RESEARCH ARTICLE

3D Modelling for Borneo Cultures Museum: UAV Photogrammetry

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Abstract

Three-dimensional (3D) modelling can be reconstructed using various methods such as terrestrial laser scanning and unmanned aerial vehicle (UAV) photogrammetry. However, limited studies have compared the performance of different UAV photogrammetry software in modelling buildings at varying flight altitudes, especially regarding accuracy and visual quality. This study evaluates UAV photogrammetry for 3D modelling of the Borneo Cultures Museum in Kuching, Sarawak. Images were captured using a DJI Phantom 4 drone with the point of interest (POI) technique at two flight altitudes, 50 m and 60 m. Ground control points (GCPs) were placed using GNSS observations, while verification points (VPs) were collected with a total station. The 3D models were reconstructed using Agisoft Metashape and ContextCapture software. Although ContextCapture produced visually better 3D models despite incomplete coverage, Agisoft Metashape delivered higher geometric accuracy with lower RMSE values. At 50 m, the RMSE for Agisoft and ContextCapture was 0.047 m and 0.090 m, respectively; at 60 m, it was 0.045 m and 0.065 m. These findings suggest that while ContextCapture excels in visual output, Agisoft Metashape is more precise, highlighting the trade-off between model quality and measurement accuracy in UAV-based 3D reconstruction.

Keywords: *3D; building; model; measurement; accuracy*

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Introduction

Three Dimensional or known as 3D is a process of developing a mathematical representation from image of 2D using a specific software and 3D modelling is a process to create a 3D object using 3D modelling programs (Ghani et al., 2019; Abd Aziz et al., 2021). In architectural and engineering field, the 3D modelling can be applied and been used to visualise as well as simulate the buildings, bridges, dam and other structures. While, in the entertainment industry, the 3D modelling has been used significantly for creating the digital characters, special effects and the environments for the films and video games. In addition, the 3D modelling also been used in other fields such as cultural heritage where it is to create the digital representation of the historical artifact and cultural spaces.

Recently, drone technology or also known as Unmanned Aerial Vehicles (UAV) have been popular and widely been used nowadays due to its development that fulfil the needs of the current technology. Therefore, in perspective of surveying, the UAV has been used in photogrammetry survey where it will capture the images of the desired site from different angle in order to create and generate the 3D models. Moreover, one of the advantages using UAV photogrammetry is where it only required a minimum of fieldwork rather than the conventional survey work as it has the capacity in direct, rapid and detailed image capture of the site area (Jiménez-Jiménez et al., 2021). In addition, UAV photogrammetry is commonly employed in terrain modeling, natural hazards assessment, agricultural research, mining operations, civil engineering projects, and the documentation of cultural heritage sites (Yilmaz et al., 2022). In the study by Yuan et al. (2023), they had been developed an apple blossom density mapping through UAV with the utilising of the algorithm by reconstructing the point clouds using the commercial 2 photogrammetry software. Besides, the UAV photogrammetry also been used in conducting the bathymetric survey for the shallow waters that not exceeding a depth of 1 meter together with a known margin of error (Del Savio et al., 2023).

Thus, the combination of the 3D modelling using UAV photogrammetry enable to create a high detailed and accurate of 3D model for the large-scale environments such as landscape, buildings, and archaeological sites. The UAV has been widely used in archaeological studies due to its cost-effective and a simple photogrammetric tool which can produce a high-resolution scaled model (Manajitprasert et al., 2019; Kabdayi et al., 2020). There had been a study by Zhou et al. (2021) where it applied the UAV tilt photography to create a 3D modelling of an urban real scene and the study has proved that the method of UAV was efficiently, faster and collecting more information compared to the traditional method. As the 3D modelling required a specific software in order to process and generate it, there are a few commercial software that mostly been used such as Pix4D Mapper, Agisoft PhotoScan, DroneDeploy, EyesMap3D, Context Capture and Photomodeler UAS. The most well-known paid for the processing of the aerial imagery and photogrammetry are Agisoft PhotoScan and Pix4D which have a simple user interfaces and comprehensible manuals together with an establishment of the tracking record for the purpose of professional aerial mapping applications (Noor et al., 2019; Jebur et al., 2020). In previous study of author (Hinge et al., 2019), it compared four different software packages to produce a 3D model of the golf course where it concludes that Pix4D and DroneDeploy are the best for modelling the local elevations as it can provide the best 3D perspective of the gold course. While, Agisoft PhotoScan has the highest resolution on the mesh and EyesMap3D can be the most accurate which might be able in providing the best 3D modelling for all the used software.

Unmanned Aerial Vehicle (UAV) photogrammetry has become a widely adopted method for 3D modelling due to its cost-effectiveness, flexibility, and high-resolution image capture capabilities. Several studies have compared the performance of different photogrammetric software in reconstructing 3D models of built structures. For instance, Agisoft Metashape and ContextCapture are frequently used due to their robust image processing algorithms and user-friendly interfaces. However, existing literature often focuses on either visual inspection or accuracy metrics independently, rather than evaluating both dimensions comprehensively. Some researchers, such as Nex and Remondino (2014), emphasize geometric accuracy, while others prioritize texture and model aesthetics (Chiabrando et al., 2017). This lack of integrated evaluation creates uncertainty in determining which software provides the optimal balance between visual fidelity and metric accuracy, particularly in complex urban environments.

Moreover, flight parameters such as altitude, image overlap, and camera angle have been shown to significantly influence the quality of 3D reconstructions (Turner et al., 2012; Mesas-Carrascosa et al., 2016). Nonetheless, many studies limit their analysis to a narrow range of flight altitudes or a single set of conditions, making it difficult to generalize findings across different scenarios. In particular, there is limited research examining the effect of varying flight altitudes on both the completeness and precision of 3D models in the context of vertical structures such as buildings. Exploring a wider range of altitudes and integrating this with performance assessments across multiple software platforms could offer a more holistic understanding of UAV photogrammetry's capabilities and limitations in architectural and heritage documentation.

Therefore, the aim of this is to evaluate the performance of UAV photogrammetry in 3D modelling of a building. The objectives of this study are to acquire UAV images from different altitudes, to investigate the processing techniques of 3D modelling reconstruction using Agisoft Metashape and ContextCapture as well as to validate the 3D model results with actual data measurement

Material and Methods

In this study, the research methodology was structured into four phases. Phase one, which constituted a preliminary study, involved selecting the study area, determining the types of instruments used, and selecting appropriate software. Phase two is data acquisition that included flight planning, establishment of GCPs around the museum as well as obtaining the VPs that located on the museum. Phase three is data processing of two different commercial photogrammetric software that were Agisoft Metashape and Context Capture. This two software were used to reconstruct a 3D model with five steps for Agisoft Metashape and three steps for Context Capture. Phase four is data visualisation where the final of 3D model that generated from two different software and phase five is data analysis where it consists of analysis based on objectives in this research. Figure 1 illustrates the detailed methodology employed in this study.

Phase 1: Preliminary Study

The study was conducted at the Borneo Cultures Museum in Kuching, Sarawak, which spans approximately 31,000 m² and comprises a five-storey structure. This site was selected due to its architectural complexity, vertical elements, and cultural significance, making it an ideal subject for evaluating the performance of UAV photogrammetry in detailed 3D building modelling. Notably, it is the second largest museum in Southeast Asia, further highlighting its relevance for large-scale reconstruction assessment. For instruments, GPS, total station and a drone were used to collect the data of UAV images together with the coordinates of GCPs and VPs. A set of SinoGNSS T300 series was used to obtain the coordinates for GCPs, and a total station of Topcon GM-50 series was used to obtain coordinates of VPs. While a drone that used was DJI Phantom 4 to capture the images of the museum. For the software, Pix4D Capture was used to plan the flight missions with conducting circularly around the museum. Moreover, the photogrammetric software utilized in this study, namely Agisoft Metashape and Context Capture, were both employed to reconstruct 3D models for analysis alongside actual measurements.

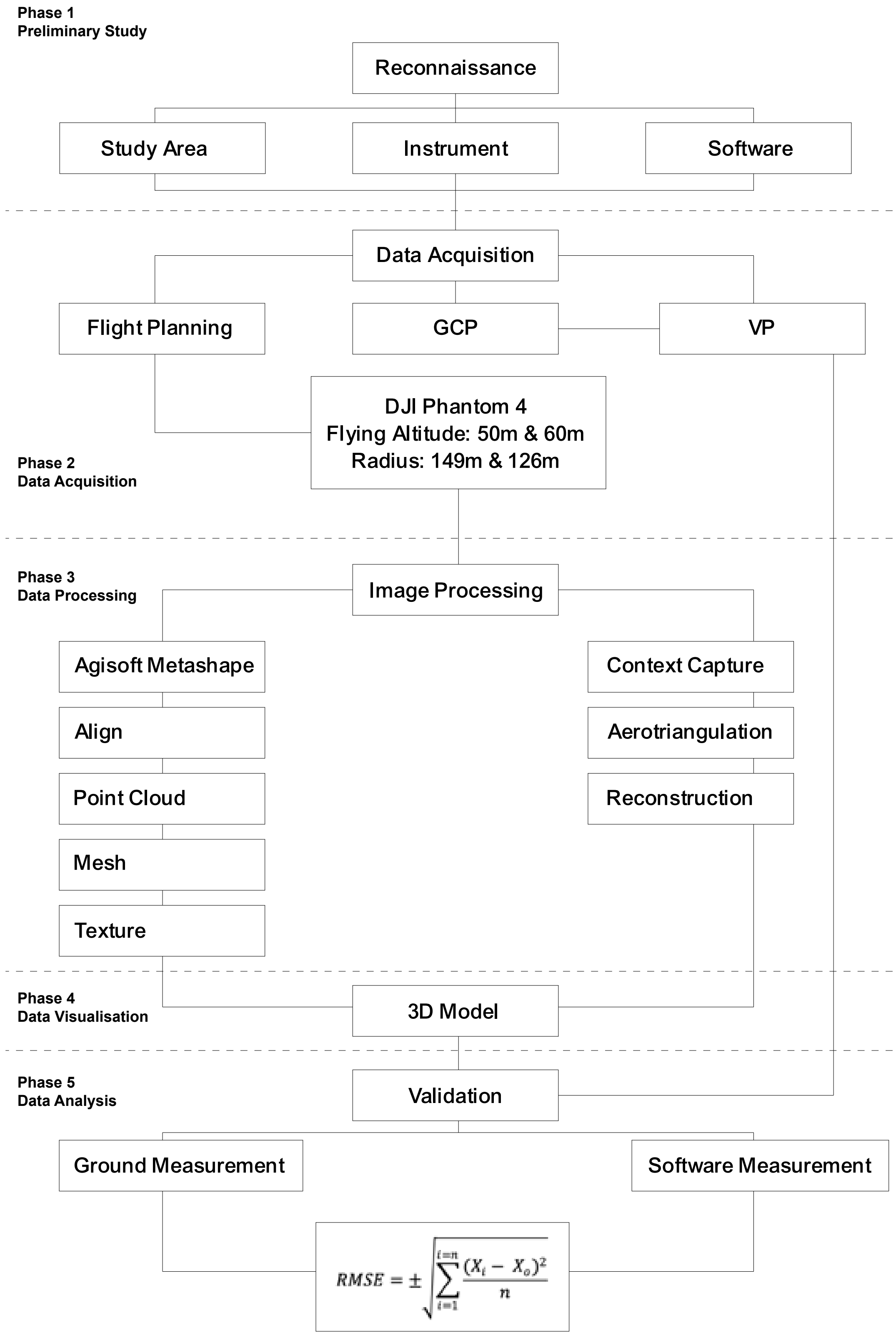


Figure 1: Detail Methodology

Phase 2: Data Acquisition

Flight planning was done before capturing the UAV images using DJI Phantom 4 with a few parameters that had been set up such as the altitude, radius and image angle. The flight mission technique that has been used in this study was POI or also known as circular where the flight path will be circular around the building which the images cover all the areas of the museum. There were two different altitudes were used in this study that were 50m and 60m with radius 149m and 126m respectively. A total of four GCPs were established around the museum by referring to two origins that were SS5474 and SS5475. In addition, GCPs been used to be reference station for obtaining thirty VPs on the building as it used to validate the accuracy of 3D model of two different software with the actual data measurement that collected using total station. The length of every two VPs were calculated using excel and the total number of lengths was fifteen which it been used as sample to validate with 3D model of two different software.

Phase 3-5: Data Processing, Data Visualisation and Data Analysis

Two distinct commercial software packages, namely Agisoft Metashape and Context Capture, were utilized in this study to reconstruct a 3D model. The processing steps in Agisoft Metashape were aligning the images to produce point cloud, meshing the model, texturing the model and tiled model that was final outcome of 3D model. The first process was aligning the collected images automatically according to the sequences of the images as well as the accuracy that been used in this process was highest. Next processing technique was generating the point cloud where the point cloud in this this software is representing the 3D model for the museum which was generated from the overlapping images in the process of aligning images. After completing the point cloud, the meshing of the images had been done where mesh is made from a series of the interconnected of the triangles that will define the shape of the desired 3D model. Thus, in this software where the image will be a 3D surface model that been created using the output of point cloud in previous process. In order to make the 3D model become more realistic, the model needs to undergo the texture processing part which is the texture processing part is where the images were textured from a 2D image to a 3D model in order to give the model become more realistic appearance. This process required after completing the previous process that is mesh which in this process the output of the model more quality rather than before. Lastly, the model had been tiled in order to reconstruct the final of 3D model in this software. A tiled model is a 3D model that had been divided into a small tiled which make it easier to load and render the model. While, in Context Capture, it consists of three steps of processing including production of 3D model that were aerotrinagulation, reconstruction and 3D model. Before the processing of aerotriangulation, the photos were imported into this software where the focal length and sensor size were determined automatically in order to proceed with the next step. Following that, aerotriangulation was conducted, aiming to determine the precise photogroup properties of each input photogroup and the pose of each input photograph. This process involved calculating the position and rotation of every image, ensuring that all images were utilized in the subsequent step. This processing step also generates the tie points automatically in order to be used for reconstruction. Reconstruction is a process where to manage a 3D reconstruction framework which includes the spatial framework, region of interest and tiling, geometric precision and 55 reference 3D model. Thus, the parameter in geometric precision was set as default. The point clouds able to be seen by viewing the 3D view in this process. Production is where the process of 3D model after being retouched in order to get the desired 3D model. The processing setting was set as default which at the end, the 3D model was generated and able to be used for data analysis. After undergone all of these processing steps in this two software, a final of 3D model was generated which used to validate with the actual measurement for obtaining the RMSE value as well as comparing the reconstruction of the 3D model itself.

Results and Discussion

In this study, the 3D model was developed based on varying altitudes and radius, with the reconstruction carried out using two distinct commercial software packages. Two altitudes and radius were used that were 50m and 60m with radius of 149m and 126m together with dimensions 203m x 218m and 176m x 179m respectively. Both altitudes and radius used image angle with 10°. Figure 2 shows some of UAV images from four point of view for both altitudes.

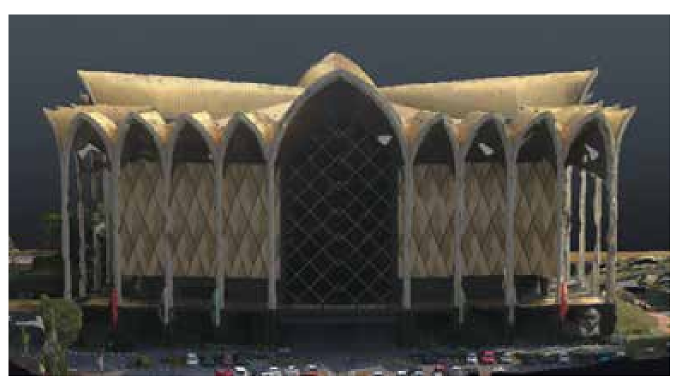
(a)

(b)

Figure 2: UAV Images; (a) Altitude 50m and Radius 149m, (b) Altitude 6m and Radius 126m

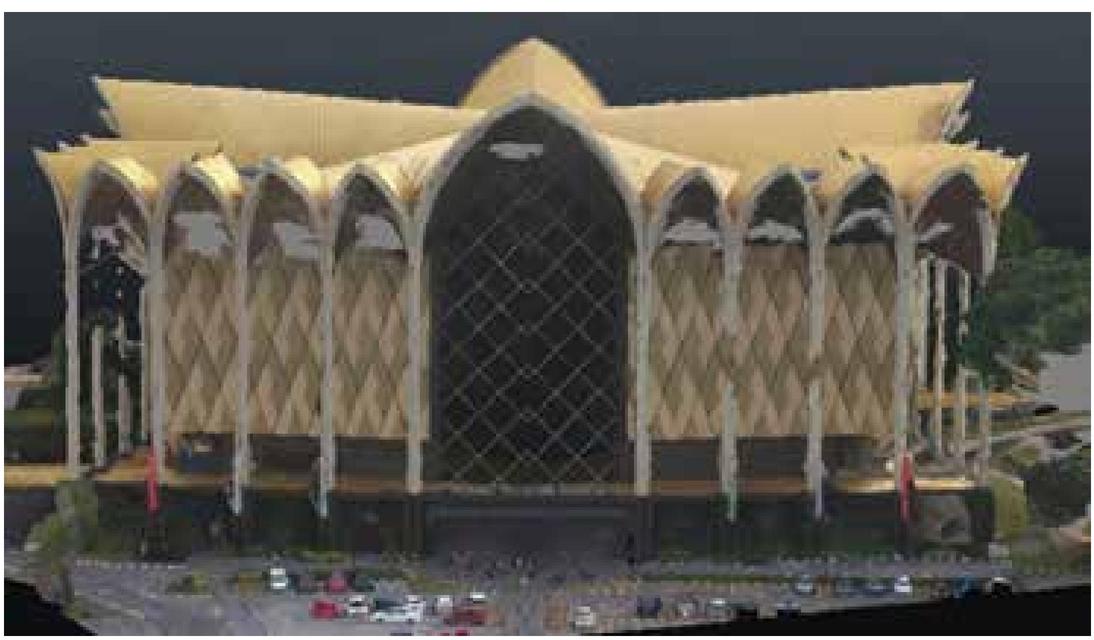
Based on the results of UAV images, the lower and farther the radius from the building where the angle was same, the more area can be captured in one image. All these UAV images was used to generate a 3D model by using two different software that were Agisoft Metashape and Context Capture. Figure 3 shows the 3D model for this two software of 50m and 60m altitudes.

(a)



(b)

(c)

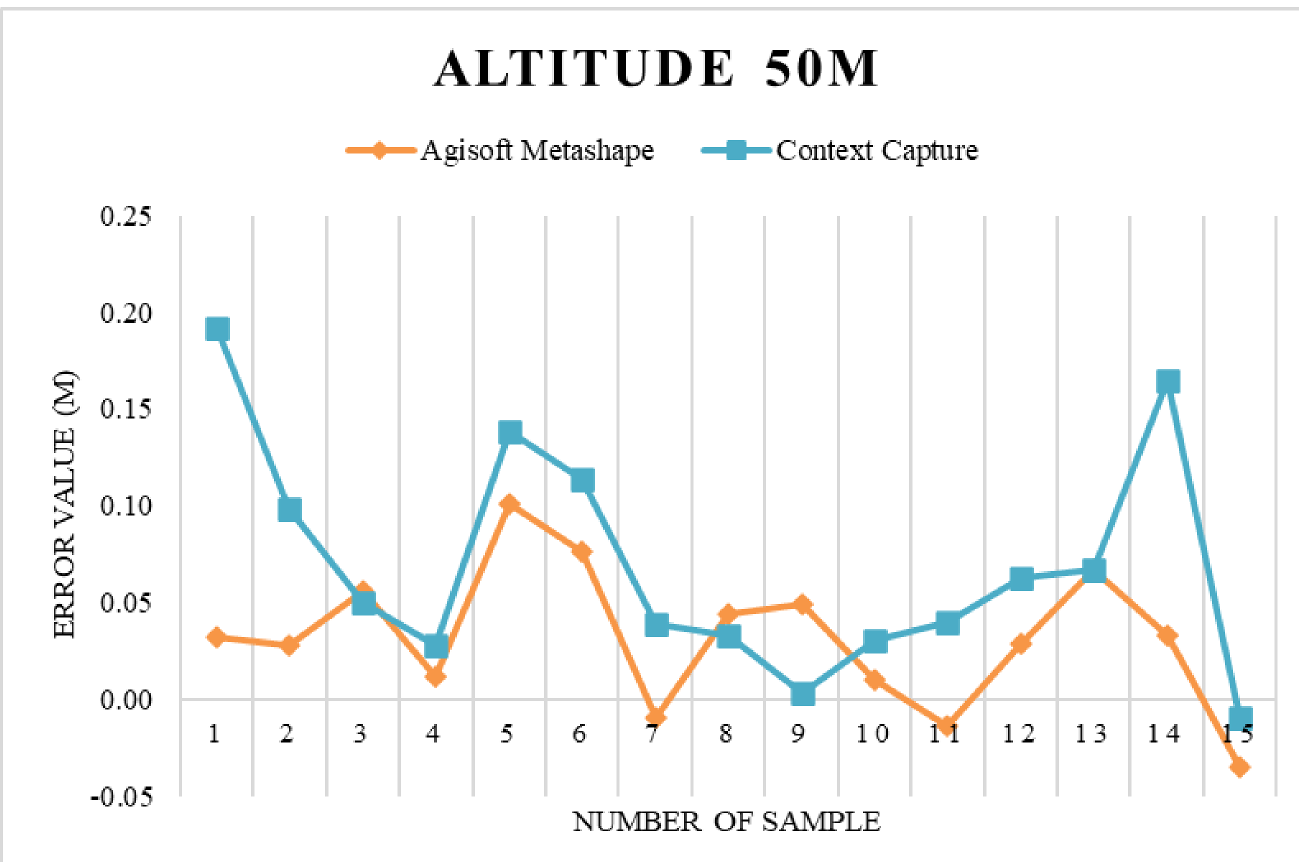


(d)

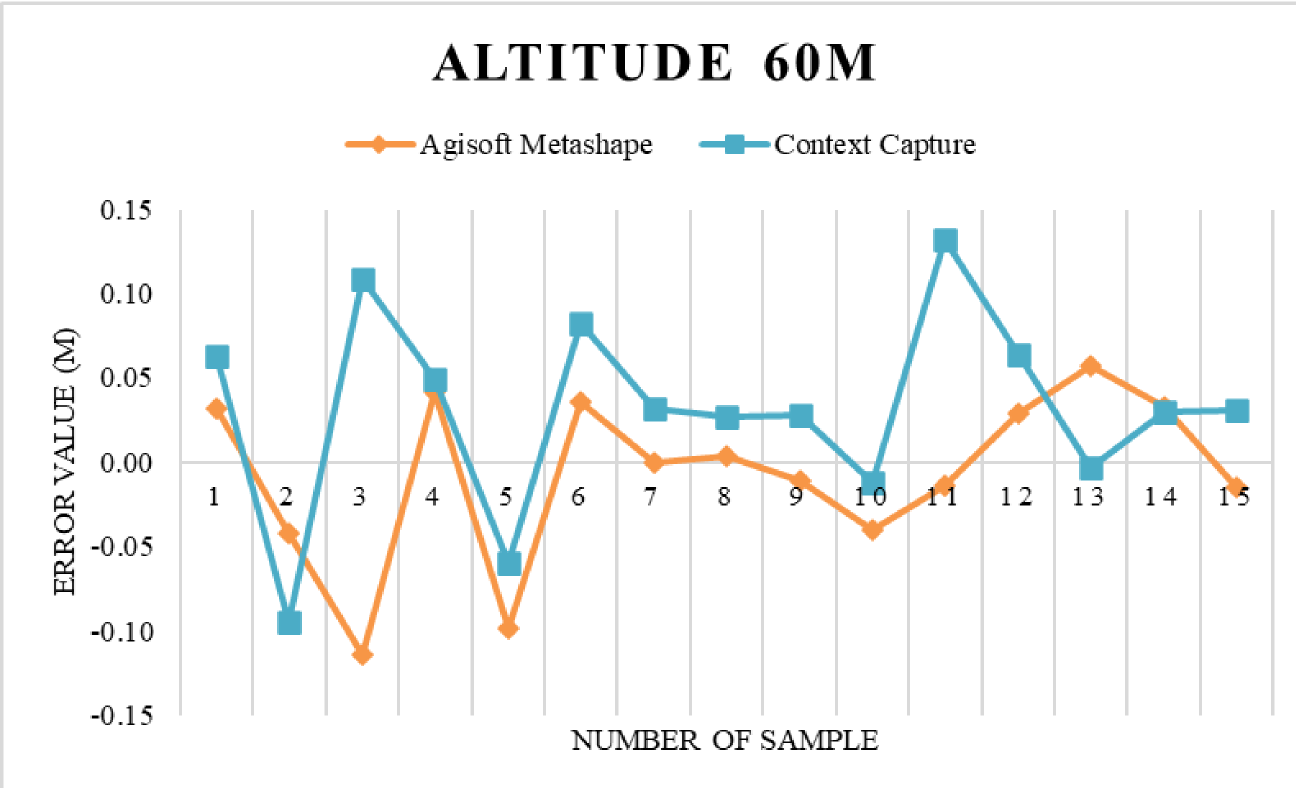
Figure 3: 3D Model; (a) Agisoft Metashape with 50m Altitude, (b) Context Capture with 50m Altitude, (c) Agisoft Metashape with 60m Altitude, (d) Context Capture with 60m Altitude

The result shows there were many uncovered areas for the image taken, especially image the below the roof as it shows the hole after the reconstruction of the 3D model for both software. Besides, the hole for Agisoft Metashape is much bigger than in Context Capture where make the 3D model looks like not fully generated. Thus, the area below the roof in Context Capture generated much better than Agisoft Metashape which for 50m altitude. While, for 60m altitude, one side of the museum was not covered very well as the image taken was captured closer to the museum. Thus, the 3D model suffered from some distortion which made the model does not same as the reality. However, the 3D model using Agisoft Metashape reconstructs much better than Context Capture although the area was not covered very well as it was interpolated and made same as the model.

Therefore, a comparison between the model of the museum and actual measurements was calculated and evaluated. The error value from the evaluations were illustrated in Figure 4. The error value for fifteen samples between two different software that are Agisoft Metashape and Context Capture with the altitude is 50m shows that the highest error among the two software is 0.19m which is in Context Capture while the lowest error is 0.01 which also equivalent to -0.01 that is in Agisoft Metashape. The error between this two software is having a big difference which affects the RMSE value as well as the accuracy. For altitude 60m, the error value in Agisoft Metashape is the highest, that is -0.11. However, the lowest error for both software is 0.00 which consists of no error at all that is in Agisoft Metashape. This shows that Agisoft Metashape has the best accuracy rather than Context Capture as it has a lot of lower values of error which makes the RMSE value become lower.



(a)



(b)

Figure 4: Error Value of Agisoft Metashape and Context Capture; (a) Altitude 50m, (b) Altitude 60m

From the error values of two software, RMSE can be calculated by using equation (1). In this study, the comparison of RMSE values for both software and altitudes is shown in Figure 5 where Context Capture for 50m altitude has the highest value of RMSE. This shows that the accuracy for Context Capture software is low while the accuracy for Agisoft Metashape is high as the RMSE is the lowest especially in 50m altitude. In Agisoft Metashape, the RMSE for both altitudes is no big difference while Context Capture software has a big difference for both altitudes. Other than that, in 50m altitude, RMSE between Agisoft Metashape and Context Capture have big difference where RMSE for Agisoft Metashape is lower than Context Capture that are 0.047 and 0.090 respectively. This shows that Agisoft Metashape has a better in term of accuracy as the lower the RMSE value, the higher the accuracy. Besides, in 60m altitude, RMSE value for Agisoft Metashape is 0.049 and Context Capture is 0.065 where Context Capture has higher value of RMSE value. Thus, the accuracy in Context Capture is lower as the RMSE value is higher.

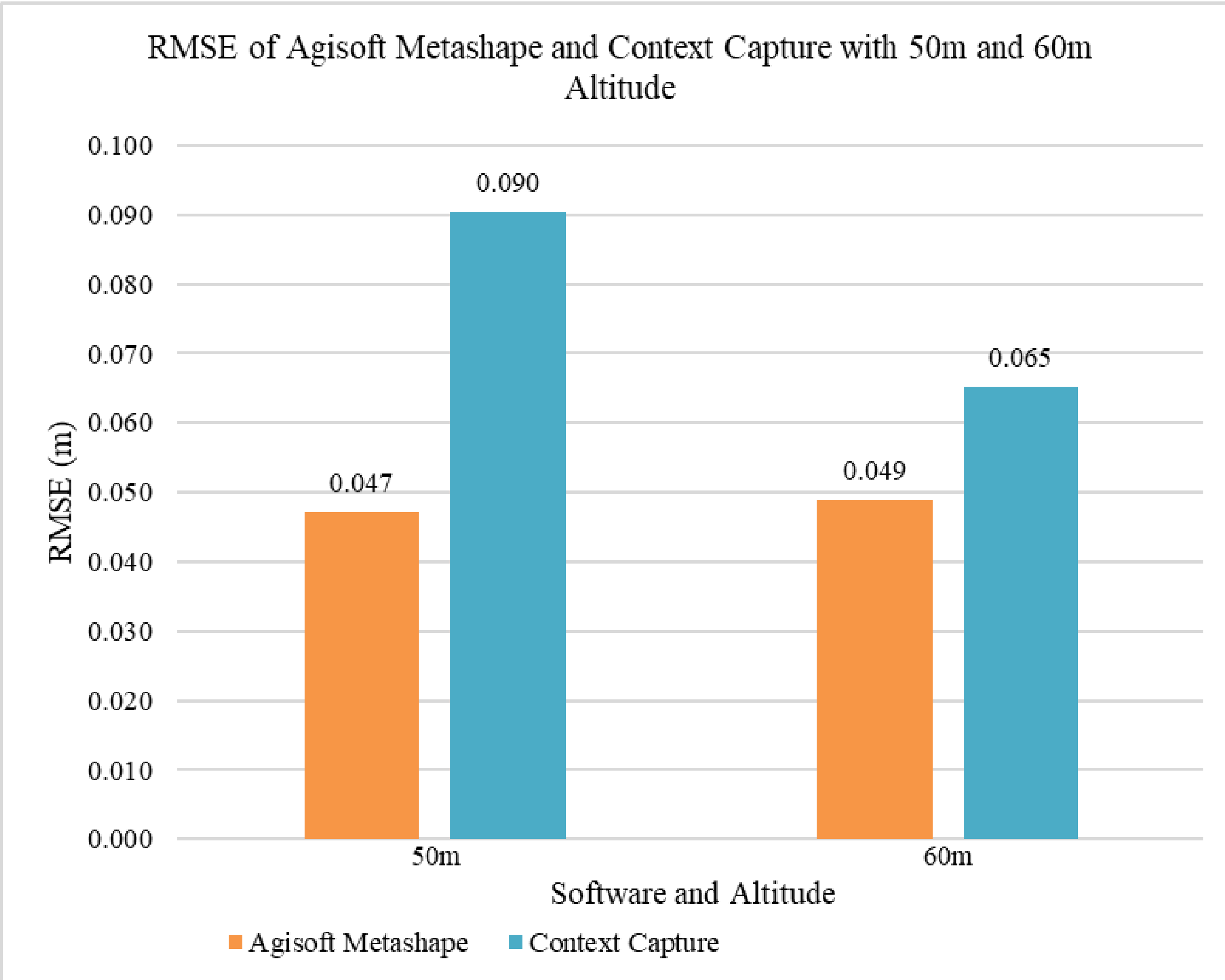


Figure 5: RMSE of Agisoft Metashape and Context Capture with 50m and 60m Altitude

According to previous study by Jebur et al. (2020) about 3D modelling and the RMSE was equal to 0.277m. Besides, another study of 3D model by Ab Aziz et al. (2021) obtained 0.195m of RMSE value. While, in another study by Kabadayı et al. (2020) was obtained 0.022m. Thus, the findings in this study were accepted as the RMSE values were within an acceptable range of value as well as the tolerance limit.

Conclusions

In this study, a DJI Phantom 4 was used to compare two software, Agisoft Metashape and Context Capture, for reconstructing a 3D model of a museum. Agisoft Metashape required more processing steps but yielded higher accuracy with lower RMSE and able to obtain no error values compared to Context Capture which obtained higher error values, 0.190m. However, Context Capture produced a better 3D model even with incomplete coverage, suggesting it may be preferable for challenging reconstruction tasks. Each software was affected by capture distance, with closer shots leading to less detail and impacting reconstruction accuracy. Despite the promising results obtained in this study, several research gaps remain. First, although ContextCapture produced visually superior 3D models, Agisoft Metashape demonstrated higher geometric accuracy based on RMSE values. This highlights a critical gap in understanding the trade-offs between visual quality and spatial accuracy in UAV-based 3D modelling. Second, this study was limited to two flight altitudes (50 m and 60 m), indicating the need for further investigation into a broader range of flight parameters to comprehensively assess their impact on 3D reconstruction quality and precision. Overall, the choice between Agisoft Metashape and Context Capture depends on the specific needs and priorities of the project. Thus, from this study, there was several suggestions for improvement of UAV photogrammetry. First, carefully consider the altitude and radius around the building of interest to maximise detail in the 3D model. Lower and farther pictures capture more features. Second, for areas with obstacles, take multiple photos from different angles to ensure complete coverage in the 3D model. Lastly, match the software used to the processing power of computer used, as processing time increases with the size of the area scanned.

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References

Ab Aziz, A. A., Muhammad, M., Sulaiman, A., A., & Tahar, K. N. (2021). Reconstruction of 3D Building Model Using Point of Interest Technique at Different Altitude and Range. *IOP Conference Series: Earth and Environmental Science*, *767*(1), 012010–012010. https://doi.org/10.1088/1755-1315/767/1/012010

Chiabrando, F., Nex, F., Piatti, D., & Rinaudo, F. (2017). A Comparison Among the Methods for 3D Modelling of Small Objects: Photogrammetry and Structured Light Scanning. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W3, 149–154.* https://doi.org/10.5194/isprs-archives-XLII-2-W3-149-2017

Del Savio, A. A., Luna Torres, A., Vergara Olivera, M. A., Llimpe Rojas, S. R., Urday Ibarra, G. T., & Neckel, A. (2023). Using UAVs and Photogrammetry in Bathymetric Surveys in Shallow Waters. *Applied Sciences, 13*(6), 34-20. https://doi.org/10.3390/app13063420

Ghani, D. A., Supian, M. N. Bin, & Abdul 'Alim, L. Z. Bin. (2019). The Research of 3D Modeling Between Visual & Creativity. *International Journal of Innovative Technology and Exploring Engineering, 8*(2), 180–186. https://doi.org/10.35940/ijitee.K1029.09811S219

Hinge, L., Gundorph, J., Ujang, U., Azri, S., Anton, F., & Rahman, A. A. (2019). Comparative Analysis of 3D Photogrammetry Modeling Software Packages for Drones Survey. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42*(4/W12), 95–100. https://doi.org/10.5194/isprs-archives-XLII-4-W12-95-2019

Jebur, A. K., Tayeb, F. A., & Jawad, Z. S. (2020). Show the Potential of Agisoft Photoscan Software to Create a 3D Model for Salhiyah Residential Complex in Baghdad Based on Aerial Photos. *IOP Conference Series: Materials Science and Engineering, 745*(1). https://doi.org/10.1088/1757-899X/745/1/012132

Jiménez-Jiménez, S. I., OOjeda-Bustamante, W., de Jesús Marcial-Pablo, M., & Enciso, J. D. (2021). Digital Terrain Models Generated with Low-Cost UAV Photogrammetry: Methodology and Accuracy. *ISPRS International Journal of Geo-Information, 10*(5), 1–27. https://doi.org/10.3390/ijgi10050285

Kabdayi, A., Kaya, Y., & Yiğit, A., Y. (2020). Comparison of Documentation Cultural Artifacts using the 3D Model in Different Software. *Mersin Photogrammetry Journal, 2*(2), 51–58.

Manajitprasert, S., Tripathi, N. K., & Arunplod, S. (2019). Three-dimensional (3D) Modeling of Cultural Heritage Site using UAV Imagery: A Case Study of The Pagodas in Wat Maha That, Thailand. *Applied Sciences (Switzerland), 9*(18). https://doi.org/10.3390/app9183640

Mesas-Carrascosa, F. J., Torres-Sánchez, J., Clavero-Rumbao, I., García-Ferrer, A., Peña, J. M., & Borra-Serrano, I. (2016). Assessing Optimal Flight Parameters for Generating Accurate Multispectral Orthomosaicks by UAV to Support Site-Specific Crop Management. *Remote Sensing, 8(*10), 873. https://doi.org/10.3390/rs8100873

Nex, F., & Remondino, F. (2014). UAV for 3D Mapping Applications: A Review. *Applied Geomatics, 6*(1), 1–15. https://doi.org/10.1007/s12518-013-0120-x

Noor, N. M., Afiq, A., Abdullah, A., Abdullah, A., Ibrahim, I., & Sabeek, S. (2019). 3D City Modeling Using Multirotor Drone for City Heritage Conservation. *Journal of the Malaysia Institute of Planners, 17*.

Turner, D., Lucieer, A., & Watson, C. (2012). An Automated Technique for Generating Georectified Mosaics from Ultra-High Resolution UAV Imagery, based on Structure from Motion (Sfm) Point Clouds. *Remote Sensing, 4*(5), 1392–1410. https://doi.org/10.3390/rs4051392

Yilmaz, H. M., Aktan, N., Çolak, A., & Alptekin, A. (2022). Modelling a Village in Computer Environment using UAV Photogrammetry. *Mersin Photogrammetry Journal*. https://doi.org/10.53093/mephoj.1132303

Yuan, W., Hua, W., Heinemann, P. H., & He, L. (2023). UAV Photogrammetry-Based Apple Orchard Blossom Density Estimation and Mapping. *Horticulturae, 9*(2). https://doi.org/10.3390/horticulturae9020266

Zhou, T., Lv, L., Liu, J., & Wan, J. (2021). Application of UAV Oblique Photography in Real Scene 3D Modeling. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 43*(B2-2021), 413–418. https://doi.org/10.5194/isprs-archives-XLIII-B2-2021-413-2021