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Comparative Evaluation of 3D Building Model Using UAV Photogrammetry and Terrestrial Laser Scanner (TLS)

Golwes Edson Anak Gaong[1], Ahmad Norhisyam Idris[1*], Lau Chong Luh[1], Abdul Aziz Ab Rahman[1], Wan Mohamed Syafuan Wan Mohamed Sabri[2], Abdul Hadi Abdul Jalil[3]

[1]*Studies for Surveying Science and Geomatics, School of Geomatics Science and Natural Resources, College of Built Environment, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA*
[2]*Department of Civil Engineering, Faculty of Engineering, National Defense University of Malaysia, Kem Perdana Sungai Besi, 57000 Kuala Lumpur, MALAYSIA*
[3]*Topcon Positioning Asia (Malaysia) Sdn. Bhd., 6, Jalan Pensyarah U1/28, Hicom-Glenmarie Industrial Park, 40150 Shah Alam, MALAYSIA*

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ABSTRACT

With the growing emphasis on sustainability and resource efficiency within the architectural, engineering, and construction (AEC) sectors, Unmanned Aerial Vehicles (UAVs) and Terrestrial Laser Scanner (TLS) have emerged as indispensable tools for the monitoring and inspection of building structures by using 3D modelling. This research is dedicated to assessing the quality and accuracy obtained from 3D modelling for a building and its structural components between UAV photogrammetry and TLS techniques. The investigation involved nadir and oblique flight missions for UAV data acquisition around the target structure, utilising six (6) Ground Control Points (GCPs), while TLS data collection employed direct georeferencing via the traversing method. The results revealed that TLS yielded superior surface reconstruction quality owing to its denser point cloud density, whereas UAV data met the requirements of numerous applications, offering a convenient and economically viable data acquisition solution. Regarding accuracy, a minimal disparity was observed for building objects discernible from both instruments, achieving centimetre-level accuracy. These findings not only highlighted the potential of UAVs and TLS in optimising 3D modelling processes but also offered practical insights for professionals engaged in urban planning, architectural design, and structural analysis endeavours.

[1*] Corresponding author. *E-mail address*: ahmad_norhisyam@uitm.edu.my

INTRODUCTION

The 3D point cloud of the object surface can be obtained by optical equipment such as laser scanners, which can provide the basis for the establishment of the 3D model of the object (He et al., 2017). UAV and TLS are becoming crucial instruments for reality capture due to the increasing demand for realistic and precise 3D models (Bouziani et al., 2021). With rapidly developing technology, both instruments have taken the place of traditional measurement and modelling techniques (Kaya & Yilmaz, 2020). Creating 3D models of buildings efficiently enhances digital library information and provides managers with essential visualisation and decision-making tools for many purposes (Bouziani et al., 2021).

UAVs capture photos to create highly detailed 3D models which enables the recreation of the shape and surface characteristics of the objects being analysed (Achille et al., 2015; Chen et al., 2019; Dreščček et al., 2020). The widespread utilisation of UAVs for data acquisition and 3D reconstruction underscores the pivotal role played by various factors, including sensor characteristics, photogrammetric network design, and image orientation outcomes, in determining the quality of the generated 3D data. Since this is a relatively uncharted area and there is little or no current regulation governing its use in many nations, its use is subject to several restrictions. Additionally, their use is severely constrained by their limited energy autonomy and weather factors. However, they have outstanding environmental sensing and perception abilities, and they may use onboard equipment to evaluate, communicate, plan, and make quick judgments. All these qualities are further enhanced by their adaptability, since they may be programmed to do different jobs and go to other places as needed (Nex et al., 2022). The new UAV technology, equipped with high-performance cameras, allows for rapid photographic coverage of the whole dam system (Buffi et al., 2018). UAVs are generally cheaper and more versatile than traditional remote-sensing techniques (Giordan et al., 2017).

The laser scanning technology is always referred to as LiDAR (light detection and ranging) technology which produces a set of data points consisted of three (3) position coordinates (X, Y, Z) in a reference frame to describe the scene in both geometric and thematic terms (Kent & Doug Specht, 2023). There are two (2) types of LiDAR systems which are known as TLS and Airborne Laser Scanner (ALS). This study is focused more on the TLS system to reconstruct the 3D building model. TLS consists of two (2) main categories: static TLS involves using a tripod-mounted laser scanner in a fixed position to acquire detailed data by scanning the surrounding environment from different angles, and mobile laser scanning (MLS) (Liu et al., 2023). Static TLS is frequently utilised in architecture, engineering, and construction (AEC) to provide accurate measurements of building and site characteristics (Bauwens et al., 2016; Del Duca & Machado, 2023; Gollob et al., 2020; Williams et al., 2020). In contrast, Mobile laser scanning (MLS) involves a laser scanner mounted on movable platforms like cars, UAVs, backpacks, or handheld devices to collect 3D data in real-time while moving through the environment, enabling quicker and more effective data collection (Liu et al., 2023).

The rapid advancement and accessibility of remote sensing technologies have led to the emergence of various methods for generating 3D building models, with UAV photogrammetry, TLS, and their integration being prominent approaches (Bouziani et al., 2021; Klapa, 2023; Mohammadi et al., 2021; Tysiac et al., 2023). Quality evaluation of 3D building models generated through UAV photogrammetry and TLS involves assessing various aspects, including geometric accuracy, completeness, level of detail, and semantic information. Geometric accuracy refers to the fidelity of the model in representing the true geometry of the building and its components, while completeness measures the extent to which the model captures all relevant features. The level of detail in the model determines its visual realism and analytical capabilities, while semantic information involves the identification and classification of building components. By comparing these attributes between UAV photogrammetry and TLS-derived models, researchers can gain insights into the strengths and limitations of each method in producing accurate and detailed 3D representations of buildings.

One of the primary factors influencing the quality of 3D building models derived from UAV photogrammetry and TLS is the data acquisition process. UAV photogrammetry typically involves capturing imagery from multiple viewpoints, which can result in a dense point cloud with detailed geometric information. However, factors such as flight altitude, camera parameters, image overlap, and weather conditions significantly impact the quality of the acquired data and, consequently, the accuracy of the resulting 3D model (Jiménez-Jiménez et al., 2021; Swayze et al., 2021; Tmušić et al., 2020). In contrast, TLS systems offer precise point cloud data with high geometric accuracy, but their effectiveness may be limited by occlusions and line-of-sight constraints when scanning points (e.g. corners of walls and windows), lines (e.g. slab or window boundary), or surfaces (e.g. a wall face, or the entire surface of an object) of the building structures (Aryan et al., 2021).

Another key consideration in the comparative evaluation of 3D building models is the data processing workflow associated with each method. UAV photogrammetry requires extensive image processing techniques such as feature extraction, image matching, and point cloud generation to transform raw imagery into 3D models. Conversely, TLS data processing involves point cloud registration, filtering, and mesh generation to produce a coherent representation of the building. The choice of processing algorithms and parameters can significantly impact the quality and accuracy of the final 3D model derived from both UAV photogrammetry and TLS, highlighting the importance of standardised evaluation methodologies for comparing the performance of these methods.

In recent years, researchers have conducted comparative studies to evaluate the quality of 3D building models generated using UAV photogrammetry and TLS. These studies often involve collecting data using both methods in the same study area and assessing the accuracy and completeness of the resulting models through quantitative and qualitative analyses. Quantitative assessments involve comparing the models with ground-truth measurements or reference datasets, while qualitative evaluations include visual inspection and interpretation by domain experts. By systematically comparing the quality of 3D building models derived from UAV photogrammetry and TLS, researchers aim to identify the strengths and limitations of each method and inform decision-making processes in various applications such as urban planning, infrastructure management, and cultural heritage preservation.

LITERATURE REVIEW

Principle and Applications of UAV

A UAV is a powered, pilotless aircraft that relies on aerodynamic forces for propulsion. It has the capability to operate autonomously or under remote control, can be either expendable or recoverable, and is capable of carrying both lethal and non-lethal payloads (US Department of Defense, 2005). UAVs can be remotely piloted or programmed to follow flight plans using software, onboard sensors, and a Global Positioning System (GPS). Historically, UAVs were predominantly associated with military applications, initially serving as platforms for weapon deployment, anti-aircraft target practice, and intelligence gathering (Francisco et al., 2017). Today, their use has expanded into various civilian sectors, including delivery services, search and rescue missions, surveillance, traffic and weather monitoring, firefighting, personal use, aerial photography, and filmmaking. UAV oblique photogrammetry, in particular, allows the capture of images from multiple angles due to the high flexibility and maneuverability of UAVs, making it possible to gather detailed point cloud data from elevated areas of ancient structures, which is advantageous for constructing large-scale 3D models (Federman et al., 2018).

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Predominantly employed by the military until the early 2000s, UAVs were costly, complex technologies. Modern improvements in hardware and software technology enable the creation of smaller, less expensive systems that are also simpler to manage. In the near future, it's anticipated that more and more UAVs will be used for a variety of civil tasks, including agriculture, construction surveillance, racing, and photography during extreme sports (Tezza & Andujar, 2019). They are also used in disaster management, geographic surveillance, journalism, agricultural monitoring, precision farming, archaeology, and pizza delivery in addition to military tasks. They may also be utilised for taxi services in the future. Comparatively speaking, using UAVs for these uses is less expensive than using manned aircraft. In many situations, collaborating to complete missions successfully calls for a number of UAVs. The network coordination amongst UAVs is one of the major components of such systems, and their security is also crucial. Dealing with UAV-Networks (UAVNets) is difficult, nevertheless (Mairaj et al., 2019). Inertial Measurement Units (IMUs), Global Positioning Systems (GPS), and microelectromechanical systems that enable auto-pilot operation. A platform's level of autonomy is determined by the software being utilised (Dreier et al., 2021). Software packages from the manufacturer and third parties are utilised to carry out automated tasks such flight path planning, picture capture, stabilisation, and landing (Greenwood et al., 2019). Generating dense point clouds from photography from small UAV has been an attractive method for mapping and 3D reconstruction due to its efficiency and largely automated workflow (Peterson et al., 2019).

Concept of TLS

Laser scanners typically include a range measurement system and a deflection mechanism for directing the laser beam towards the target to be measured (Fröhlich & Mettenleiter, 2004). The distance measurement system of a laser scanner is relevant to both the system's range and its accuracy. The laser scanner uses three (3) distinct range measurement technologies: time of flight concept, phase measurement principle, and optical triangulation (Vosselman & Maas, 2010). TLS creates several 3D coordinate points of an object via the transmission and reception of laser beams to measure the distance, horizontal angle, and vertical angle between objects. These 3D coordinate points called as point cloud data which represent an entire object surface precisely and facilitates users to obtain accurate 3D-model creation. In addition to the object's physical coordinates, the latest TLS unit's built-in RGB camera can produce spherical panoramic RGB photos. The colorimetric RGB values will be assigned and linked to a 3D point in the software using the transformation matrix (Mohammadi et al., 2023).

3D Building Modelling

There are several previous studies that focused on the 3D building modelling using UAV and TLS methods. Mohammadi et al., (2021) studied the geometric precision of two (2) 3D reality models created from a heritage bridge in Australia using UAV-based photogrammetry and TLS-based point clouds. His research highlighted the potential of both technologies to improve the precision of 3D representations. UAV photogrammetry had centimetre-level errors in 3D distance measurements, though TLS demonstrated millimetre-level precision. As a result of the density of point clouds, TLS collected surfaces at a greater range than UAV photogrammetry.

Sari et al., (2020) conducted a hybrid 3D modelling approach on the Sütunlu Cadde in the ancient city of Soli-Pompeiopolis located in Mersin province. He recognises that hybrid methods are crucial for precise analysis since they provide comprehensive coverage of building details on upper facades and lateral facades using UAV and TLS, respectively. The study demonstrated that a hybrid approach combining TLS and UAV photogrammetry can effectively model complicated structures, extract metric information, and conduct diverse analysis.

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According to Karaska et al., (2023), the integration of point cloud data was conducted towards the building surfaces. He stated that combining both datasets could lead to a more accurate facade 3D model and a decrease in the number of void spaces. He assesses the precision of the 3D model by measuring the lengths of the building's horizontal and vertical facades using conventional measurement techniques and then comparing them with the integrated 3D model. The results indicate that the Root Mean Square Error (RMSE) is 2.29 cm, with a 95% confidence interval and a standard deviation of 2.34 cm.

METHODOLOGY

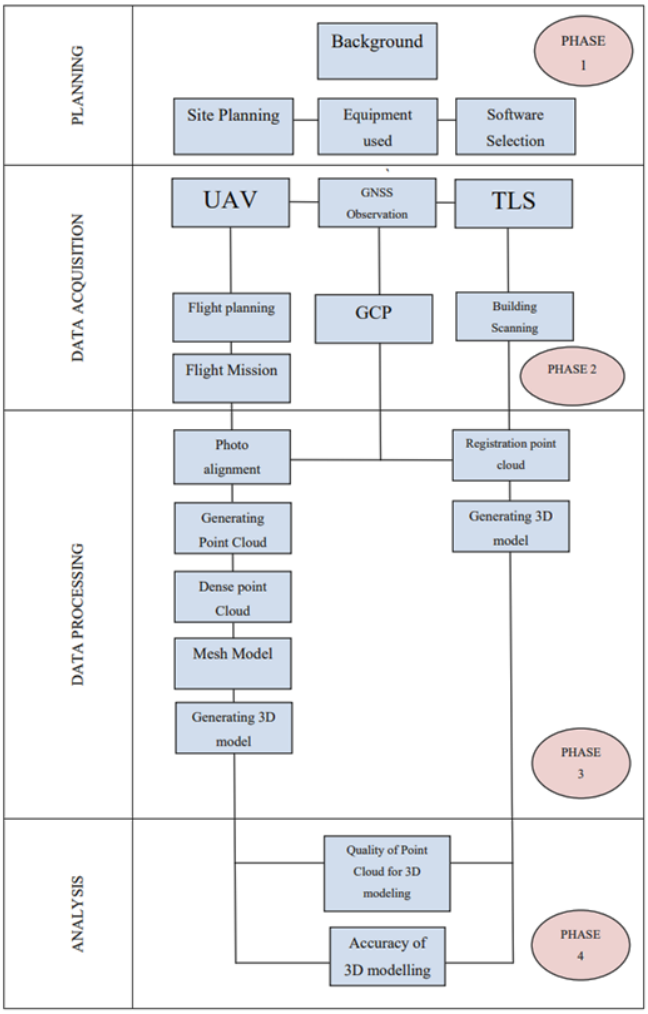

Fig. 1. General research methodology flowchart

Source: Authors (2023)

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The work intends to develop a 3D model of the small building situated at Universiti Teknologi MARA Campus. UAV photogrammetry and the TLS approaches were conducted to capture data of the top-view and building facades to create the needed 3D model. To be able to obtain the complete facades' views of the building, both nadir and oblique flight missions were applied together with several scanning setups for TLS operations. These steps are necessary to ensure the 3D building model gathered from each method can cover the entire facades. Fig. 1 shows the workflow chart illustrating the study's scope.

Study Area

The building near Anggerik College in UiTM Shah Alam was selected as the study site (Fig. 2). This building's location was selected due to its suitability for both TLS and UAV operations.

Fig. 2. Building near Anggerik College, UiTM

Source: Authors (2023)

DJI Mavic 2 Pro

Fig. 3. DJI Mavic 2 Pro

Source: Authors (2023)

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The DJI Mavic 2 Pro is a compact yet powerful UAV renowned for its advanced features and exceptional aerial imaging capabilities (Fig. 3). It is equipped with a Hasselblad sensor camera, featuring a 1-inch CMOS sensor capable of capturing stunning 20-megapixel photos and 4K 10-bit HDR video at 30 frames per second. With its intelligent flight modes and GPS/GLONASS positioning systems, the Mavic 2 Pro can autonomously navigate and capture high-resolution images for mapping and 3D modelling purposes. Its stability, omnidirectional obstacle avoidance sensors, and extended flight time of up to 31 minutes make it a reliable choice for professionals in various industries requiring precise aerial imaging solutions.

Topcon GLS-2000

The study utilised the Topcon GLS2000 TLS with a range of 40 to 500 meters and three (3) scanning modes (short, middle, long) for versatility (Fig. 4). Referring to Corporation, 2014, this device can capture 120,000 points per second (scan rate high speed) with a 4 mm spot size at 20 meters. It boasts a wide field of view (270º vertical / 360º horizontal), accurate angular precision (6 arcseconds for vertical/horizontal angles), and a single point accuracy of 3.5 mm at a range of 1-150 m. For the Laser Class, it was classified as a 3R for safety and weights around 10kg, including the battery and case. This TLS, on the other hand, has a 5-megapixel camera with wide-angle and telephoto capabilities, as well as a touchscreen display and WLAN networking for easy operation.

Fig. 4. Topcon GLS-2000 (TLS)

Source: Corporation, T. (2014)

Ground Survey for GCP

Before the UAV flight and TLS observations were carried out around the building, six (6) GCPs have been established. The GCPs ought to be positioned in appropriate areas to guarantee their well- distribution, as stipulated in the photogrammetry concept, and for each to be intervisible during the traversing method for TLS measurements. The GPS observations have been conducted to obtain the actual coordinates of these GCPs. In order to determine the building's accuracy, the actual measurements of the building's features obtained from the ground survey are compared to the 3D model produced by UAV Photogrammetry and TLS. This procedure is carried out using a Total Station, which is accomplished through the traversing method. The process is initiated by using the Ground Control Points (GCPs) as the

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reference station. Measurements were conducted to determine the distance between two (2) observing points of various building features, including windows, doors, and walls. The Pythagorean theorem (Equation 1) was utilised for this purpose.

$$d=\sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)} \quad \text{… Equation 1}$$

Where:

d_{A-B} = Distance between Point A and B
x_1, y_1 = Coordinate of Point A
x_2, y_2 = Coordinate of Point B

UAV's Flight Planning

This study used specific parameters for the UAV to ensure effective data collection and accurate results. The UAV's camera had a focal length of 3.75 mm and captured images with a format size of 6.4 mm x 4.8 mm at a resolution of 4000 x 3000 pixels. A high overlap of 80% between images and a side lap of 80% were chosen to ensure comprehensive coverage and smooth image stitching. The altitudes were set at 30 meters and 5 meters for nadir and oblique, respectively. These carefully selected parameters enabled high-quality data collection and accurate 3D model generation for the study.

Building Scanning for TLS

The TLS was employed to acquire 3D point cloud modelling of the building and gathered several data, including ground control points (GCPs) for georeferencing. The dataset encompasses images and comprehensive information concerning the scanned area. During data acquisition, TLS has been operated at a middle range of observations. The traversing method was applied for scanning procedures, comprising the TLS station, as well as back and forward stations. By doing this, TLS can capture diverse perspectives of the building from various angles and sides. This systematic approach ensures precise point clouds which expected to produce better accuracy of 3D model of the building.

UAV 3D Modelling

Data processing for the UAV 3D model involves several steps. Initially, all aerial photos used to build the 3D model were calibrated and flattened. The SfM approach was applied using Pix4Dmapper software to extract the three-dimensional structure from the 247 UAV photos, resulting in a 3D point cloud model.

During data processing, the photo alignment is the first step which created a single structural image with the output coordinate system was set to WGS 84 for georeferencing then. The next step involves connecting GCPs to the aligned pictures geometric accuracy enhancement using the ray cloud editor. After tie point marking, the reoptimise function was applied to correct the image geolocation. Lastly is the Point Densification process which produced a Densified Point Cloud model. As an option, a 3D Textured Mesh can be selected to enhance the visualisation quality view of the 3D building model based on the existing Densified Point Cloud model.

Building extraction is performed to obtain building footprints from the classified dense point cloud. This is important to ensure that the generated 3D model just focused on the selected object (i.e., building). It was also assisted in the evaluation of the visualisation quality and accuracy assessments of the whole building and its component parts.

TLS 3D Modelling

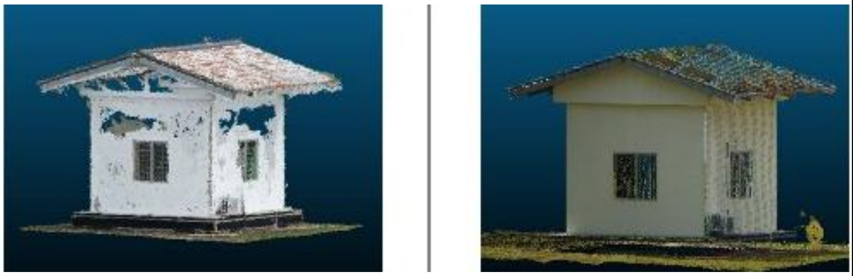
The processing of TLS 3D models was conducted using Magnet Collage software following the data collection through the laser scan method. The registration process played a pivotal role in aligning multiple scans accurately relative to each other, a procedure known as "cloud-to-cloud registration," where clouds are aligned based on features in their overlapping areas without the requirement for targets.

In Magnet Collage, the point cloud registration commenced with importing the TLS data into the software, followed by executing the scan process to visualise the data. Identification of TLS stations involved selecting the current occupation point, backsight point, and backsight target. Subsequently, after registering all stations, GCP coordinates were imported into the software for georeferencing purposes.

In cases where a laser scanning station was employed without the traverse technique, the accuracy of the data might have been impacted, necessitating examination of rotations in the X and Y axes in 3D to ascertain the data's location on the Z axis. Cloud-to-cloud registration required data from at least two (2) stations, with the user specifying the station to be registered, the reference station (typically with higher data overlap), and the sampling interval distance. The flexibility of cloud-to-cloud registration allowed for adjusting the sample interval distance, typically set in centimetres depending on the specific circumstances.

For building extraction, CloudCompare software was utilised. This software is designed to process 3D point clouds generated by laser scanners and UAVs, supporting triangular meshes and calibrated images. CloudCompare provides a basic toolkit for manual manipulation and rendering of 3D point clouds and triangular meshes, alongside offering a variety of advanced processing methods.

RESULT AND ANALYSIS



(a) (b)

Fig. 5. Overview of the 3D point clouds of the building, (a) UAV, (b) TLS

Source: Authors (2023)

The 3D point cloud obtained from the UAV, as depicted in Fig. 5, offers an overview of the structure. The UAV technique yielded a total of 4,812,494 points, while the TLS approach generated 8,586,950 points for their respective 3D point clouds. The TLS method produced a more intricate and denser point cloud compared to the UAV method. Nonetheless, despite its coarser and less detailed nature, the UAV data remained beneficial for acquiring surface area measurements. The meticulous setup of the TLS scanning station played a pivotal role in achieving such detailed structural information, facilitating precise measurements and documentation for subsequent analysis.

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Visualisation of 3D Point Cloud

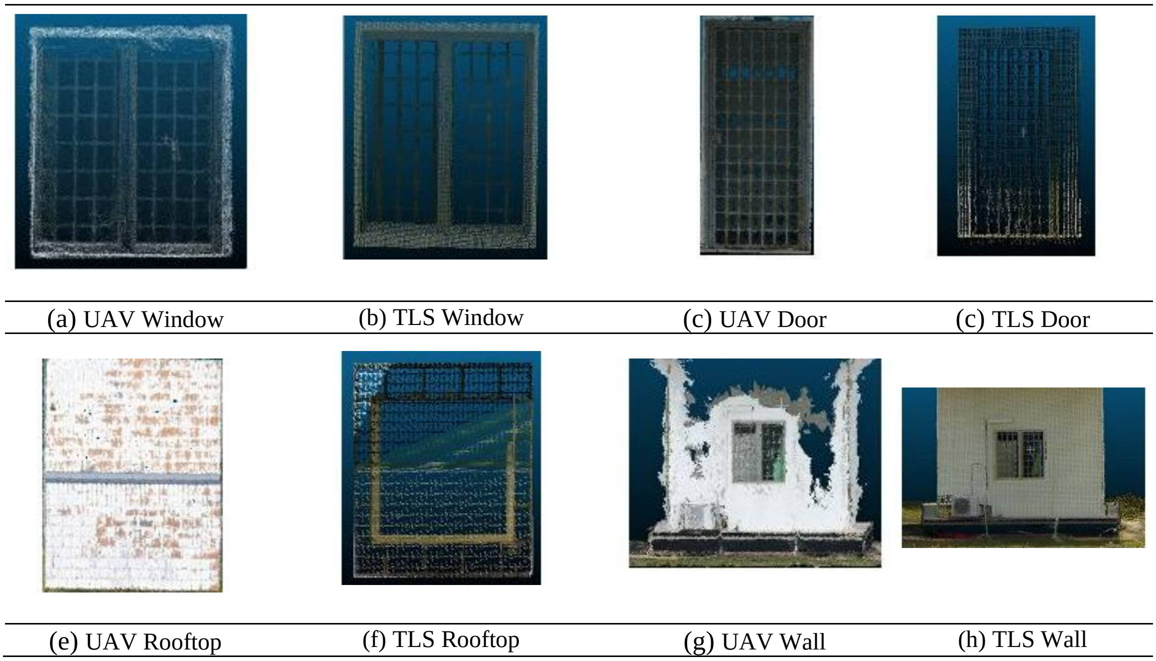

Fig. 6. Segmentation of 3D Point Cloud

Source: Authors (2023)

The distribution of the point cloud exhibits significant variation between the UAV and TLS methods. While both methods generally yield commendable 3D model point clouds, there exist disparities in the point count within each segment. As depicted in Fig. 6, TLS offers richer point cloud information overall, albeit it includes extraneous objects that prove challenging to filter out, particularly in the window section. Conversely, the door segment displays satisfactory point cloud quality for both UAV and TLS. However, in the rooftop perspective, the UAV surpasses TLS in generating more intricate point clouds. Conversely, the wall segment in the UAV point cloud reveals gaps, indicative of inferior quality compared to TLS, which captures all points at ground level.

Overall, TLS consistently produces high-density point clouds with sufficient detail across most segments, whereas the UAV exhibits limitations in capturing fine details. Table 1 presents a comparison of the point cloud quantities for each segment, demonstrating that TLS generally yields greater numbers of point clouds, except in the case of the rooftop segment, where the UAV excels. This analysis showed that the ability of the UAV to cover the building details on upper facades and while lateral facades by TLS measurement (Sari et al., 2020). These methodological disparities and capabilities lead to divergent qualities of point clouds across various structures.

Table 1. Number of Point Clouds

Structure	Number of point cloud UAV	Number of point cloud TLS
Rooftop	2,342,816	133,950
Window	65,662	149,9201
Door	83,851	1,861,204
Wall	475,351	4,048,822

Source: Authors (2023)

Consequently, TLS demonstrated superiority over UAV in generating precise and detailed point clouds, except in certain instances such as the rooftop segment. The selection of the method depends on the specific application and the desired level of detail.

Accuracy Assessment by Distance Measurements

The assessment of distance measurement accuracy for various structures was conducted for both the UAV and TLS methods. Root Mean Square Error (RMSE) values were computed using real measurement data, indicating that both methods exhibited respectable accuracy in distance measurement, with RMSE values falling within an acceptable range around 2-3 cm (Klapa, 2023).

The RMSE values were obtained at specific dimension IDs of buildings' components (Table 2). In this table, the Dimension ID is referred to the two (2) dimensional points of building's component. For example, D1W1 is the dimension length between the first part of Door (D) and Width (W).

Table 1. Descriptions of Dimension IDs.

Dimension ID	Description	Location View
D1W1	Door 1, Width 1	
D1L1	Door 1, Length 1	
W1L1	Window 1, Length 1	
WaL1	Wall, Length 1	
AL1	Air conditioner, Length 1	

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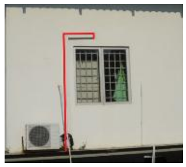
BWX1	Window Wall, X- axis	
BWY1	Window Wall, Y- axis	
DX1	Door Wall Wall, X- axis	
PX1	Wire Cover, X-Axis	

Source: Authors (2023)

Table 3 and 4 revealed encouraging outcomes for UAV and TLS-based distance measurements, respectively. Other IDs are listed in in Table The comparison of RMSE values between UAV and TLS differed by only 2 cm, indicating a relatively small difference. Throughout the preceding analyses, variations were observed in the distances between point clouds and points, which could potentially result in the omission of vital x, y, and z points during dimensional measurement. Conversely, TLS attained a superior level of RMSE at the centimetre level compared to the UAV dataset, attributable to its production of high-quality and closely spaced point clouds.

Table 3. RMSE of UAV

No.	Dimension ID	Actual Measurement (m)	UAV (m)	Residual, r (m)	(Residual)², r² (m)
1	D1W1	0.968	0.964	-0.004	0.000016
2	D1W2	0.968	0.966	-0.002	0.000081
3	D1L1	2.103	2.098	-0.005	0.000025
4	D1L2	2.103	2.099	-0.004	0.000016
5	W1L1	1.198	1.194	-0.004	0.000016
6	W1L2	1.198	1.193	-0.005	0.000025
7	W1W1	1.199	1.191	-0.008	0.000064
8	W1W2	1.199	1.191	-0.008	0.000064
9	W2L1	1.196	1.199	0.003	0.000009
10	W2L2	1.196	1.198	0.002	0.000004
11	W2W1	1.199	1.196	-0.003	0.000009
12	W2W2	1.199	1.197	-0.002	0.000004
13	WaL1	3.854	3.851	0.003	0.000009
14	WaL2	3.854	3.850	0.004	0.000016
15	WaW1	3.259	3.257	0.002	0.000004
16	WaW2	3.259	3.257	0.002	0.000004
17	AL1	0.596	0.595	0.001	0.000002
18	AL2	0.596	0.593	0.003	0.000009
19	AW1	0.477	0.479	-0.002	0.000004
20	AW2	0.477	0.480	-0.003	0.000009
21	BWX1	1.355	1.357	-0.002	0.000004
22	BWX2	1.355	1.356	0.001	0.000002
23	BWY1	1.003	1.001	0.002	0.000004
24	BWY2	1.003	1.002	0.001	0.000002
25	DX1	1.443	1.440	0.003	0.000009
26	DX2	1.486	1.488	-0.002	0.000004
27	DY1	1.169	1.167	0.002	0.000004
28	PX1	2.215	2.218	-0.003	0.000009
29	PY1	0.071	0.069	0.002	0.000004
30	PY2	0.546	0.544	0.002	0.000004
				Sum (m)	0.000436
				Average	0.000014533
				RMSE	0.0038

Source: Authors (2023)

Table 4. RMSE of TLS

No.	Dimension	Actual Measurement (m)	TLS (m)	Residual, r (m)	(Residual)², r² (m)
1	D1W1	0.968	0.964	-0.004	0.000016
2	D1W2	0.968	0.961	-0.007	0.000049
3	D1L1	2.103	2.105	0.002	0.000004
4	D1L2	2.103	2.104	0.001	0.000001
5	W1L1	1.198	1.201	0.003	0.000009
6	W1L2	1.198	1.202	0.004	0.000016

7	W1W1	1.199	1.200	0.001	0.000001
8	W1W2	1.199	1.201	0.002	0.000004
9	W2L1	1.196	1.195	-0.001	0.000001
10	W2L2	1.196	1.197	0.001	0.000001
11	W2W1	1.199	1.198	-0.001	0.000001
12	W2W2	1.199	1.197	-0.002	0.000004
13	WaL1	3.854	3.853	0.001	0.000002
14	WaL2	3.854	3.852	0.002	0.000004
15	WaW1	3.259	3.258	0.001	0.000002
16	WaW2	3.259	3.258	0.001	0.000002
17	AL1	0.596	0.595	0.001	0.000002
18	AL2	0.596	0.595	0.001	0.000002
19	AW1	0.477	0.479	-0.002	0.000004
20	AW2	0.477	0.478	-0.001	0.000002
21	BWX1	1.355	1.356	0.001	0.000002
22	BWX2	1.355	1.356	0.001	0.000002
23	BWY1	1.003	1.001	0.002	0.000004
24	BWY2	1.003	1.002	0.001	0.000002
25	DX1	1.443	1.442	0.001	0.000002
26	DX2	1.486	1.485	0.001	0.000002
27	DY1	1.169	1.170	-0.001	0.000002
28	PX1	2.215	2.216	-0.001	0.000002
29	PY1	0.071	0.070	0.001	0.000002
30	PY2	0.546	0.544	0.002	0.000004
				Sum (m)	0.000151
				Average	0.00000503
				RMSE	0.0022

Source: Authors (2023)

Prior to analysing the RMSE, accuracy was evaluated by examining the distribution of differences. Fig. 7 illustrates a graphical comparison of differences (in meter) from 30 dimensional measurements (dimension IDs) obtained using UAV and TLS. The distribution of differences from the TLS dataset has a stronger alignment with zero (0) and greater consistency, while the distribution of differences from the UAV dataset displays some deviation from zero and a lesser degree of inconsistency.

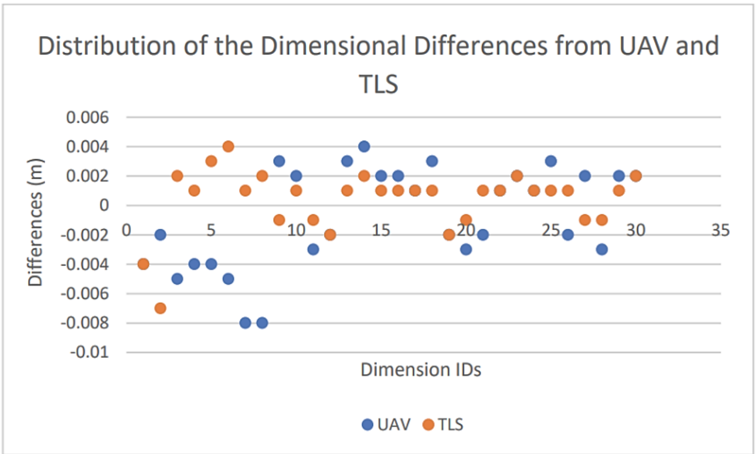


Fig. 7. Distribution of Dimensional Differences from UAV and TLS

Source: Authors (2023)

Fig. 8 illustrates the graph analysis comparing the accuracy of distance measurements obtained through UAV and TLS approaches. The accuracy of UAV was inferior to that of TLS, achieving only precision at the decimal level. However, it was demonstrated that UAV-based distance measuring can still hold value in situations where precise data accuracy is not imperative, such as large field measurements or inspections of high-rise outdoor buildings. Despite not matching the accuracy of TLS, the UAV approach remains a practical and cost-effective option that provides valuable data.

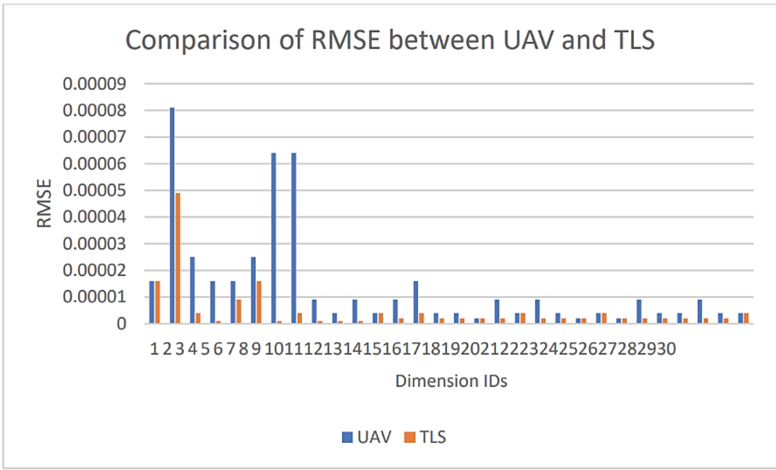


Fig. 8. RMSE Value Between UAV and TLS by Distance Measurements

Source: Authors (2023)

CONCLUSION

https://doi.org/10.24191/bej.v22i1.1066

In conclusion, this study has successfully achieved its aim of evaluating 3D point cloud modelling of a building using both UAV and TLS methods. The meticulous execution of the flight planning process, from software selection to parameter setup, ensured the collection of comprehensive data sets. Through various data analyses, differences and inconsistencies were identified, influencing the final output of the 3D building model. Segmentation analysis revealed nuances in point cloud distribution across different building segments. While TLS provided superior detail, the UAV and TLS methods could achieve acceptable accuracy centimetre level, making it suitable for various applications. Given the higher cost associated with TLS data collection, the UAV method presents a cost-effective and convenient alternative for specific requirements. These findings contribute to informed decision-making regarding technology selection for 3D modelling in architectural and engineering contexts.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interests regarding the publication of the paper.

AUTHOR’S CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Golwes Edson Anak Gaong and Ahmad Norhisyam Idris; data collection: Golwes Edson Anak Gaong and Ahmad Norhisyam Idris, and Abdul Hadi Abdul Jalil; analysis and interpretation of results: Golwes Edson Anak Gaong, Ahmad Norhisyam Idris, and Abdul Hadi Abdul Jalil; draft manuscript preparation: Golwes Edson Anak Gaong and Ahmad Norhisyam Idris, Lau Chong Luh, Abdul Aziz Ab Rahman, and Wan Mohamed Syafuan Wan Mohamed Sabri. All authors reviewed the results and approved the final version of the manuscript.

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