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Unmanned Aerial Vehicle (UAV) Photogrammetry for Heritage Building Documentation

A Case Study on Sasaksaat Train Station, Bandung, Indonesia

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Abstract – Historic buildings are silent witnesses, bridging past, present, and future generations. The Sasaksaat Railway Station, which is inseparable from the 950-meter-long Sasaksaat Tunnel, is a treasure trove of historical heritage in West Java; it holds many stories and memories that are very closely related to the nation's history, protected by Law Number 11 of 2010 concerning Cultural Heritage. This station is located in contoured land filled with dense vegetation, so a UAV photogrammetry method is needed following the character of the building and the area to be documented. The research documentation on these historical sites employs the UAV photogrammetry method, combining crosshatch flight plans, 60-degree tilt camera configurations, and making 3D BIM models using point cloud photogrammetry techniques. The research yielded impressive results, demonstrating the effectiveness of UAV Photogrammetry in accelerating the process of archiving historic buildings and their surroundings. The integration of this method significantly improves the documentation workflow, enabling comprehensive and detailed recording of the Sasak railway stations. This ANOVA test found no significant difference between manual size comparisons and photogrammetric results, even using direct geo-reference via UAV technology. The ease and reliability of this method approach can be recommended for low-cost historic building documentation activities.

Keywords: *heritage BIM, oblique camera, point cloud, 3D model.*

I. INTRODUCTION

Preserving historic buildings is essential in protecting and maintaining a Nation's cultural and historical heritage. Historic buildings are priceless because they represent an area's development and reflect a community's identity. In addition, historical buildings are silent witnesses that connect past, present, and future generations. Historic buildings possess symbolic, solid, and emotional value to society (Putri & Adishakti, 2023). They keep stories and memories of the past and become an essential reference in the history of a region. Moreover, in various areas of Indonesia, they have tangible and intangible heritage assets (BPPI, 2013). Thus, preserving historic buildings is about maintaining the physical appearance, emotional connection, and cultural identity.

One of the heritage buildings currently properly preserved is the Sasaksaat Train Station, inseparable from the longest Sasaksaat tunnel, Sumurbandung, Cipatat, West Bandung. This station includes two rails; line 1 is for crossing while line 2 is straight track. The western side of the train station will pass through the Sasaksaat Tunnel for 950 meters to Jakarta, while to the east, the train station will pass through the Cikubang Bridge for 300 meters to Bandung. Sasaksaat Tunnel was built in 1902 by the State Railway Company, Staatsspoorwegen. The Sasaksaat Station Complex is equipped with six official houses that were uninhabitable because they were devastated. Stasiun Sasaksaat is a cultural heritage building owned by PT KAI, protected under Law No. 11 of 2010 on Cultural Heritage. Documenting important heritage buildings is essential to ensure their preservation for succeeding generations. Documentation serves various functions, including archiving, conservation, preservation, and education. Documenting heritage buildings, particularly in a user-friendly digital format, involves converting physical structures into digital representations. These digital documents are instrumental in archiving and ongoing monitoring, safeguarding historical assets, and fulfilling diverse objectives (Putri & Adishakti, 2023).

Preservation of historic buildings conveys immense importance as a tribute to the past. Previous research has examined various methods and techniques for documenting historical buildings to produce accurate and comprehensive information (Remondino, 2011). Technological developments have delivered significant changes in documentation methods, including the growing use of digital technology. Historical building documentation methods have evolved from manual, semi-digital to fully digital. Digitalisation has opened up unprecedented opportunities to preserve historic buildings, including using 3D modeling to reconstruct and visualize buildings digitally. This documentation method provides more significant benefits than conventional photo and video documentation (Dewi, 2020).

Digitization or 3D virtualization based on photographs, nowadays, represents an excellent approach to cultural heritage, specifically in unmanned aerial vehicles (UAVs) data collection photogrammetry surveys (Carvajal-Ramírez et al., 2019). The 3D digitization of buildings in the field of historic building preservation helps in better archival maintenance and allows experts and researchers to easily obtain this information in the future (Rodríguez-Martín & Rodríguez-Gonzálvez, 2020). Conservation is a follow-up effort to protect and preserve the architecture and the environment after an artifact is broken down to maintain its sustainability because it secures a robust social-cultural bond with a community in the area because its cultural meaning contains a historical value, architectural beauty, scientific value, and social value (Zain, 2014).

Photogrammetry, specifically Structure from Motion (SfM), is among the techniques for digitizing historic buildings. Active scanning systems have been prominent in recent years. SfM, on the other hand, has become very versatile and integrated and combined into numerous types of platforms (Rodríguez-Martín & Rodríguez-Gonzálvez, 2020). This technique enables the transfer of physical items from the location into a digital form with retained material qualities, which is crucial for archiving, routine monitoring, and granting communities unrestricted access to preserve cultural heritage. The basis for the reconstruction is solid proof and reliable documents (Kingsland, 2019).

The SfM approach is increasingly universal because it requires no elaborate equipment or expertise; it is more economical because it requires a typical photographic camera and lens (Barazzetti et al., 2011). A UAV photogrammetry system is a photogrammetry procedure performed remotely without a pilot operating in the vehicle, operated semi- or automagically (Eisenbeiss, 2009). Overlapping photos are crucial for proper 3D reconstruction. A minimum of 60% overlap is ideal to avoid unnecessary post-processing (Durou et al., 2020).

This study discusses the technique of documenting historic buildings employing the photogrammetric method using the UAV (Unmanned Aerial Vehicle) to document the building and the surrounding area. This technology collects and processes photogrammetric data to produce point clouds integrated with various 3D modeling platforms. It complements the existing documentation by producing a 3D model of the building and the surrounding area (Yang et al., 2022). Manual measurements are used as dimensional controls obtained, comparing the results of digital point cloud measurements and measurements in the locus. Furthermore, the data can be integrated into the HBIM (Historic Building Information Modeling) format for storage and further research (Sun & Zhang, 2018). Historic buildings are digitally documented throughout their life cycle through HBIM to preserve critical information and maintain the character of the building (Albourae et al., 2017). This research aimed to recognize the results of using the cross-flight UAV data collection method with a flying altitude of 70 meters and a camera tilt setting of 60 degrees and whether it can produce good building and area documentation data. The Sasaksaat station was designated because it witnessed the history of the development of the Greater Bandung area and the cities around it.

II. LITERARY REVIEWS

A. UAV Photogrammetry Concept

A UAV Photogrammetry measurement platform comprises a photogrammetric measuring system that functions without a pilot physically on the platform, instead being controlled remotely, semi-automatically, or autonomously. UAV capture images are photogrammetrically processed (Eisenbeiss, 2009). At present, the photogrammetry method is used in many scientific disciplines. This technology focuses on the methods and devices used as an essential key to getting good data processed (Firzal, 2021). Digital photographic techniques have long been practiced to produce realistic 3D photos with extraordinarily accurate archaeological sites and structures (Klapa et al., 2017). Transforming geometric data into a digital format through software demonstrates efficient and effective data processing (Dewi, 2020).

Photogrammetry holds immense value in architectural design, construction, reconstruction, and inventory (Piech et al., 2018). Projects involving maintenance activities, integrating cultural heritage sites, and employing 3D digital technology are significant fields (Jo & Hong, 2019). Recent developments in Cultural Heritage documentation resulted from camera and UAV equipment development and high-performance, user-friendly photogrammetric software (Remondino, 2011). The primary source of data input 3D photogrammetry modeling is the catch of regional drawings taken using a high-resolution UAV camera, and a calibrated coordinate system will provide better 3-dimensional production results (Nex & Remondino, 2014).

When processing the images, select those that will be used and adjust the camera's calibration parameters automatically. The orientations of the images are calculated by Agisoft PhotoScan using image data. From this data, the initial values are extracted and used for the calibration process. Once the internal orientation and scattered 3D point cloud with correspondences between images are calculated, the program employs various algorithms to detect points and acquire the orientation and position of the images (Paneque, 2021). Subsequently, the images are aligned by calculating internal orientation parameters, enabling the creation of a dispersed 3D point cloud with correspondences established between the images (Putra et al., 2022).

The amalgamation of photogrammetric data and historical expertise regarding architectural objects enables the reconstruction of intricate structural components, including more minor elements like statues or memorials, enhancing the ability to restore the past accurately (Dewi & Putra, 2022). Reconstruction of authentic images can be obtained through information about goods in digital form, merging images using programs, and creating three-dimensional images (Klapa et al., 2017). The most significant limitation of using mini UAVs is their weather dependency (Eisenbeiss, 2009).

B. The Research Object

The research subject is Stasiun Sasaksaat, which is situated in Padalarang. It has been highlighted that there have been several modifications based on observations from Google's historical image, including the presence of structures that have been destroyed and are now level with the ground. It is unknown at this time if the demolished structures were ever a part of the historic building complex.

Considering the historical context of the Stasiun Sasaksaat building, in 1901, Staatssporwegen (SS) continued constructing a railway line from Karawang to Padalarang. The construction of the Batavia-Bandung railway network through Karawang, Purwakarta, and Padalarang by the SS in the Priangan area was aimed at controlling the railway line from Batavia to the Priangan area due to economic interests connecting the fertile region of Priangan as a plantation center with the port of Batavia as an export gateway. The existence of this route was additionally for military purposes to legitimize the power of the Dutch East Indies government in Indonesia. In addition, as a state company, SS should improve the welfare of society by opening isolated areas. At that time, the Dutch East Indies government thought constructing the Karawang – Padalarang railway line would be the best alternative to constructing a direct connection for the state railway line from Batavia to Bandung (Utami et al., 2022).

On May 2, 1906, the official operation of the Batavia to Bandung railway was via Karawang. Some stations are connected, namely Tjikampek Station (now Cikampek), Sadang Station, Purwakarta Station, Ciganea Station, Sukatani Station, Plered Station, Darangdan Station (now Cisomang), Sasaksaat Station, Cilame Station, Padalarang Station, Cimahi Station, and Bandung Station (Utami et al., 2022). The construction of the Batavia-Bandung railway line affected the growth of markets around the station as a center of social-economic activities (Lamiyati, 2017). Currently, the Sasaksaat station serves the Cibatu-Purwakarta route.

According to the landscape data, historical images have been captured from Google Earth. The building has perceived a change in building massing, nevertheless a few notable alterations to the primary structure of Sasaksaat Station.

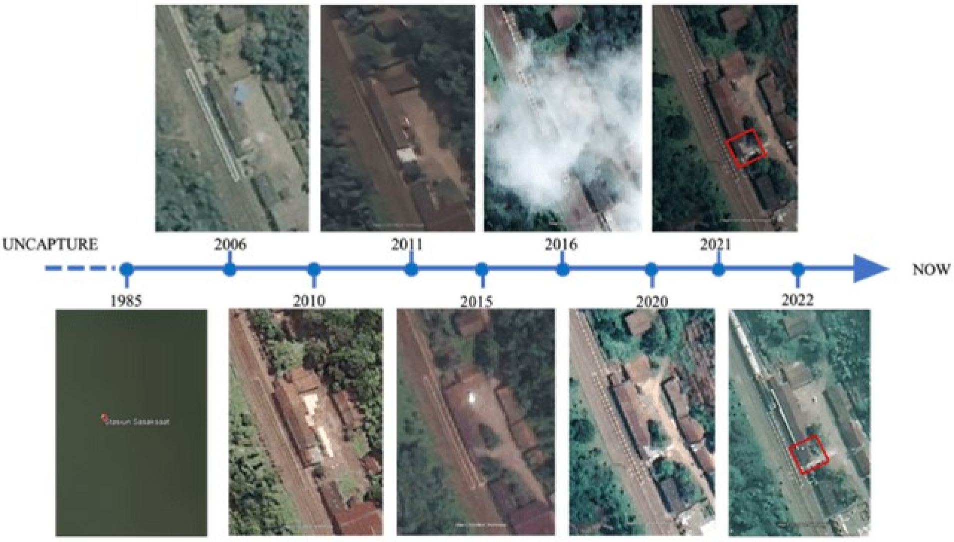


Fig. 1. Historical Image of the Captured Site
Source: Authors (2023)

The station site data was obtained from data based on Google Historical Google Earth Pro image data searches, informed in historical image data in Figure 1; in 1985, it had captured the station area in the image, but it was unclear, so it could not be identified clearly, and the information that could be read was insufficient. From 2006 until now, the historical image of Google Earth's quality has improved. The data informs the shape of the roof and the roofing material used in the areas marked with a box with a red line. The station site in Figure 2 shows several building masses in the station area.

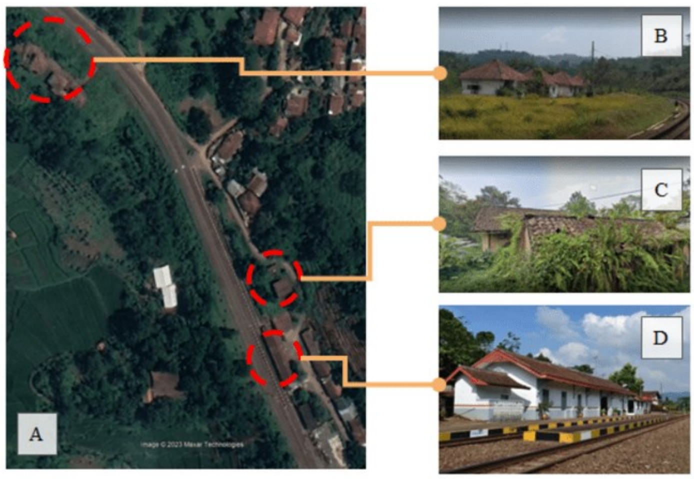


Fig. 2. (A) Site of Sasaksaat Station; (B) and (C) The Current Condition of the Residence; (D) Train Station
Source: Authors (2023)

Figure 1 depicts an aerial photograph of the Stasiun Sasaksaat complex. Figure A shows a photo of the main building of Stasiun Sasaksaat, while Figures B and C represent the PT KAI official residence. The image illustrates the site's current state, highlighting the condition of the heritage buildings and revealing the impact of natural aging on heritage buildings. These structures have endured deterioration over time, displaying visible damage. Furthermore, buildings B and C give the impression of being abandoned and neglected, demonstrating an evident lack of maintenance.

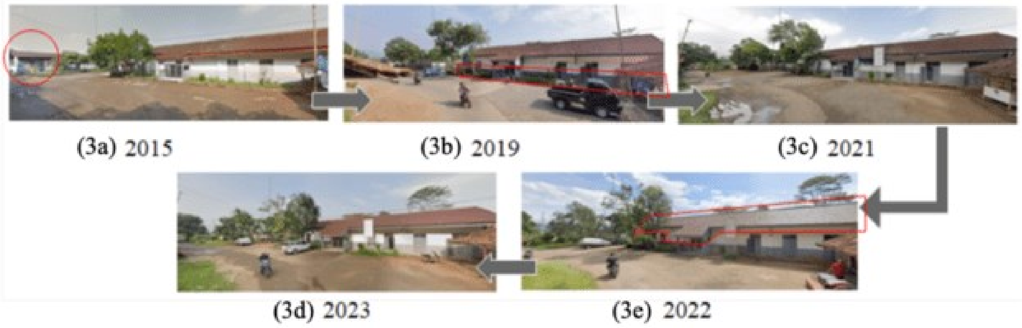


Fig. 3. Historical Facade of Sasaksaat Station by Google Street Image
Source: Authors (2023)

The building roof's material and massing showed the building's change. Back in 2015, a warehouse building was made from stacked shipping containers in Figure 3a. Still, it was no longer present by 2016 in Figure 3b. However, upon closer examination of the building's facade, these changes have had minimal impact on the main structure of Stasiun Sasaksaat. The alterations can be observed in the site's layout in the year 2022 in Figure 3e.

The building roof's material and massing revealed the building's change. Back in 2015, a warehouse building was made from stacked shipping containers in Figure 3a. Still, it was no longer present by 2016 in Figure 3b. However, upon a more thorough examination of the building's facade, these changes have experienced minimal impact on the main structure of Stasiun Sasaksaat. The alterations can be observed in the site's layout in the year 2022 in Figure 3e.

Removal of recorded Cultural Conservation status can be carried out by referring to Article 50 if the Cultural Conservation is destroyed, lost, and within six years is not found, changes in shape and pattern so that its authenticity is lost, or in the future, it is perceived that the status is not Cultural Conservation. Until now, researchers have not found documentation accessed publicly, especially digital documentation needed to preserve cultural heritage. To ensure the preservation of cultural heritage, it is imperative for individuals to enthusiastically participate in its protection by recognizing its significance in social, educational, scientific, religious, cultural, and tourism contexts. By acknowledging and respecting the diverse interests associated with cultural conservation, everyone contributes to its safeguarding (Presiden Republik Indonesia, 2010).

III. METHODOLOGY

A. *Research Pipeline*

This study implements a quantitative method, with image data collection using UAV. The UAV used is the DJI Mavic-2 Pro quadcopter type, which flies manually, semi-automatically, and automatically based on the flight plan that has been made. The Mavic-2 Pro has stable flight performance, is designed to perform aerial, video, discovery, and inspection tasks, and is flexible for shooting purposes in various locations. In addition, the UAV is equipped with multiple onboard sensors, including GPS+GLONASS, Precision Measurement Range, and an intelligent camera system. The Hasselblad 35mm:28mm camera, f/2.8-f/11, is installed by default and capable of producing photos for close-range photogrammetry needs. The DJI Assistance software's built-in adjustment option performs GPS, IMU, and camera calibrations. This study did not use a Ground Control Point (GCP) as a coordinate control point, merely relying on GPS + GLONASS coordinate readings that are already available in the UAV—intending to appreciate how the photogrammetry results of heritage buildings with the UAV photogrammetry method without the additional cost of using GPS-Geodetic, so that the

3D model results are unbound to specific coordinates.

The subsequent stage is making a UAV flight plan, as seen in Table 1. An initial stage is crucial in getting clear shots of every part of the object. It can be done effectively according to the desired area and efficiently in terms of flight time and the number of images captured. This planning stage involves factors that must be considered thoroughly to achieve optimal results. Things considered and mutually influence each other are (a) barrier factors or obstacles that affect the height of the UAV and the length of the flight path; (b) The percentage of overlapping photos that will affect the length of the flight path and the number of photos obtained and the duration of the flight; (c) Weather conditions will affect the intensity of light on the object, will affect the flight speed and lens speed in capturing pictures will have an impact on the photos you get; (d) Furthermore, the wind speed at the location will affect the performance of the UAV propeller, has an impact on the use of power on the battery so that it will affect the duration of flight time. The duration of flight time will affect the number of batteries that must be provided when in the locus.

Table 1. Flight Plan Parameter Settings

Parameter	Value	Flight Plan
Duration	21:30	
Area	2	
Battery	2	
Flight Altitude	70 m	
Est Image	340	
Enhanced 3D	On	
Front Overlap	80%	
Side Overlap	80%	
Flight Direction	62 Degree	
Flight Speed	5 m/s	
Angle Camera	60 Degree	
Crosshatch 3D	On	
Perimeter 3D	On	

Source: Authors (2023)

The flight plan is made based on the coverage area of the Sasaksaat Station building and official residences. The height of the UAV from the flight point is 70 meters, considering the location of the research object with hilly contours and many towering trees. Multi-image restoration of a block of overlapping images and collinearity equations is the most basic setting (Luhmann et al., 2019). An adequate overlap factor will result in more accurate and representative 3D modeling. The recommended overlap factor for photogrammetry processing software represents a minimum of 60% side overlap and 80% forward overlap; in this study, the side overlap and forward overlap factors used are 80%. The position of the building that extends following the direction of the railroad is a consideration in determining the flight direction angle of 62 degrees to the north axis to obtain an optimal angle of view of buildings and areas. In contrast, the flight speed settings follow the recommendations from the drone-deploy application 5 m/s. However, the pilot possibly adjusts the flight speed again according to the lighting conditions in the locus.

Determination of the camera's tilt angle against the vertical area comprises a significant factor, including (a) the site's character dominated by contour and (b) The surroundings of the building exhibit abundant vegetation and trees resulting in shaded areas underneath the tree canopies. There is a difference in the camera's tilt angle in each data collection of images captured with UAV; (a) By employing a vertical camera angle or capturing images at a 90-degree angle against a horizontal field, it is possible to generate improved orthophotos. This technique serves as an alternative to traditional mapping methods. However, it is essential to note that this approach may not effectively capture the shadowed areas at the base of objects since the images are captured perpendicularly to the horizontal field. (b) The Low Oblique Camera Angle refers to a tilted aerial photograph encompassing a broader area than vertical aerial photos. This type of photo allows for the visibility of objects beneath lofty buildings, capturing them at the corners of the frame in the Low Oblique Camera Angle. (c) The High Oblique Camera Angle is an aerial photograph captured with a significant tilt, where the horizon line is prominently visible, providing a clear representation of the landscape. The corner of the camera in a High Oblique photo captures a distinct perspective of the horizon (Putra et al., 2022). The SfM Photogrammetry can be enhanced by using oblique photographs to view details of hidden essential views (Aicardi et al., 2016).

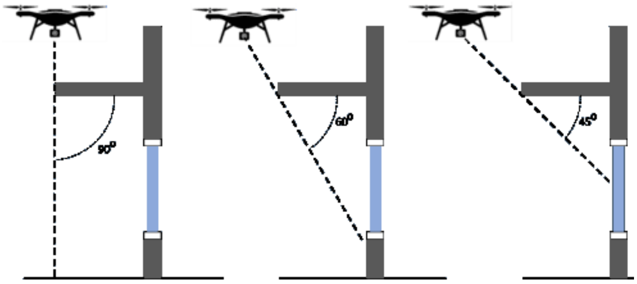


Fig. 4. Camera Angles
Source: Authors (2023)

The research locus has a reasonably steep contour and many trees, so the captured aerial photos with an oblique camera setting of 60 degrees can be used. This method ensures that the image capture can reach the underside of the roof area and existing vegetation. Adjusting the camera tilt angle of 60 degrees will make the shooting results more comprehensive and provide more detailed information, as seen in Figure 4. This is conspicuous in investigating objects with structural complexity and unknown objects.

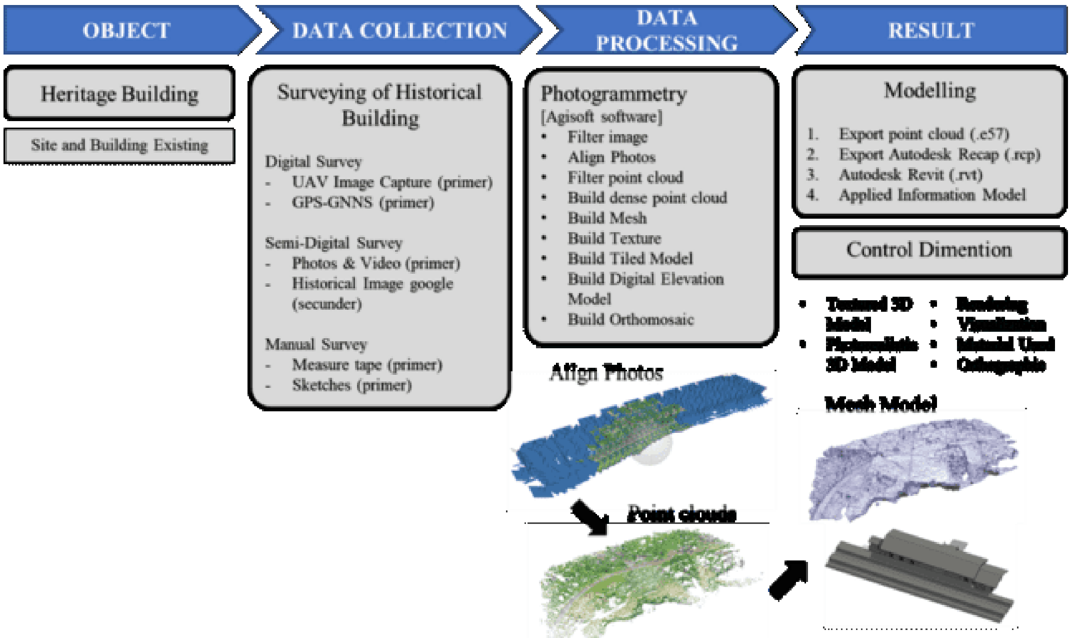


Fig. 5. Research Pipeline
Source: Authors (2023)

The UAV will fly employing the Crosshatch method to obtain image data that crosses or intersects in both X and Y directions. (Table 1). In the Crosshatch method, the UAV will fly with a repeating flight pattern, forming a transverse trajectory pattern and an angle with the previous trajectory. The flying method ensures that the intact area to be observed is adequately covered and that there is sufficient overlap between the captured images. Utilizing the Crosshatch method, the UAV systematically collects image data from numerous angles and positions to complement each other. This image data can be used in 3D modeling to create an accurate digital representation of the building and its surroundings. The Crosshatch method provides the advantage of collecting consistent and comprehensive data. Carrying out flights with a structured pattern minimizes the risk of data shortages in 3D modeling (Table 1).

After making a flight plan from the UAV and ensuring the conditions on the ground are at a height that allows for aerial photography, the sensor image must be integrated into the coordinate system in photogrammetry. This reference is made through direct or indirect geographic reference, also known as independent land control. Direct use of geographic references is possible because the UAV is directly integrated with the Global Navigation Satellite System/Inertial Navigation Sensor (GNSS/INS) embedded in the UAV and the Inertial Measurement Unit (IMU) on the COTS sensor (Rabah et al., 2018). For some reference conditions, the GNSS/IMU data from the UAV may not be accurate enough for specific applications but sufficient to initialize photogrammetric calculations and provide initial results before using independent ground control points. Using the COTS sensor for direct geo-reference in the future will be better and more accurate, making it easier for everyone to document cultural heritage buildings at a reasonable cost.

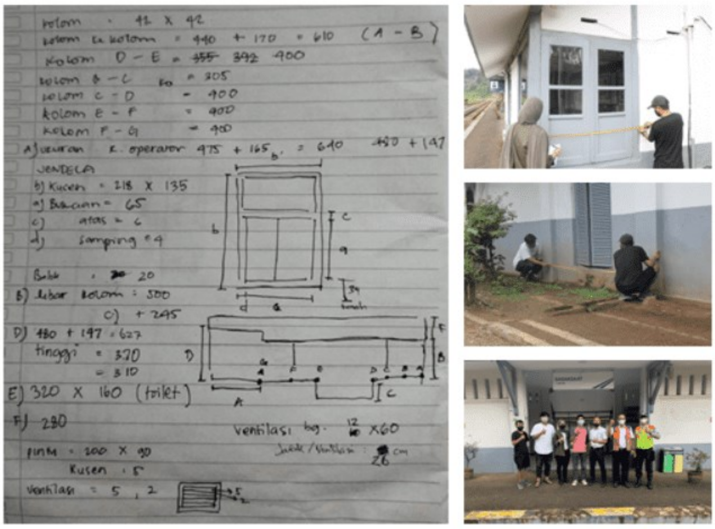


Fig. 6. Sketching the Measurement in the Locus (left); Measurement Activities (right)
Source: Panutandia et al. (2023).

Furthermore, in Figure 6, manual measurements were carried out by managing a tape measure as dimensional control, sketches of object conditions, and detailed photos of objects operating a camera and video as additional documentation to complete the UAV photo data. However, manual data control is still needed so that the quality of the data obtained is getting better. After data collection in the locus, the UAV data is processed using the Agisoft Photoscan software to produce point clouds and meshes stored in ".e57" format to open in the Autodesk Recap and export to Autodesk Revit 3D modeling software. The procedure of the research study is illustrated in Figure 5.

IV. RESULT AND DISCUSSION

The stage of the photogrammetry method becomes a BIM modeling object, and the first step is scanning the building using UAV to retrieve data in the image and then convert it into Point Cloud Data (PCD). In photogrammetry, a point cloud refers to a collection of points within a three-dimensional coordinate system, accurately representing the surface of the image capture. In this case, the point cloud encompasses the building and its surrounding environment, providing a detailed representation of their geometries and spatial characteristics. The results of taking UAV photogrammetry images are 363 images, then align photo processing is carried out and produces a tie point of 123,188 points. The above processing found many features or points that can be used as references (tie points) in registering these images. The considerable number of tie points means that many features can be found and mapped accurately between the images in the dataset. These tie points were then used to produce a point cloud of 11,765,559 points, with medium quality that took 1.5 hours to process. Many point clouds indicate that the image processing successfully produces a dense and detailed 3D representation of the area captured. These point clouds included more detailed information about objects' shape, structure, or texture in the UAV-captured images. More isolated evaluation regarding the accuracy, positional errors, and visualization of modeling results will provide complete information to understand the extent to which the point cloud represents the object or area taken from the UAV images that have been carried out.

Fig. 7. (Left) Selection; (Right) Aligning Photos to Process Generate Point Cloud
Source: Authors (2023)

Figure 7 shows that the point cloud resulting from the align photo process has a more extensive point distribution area than the UAV flight plan coverage. This difference is caused by the oblique camera angle used when shooting using the UAV. Oblique camera angles are more prominent, about 60 degrees to the camera's horizon line. With a tilted camera angle, the UAV manages images from a broader perspective by enclosing a more massive area. This results in a more extensive distribution of points in the resulting point cloud.

Table 2. Processing Parameters

Parameter	Result Value
Cameras	363
Coordinate system	WGS 84 (EPSG::4326)
Points	123,188 of 283,297
Mean key point size	7.34692 pix
Accuracy	Medium
Dense Point Cloud	11,765,559
Faces Model	784,369
Vertices Model	394,911
Orthomosaic Size	20,780 x 22,868

Source: Authors (2023)

This study employed 363 camera images for photogrammetric processing. Using the WGS 84 default coordinate system (EPSG::4326) connecting geographic data default. The 123,188 points cloud was securely processed from the 283,297 points collected, see Table 2. The average key point size is 7.34692 pixels, reflecting the sharpness and quality of the resulting image. On average, the accuracy of this project is moderate. There are 11,765,559 points in the point cloud density resulting from data processing. The model assembled contains 394,911 vertices and 784,369 faces, providing a sufficiently detailed representation of the structure of the scanned object. Meanwhile, an orthomosaic image of 20,780 x 22,868 represents a composite image that displays objects and surfaces at the location, as seen in Figure 8.

Fig. 8. Photogrammetry Processing
Source: Authors (2023)

Camera optimization operating Agisoft software is carried out to ensure the shooting results provide optimal quality. This optimization process involves adjusting camera parameters, like focal length and distortion coefficient, to produce more accurate images free from unwanted distortion. In addition, a filtering process is also carried out to eliminate noise or points in the clouds that are inappropriate or irrelevant to the object being mapped. This filtering is essential to increase the clarity and precision of the data so that only high-quality, valid points are retained in the point density cloud. By optimizing the camera and filtering process, it can be ensured that the resulting data is of better quality, reduces noise and errors that may occur, and provides a more accurate and valuable representation of the object being mapped.

Table 3. Calibration coefficients and correlation matrix from Agisoft

Variable	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	4361.18	0.11	1.00	-0.03	-0.91	0.04	0.12	-0.12	-0.01	-0.76
Cx	37.5024	0.065		1.00	0.02	0.00	-0.00	0.01	0.95	-0.01
Cy	-70.7174	0.13			1.00	-0.22	0.03	-0.01	0.02	0.91
K1	0.00693205	7e-05				1.00	-0.95	0.89	0.01	-0.24
K2	0.00424766	0.00028					1.00	-0.98	-0.01	0.06
K3	-0.00642551	0.00035						1.00	0.02	-0.04
P1	0.00284537	5.3e-06							1.00	-0.01
P2	-0.00126501	7.5e-06								1.00

Source: Authors (2023)

Based on Table 3, although there are errors in the estimation of several parameters like focal length, main point coordinates (Cx, Cy), radial distortion coefficients (K1, K2, K3), and tangential distortion coefficients (P1, P2), the errors are still within an acceptable range. Parameter calibration errors affect the conclusive result's accuracy and precision in photogrammetric processing. However, error rates based on the table above (e.g., 0.11 pixels for focal length from and 0.065 pixels for Cx coordinates) tend to be relatively small compared to the parameter values. This indicates that even though there are demands in parameter estimation, this photogrammetric processing provides decent results.

After completing the photogrammetric processing using Agisoft software, the following step is modeling using Autodesk Revit software. However, Autodesk Revit cannot directly open point cloud results generated by Agisoft (Dore & Murphy, 2017). Therefore, an intermediary is required, namely, Autodesk Recap software, to import photogrammetric processing results into Autodesk Revit. It is necessary to convert the file format to ".e57". In addition, the coordinate system needs to be adjusted to the coordinates of the data collection locations, in this case, using the WGS 84-48s coordinate system. WGS 84-48s coordinates remain a geographic coordinate system referencing the 1984 World Geodetic System and UTM 48 zone south.

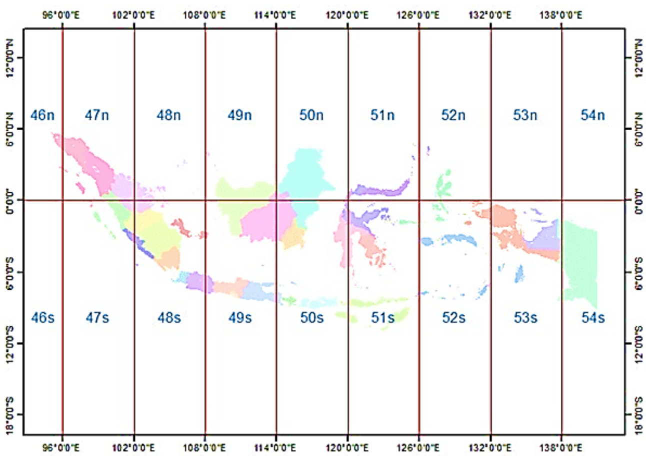


Fig. 8. Coordinate System in Indonesia
Source: Authors (2023)

Figure 8 presents WGS 84-48s coordinate system, which typically represents geographic locations in the Bandung area of West Java. After successfully converting the data to ".e57" format and adjusting the coordinate system, the files can be imported into Autodesk Recap software to produce files in ".rcp" format. This ".rcp" file can be executed and accessed within Autodesk Revit. Using point cloud reference, users create accurate 3D models within the Autodesk Revit environment. Through these steps, photogrammetry result data is processed using Agisoft integrated into Autodesk Revit to design, model, and document building projects that are more structured and efficient.

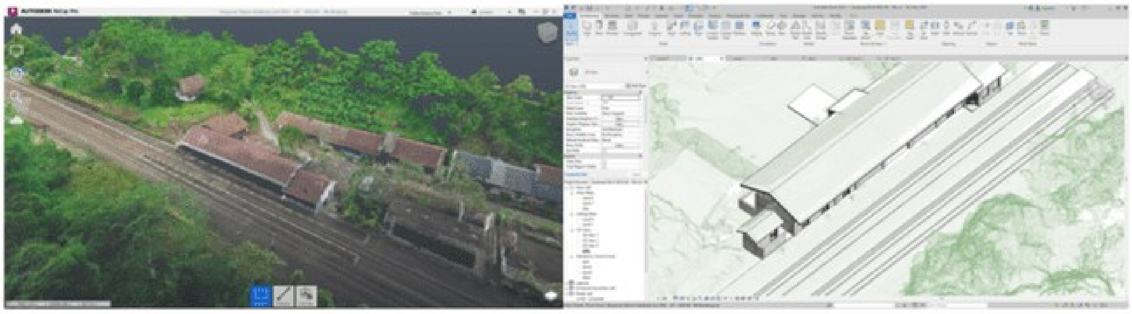


Fig. 9. (Left) e57 Point Cloud Autodesk Recap; (Right) 3D Modeling BIM with Point Cloud in Autodesk Revit
Source: Authors (2023)

In Figure 9, 3D modeling using BIM (Building Information Modeling) software is made by referring to the point cloud data generated and the results of manual measurements performed in the locus area as confirmation of size. This approach combines the accuracy and detail of manual measurements with photogrammetry technology's efficiency and speed advantages. Using a point cloud reference makes creating 3D models with precise measurements easy. The information in the point cloud, such as building coordinates, shape, and texture, can be used to determine the correct geometry, material type, color, and components in a 3D model. The 3D model produced will accurately reflect the shape and physical structure of the present field. Considering the results of manual measurements carried out in the field, there is information not included in the point cloud, such as dimensions that are difficult to access or unique details under the roof of a building that are difficult to identify by scanning technology, shown in Figure 10.

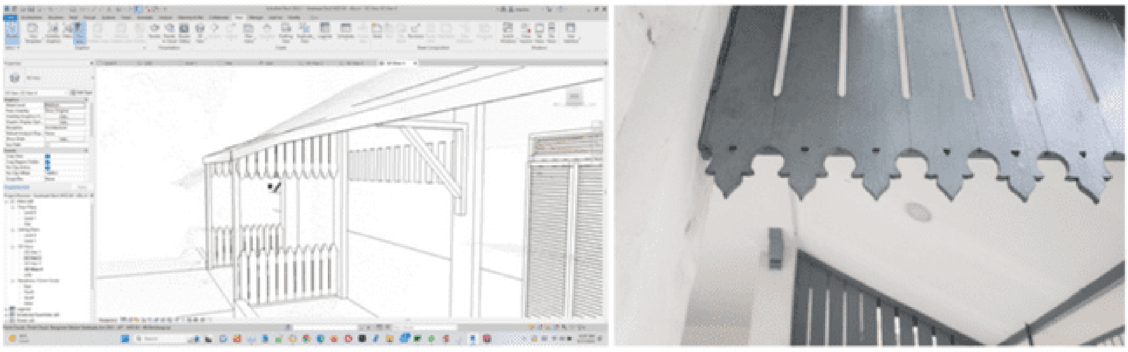
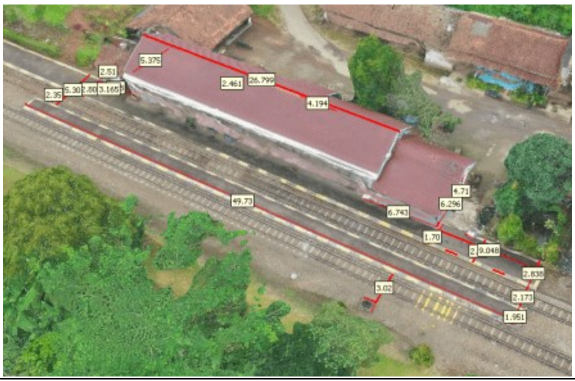


Fig. 10. (Left) 3D Modeling Autodesk Revit; (Right) Actual Object
Source: Authors (2023)

Ten sample dimensions were captured to compare the results between manual measurements and photogrammetric processing; consult Table 4. The purpose of this comparison is to evaluate the extent of accuracy and consistency between the two methods. By taking a representative sample, it can be seen whether manual measurements and photogrammetric processing produce similar dimensions or whether there are significant differences. The process of taking sample dimensions is conducted carefully and thoroughly, each dimension measured manually recorded, and the measurement results are obtained from photogrammetric processing. The samples were randomly selected and included various dimensions relevant to the analyzed object. However, there is a significant variation in the time for these two procedures. With a measuring crew of four people, manual measures would typically require two hours, but with a single UAV operator, they would merely consume 30 minutes.

Table 4. Comparison Between Manual (X1) and Photogrammetric Measurements (X2).

Code	Manual Measurements (X1)	Point cloud Measurements (X2)	Deviation	Measurement Point Cloud
a	4.00	4.194	-0.194	
b	6.27	6.297	-0.027	
c	1.00	0.921	0.079	
d	2.18	2.173	0.007	
e	2.00	1.951	0.049	
f	9.07	9.048	0.022	
g	3.20	3.165	0.035	
h	2.80	2.809	-0.009	
i	5.40	5.220	0.18	
j	2.45	2.461	-0.011	
RMS = √(Σ((X1 - X2)²) / n) = √(0.081141 / 10) = √0.0081141 = 0.0901				

Source: Authors (2023)

The RMS error is calculated for each data pair by comparing manual measurements (X1) and Photogrammetric Measurements (X2). After calculating the squared difference between the values X1 and X2, the results are calculated and divided by the number of existing samples. In this case, there are ten measurement samples. The calculation results show that the sum of the squared differences is 0.081141. Then, the RMS Error is calculated by taking the square root of the result of dividing the sum of the squared differences by the number of samples is 10. In this case, the RMS Error obtained is around 0.0901. This indicates the average error rate between manual measurements and measurements using photogrammetry. The analysis proceeded with an Independent Sample T-Test based on data presented in Table 1, a statistical test to assess the disparities in the scanning outcomes among the various variables under examination. The resulting findings are as follows in Table 5.

Table 5. Independent T-Test Sample

t-Test: Paired Two Sample for Means	Manual Measurements(X1)	Photogrammetric Measurements (X2)
Mean	3.837	3.8239
Variance	5.927445556	5.941692767
Observations	10	10
Pearson Correlation	0.99925508	
Hypothesized Mean Difference	0	
df	9	
t Stat	0.440349195	
P(T<=t) one-tail	0.335035217	
t Critical one-tail	1.833112933	
P(T<=t) two-tail	0.670070435	
t Critical two-tail	2.262157163	

Source: Authors (2023)

The analysis of the X1 values reveals a negligible disparity between the average measurements obtained through manual measurements assessment and photogrammetry, with a minimal difference of 0.013. The high correlation coefficient 0.99 indicates an established association between the two methods. Furthermore, the two-tailed P-value analysis demonstrates that the obtained P>0.05. It means the P-value is greater than 0.05, indicating the absence of a significant distinction in the scanning outcomes. Based on the data analysis, it can be inferred that there is no discernible variance in the dimensions obtained from manual measurements and photogrammetric measurements. Based on the available data in the measurement area, a graphical representation visually depicts the results obtained from manual measurements and photogrammetry. Chart 1 provides a comparative overview of the data obtained through manual measurements (X1) and photogrammetric measurements (X2), presented in the chart below (Fig. 11).

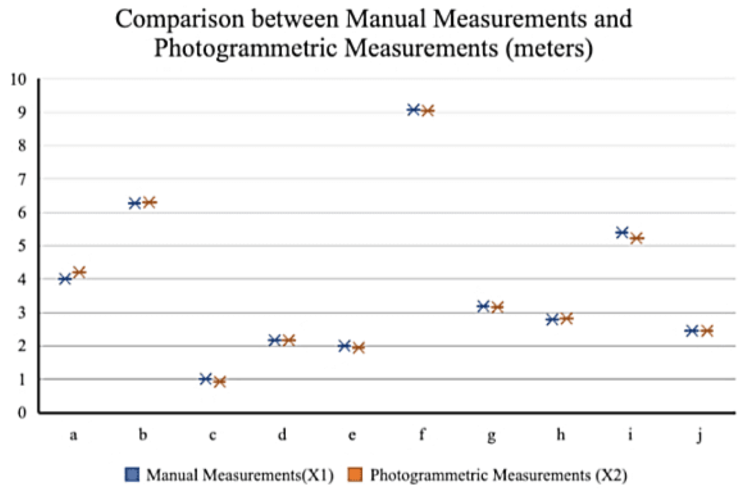


Fig. 11. Comparison between Manual Measurements and Photogrammetric Measurements (meters)
Source: Authors (2023)

Figure 11 compares the discrepancies between Manual Measurements (X1) and photogrammetric measurements (X2). Both lines on the graph exhibit a similar pattern, although certain areas in the data exhibit more significant differences than others. Notably, measurements for points (a), (c), (e), and (i) demonstrate relatively more significant deviations. However, these disparities did not possess substantial statistical implications. The data points plotted on the graph represent the measurement values, exhibiting a consistent pattern with minimal variability, as indicated by slight standard deviations. The chart effectively illustrates the visual comparison between the two datasets, further corroborating the statistical analysis and demonstrating no significant differences between the results obtained from manual measurements and photogrammetry. To more significantly strengthen the examination of differences among the three-dimensional variables, an ANOVA test on the measurements obtained from the Manual Measurements (X1) and photogrammetric measurements (X2). The test results from the one-way Anova test analysis are represented by Figure 12.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	10	38.37	3.837	5.9274456
Column 2	10	38.239	3.8239	5.9416928

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0008581	1	0.0008581	0.0001446	0.9905385	4.4138734
Within Groups	106.82224	18	5.9345692			
Total	106.8231	19				

Fig. 12. One-Way ANOVA Test Analysis Result
Source: Authors (2023)

Based on the One-Way ANOVA test analysis, the obtained P-value is 0.99>0,05, indicating no statistically significant difference between manual measurements (X1) and photogrammetric measurements (X2). This finding is reinforced by the RMS test result of 0.09 and the One-way ANOVA test Analysis, indicating no significant disparity between X1 and X2. Consequently, the results suggest no substantial variation between the locus measurements obtained through the manual method and those derived from photogrammetric processing. Furthermore, both approaches demonstrate a considerable degree of accuracy.

V. CONCLUSION

UAV technology and photogrammetric methods allow individuals to archive historic buildings more effectively and efficiently in terms of time and effort. This will influence cutting down on expenses. Every corner of the structure and surrounding region can be effectively collected by employing the cross-flying approach for UAV data collection; the complementary nature of each image created fills in any gaps in the capture process. The 3D mesh generated by very competent photogrammetric processing shows that the 60-degree camera angle adequately reaches every area recorded by the shadowing object below. Although photogrammetry produces accurate dimensions, manual measurements are required to maintain dimensional accuracy. This is reinforced by the results of the ANOVA test, which show no significant difference in size between the measurement results of the photogrammetric method and the manual method. Even though it barely uses the standard direct geo-referencing method of UAV devices.

Furthermore, combining the photogrammetric method with BIM Heritage completes the historical documentation process. Other purposes include providing a more comprehensive picture of heritage buildings and making it easier for users to analyze and maintain them in the future. Thus, employing UAV technology and photogrammetric methods combined with BIM heritage significantly contributes to efforts to preserve historic buildings. Through easier, more accurate, and efficient archiving, the authenticity of cultural heritage buildings is maintained as an essential part of national identity and valuable cultural heritage.

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