff, Ismail, & Majid, 2018). It is now possible to create 3D scanning, which has never been done before, appreciations to the LiDAR scanner that has been merged into smartphone technology. The Polycam tool may help in producing a 3D model of the whole room in under a minute. Creating point clouds through smartphone sensors could provide a faster, more cost-effective, and less complex alternative to generate local point clouds. This approach could be utilized for updating 3D archives or quickly assessing damages (Lindenbergh & Sirmacek, 2014). When there is little light or the object has few attributes, LiDAR is also useful. This allows for the collection and export of point cloud data. A mobile laser scanner is a device that integrates various components, such as a navigation system, sensors, and the scanner unit itself, to capture data and assign the position of each point in a point cloud to a coordinate system for georeferencing purposes (Wang, Peethambaran, & Chen, 2018).

Point cloud data may be cleaned and filtered using Autodesk Recap. The point cloud is noisy and not uniform therefore specific surface features that the laser encounters can be classified further after the initial point cloud is processed (Chen & Cho, 2016). It contains the technological capabilities to analyse and validate current conditions as well as built-in resources to gather information and make better decisions. The segmentation of point clouds into foreground and background is a fundamental step in processing 3D point clouds (Nguyen & Le, 2013). After that, load it into Revit to begin a precise 3D BIM design so you can be certain there are no conflicts with components that currently exist. You may use the point cloud data in Civil 3D in a manner similar to how you can import a ReCap cleaned-up cloud there to rapidly and precisely design surfaces, etc. for your specific site conditions. Accuracy is referring to the median value of the absolute distances between the vertices of a reconstructed geometric model and a surface used as a reference (Ingman, Virtanen, Vaaja, & Hyyppa, 2020).

Creating a successful 3D model for the planning, design, and managing of building projects is made possible with the support of Autodesk Revit. Revit, which also produces replicated project outputs, may be used to coordinate all the collected data, including CAD. Both technologies are routinely used by the same business, with BIM and CAD experts working on different project components. Building Information Modelling (BIM) is a technology used in civil engineering, allows for the creation of highly detailed models that encompass all construction elements and furniture (Isikdag, Horhammer, Zlatanova, Kathmann, & Oosterom, 2015). When creating both interior and exterior elements, Revit improves team communication while also speeding up and decreasing project costs.

c. Data Analysis

Once the result has been generated, continue by computing the accuracy analysis of the various results. Root mean square error (RMSE), also referred to as root mean square deviation, is one of the techniques most commonly used to evaluate the accuracy of predictions. It demonstrates the Euclidean separation between predictions and observed actual values (Chicco, Warrens, & Jurman, 2021). Determine the RMSE by calculating the residual (difference between prediction and reality) for each data point, together with its norm, mean, and square root. As a natural derivation, the square root of mean square error has been widely adopted (Shukor, Wong, Rushforth, Basah, & Zakaria, 2015) to standardize the units of measures of mean square error. RMSE is often used in supervised learning applications since it needs and makes use of actual measurements at each predicted data point.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Observed\ Value_i - True\ Value_i)^2}{N}} \tag{1}$$

Where:

N is the number of measurements

4. RESULTS AND DISCUSSION

This section is to determine if smartphone LiDAR can verify strata buildings within 3D modelling environment and a point cloud analysis were conducted. The first step is to evaluate the 3D model of building interior produced from an iPhone 14 Pro by comparing it with the more precise Terrestrial Laser Scanner. The RMSE highly available from the measurements acquired by the distometer, TLS, and iPhone 14 Pro will then be analysed. The RMSE statistics will show how differently accurate various LiDAR systems are from one another. By contrasting the outcomes, the correctness of the findings was assessed.

a. Plan Of Building Facade Dimension

The outcomes of the 3D modelling indicates that both strategies achieved physically comparable solutions. The iPhone 14 Pro's dimensions were different from those of the terrestrial laser scanner kind. Incomplete LiDAR point clouds produced by smartphones. This is as a result of its limited capacity to scan higher and further away surfaces. As a result, the point clouds do not properly display the inside of the structure. The point cloud also has a lot of noise since it was constantly scanned on the same facade. This demonstrates how various point clouds and the smartphone LiDAR point cloud overlapped. The precision of the model is compromised since the point cloud generated by smartphone LiDAR is smaller.

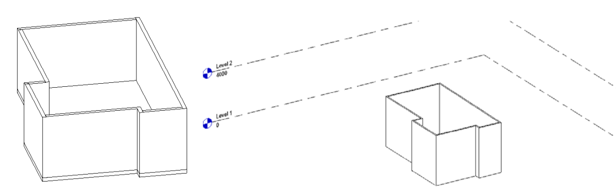


Figure 3: *Smartphone drawing data (left) and TLS drawing data (right)*

b. Results Of Point Clouds

Making a 3D model is challenging since the point cloud from the smartphone LiDAR includes so many problems. The point cloud inaccuracies that increase the residual values have an effect on the size of the 3D model as well. The differential values and the RMSE have a direct correlation. Even if the point cloud produced by the smartphone's LiDAR is less precise, a 3D model of a building's interior may still be made with it (Figure 4).

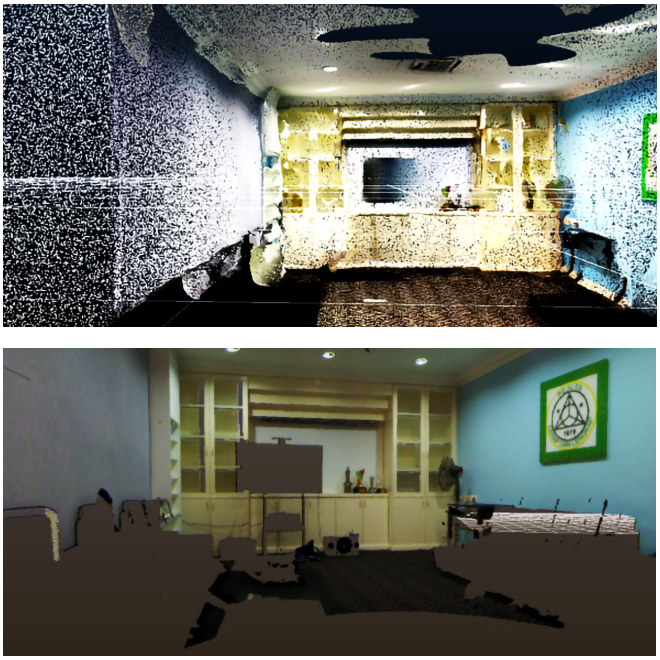


Figure 4: Smartphone point cloud (left) and TLS point cloud (right)

c. Results of Accuracy Assessment

The following Figure 5 shows the facade of the building interior. All the eight facades have been collected and shows where all the facade in that building. The figure below has been drawn in Autodesk Revit from the top of view. During the collecting data of distometer, it started from A to H for 3 times reading. Smartphone LiDAR scanner started from the edge between A and B to the edge H and G using zigzag scanning method. This captures all the surrounding of the building. For terrestrial laser scanning, it only put in the middle of the room while it collects the data.

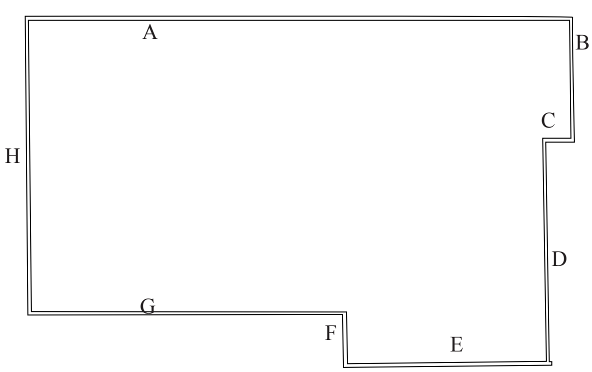


Figure 5: Facades of the building

The accuracy assessment is assessed using statistical analysis. The first step is to use the smartphone LiDAR, TLS and distometer methods to measure each facade and conduct a dimensional calculation. The following Table 3 indicates the building dimension of facades using different devices measurement.

Table 3: Comparison of measurement using different devices

Facade	Interior building dimension (m)		
	Smartphone LiDAR	TLS	Distometer
A	8.567	8.499	8.492
B	1.550	1.881	1.783
C	0.368	0.430	0.458
D	3.700	3.418	3.482
E	3.050	3.120	3.139
F	0.650	0.808	0.804
G	4.850	4.900	4.862
H	4.450	4.540	4.524

d. Comparison Analysis

Figure 6 below shows the graph of the dimension comparison of each facade between the terrestrial laser scanning, distometer and smartphone scanner LiDAR. As we can see from the graph, the facade A has the longest dimension of the room which smartphone LiDAR scanner has the top of graph with 8.567m and the lowest of the facade A is terrestrial laser scanning with the reading of 8.499m. The facade C has the shortest dimension of the room. Smartphone LiDAR scanner only collect 0.368m for the facade C which is the lowest and distometer has the highest for the facade C which is 0.458m. For area and perimeter comparison (Figure 7), TLS measured the area and perimeter at 39.438m² and 27.498m respectively. This is because of the accuracy of the point cloud data that have been collected using TLS is 1mm point interval. Compare to smartphone LiDAR sensor which measured the area of building 38.915m² and perimeter is 27.520m where the point cloud data interval is 5.5mm. In its crudest form is just a collection of range measurements and sensor orientation parameters (Fernandez-Diaz, Carter, Shrestha, & Glennie, 2014).

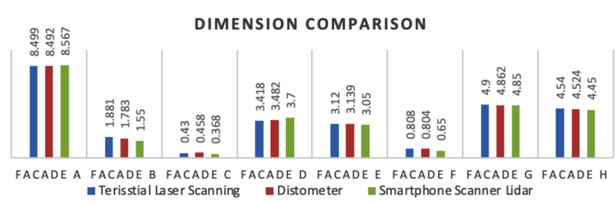


Figure 6: Dimension comparison

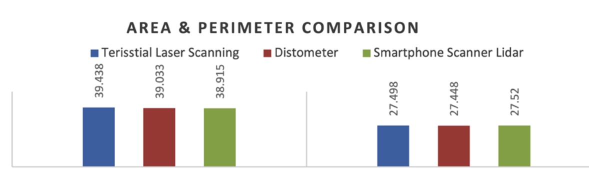


Figure 7: Area and perimeter comparison

The evaluation of data accuracy is carried out using a method called the residual standard deviation, commonly referred to as RMSE. In accordance with the RMSE calculation, the accuracy of the dimension's measurement, which includes eight (8) facades, has been obtained to the centimetre level (Table 4).

Table 4: *Accuracy Assessment*

Facade	Disto – TLS (X)	X^2	Disto – Smartphone (Y)	Y^2
A	0.002	0.000049	-0.075	0.005625
B	0.018	-0.009604	0.233	0.054289
C	0.006	0.000784	0.090	0.0081
D	0.041	0.004096	-0.218	0.047524
E	0.006	0.000361	0.089	0.007921
F	0.001	-0.000016	0.154	0.023716
G	0.011	-0.001444	0.012	0.000144
H	0.081	-0.000256	0.074	0.0005476
	SUM	0.01661	**SUM**	-0.026492
	RMSE	+-0.045	**RMSE**	+-0.136

The RMSE values for the smartphone LiDAR 3D model against distometer are $\pm$0.045m while $\pm$0.136m for the TLS 3D model versus distometer as shown in Table 4. Achieving a low RMSE value requires the point cloud to be free of errors or have a minimal number of errors. The dimensions of the smartphone LiDAR model are relatively precise, as evidenced by the RMSE measurements.

Overall, the results show that it is significantly feasible to apply polylines into the required properties in order to create a 3D model from a point cloud. The findings of this experiment show, among other things, that point clouds may be taken with a smartphone that has a LiDAR. This work shows that even a massive structure can be simulated, and that the structure's dimensions can be determined. There are areas of the point cloud that have been layered and reduced, and the point cloud produced by the smartphone LiDAR is not as dense as the TLS point cloud. Because of this, and in light of the approach used, its accuracy is respectable.

5. CONCLUSION

A smartphone's LiDAR was used to record the point cloud of a building inside. The created point cloud model assists to dimensional measuring without difficulty. It is possible to determine the structure of the scanned point cloud and the precision of the dimensions using the final 3D model. Additionally, this study showed that using a smartphone for strata surveying instead of a traditional approach or TLS saves a substantial amount of time and money, requires little knowledge, and can be completed by one person.

The smartphone LiDAR 3D model size is examined by calculating the RMSE compared to the TLS 3D model and distometer measurement. However, the TLS has an excellent point cloud appearance that faithfully depicts the original inner form and is dense. The smartphone LiDAR may also be used to collect the point cloud of the building. Even while smartphone LiDAR can scan and collect point clouds, it has several flaws and inconsistencies, which makes rendering rather difficult. For a new technology and a small size LiDAR, the resulting point cloud may be trusted to be turned into a 3D model. With further research, the accuracy and dependability of smartphone LiDAR may undoubtedly be improved.

In this study, only the interior dimensions of the building are measured and evaluated. Several limitations of this work have been identified, and some suggestions for further research have been given such are create a variation with the distance between smartphone LiDAR and the object. By using the application, the method is preferred one meter away with the object that need to be capture. It needs to make an experiment between each different distance. It can be captured from below minimum range, max range of iphone LiDAR sensor and out of range. For example, capture the point clouds from 0.5m for below minimum range, 1.0m for the max range iphone LiDAR sensor and 10m for out range method. Next, compare the LiDAR capabilities of various smartphones, and carry out studies including accuracy evaluation in comparison to the building plan. This need to be check if all of LiDAR camera for smartphone used the same LiDAR scanner. If not, check the accuracy differences. Lastly, compare the actual strata certified plan [PA(S)] with the 3D model generated by iphone LiDAR sensor. This can help on knowing the actual differences of the facade building.

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