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Comparison Between AliceVision Meshroom and Pix4Dmapper Software in Generating Three-Dimensional (3D) Photogrammetry

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Abstract - The act of powerful photogrammetry software is important to transform photographs into a 3D model that is good and accurate for the as-built survey. Nowadays, there are a lot of choices available on the internet that can be divided into open-source software and commercial software, which produce different outputs of 3D models due to different algorithms used. Thus, this research compares two photogrammetry software (AliceVision Meshroom from open-sourced software and Pix4Dmapper from commercial software) to give a clear view of the accuracy performance of the software. Aerial photographs were taken at Building G24, Kolej Rahman Putra, Universiti Teknologi Malaysia, Johor. The same data was used in processing both software to generate the 3D point cloud model and the 3D mesh model as the final output. The comparison between the two software was based on four aspects, including 3D point-cloud model density, 3D-mesh model appearance, Mean Absolute Error (MAE) accuracy assessment and the processing environment. The results showed that commercial Pix4Dmapper software offered better services and accuracy of the products (MAE = 0.016m). In contrast, the open-source AliceVision Meshroom software required third-party software to complete the photogrammetry process (MAE = 0.035m). Thus, Pix4Dmapper is a better choice in an as-built surveying application than AliceVision Meshroom.

Keywords - Photogrammetry, 3D Modelling, Photogrammetry Software, As-Built Survey

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1. Introduction

In recent years, the rapid modernisation in the world has led to massive evolution of the technology in country's development aspects. Various industries have benefited from this technological advancement, including the survey and mapping fields. One of the modern surveying technologies practised worldwide recently is known as photogrammetry. Photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects without physical contact with the objects and measuring and interpreting this information (Schenk, 2005). Photogrammetry uses the principle of triangulation in imaging, which involves determining spatial properties and dimensions of the objects or details captured in the photographs. The triangulation was the process of joining the "line of sight" of a minimum of 2 different photographs taken from different perspectives or locations, then using the mathematical intersection of these lines to generate the precise location of the point cloud concerning photographs. The principle of triangulation in photogrammetry is shown in Figure 1.

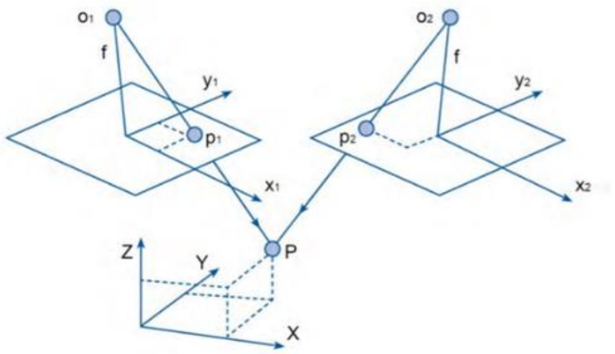

Figure 1. Principles of Triangulation in Photogrammetry (Ezekiel Enterprises, 2022)

Aerial Photogrammetry is one technique that uses an Unmanned Aerial Vehicle (UAV) to capture photographs of an area for digital terrain modelling, topographic mapping, 3D-point clouds and other mapping application for engineering and design purposes. In the as-built survey, the aerial photographs were captured from different perspectives as input for the 3D reconstruction modelling. The model can provide accurate mapping with the 3D coordinates from the planar coordinates of the photographs. The advantage aerial photogrammetry offers in an as-built survey is fast and cost-effectiveness. Besides, it provides comprehensive coverage and the ability to capture data in remote, unsafe or difficult to access locations, promoting this technique as a platform for data acquisition for various applications.

Meanwhile, 3D modelling is not only a process of converting a measured point cloud into a triangulated network but a complete process that starts from data acquisition and ends with a 3D virtual model visually interactive on a computer (Remondino and El-hakim, 2006). The result from the study (Kaamin et al., 2020) proves that the UAV's ability to produce as-built survey mapping can be achieved and also ease the as-built survey work in terms of time-saving and less skilled surveyors are required.

The application of UAV photogrammetry in survey and mapping is highly dependent on the ability and power of photogrammetry software. Due to the growing number of acquired photographs, there is a need to search for the tools that will transform tens or hundreds of overlapping photographs and perform 3D reconstructions to enable further analyses of them (Kloc, Mazur and Szumiło, 2021). Currently, several commercial and open-source tools and software are available to handle all steps of an image-based 3D modelling framework, from image pre-processing to the generation of 3D geospatial products like point clouds, DSMs, and orthophotos mesh models, texture models and many more (Alidoost and Arefi, 2017). This process of estimating 3D structures from multiple photographs is called structure-from-motion (SfM) paired with multi-view stereo (MVS). SfM is known as an advanced photogrammetric technique that has emerged from advances in computer vision and traditional photogrammetry, which utilises a series of 2D images of an object or a specific region obtained by a moving sensor as input to extract features and produce high-quality 3D structures (Deliry and Avdan, 2021) while MVS is known as a refinement of the 3D model from the SfM method (Cho and Clary, 2018). Tie points were produced from the feature extraction and underwent bundle adjustment to get the sparse point cloud as output. Then, dense geometry was ready to be constructed with its accuracy set to a high level to produce the dense point cloud.

Photogrammetry software is essential in carrying out the SfM-MVS workflow and producing the outputs of 3D models from the aerial photographs during the as-built survey. Many photogrammetry software is available in the market, from open-source and commercial platforms. In this study, the review focused on AliceVision Meshroom (open-source) and Pix4Dmapper (commercial). Meshroom is a free, open-source photogrammetry software based on the AliceVision framework. Meshroom has been used since 2014 in a digital environment created for the Visual Effects industry and now in many other sectors, including manufacturing, medical, cultural heritage, tourism, archaeology, biology, surveillance and 3D printing (Griwodz et al., 2021). The main objective of this software is to provide a processing environment in which users can use the existing pipeline or change it arbitrarily during the 3D reconstruction of the photogrammetric model from multiple images. The default pipeline started with feature extraction, image matching, SfM, depth map estimation, point meshing and texturing. Pix4Dmapper is a commercialised and leading photogrammetry software for the professional drone mapping application (Pix4Dmapper, 2022). This software transforms photographs into an accurate, precise and georeferenced 3D model. This comprises the point cloud generation, 3D meshes or the elevation maps from the photographs to fulfil the user needs in producing various kinds of output. From Pix4D official website, five major processes involved in Pix4Dmapper software are capture, digitise, control, measure and inspect, and collaborate and share. Various kinds of products can be obtained from this software, such as full-coloured point cloud, orthomosaic, DSM, 3D textured mesh, index map, thermal maps, etc., which come with the analysis and report on the accuracy.

To achieve the research goal, two research objectives needed to be highlighted. The first objective of this research is to generate a 3D point cloud and 3D mesh model of a building from the aerial photographs through AliceVision Meshroom and Pix4Dmapper software. The second objective is to evaluate the measurement accuracy of the 3D model point cloud produced from AliceVision Meshroom and Pix4Dmapper software. To achieve the objectives of this study, the aerial photographs of building G24 located at Kolej Rahman Putra (KRP), Universiti Teknologi Malaysia (UTM), were captured using DJI Phantom 4 drone for the use of 3D modelling. AliceVision Meshroom and Pix4Dmapper were used to do the modelling of the building. The results from both software are compared to assess their reliability and accuracy with the Terrestrial Laser Scanning (TLS) measure benchmark.

2. Materials and Methods

The research methodology was implemented to ensure the achievement of the research goal and objectives of open-sourced (AliceVision Meshroom) and commercial (Pix4Dmapper) photogrammetry software evaluation on the ability and quality of 3D modelling. The workflow is designed as shown in Figure 2.

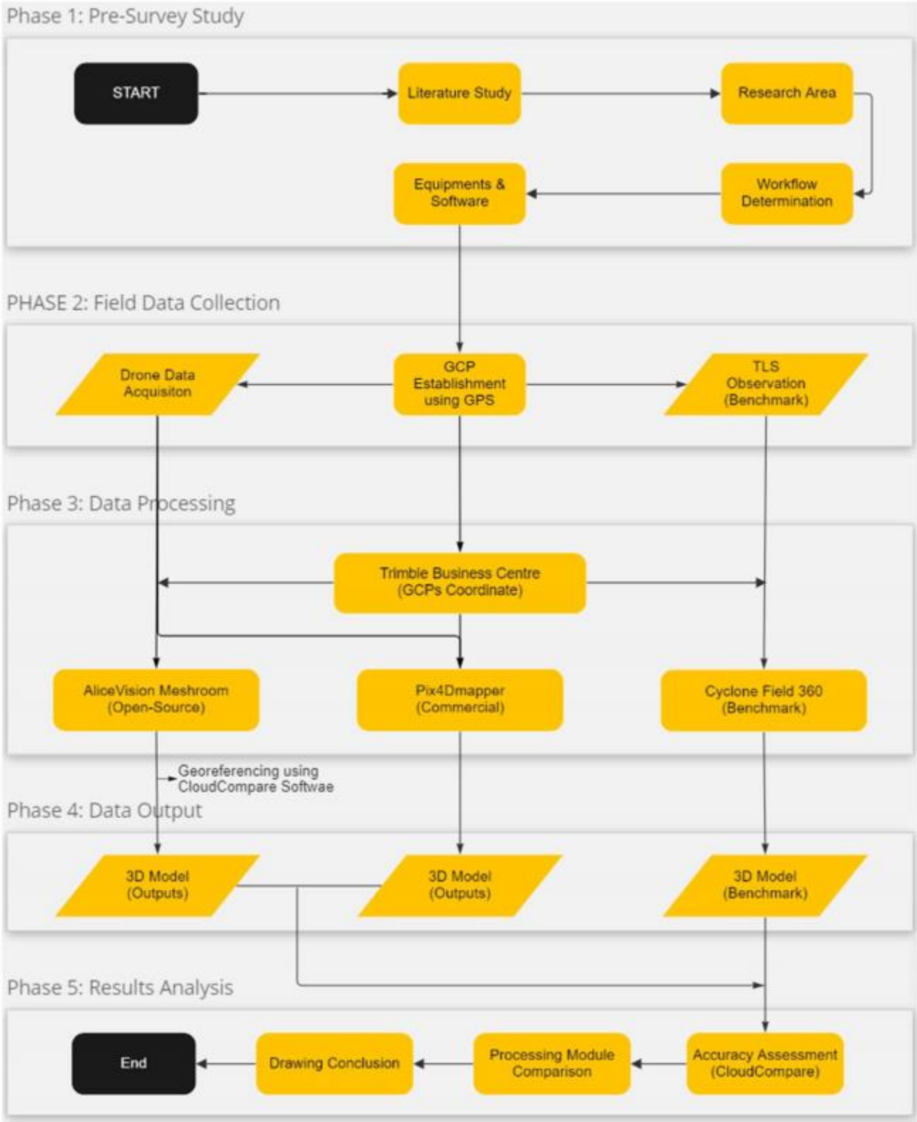

Figure 2. Research methodology workflow

2.1 Phase 1: Pre-survey Study

This phase is mainly the preparation and planning phase for the entire research study. After the literature study, the research area, workflow determination, and equipment and software determination were done in this phase.

2.1.1 Research Area

Since the application of photogrammetry in this study was a survey, the building was chosen to model. After the reconnaissance, Building G24, Kolej Rahman Putra, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia, was selected as the target of this study. The reason for choosing this building was located in a relatively open area with a clear sky view that can ensure the aerial photographs captured will be good and include the details of the target. The location of building G24 is presented in the figures below.

Figure 3. Location of G24, Kolej Rahman Putra on Google Map

Figure 4. Close up of each site of building G24

2.1.2 *Workflow Determination*

Workflow determination was done after the general idea of the research study was gained from the literature review. In this section, the project planning on the ground control point (GCPs) distribution and the flight planning on DroneDeploy and Pix4Dcaptures are presented in the figures below.

Figure 5. GCPs distribution in the area of study

In this study, a total of 6 GCPs were planned in the area of study for georeferencing the aerial photographs. The condition of the distribution of GCPs must include a clear sky view of the GCPs' location to avoid the signal lost during the GNSS data observation to maximise the accuracy of the coordinates. This could ensure the model produced was on the correct geolocation and correct scale.

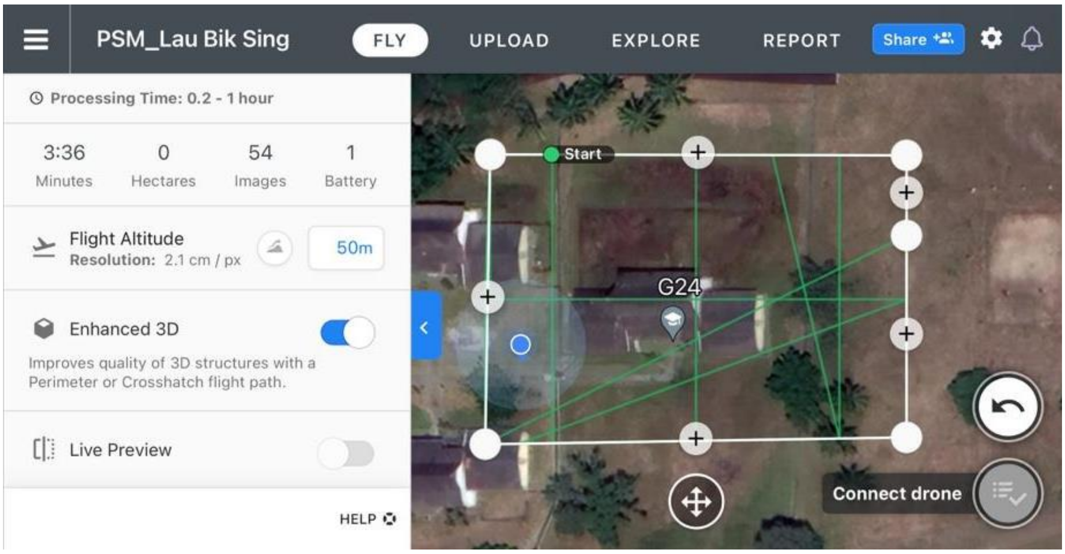

Figure 6. Nadir flight planning using DroneDeploy software

Figure 7. Oblique flight planning using Pix4Dcapture software

Initially, the flight planning was done in DroneDeploy, but this only covered the nadir flight data collection as the oblique view function is unavailable in DroneDeploy software. Thus, Pix4Dcapture was used to obtain the oblique view data in this study to increase the amount of data and to get the 3D model as complete as possible.

2.1.3 Equipment

Various kinds of equipment were used in this study to gather the information of the input data as well as the benchmark for this study. Three equipment were used: Topcon HiPer HR receiver for GCPs data collection using GNSS data, DJI Phantom 4 to capture aerial photographs and Leica RTC 360 for benchmark data collection. During the processing, GCPs coordinate will be generated from Trimble Business Centre (TBC) and imported with aerial photographs to the chosen photogrammetry software, AliceVision Meshroom and Pix4Dmapper performance evaluation on 3D modelling.

2.2 Phase 2: Data Acquisition

The data acquisitions were divided into three parts: GCPs data acquisition for GCPs establishment, TLS data acquisition to get the benchmark of this study and drone data acquisition to get the aerial photographs of this study.

2.2.1 GCPs Data Acquisition

GCPs data acquisition is made using the GNSS observation to get the coordinates of the GCPs. The technique is fast static with 30 minutes of observation time per station. Since only 4 GNSS instruments were available, the GNSS observation was divided into two sessions. BM1 is a known benchmark used as the base of this GCPs establishment during the data processing in TBC software. Another three control points of the GNSS network were obtained from ISKANDARnet1 (ISK1) and 2 Continuous Operating Reference System (CORS) stations (JHJY and SPRG). The network design and the observation session are shown in the figure below.

Figure 8. GNSS observation session for GCPs establishment

~~2.2.1~~ 2.2.2 TLS Data Acquisition

TLS data acquisition was made using the Leica RTC360 with the software of Cyclone Field 360 to monitor and control the entire data collection process. This research will use this data as the benchmark for accuracy assessment. The station occupied by Leica RTC 360 was beside the GCP stations to ensure all the GCP stations were included in the data obtained for georeferencing purposes.

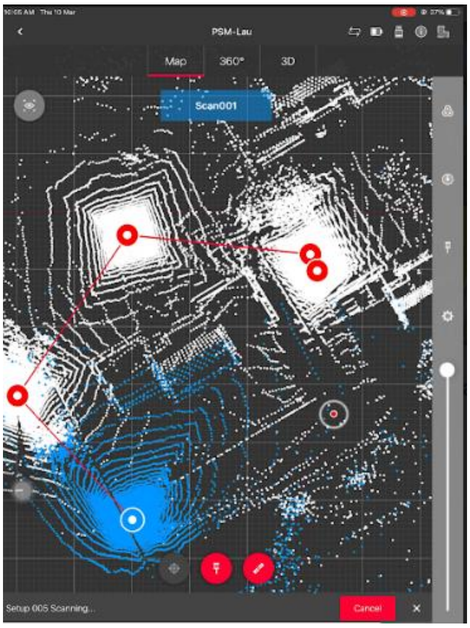

Figure 9. Cyclone Field 360 window interface during Leica RTC 360 data collection

~~2.2.2~~ 2.2.3 *Drone Data Acquisition*

Drone data acquisitions are made using the DJI Phantom 4 with the assistance of DroneDeploy software and Pix4Dcapture software. Two hundred thirty-six (236) aerial photographs are used as the input for photogrammetry processing.

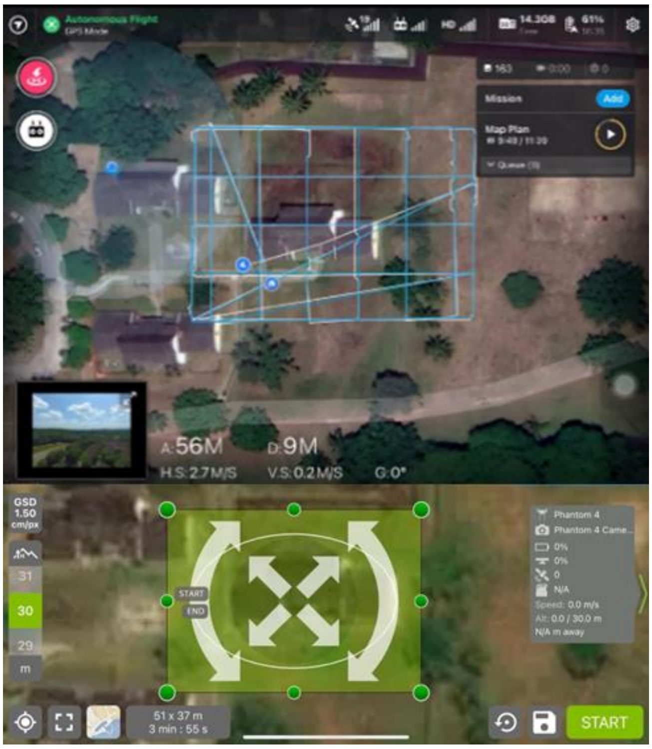

Figure 10. Aerial data collection

2.3 Phase 3: Data Processing

The data processing of this research was done in 3 software, including TBC software for GNSS data, AliceVision Meshroom and Pix4Dmapper for photogrammetry data.

2.3.1 Processing in TBC software

The GNSS data was imported to the TBC software to perform 3D network adjustment and short baseline processing to get the coordinates of the GCPs.

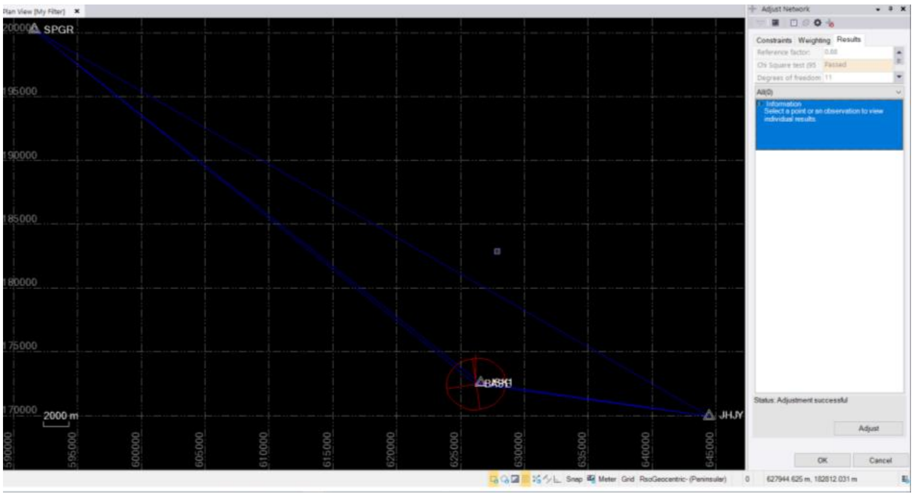

Figure 11. The processing in TBC software to get GCPs' coordinates

2.3.2 Processing in AliceVision Meshroom and Pix4Dmapper

The aerial photographs were used as the input data for the 3D reconstruction processing in the photogrammetry software. The GCPs coordinate was used for georeferencing purposes.

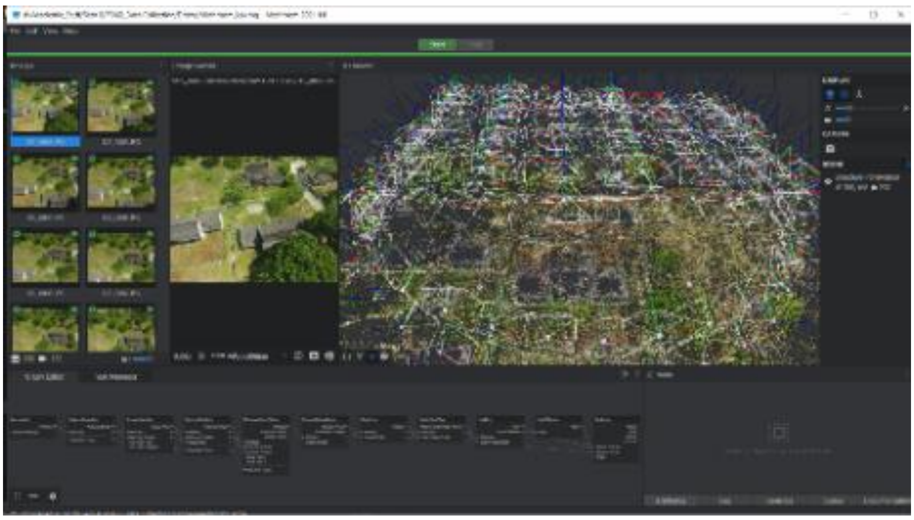

Figure 12. Aerial data processing in AliceVision Meshroom

Figure 13. Aerial data processing in Pix4Dmapper

3. Result and Discussion

After processing GNSS and aerial photographs in respective software, the results were presented in the form of the 3D point cloud model, 3D mesh model and accuracy assessments. The visualisation of each model and accuracy assessment statistics were presented in the following section. The discussion will be further elaborated on in each section.

3.1 3D Point Cloud Model

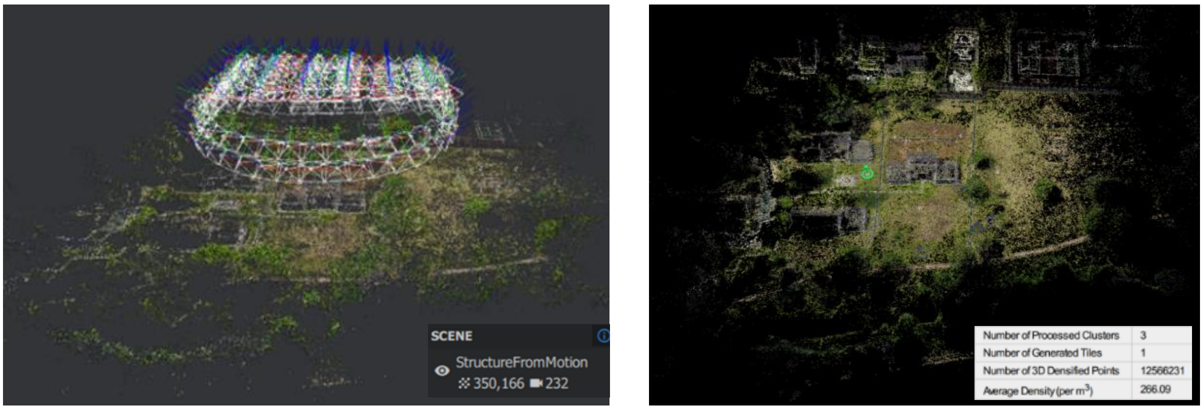

Figure 14. 3D-point cloud model generated from AliceVision Meshroom (left) and Pix4Dmapper (right)

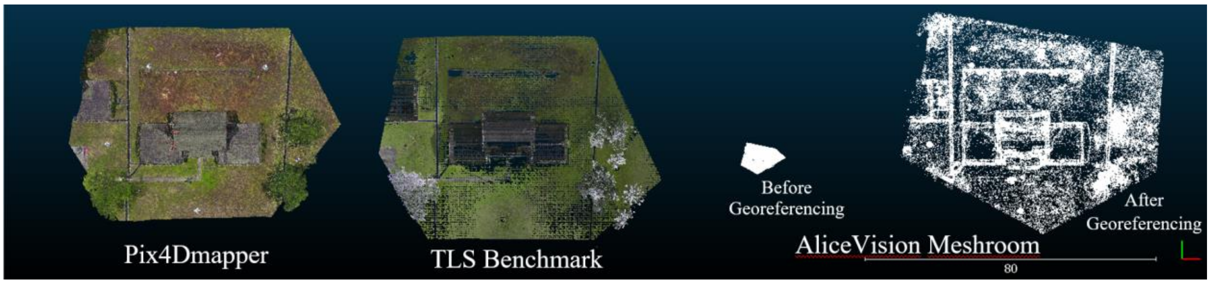

Figure 15. Side-by-side comparison of 3D point cloud generated

The point cloud generated from Pix4Dmapper is denser (12 566 213 points), similar to the TLS benchmark model. In contrast, the point cloud generated from AliceVision Meshroom is less dense (350 166 points) and does not match due to the limitation on georeferencing in the software. The georeferencing is done in the CloudCompare software to get the final model, as shown in Figure 15. From the side-by-side comparison, the 3D point cloud generated from both software was similar but less dense than the TLS benchmark model after the georeferencing.

3.2 3D Mesh Model

The 3D mesh model is the product after the point cloud model is refined to get the complete surface 3D model. A triangulation mesh will be created to link all the point clouds together to produce the surface model as the final output.

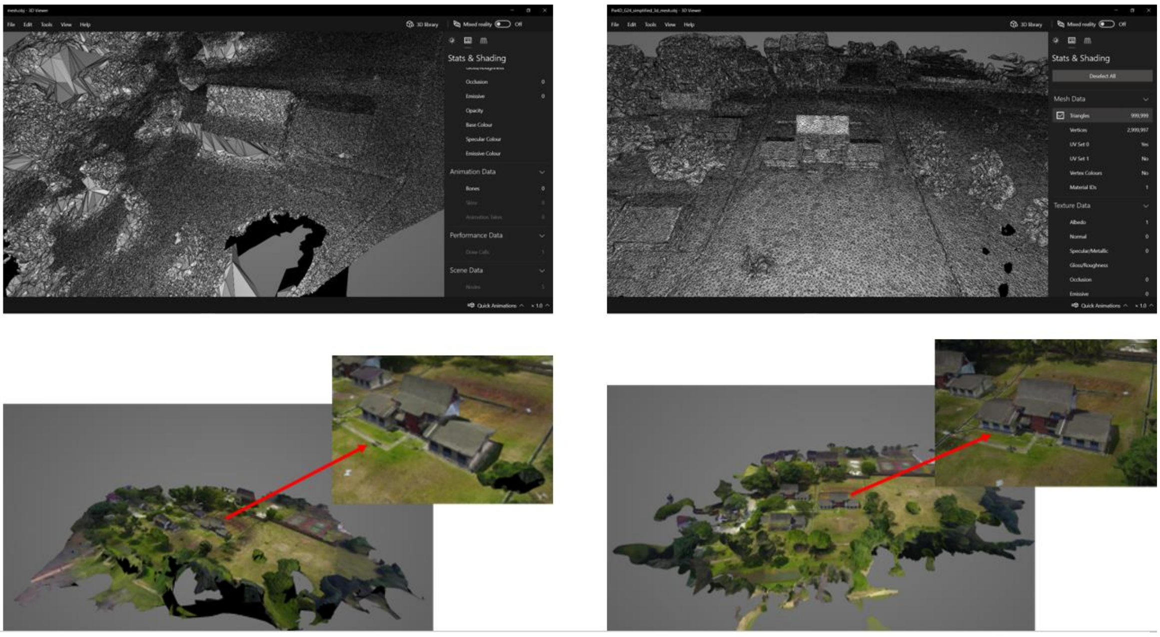

Figure 16. 3D triangulation mesh model from AliceVision Meshroom (left) and Pix4Dmapper (right)

Generally, the mesh model of the AliceVision Meshroom was inconsistent, while the output from Pix4Dmapper is relatively more consistent. This might be caused by several issues, including the limitation of feature extraction and the algorithm of triangulation of AliceVision Meshroom is weaker than Pix4Dmapper. The better triangulation mesh from the Pix4Dmapper contributed to more accurate and detailed mesh models.

3.3 Accuracy Assessment

The accuracy assessment compares the dimensional measurement on the 3D point cloud generated from AliceVision Meshroom and Pix4Dmapper with the benchmark model (from TLS) in CloudCompare. Ten dimensions of the features within the model were measured, and the Mean Absolute Error (MAE) was calculated to assess the model's accuracy concerning the measurement of the TLS model.

$$MAE = \frac{1}{N}\sum_{i=1}^{n} |X_t - X_a| \qquad \text{Equation 1}$$

Where $|X_t - X_a|$ is the absolute errors with X_t is the distance measured on TLS point cloud while X_a is the distance measured on the aerial point cloud model, and N represents the sample size.

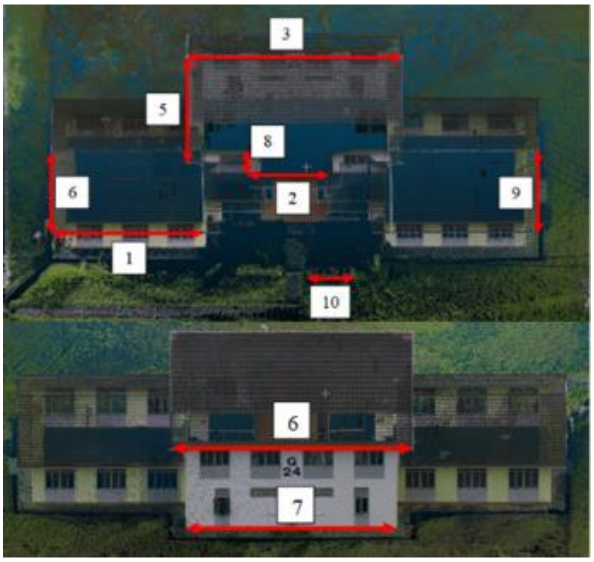

Figure 17. The distribution of measurement for accuracy assessment

The calculations of MAE of each point cloud model were tabulated in the tables below.

Table 1. MAE for AliceVision Meshroom (without georeferencing)

Line ID	Measured Distance from Benchmark, TLS (m)	Measured Distance from AliceVision Meshroom without Georeferencing (m)	Differences (m)
1	11.005	1.214	9.791
2	6.182	0.770	5.411
3	14.375	1.766	12.610
4	5.731	0.750	4.981
5	4.854	0.576	4.278
6	14.168	1.777	12.391
7	12.266	1.523	10.743
8	1.773	0.226	1.547
9	5.659	0.889	4.770
10	3.159	0.392	2.767
		Sum of Absolute Errors	69.289
		Mean of Absolute Error (MAE)	6.929

The results shown in Table 1 refer to the measurements on the point cloud model obtained from AliceVision Meshroom. From the table, the MAE obtained is 6.929m which indicates a huge difference between the measurement of the model and indicates that the result does not match the actual model (TLS as a benchmark). The most significant errors obtained were line ID 3 (12.609m) and 6 (12.391m), directly causing the large MAE value. The main reason for this issue is that the model used is the original model with no georeferenced due to the limitation of the software. Thus, this result shows that AliceVision Meshroom cannot produce the actual accurate scale model with the build-in algorithm; a third-party software is required to perform the georeferencing to get the model close to the actual model.

Table 2. MAE for AliceVision Meshroom (with georeferencing)

Line ID	Measured Distance from Benchmark, TLS (m)	Measured Distance from AliceVision Meshroom without Georeferencing (m)	Differences (m)
1	11.005	10.863	0.142
2	6.182	6.167	0.015
3	14.375	14.260	0.115
4	5.731	5.349	0.382
5	4.854	4.768	0.086
6	14.168	14.276	-0.107
7	12.266	12.517	-0.251
8	1.773	1.630	0.143
9	5.659	5.965	-0.306
10	3.159	3.027	0.132
		Sum of Absolute Errors	0.350
		Mean of Absolute Error (MAE)	0.035

To test the accuracy of the point cloud model obtained from AliceVision Meshroom with proper size and orientation, georeferencing has been performed to the point cloud in the CloudCompare environment. The measurements are done with the same feature on the georeferenced model. After size and orientation have been corrected, the dimensional measurement of the point cloud model has improved with MAE approximate to 0.035m, as shown in Table 2 above. Thus, the algorithm in AliceVision Meshroom was still acceptable if there was the act of third-party software to provide the georeferencing module. Except for the lines ID 2 and 5, other measurements that were more significant than 0.100m might be because the model produced was inaccurate. Human errors during point selection might occur when the measurement is carried out.

Table 3. MAE for Pix4Dmapper

Line ID	Measured Distance from Benchmark, TLS (m)	Measured Distance from AliceVision Meshroom without Georeferencing (m)	Differences (m)
1	11.005	11.065	-0.060
2	6.182	6.256	-0.075
3	14.375	14.160	0.215
4	5.731	5.536	0.195
5	4.854	4.966	-0.112
6	14.168	14.142	0.026
7	12.266	12.218	0.048
8	1.773	1.868	-0.095
9	5.659	5.685	-0.027
10	3.159	3.112	0.047
		Sum of Absolute Errors	0.162
		Mean of Absolute Error (MAE)	0.016

The point cloud model of Pix4Dmapper has also been tested in this accuracy assessment. The ten measurements were taken from the point cloud model and tabulated in Table 4.3, followed by the calculation for the MAE. From Table 3, the MAE value for the point cloud from Pix4Dmapper is 0.016m with respect to the benchmark (TLS data). This means that the model of the Pix4Dmapper is excellent and accurate to the actual model. The bad results are measurements from lines ID 3, 4 and 5 with higher than 0.100m which might be due to the different points that were picked due to human errors during the measurement and can be the outliers for this MAE calculation.

From the comparison between two point-cloud models from AliceVision Meshroom and Pix4Dmapper, the results of MAE are significant in that the model generated from Pix4Dmapper is more accurate (lower MAE value) than the AliceVision Meshroom even though the georeferencing is applied to encounter the limitation of the AliceVision Meshroom. Thus, in terms of accuracy, commercial software, Pix4Dmapper is, still having better performance than open-sourced software, AliceVision Meshroom.

3.4 Analysis Summary

Throughout the analysis, a complete summary of the comparison between AliceVision Meshroom and Pix4Dmapper was tabulated below.

Table 4. Comparison Summary between AliceVision Meshroom and Pix4Dmapper

AliceVision Meshroom	Aspects	Pix4Dmapper
Less dense point cloud generated (350 166 points)	3D point cloud performance	More dense point cloud generated (12 566 213 points)
Not matched with an actual model	Size of 3D point cloud	Geographically matched
Cannot perform georeferencing in the software	Georeferencing	Models are georeferenced
Inconsistent triangulation mesh	3D mesh model	Consistent triangulation mesh
Off without georeferencing but become better with georeferencing. (MAE=0.035m)	Accuracy Assessment	Good accuracy presented (MAE=0.016m)
Blur texture detail due to less dense point cloud generated	Visualization	Precise texture detail generated from dense point cloud
3D point cloud, 3D mesh model, and 3D surface model but not all the format is supported in other photogrammetry software	Output	3D point cloud, 3D mesh model, 3D surface model, quality report and orthomosaic that can be supported in other photogrammetry software
Approximately 13 hours in this research	Time spent	Approximately 4 hours in this research
Self-customized workflow is available. No orthomosaic module provided	Modules	3D maps, 3D models, and 3D multispectral modules with a one-click button to start-up
Required for georeferencing and converting output file format	Assistant of third-party software	Does not required
User-friendly but fewer modules are provided	Processing environment	User-friendly and professional for photogrammetry application

To summarize this chapter, a complete comparison between open-source photogrammetry software (AliceVision Meshroom) and commercial photogrammetry software (Pix4Dmapper) has been shown in Table 4.4. Both software offered the ability to generate photogrammetry outputs with different level of accuracy and different processing environment. Overall, the performance of commercial software was a better choice for professional photogrammetry purposes since the black box algorithms can provide better accurate estimation and triangulation to get the outputs with highest similarity and matched with the actual model.

Furthermore, AliceVision Meshroom, free, open-source software, can also be used for basic photogrammetry applications, especially for the application of 3D reconstruction. However, for mapping applications, AliceVision Meshroom requires assistance from third-party software as the most significant limitation of this software is the limitation to perform georeferencing. Also, third-party software was required to convert exported point cloud files from .abc files to another readable format for other photogrammetry software.

4. Conclusion and Recommendation

Throughout the complete research study, all the research questions have been answered beside the objectives have been achieved successfully. First, back to the research question, the results show differences between the results obtained from both AliceVision Meshroom and Pix4Dmapper software, as there exists a limitation in the AliceVision Meshroom. The alternative way to encounter the issue has been done and the models obtained have been improved in scale and orientation. However, there are still slightly different results from both software in terms of accuracy; the MAE was not the same, but they are within the acceptable range. Both AliceVision Meshroom and Pix4Dmappe software were considered user-friendly and user convenient processing environment, but Pix4Dmapper still provides better processing advantages than AliceVision Meshroom. Next, the research goal and objectives have been achieved successfully. The research study's outputs of the 3D point cloud and 3D mesh model are obtained from AliceVision Meshroom and Pix4Dmapper. In addition, the evaluation of the model's accuracy from AliceVision Meshroom and Pix4Dmapper software with the benchmark (TLS model) has been done.

To summarise the data analysis, the open-source software AliceVision Meshroom can be used in 3D reconstruction modelling work but is unsuitable for surveying work. This software provides the 3D modelling modules, and the general visualisation and presentation of the model are considered reasonable and acceptable for 3D reconstruction work. Besides, this software also allows users to customise the reconstruction process in the provided modules. However, to fulfil the surveying and mapping purposes, this software cannot be the standalone software to complete the task of producing orthophoto. This is due to the limitation of lacking an orthophoto generation module, which significantly affects this software's ability.

Moreover, the outputs in the .abc file format are not readable by usual surveying software and need to be imported into third-party software to convert into a .obj file format. Apart from that, georeferencing is also required with the help of other software to get a scaled and oriented model similar to the actual model (MAE = 0.035m in this research study). Thus, this software's functionality is limited to the 3D model reconstruction and is not suitable for mapping purposes using this software alone, but can be encountered with the involvement of third-party software. Users have to accept the limitation, and the lower quality products were obtained with less dense point cloud and less detailed texture. On the other hand, the commercial software, Pix4Dmapper, showed better performance in various aspects, including the texture of details, the accuracy, the ability of the software, faster processing time and the denser point cloud. Overall, this software is the better choice for the photogrammetry application since this software offers multiple built-in modules to fulfil the daily photogrammetry and surveying purposes. Even though it is paid and the software cannot modify the processing module, the output types of Pix4Dmapper are more applicable for all surveying purposes.

Moreover, the ability of georeferencing and generation of orthophoto is another bonus point for this software, making it a better choice than AliceVision Meshroom. This helps the user to save more time and work as the user can perform these tasks within one software. Thus, Pix4Dmapper can be a standalone software with the high accuracy models provided (MAE = 0.016m in this research study) and consistent 3D triangulation mesh with detailed textures.

Some recommendations were presented in this section as a reference for future studies on the related topics. First, this study has only focused on the 3D modelling of the building. The ability to generate the orthomosaic is just an additional point found during the process. Apart from the ability to carry out 3D as-built modelling, various kinds of photogrammetry applications in medical rehabilitation, archaeology, architecture and many more can be tested in future studies. This could significantly impact the exploration of photogrammetry in the non-surveying field. The prospective study can be extended to different camera models to capture the input photographs. The camera used in this study is the drone camera, where the process of camera calibration is done outside the photogrammetry software involved in this study. Future studies on the metric and non-metric cameras can also be done with the implementation of a DSLR or smartphone camera to test the ability of the camera calibration using the photogrammetry software. Next, the accuracy of the vertical heightening of the product can also be involved in the assessment for the software comparison as it is also crucial in surveying and mapping applications. Last but not least, different software can also be involved in the future study to get an overview of the comparison between open-source and commercial photogrammetry software.

In short, the commercial software, Pix4Dmapper, helps the user purchase high-quality and efficient services with multiple built-in modules that can handle most photogrammetry applications (building as-built survey in this study). In contrast, the AliceVision Meshroom can only perform the 3D reconstruction modules with standalone software. The help can make the as-built survey application using AliceVision Meshroom of third-party software to perform the georeferencing for the scaling and orientation manner to achieve surveying purposes.

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