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Comparative Analysis Of Three-Dimensional Models Using Terrestrial Laser Scanner And Autonomous Flying Laser Scanner (Uav Lidar) Measurement Technology (Case Study: PT Bukit Asam Tbk Exploration Office Location)

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Abstract

The development of survey technology encourages the use of UAV LiDAR and Terrestrial Laser Scanner (TLS) in three-dimensional modeling of buildings, but the difference in accuracy of both needs to be evaluated against reference data. This study aims to compare the accuracy of horizontal position and geometric dimensions of UAV LiDAR and TLS modeling results. The study uses a comparative quantitative method. The population is building objects in the PT Bukit Asam Tbk Exploration Office area, with point cloud samples from Leica BLK2FLY and RIEGL VZ-2000i. The research instruments include LiDAR, TLS, GNSS devices, and point cloud processing software. The analysis uses deviation, RMSE, Shapiro-Wilk, and Paired Sample T-Test. The results show that the RMSE of UAV LiDAR position is 0.098 m and TLS is 0.061 m, while the RMSE of dimensions is 0.044 m and 0.038 m, respectively. In conclusion, TLS is more accurate, while UAV LiDAR is more efficient in acquisition and area coverage.

Keywords*: *3D Modeling, LiDAR, Point Cloud, Terrestrial Laser Scanning, UAV

INTRODUCTION

The development of surveying and mapping technology has progressed rapidly through the integration of Global Navigation Satellite Systems (GNSS), Geographic Information Systems (GIS), Unmanned Aerial Vehicles (UAVs), and Light Detection and Ranging (LiDAR). These technologies are capable of producing high-density three-dimensional point clouds that support 3D modeling, geometric analysis, and building and infrastructure documentation (Shan & Toth, 2018). One technology used for detailed object modeling is the Terrestrial Laser Scanner (TLS), which is capable of producing three-dimensional coordinates with a high degree of accuracy (Vosselman & Maas, 2010).

UAV LiDAR enables aerial data acquisition with wider coverage, relatively faster time, and the ability to reach difficult-to-access areas. Meanwhile, TLS is effective for close-range measurements of objects with complex geometric details. Both methods have their own characteristics, advantages, and limitations in three-dimensional building modeling. In the mining sector, the need for accurate spatial data is crucial to support technical, operational, and occupational safety aspects, including in PT Bukit Asam Tbk's activities in Tanjung Enim, Muara Enim Regency, South Sumatra.

Differences in the characteristics of UAV LiDAR and TLS measurement systems can potentially result in differences in the positional and dimensional accuracy of building models. Therefore, modeling results need to be compared with reference data in the form of As-Built Drawings to determine the level of geometric conformity. Analysis is required not only visually but also quantitatively by measuring the horizontal positions (X and Y) of corner points and the dimensions between building sides.

Previous research on building modeling using TLS and three-dimensional mapping methods has been conducted. However, studies specifically comparing UAV LiDAR and TLS modeling results against As-Built Drawing reference data using inferential statistical analysis are still relatively limited. This situation indicates the need for an evaluation that can provide an objective overview of the level of accuracy and differences in modeling results between the two methods.

Accuracy evaluation was performed using the Root Mean Square Error (RMSE) to determine the level of error of the modeling results against the reference data, while the Paired Sample T-Test was used to determine the significance of differences in UAV LiDAR and TLS measurement results. This approach allows for quantitative analysis of differences in modeling results to determine whether the differences obtained are statistically significant or due to measurement variation.

This study aims to analyze the characteristics of three-dimensional modeling results using Autonomous Flying Laser Scanner (UAV LiDAR) and Terrestrial Laser Scanner (TLS), compare the accuracy of horizontal position and building dimensions based on As Built Drawing data, and analyze the significance of the differences using inferential statistical tests. This study is important to provide an objective evaluation of the accuracy of both methods in building modeling. The novelty of the study lies in the comparison of UAV LiDAR and TLS against As Built Drawing data with analysis of horizontal position, building dimensions, RMSE, and Paired Sample T-Test at a significance level of 5% ($\alpha = 0.05$).

RESEARCH METHODS

This study uses a comparative quantitative research type that aims to analyze the comparison of three-dimensional (3D) modeling results using Unmanned Aerial Vehicle Light Detection and Ranging (UAV LiDAR) and Terrestrial Laser Scanner (TLS) technology to evaluate the effectiveness and accuracy level of both methods in the mining area of PT Bukit Asam Tbk. The quantitative approach is used because the study focuses on numerical measurements, deviation calculations, and statistical analysis, while the comparative approach is used to identify differences in characteristics, geometric accuracy, and consistency of measurement results of both methods on the same object. The data analyzed include the accuracy of the X and Y coordinates of the building corner points against the As Built Drawing reference data as well as the dimensional accuracy and geometric suitability of the 3D model. The analysis is carried out through deviation calculations, Root Mean Square Error (RMSE), and Paired Sample T-Test to determine the differences in measurement results between UAV LiDAR and TLS.

The research was conducted in the area of the Exploration Office of PT Bukit Asam Tbk, Tanjung Enim Mining Unit, Muara Enim Regency, South Sumatra Province, with data collection carried out on the exterior of the main building which includes the office building, roads, open yards, and surrounding vegetation. Field conditions were relatively supportive of the data acquisition process, although there were trees, vehicles, and other building structures that could potentially affect the density and quality of the point cloud. The coordinate system used in the research was the Universal Transverse Mercator (UTM) Zone 48S as a reference in the georeferencing process and coordinate comparison analysis.

The equipment used in the research includes a Leica BLK2FLY set, a RIEGL Laser Scanner set, a Leica GS18 GPS set, and a computer with an Intel(R) Core(TM) i7-9750H CPU @ 2.60GHz. The software used consists of Leica Cyclone REGISTER 360 (BLK Edition), BLK Data Manager, Cyclone 3DR, RiSCAN PRO, and Global Mapper. The research materials are point cloud data from the Leica BLK2FLY LiDAR Drone and RIEGL Laser Scanner measurements taken in August 2025, office As Built Drawing data in 2022, BM point references as measurement references, and office area boundary data.

The research population consisted of building objects and measurement data in the PT Bukit Asam Tbk Exploration Office area, Tanjung Enim Mining Unit, while the research sample consisted of point cloud data from measurements using Leica BLK2FLY as a UAV LiDAR and RIEGL Laser Scanner as TLS on the same object. The measurement data from both methods were compared with the office's 2022 As Built Drawing data as reference data. The TLS measurement used a multi-station method with seven station points placed around the research object, while the coordinates of each station were obtained using the Leica GS18 GNSS with the NTRIP-based Real Time Kinematic (RTK) method in the UTM Zone 48S coordinate system.

The research procedure begins with a literature study to examine the theory, concept, and results of previous research regarding the use of Drone LiDAR and Terrestrial Laser Scanner for 3D modeling, then continued with a preliminary survey to determine the condition of the area, obstacles, technical needs, and determine the data collection points. The next stage is the preparation of UAV LiDAR and TLS data collection by ensuring the condition of the equipment, sensors, GNSS, batteries, storage media, and the UTM coordinate system of Zone 48S. On the UAV LiDAR, flight path planning was carried out using BLK2FLY Live, while on the TLS, station point determination, installation of the tool on a tripod, leveling checking, and planning of station coordinate measurements using GNSS Leica GS18 with the NTRIP-based RTK method were carried out.

UAV LiDAR data acquisition was carried out using a Leica BLK2FLY with internal GNSS support and real-time NTRIP-based differential correction. The drone followed the planned flight path using object-following mode at an altitude of approximately 5 to 20 meters above the object's surface, while during the flight monitoring of GNSS status, correction signal quality, and battery capacity was carried out. TLS data acquisition was carried out using a Riegl VZ-2000i with a multi-station method at seven station points, with station coordinates measured using a Leica GS18 GNSS RTK method based on NTRIP. The TLS scan results produced approximately 102,565,885 points with an average density of 12,223 pts/m^2, then an initial check was carried out on the data to ensure there were no blank data or recording errors.

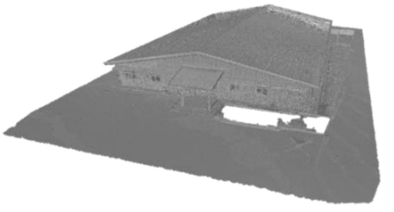
UAV LiDAR data was processed using Leica Cyclone Register 360 through point cloud import, automatic registration utilizing GNSS and IMU data, and verification of the projection system and adjustment to UTM Zone 48S based on WGS 84 datum. Riegl VZ-2000i TLS data was processed using RiSCAN PRO through importing data from each station and point-to-point registration based on reference points with known coordinates. After all stations were combined, the registration quality was evaluated based on the error value. The processing results showed that the UAV LiDAR registration error was less than 2 cm, while the TLS reached around 1 cm.

The filtering process was carried out to improve the quality of the point cloud before 3D modeling and accuracy analysis. UAV LiDAR data was processed using Cyclone 3DR through noise and isolated point removal, land surface segmentation, buildings, and other objects, manual cleaning, point number optimization, and data export. Meanwhile, TLS data was processed using RiSCAN PRO through distance and intensity filters, outlier removal, masking of specific areas or objects, manual cleaning, and data export to .LAS format.

Three-dimensional modeling was performed by processing UAV LiDAR and TLS point cloud data that had been cleaned and filtered using Cyclone 3DR. The modeling process included mesh formation and surface reconstruction to produce a digital representation of the building. The resulting 3D model was used to evaluate building dimensions, extract longitudinal and transverse profiles, and measure geometric parameters of the research object as a basis for comparison with reference data.

A comparative analysis of accuracy was conducted by comparing the X and Y coordinates of the building's corner points and geometric dimensions including the building's sides, roof, and window dimensions to the As Built Drawing data. The accuracy level of each method was calculated using the Root Mean Square Error (RMSE), then a normality test was performed using Shapiro-Wilk as a prerequisite for the Paired Sample T-Test. If the data met the normality assumption, the Paired Sample T-Test was used to determine the significance of the differences in measurement results between UAV LiDAR and TLS, and the results of this analysis became the basis for compiling research conclusions.

RESULTS AND DISCUSSION



Picture 1 Point Cloud results from the BLK2FLY UAV LiDAR

Picture 2 TLS result Point Cloud

Data Acquisition Results Summary

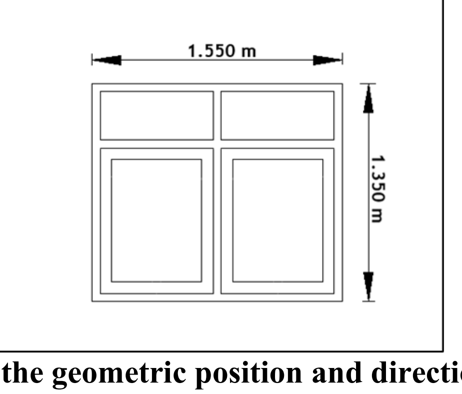
Table 1. Comparison of UAV LiDAR and TLS data acquisition results

Parameter	UAV LiDAR BLK 2 FLY	TLS Riegl VZ-2000i
Number of point clouds	87,165,925	102,565,885
Acquisition time	25 minutes	65 minutes
Number of flights/stations	1 flight path	7 stations
Area covered	5776 m²	8391 m²
Average data density	15,091 pts/m²	12,223 pts/m²

Based on Table 1, TLS produces a larger number of point clouds with a longer acquisition time, while UAV LiDAR has a shorter acquisition time and wider coverage area. UAV LiDAR has a higher data density, while TLS excels in the total number of points, which impacts the visualization and analysis of building geometry.

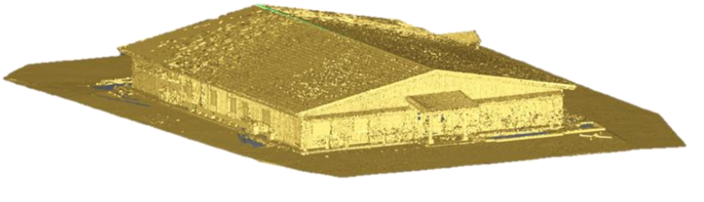
As Built Drawing Reference Data

Picture 3 As Built Drawing Data



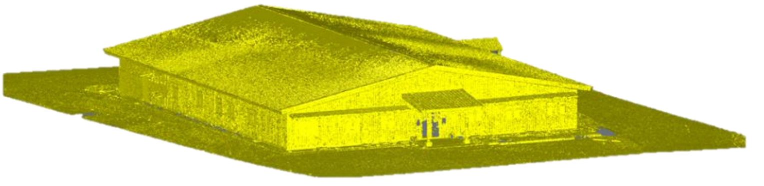
Picture 4 Visualization of the geometric position and direction of window dimension measurements.

Building Model Visualization Analysis



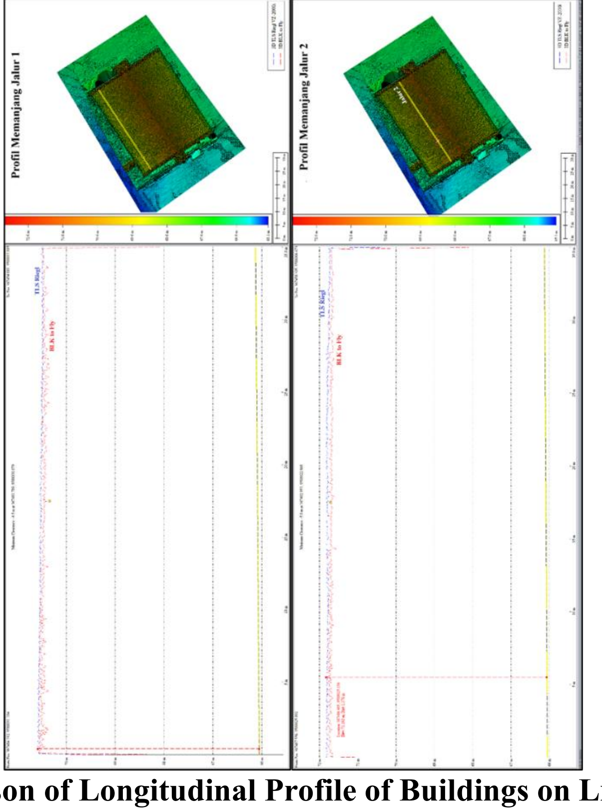
Picture 5 3D model of UAV LiDAR results

However, small irregularities are still visible in some areas, affecting surface smoothness. This indicates that while UAV LiDAR excels in area coverage, its detailed geometry still requires further analysis using longitudinal and transverse profiles.



Picture 6 TLS 3D model results

Although the coverage area is more limited than UAV LiDAR, the resulting detail quality demonstrates a high level of accuracy. This difference provides the basis for further analysis using longitudinal and transverse profiles to assess shape consistency and geometric precision.



Picture 7 Comparison of Longitudinal Profile of Buildings on Line 01 and Line 02

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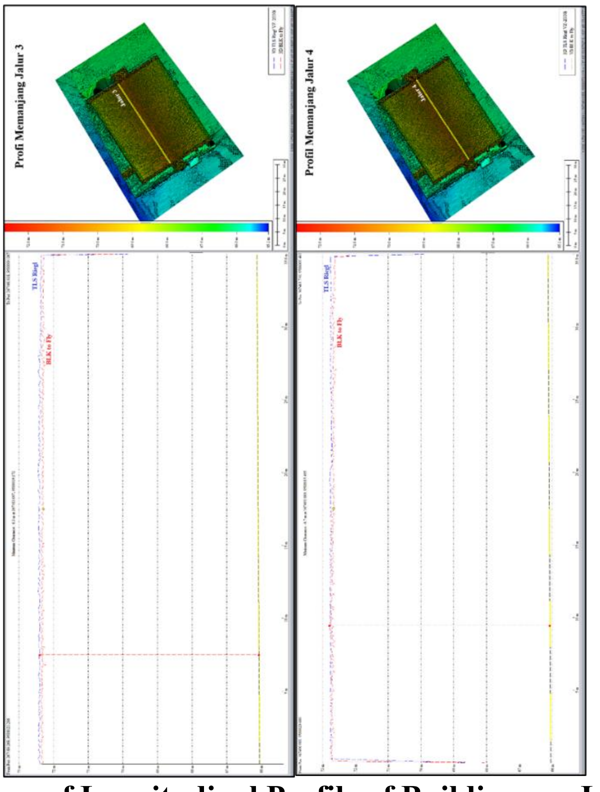
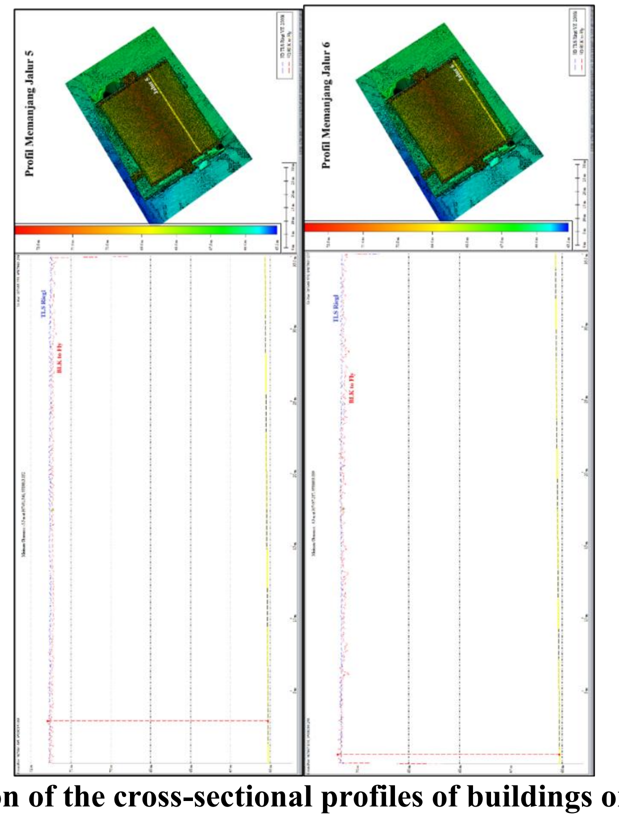
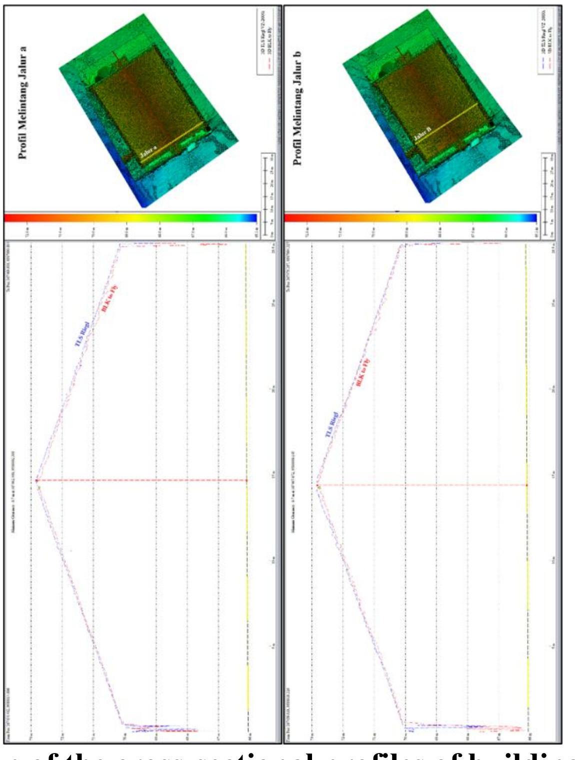


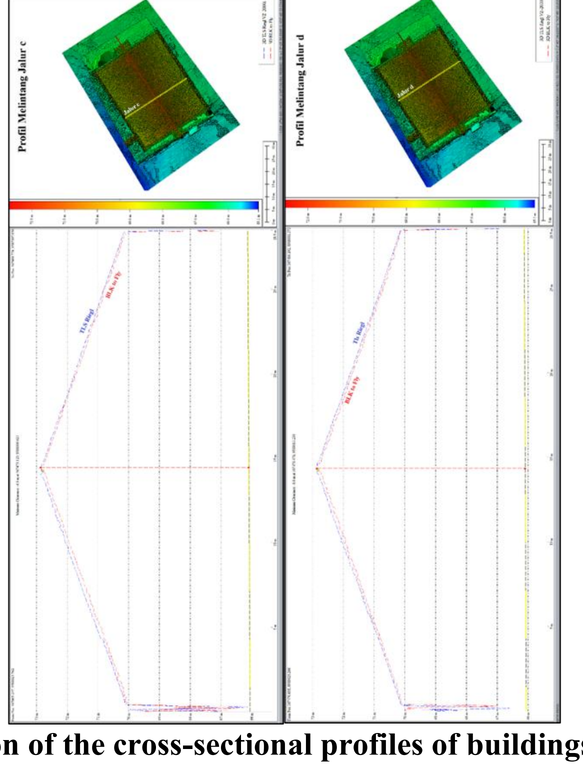
Picture 8 Comparison of Longitudinal Profile of Buildings on Line 03 and Line 04



Picture 9 Comparison of the cross-sectional profiles of buildings on line 05 and line 06



Picture 10 Comparison of the cross-sectional profiles of buildings on line a and line b



Picture 11 Comparison of the cross-sectional profiles of buildings on line c and line d.

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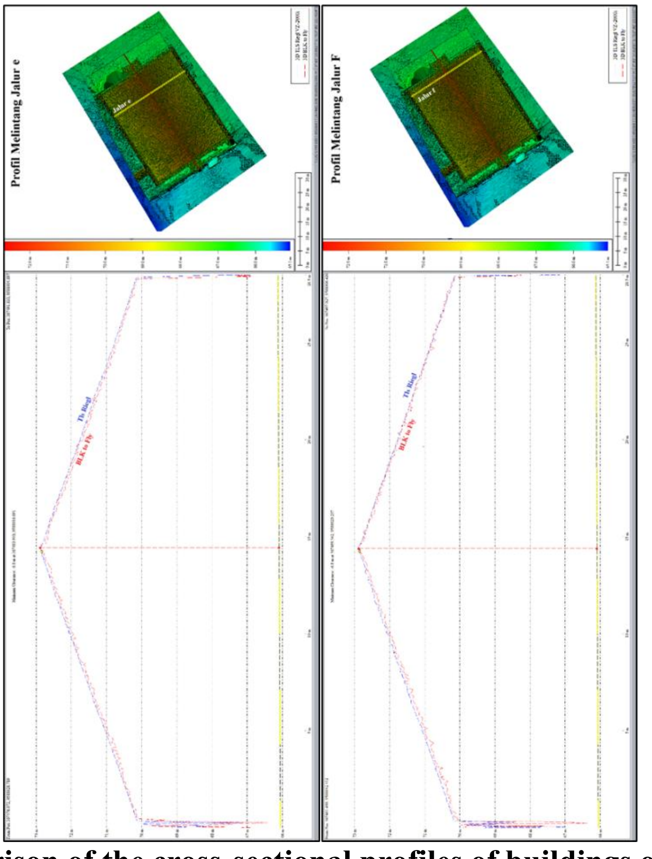
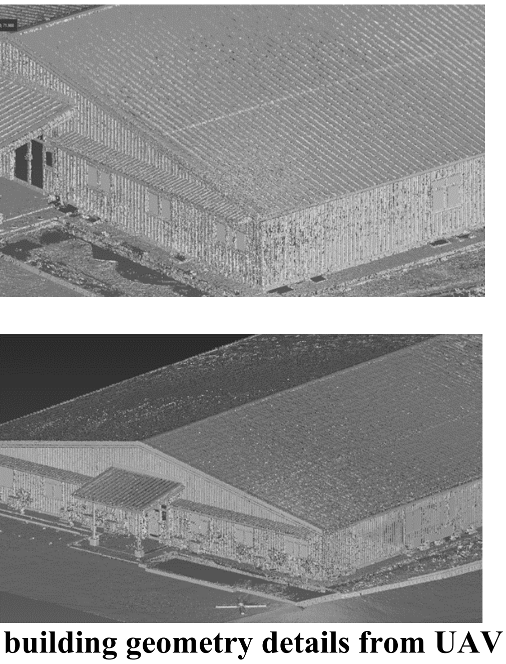


Picture 12 Comparison of the cross-sectional profiles of buildings on line e and line f.

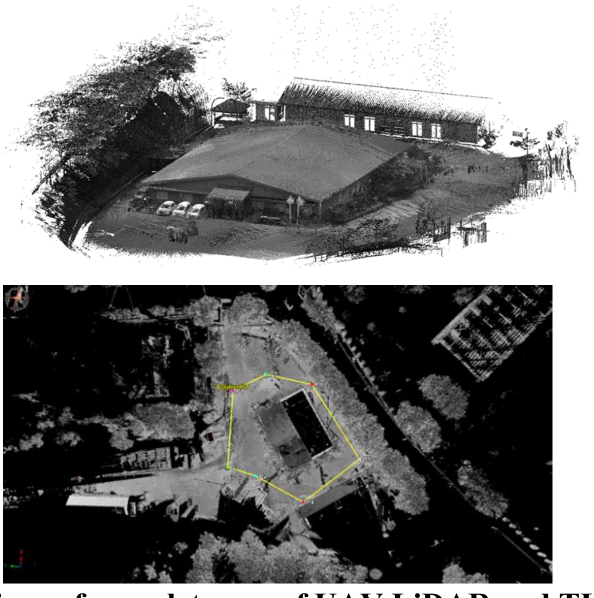
Table 2. Comparison of UAV LiDAR and TLS Model Visualizations

Aspect	UAV LiDAR	TLS (Terrestrial Laser Scanner)
Geometry Details	Low on walls, both on roofs & open areas	High on the wall, the vertical structure is clearly visible.
Data Completeness	Able to cover the entire building quickly	Limited, need multiple stations for full coverage
Surface Smoothness	The surface is not smooth, there is noise	Smoother surface, realistic texture
Acquisition Time	Fast, efficient for large areas	Relatively long, depending on the number of stations

To clarify the observations in Table 2, a direct visual comparison was performed between the UAV LiDAR and TLS models in the same observation area. The visual presentation is based on each assessment aspect to more clearly observe the differences in the characteristics of the two methods.



Picture 13 Comparison of building geometry details from UAV LiDAR and TLS results



Picture 14 Comparison of completeness of UAV LiDAR and TLS modeling data

Picture 15 Comparison of surface smoothness of UAV LiDAR and TLS models

Building Geometry Analysis

Table 1. Building corner coordinates data As Built Drawing

POINT	DATA AS BUILT DRAWING	
	X	Y
P1	367498,500	9588009,270
P2	367494,620	9588021,230
P3	367492,440	9588024,710
P4	367483,100	9588033,000
P5	367453,560	9588013,790
P6	367469,020	9587990,160

In the UAV LiDAR and TLS models, corner points were obtained from a 3D (XYZ) point cloud by identifying the intersection of two wall planes at the base of the building using Cyclone 3DR. The analysis focused on the horizontal X and Y coordinates to match the reference data. Corner points in both methods were selected at the same geometric location, then compared with the As Built Drawing coordinates as the basis for calculating the difference in horizontal position and dimensions between the building sides.

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Building Corner Position Analysis

Table 4. X and Y Coordinate Data from As Built Drawing, UAV LiDAR, and TLS Results

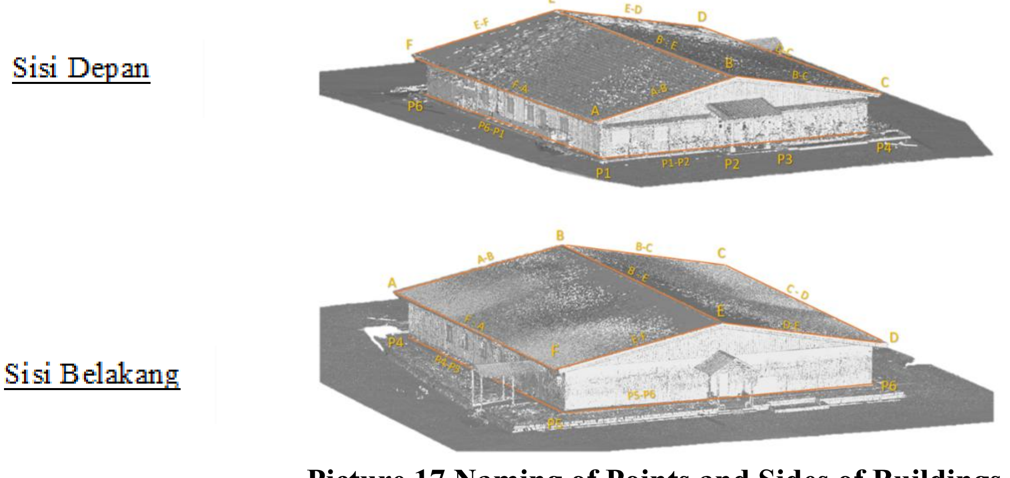
POINT	DATA AS BUILT DRAWING		TLS DATA		BLACK DATA	
	X	Y	X	Y	X	Y
P1	367498,500	9588009,270	367498,471	9588009,296	367498,518	9588009,308
P2	367494,620	9588021,230	367494,638	9588021,357	367494,685	9588021,343
P3	367492,440	9588024,710	367492,460	9588024,751	367492,464	9588024,804
P4	367483,100	9588033,000	367483,059	9588032,981	367482,994	9588033,091
P5	367453,560	9588013,790	367453,543	9588013,799	367453,481	9588013,774
P6	367469,020	9587990,160	367469,016	9587990,175	367468,969	9587990,158

Table 5. Coordinate difference values (ΔX and ΔY)

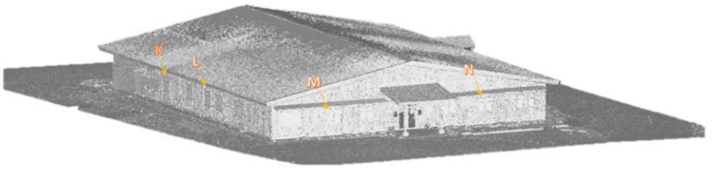
Point	ΔX LiDAR (m)	ΔY LiDAR (m)	ΔXY LiDAR (m)	ΔX TLS (m)	ΔY TLS (m)	ΔXY TLS (m)
P1	-0.018	-0.038	0.042	0.029	-0.026	0.039
P2	-0.065	-0.113	0.130	-0.018	-0.127	0.128
P3	-0.024	-0.094	0.097	-0.020	-0.041	0.046
P4	0.106	-0.091	0.139	0.041	0.019	0.045
P5	0.079	0.016	0.081	0.017	-0.009	0.019
P6	0.051	0.002	0.051	0.004	-0.015	0.015

Picture 16 Graph of the difference in building corner coordinates

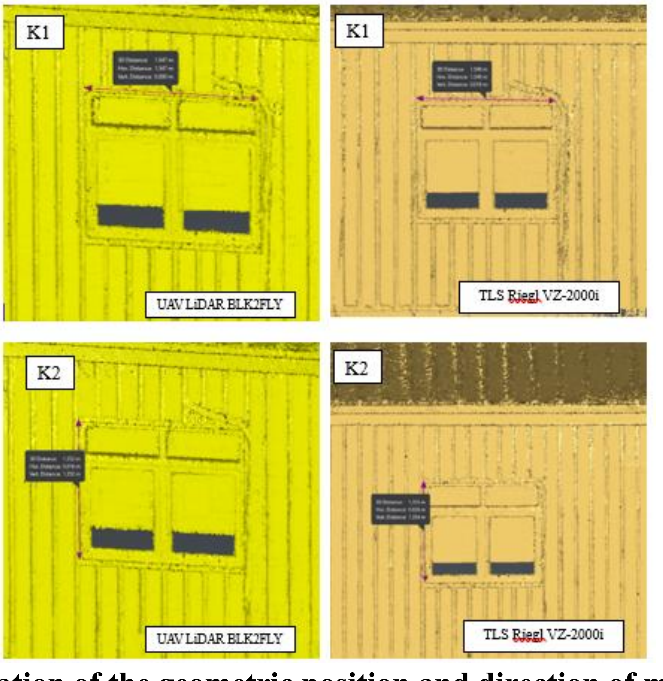
Visualization of Points, Sides, and Building Elements



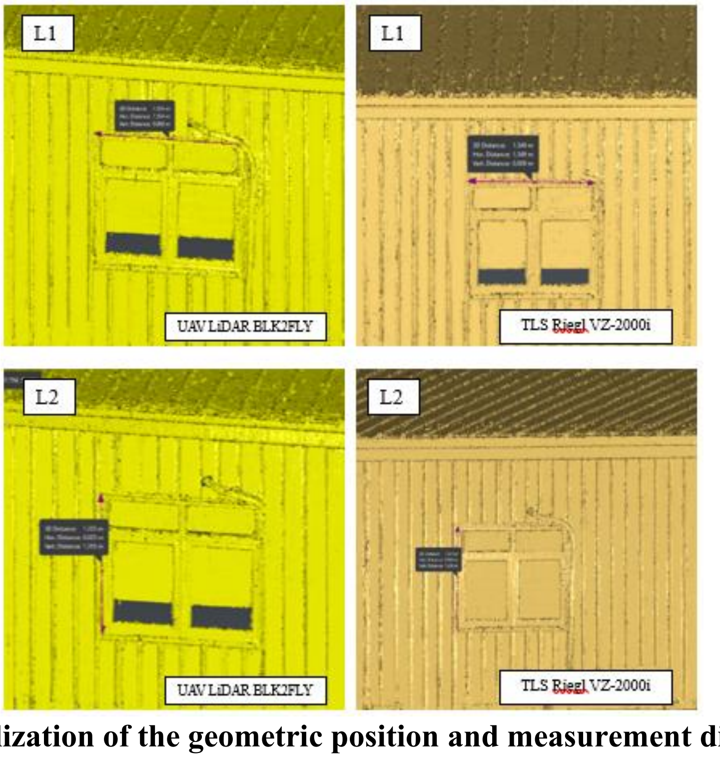
Picture 17 Naming of Points and Sides of Buildings



Picture 18 Overall Window Position Visualization



Picture 19 Visualization of the geometric position and direction of measurement of the K window dimensions



Picture 20 Visualization of the geometric position and measurement direction of the L window dimensions

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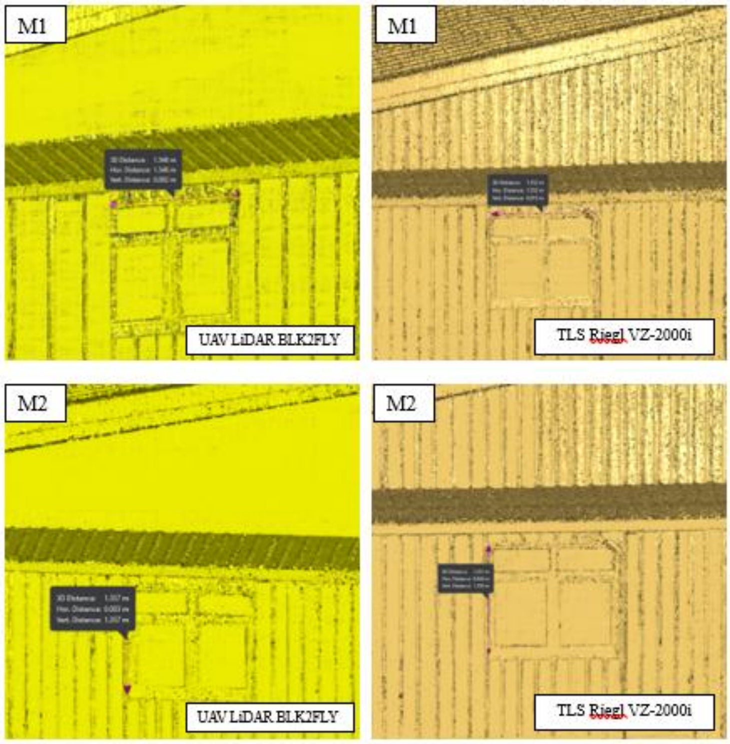
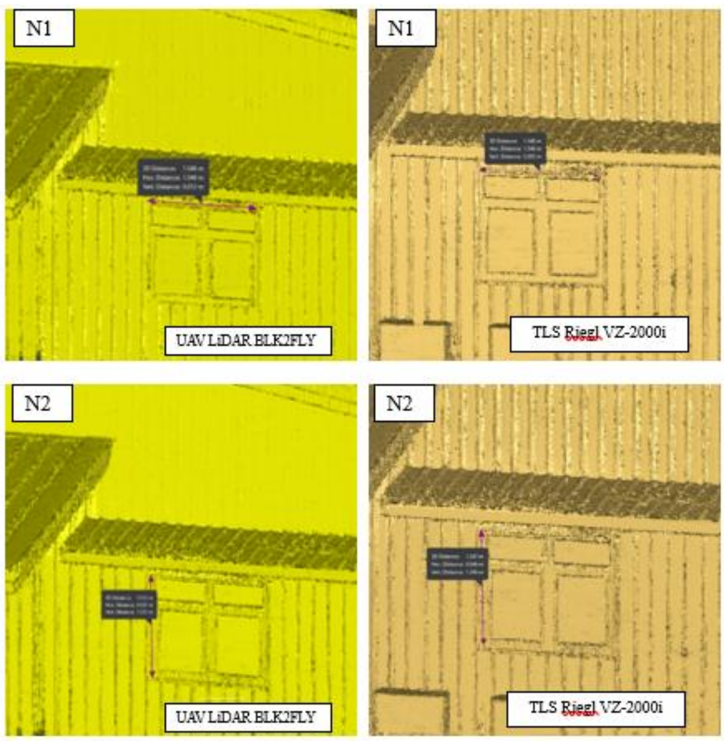


Picture 21 Visualization of the geometric position and measurement direction of the N window dimensions



Picture 22 Visualization of the geometric position and measurement direction of the N window dimensions

Dimensional Analysis Between Building Sides

Table 6. Building Dimensions Data As Built Drawing, TLS, and UAV LiDAR

No	Building Side	As Built Drawing (M)	TLS (M)	UAV Lidar (M)	INFORMATION
1	P1 - P4	28,289	28,257	28,401	Front Side
2	P2 - P3	4,106	4,034	4,112	Front Side
3	P4 - P5	35,237	35,202	35,273	Side
4	P5 - P6	28,238	28,240	28,242	Side
5	P6 - P1	35,132	35,118	35,212	Back Side
No	Building Side	As Built Drawing (M)	TLS (M)	UAV Lidar (M)	INFORMATION
6	AB	15,252	15,198	15,218	Roof
7	BC	15,252	15,255	15,274	Roof
8	CA	30,424	30,453	30,492	Roof
9	DE	15,252	15,219	15,258	Roof
10	EF	15,252	15,264	15,232	Roof
11	DF	30.40	30,483	30,490	Roof
12	AD	37.10	37,072	37,120	Roof
13	BE	37.10	37,127	37,182	Roof
14	CF	37.10	36,997	37,071	Roof

Table 7. As Built Drawing, TLS, and UAV LiDAR Data Window Dimensions

No	Window Side	As Built Drawing (m)	TLS (m)	UAV LiDAR (m)	INFORMATION
1	K1	1,550	1,549	1,547	WINDOW 1 Horizontal
2	K2	1,350	1,355	1,352	WINDOW 1 Vertical
3	L1	1,550	1,549	1,554	WINDOW 2 Horizontal
4	L2	1,350	1,351	1,355	WINDOW 2 Vertical
5	M1	1,550	1,552	1,548	WINDOW 3 Horizontal
6	M2	1,350	1,351	1,357	WINDOW 3 Vertical
7	N1	1,550	1,548	1,546	WINDOW 4 Horizontal
8	N2	1,350	1,347	1,353	WINDOW 4 Vertical

Table 8. Comparison of Geometric Dimensions of Buildings Using As Built Drawing, TLS, and UAV LiDAR

No	Building Side	Δ TLS (m)	Δ UAV LiDAR (m)
1	P1 - P4	0.032	-0.112
2	P2 - P3	0.073	-0.006
3	P4 - P5	0.035	-0.036
4	P5 - P6	-0.002	-0.004
5	P6 - P1	0.014	-0.080
6	AB	0.054	0.034
7	BC	-0.003	-0.022
8	CA	-0.029	-0.068
9	DE	0.033	-0.006
10	EF	-0.012	0.020
11	DF	-0.083	-0.090
12	AD	0.028	-0.020
13	BE	-0.027	-0.082
14	CF	0.103	0.029
15	K1	0.001	0.003
16	K2	-0.005	-0.002
17	L1	0.001	-0.004
18	L2	-0.001	-0.005
19	M1	-0.002	0.002
20	M2	-0.001	-0.007
21	N1	0.002	0.004
22	N2	0.003	-0.003
Total Dimension Difference		0.010	-0.025

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Accuracy Analysis Using RMSE

Table 9. Summary of Horizontal Position RMSE

Parameter	n	UAV LiDAR (m)	TLS (m)	Difference (m)
ΔXY Building Angle	6	0.098	0.061	0.037

Based on the calculation results, the RMSE value for the horizontal position of the UAV LiDAR was 0.098 m, while the TLS was 0.061 m. The difference in accuracy of 0.037 m indicates that the TLS has a higher level of position precision than the UAV LiDAR.

Table 2. Building Dimension RMSE Summary

Parameter	n	UAV LiDAR (m)	TLS (m)	Difference (m)
Dimension Between Sides	22	0.044	0.038	0.006

Based on the calculation results for 22 building dimension samples, the RMSE value for UAV LiDAR was 0.044 m, while for TLS it was 0.038 m. The RMSE difference of 0.006 m indicates that the accuracy levels of the two methods in measuring dimensions are relatively close. Based on these results, TLS has a smaller RMSE value, thus indicating higher accuracy than UAV LiDAR in representing building dimensions.

Statistical Analysis

Table 3. Shapiro-Wilk Normality Test Results

Variables	n	Shapiro-Wilk Statistics	Sig.	Conclusion
TLS Error	14	0.982	0.983	Normally distributed
UAV LiDAR Error	14	0.935	0.363	Normally distributed

Based on the normality test results, a significance value of 0.983 was obtained for the TLS error data and 0.363 for the UAV LiDAR error data. Both values are greater than the 0.05 significance level, so H_0 is accepted. Thus, the error data from the measurements of both methods are normally distributed and meet the assumptions for testing using the Paired Sample T-Test.

Table 4. Paired Sample T-Test Error Results for TLS and UAV LiDAR

Parameter	Mark
Number of data pairs (n)	14
Mean TLS Error	-0.015394 m
Mean Error of UAV LiDAR	0.031642 m
Mean Difference (TLS − UAV LiDAR)	-0.047036 m
Standard Deviation Difference	0.044236 m
t count	-3,978
Degrees of freedom (df)	13
Sig. (2-tailed)	0.002
Conclusion	H_0 rejected

Based on the results of the Paired Sample T-Test, the calculated t value was -3.978 with a degree of freedom (df) of 13 and a significance value (Sig. 2-tailed) of 0.002.

CONCLUSION

Based on the research results, UAV LiDAR and TLS are able to produce 3D building models for geometric position and dimension analysis. UAV LiDAR excels in time efficiency and area coverage, while TLS produces better geometric details and surface smoothness. The RMSE value of the horizontal position of UAV LiDAR is 0.098 m and TLS is 0.061 m, while the RMSE of the dimensions are 0.044 m and 0.038 m, respectively. The results of the Paired Sample T-Test show a t value of -3.978, df = 13, and Sig. 0.002, so there is a significant difference between the two methods.

This study was limited to a single location and building object, and used a single data acquisition, so the results cannot be generalized to different conditions. Future research is recommended to involve more locations and building characteristics and repeat measurements to obtain more comprehensive results. Practically, TLS can be prioritized when geometric accuracy and detail are the primary requirements, while UAV LiDAR can be used when time efficiency and area coverage are more important.

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