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INTEGRATING BUILDING INFORMATION MODELING (BIM) AND UNMANNED AERIAL VEHICLE (UAV) FOR BUILDING 3D MODELING: A CASE STUDY OF WISMA SRI MAHKOTA BENGKALIS

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ABSTRACT

The demand for geospatial information of a region grows in numerous sectors, as does the method of mapping operations. Various advanced technology has been utilized to support survey and mapping activities, including Unmanned Aerial Vehicles (UAVs). This study aims to develop a method to digitize building documentation by integrating the UAV in the Building Information Modelling (BIM) by considering a lodging property in Bengkalis regency as the case study. Orthophoto data obtained from processing aerial photos taken using three flight paths, namely Nadir, Oblique, and Circular, was used to develop the BIM 3D model. The accuracy of the developed BIM model was evaluated using the orthophoto data as the horizontal accuracy using the Root Mean Square Error (RMSE) metrics. The accuracy calculation of Point Cloud 3D resulted from the integration of BIM and UAV, resulting in RMSExy of 0.0834 m, a height ratio of 0.05, and Circular Error (CE) accuracy of 0.1265 m included in the Level of Detail (LOD) 3, confirming the high accuracy of BIM-UAV integration.

Keywords: Building Information Modelling (BIM), Unmanned Aerial Vehicle (UAV)

1. INTRODUCTION

Over the last decade, 3D digitization and geomatics technologies have entered the cultural heritage building documentation to meet the needs of preservation, management, and protection (Logothetis et al., 2015). It aims to ensure that the information regarding a cultural heritage entity's significant historical characteristics, such as its shape and appearance, is reserved in case of natural or other damages (Karachaliou et al., 2019). Various advanced technology has been utilized to obtain this objective, one of which is Building Information Modeling (BIM).

BIM is a process that leads to creating and managing a model that digitally represents a construction project, in which all the information regarding its characteristics is contained (Doumbouya et al., 2016). BIM 3D models in a particular Level of Detail (LOD) are the simplified versions of more complex models that use simple geometric primitives while retaining essential details (Pantoja-Rosero et al., 2022). While BIM can be used to create, manage, and share the lifecycle data of vertical facilities such as buildings, Geographic Information System (GIS) can be used to store, manage, and analyze data describing the urban environment (Ma & Ren, 2017).

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UAVs have become an extremely important tool for cultural heritage specialists to document and analyze cultural heritage sites and structures as they provide a cost-effective and efficient manner to acquire high spatial resolution data and generate reliable documentation on time (Hoon & Hong, 2019; Murtiyoso & Grussenmeyer, 2017; Themistocleous et al., 2016). On the other hand, BIM is well suited to modelling point clouds, the collections of high points in the thousands to millions of points resulting from photogrammetric processing of aerial photographs generated by geomatics procedures, such as UAV's photogrammetry (Barrile et al., 2019; Kim et al., 2021; Rizo-Maestre et al., 2020).

This study aims to develop a 3D model for an existing cultural building by integrating BIM and UAV, taking into account the Wisma Sri Mahkota building as the case study. Wisma Sri Mahkota is located at Antara Street of Bengkalis Regency in Indonesia's Riau Province. It is a government-owned lodging property designed with magnificent European architecture. The accuracy of the UAV-based 3D building modeling resulting in this study will be validated with several approaches, which include comparing the distance and height of the building object in the modeling with actual conditions using manual measuring equipment in the field.

2. METHODS

This study was conducted in two stages to obtain its objective of developing a 3D model of a building by integrating the BIM and UAV approaches. Figure 1 illustrates the location of Wisma Sri Mahkota in the Senggoro Village of Bengkalis, Riau, Indonesia.

Figure 1 Location of the Case Study

2.1. Pre-Field Stage

In this first stage, the Area of Interest (AOI) as the boundary was determined, and the distribution of Ground Control Point (GCP) and Independent Check Point (ICP) binding points was planned using Google Earth Pro software. Afterward, the flight path regarding AOI in KML/KMZ format was selected and converted into Pix4D Capture.

2.2. At-Field Stage

The measurement of the GCP binding point is 5 points, and the ICP object check binding point is 6 points. GCP and ICP binding points were measured using Global Navigation Satellite System (GNSS) Geodetic Trimble R8s Dual Frequency with the Networked Transport of RTCM via Internet Protocol (NTRIP), a Real-Time Kinematic (RTK) positioning correction transmission protocol. The measurement reference point uses Indonesia’s Continuously Operating Reference Station (Ina-CORS) from the Geospatial Information Agency (GIA): Radio Technical Commission for Maritime (RTCM) of 0173 Apit River, Siak Sri Indrapura Regency, Riau Province (see Figure 3c), with coordinates (X= 183465.294, Y= 124140,477, Z= 8056 m (ellipsoid)).

Subsequently, the aerial photo data was taken using (see Figure 3b) UAV Multirotor DJI Phantom 4 Pro v 2.0 with 3 flight methods (Nadir, Oblique, and Circular). Aerial photo data capture is Nadir at an angle of 90º with a height of 50 meters, while the Oblique method focuses the camera at 60º with a height of 50 meters. Nadir and oblique aerial photos were taken automatically using the Pix4D Capture application. Furthermore, the Circular UAV flight method was flown using the free flight mission method or manually flying around the AoI to get 3D details of the building. The settings in the application pix4d were captured as follows: (a) altitude 50 m Above Ground Level (AGL); (b); side lap = 80%, overlap = 80%; (c) Area of Interest (AoI) = 112 m x 112 m, as shown in Figure 2.

(a)

(b)

Figure 2. GCP and ICP Distribution (a), Area of Interest (b)

(b)

(a) (c)

Figure 3. Measurement of GCP coordinates (a), Drone DJI Phantom 4 Pro v2 (b), Cors GIA (c)

2.3. Data Processing

Agisoft Metashape Professional Version 1.7.0, photogrammetry software, was used to perform modeling processing. It can create 3D models of buildings from aerial photo data using UAVs. The steps for processing aerial photo data were as follows:

1) Align photo: a module that packs two methods: image matching and bundle adjustment.
2) Self-Calibration: A process during the align photos so that camera distortion parameters can be estimated, which can be applied to improve the quality of data processing results.
3) Geometric Correction: a process carried out with GCP data in previous measurements using geodetics. The GCP position seen on the premark is identified. Premark is a field mark that is placed at a point on the ground so that it can be seen on aerial photographs for the purpose of measuring control points.
4) Build Point Clouds: which were processed further to produce data in the form of 3D modelling, Digital Surface Model (DSM), Digital Terrain Model (DTM), and input materials in the Orthophoto manufacturing process, as well as 3D Point Clouds modelling, integrated with Autodesk Revit as the BIM application.
5) Build 3D Mesh: a process of 3D model development in Agisoft Metashape software as the basis for creating DEM, DTM, and DSM. Height Field and Arbitrary are parameters in this

process selected according to their function. Arbitrary parameters are used to get better building details.

6) Export Point Clouds: it was carried out to integrate modelling from aerial photographs into the BIM application. Point Clouds from Agisoft Metashape were exported to Autodesk Revit for further analysis. Export Point Clouds supports several formats, such as Rcp and Rcs.

7) Import Point Clouds to Autodesk Recap student license: converting the export point clouds data into *.RCP format, which was then imported into Autodesk Revit.

8) Import Point Clouds *RCP to BIM: the Points Clouds in *RCP format were imported into Autodesk Revit to see if they can be used as a reference for further development. Once imported, the object's colour, distance, and height can be seen.

Figure 4 and Figure 5 illustrate the stages and steps in the research workflow.

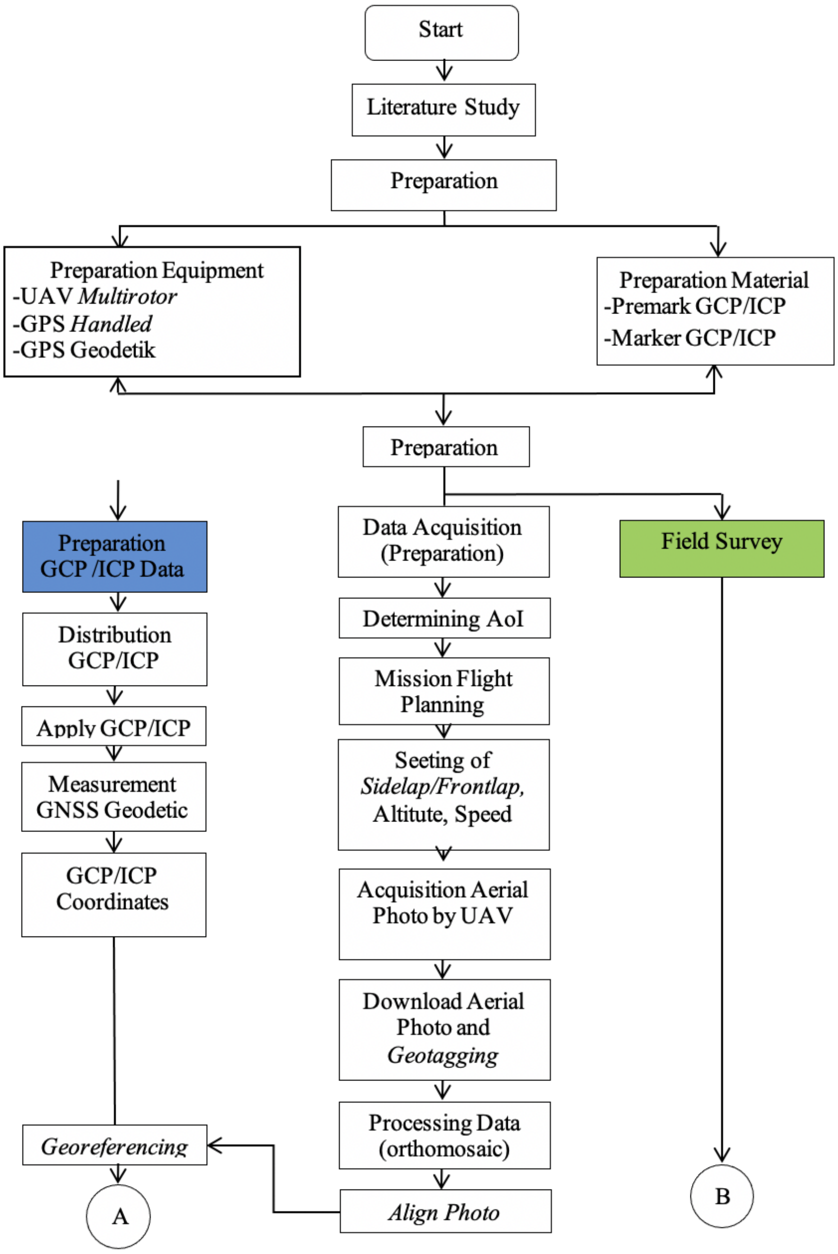

Figure 4 Research Workflow

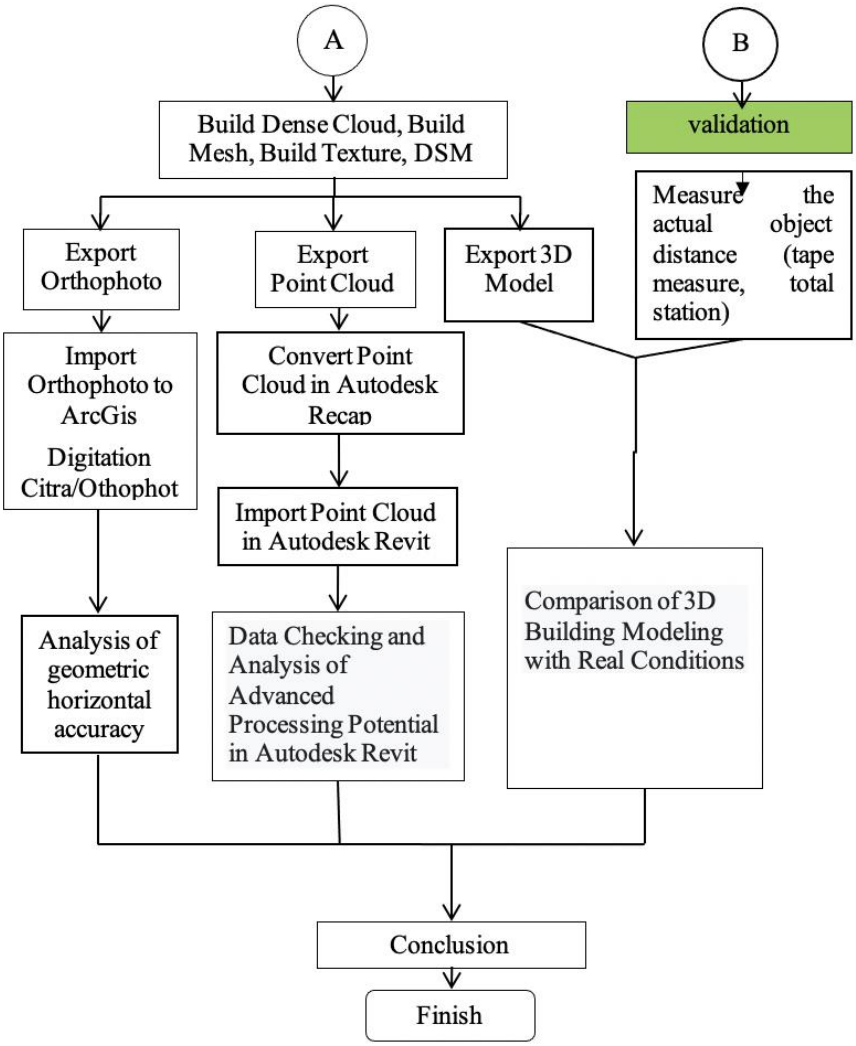

Figure 5 Research Workflow (continued)

3. RESULTS AND DISCUSSION

3.1. Fotogrammetry and GCP Data Acquisition

There were 272 photos from the Photogrammetric data acquisition using the DJI Phantom 4 Pro v2.0 Multirotor UAV, obtained by manual flight method and with pix4d capture flight path. GCP data acquisition was obtained using the Trimble R8s Geodetic GPS (see Table 1). The method of observation used was RTK-NTRIP observations with the Ina-CORS system.

Table 1 Position of object point (GCP)

Premark	Easting (X)	Northing (Y)	Elevation (Z)
GCP 1	179828.69	163358.643	2.903
GCP 2	179781.19	163297.215	2.994
GCP 3	179839.75	163250.841	2.96
GCP 4	179877.87	163313.62	3.183
GCP 5	179861.28	163273.228	3.234

3.3. Horizontal Accuracy

The horizontal position accuracy test refers to the difference in coordinates (X, Y) between the test point on the map and the actual test point on the ground surface (see Table 2). Measurement of accuracy using Root Mean Square Error (RMSE). RMSE is used to describe accuracy, including random and systematic errors; this RMSE can be calculated when the coordinate transformation is complete with the formula:

$$CE90 = 1{,}5175 \text{ x } RMSExy \quad (1)$$

$$(RMSE)\_xy=\sqrt{((2*((RMSE)x)^2)} \quad (2)$$

Table 2 The horizontal position accuracy (RMSE)

NO	Name	X Orthophoto (m)	X Field (m)	(DX)	$(DX)^2$	Y Orthophoto (m)	Y Field (m)	(DY)	$(DY)^2$	DX^2+DY^2
1	ICP 1	179819.7983	179819.785	0.013	0.000178	163272.0274	163271.997	0.030	0.000921	0.0011
2	ICP 2	179839.0181	179839.02	-0.002	0.000003	163270.5466	163270.531	0.016	0.000244	0.0002
3	ICP 3	179866.1696	179866.186	-0.016	0.000269	163329.9248	163330.025	-0.100	0.010039	0.0103
4	ICP 4	179843.7179	179843.766	-0.048	0.002315	163344.9476	163345.016	-0.068	0.004675	0.0070
5	ICP 5	179821.199	179821.335	-0.136	0.018487	163343.0792	163343.063	0.016	0.000263	0.0188
6	ICP 6	179790.5609	179790.552	0.009	0.000080	163309.3409	163309.276	0.065	0.004213	0.0043
								∑		0.0417
								Means		0.0069
								RMSExy		0.0834
								CE90		0.1265

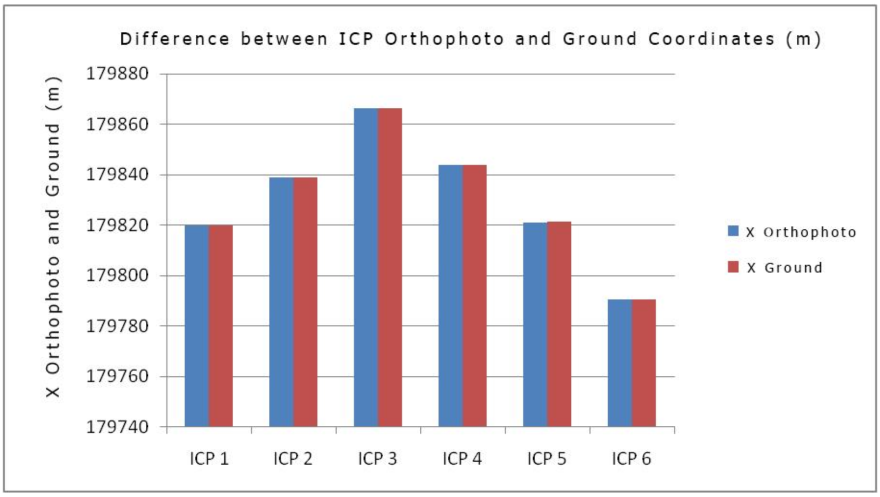

Figure 5 Comparison between orthophoto coordinates and Geodetic coordinates

Based on Table 2, the RMSExy value is 0.0834 m. The orthophoto accuracy value is the CE90 (Circular Error) value of 0.1265 for horizontal accuracy. It indicates that the orthophoto position error does not exceed the accuracy value and has a 90% confidence level obtained using the standard geometric accuracy.

3.4. Accuracy Test of Distance Measurement

The distance measurement accuracy test is carried out by comparing the distance on the orthophoto that has been rectified using the Ground Control Point (GCP) in the 48N zone UTM coordinate system with the actual distance in the Field using a meter. The distance comparison between the aerial photographs and field measurements is summarized in Table 3.

Table 3 Accuracy of distance measurement in the field and orthophoto

No	Orthophoto	Field Check	Distance		Result
			Orthophoto (m)	Field (m)	
1			12	12	0
2			7.41	7.41	0
3			2.55	2.55	0
4			39.5	39.5	0

The results in the table above show that the size is to provide confidence and certainty as well as the accuracy of an image.

3.5. Level of Detail (LoD) Identification

Identifying the LOD was intended to determine the level of detail of the 3D model developed in the BIM application. Position accuracy, or the average difference in coordinates between the X orthophoto and X field, is 0.037333 m, while the difference between the Y orthophoto and Y field is 0.0491897 m. In addition, the altitude accuracy (z) is 0.03 m. Table 4 shows the identified LOD of the building.

Table 4 LOD identification

Geomatic Accuracy	Accuracy Result	Model	LOD Accuracy (m)
Horizontal X	0.037333	Architectural Models (exteriors) landmark	0.5
Horizontal Y	0.491897		
Height	0.03		

Table 4 above identifies that the 3D modeling of aerial photographs processed with Agisoft Metashape software meets the requirements to be classified at LOD 3.

3.6. Comparison between the Physical Building Height and the Model

The height comparison is made using the Focus-Spectra Total Station Measuring Tool by comparing the height data of field objects with data from aerial photo processing (see Figure 6). A total station in the field measurement was carried out by taking vertical angles and oblique distances in the field.

Figure 6 Altitude test point

Tabel 5 Altitude measurement results using total station

NO	HEIGHT OF EQUIPMENT(M)	VERTICAL ANGLE	HORIZONTAL ANGLE	SLOP DISTANCE (M)	ELEVATION (M)
1	1,103	68° 50' 43"	71° 34 54"	66,094	24,955
2	1,103	71° 34' 54"	214° 50 11"	63,569	21,187
3	1,103	73° 48' 42"	211° 29 2"	58,228	17,337
4	1,103	74° 55' 27"	200° 45 10"	64,032	17,757
5	1,103	78° 8' 14"	194° 46 4"	64,044	14,268
6	1,103	77° 10' 8"	221° 19 0"	37,644	9,462
7	1,103	78° 41' 59"	237° 14 3"	42,441	9,420

The data obtained at point 7 from the collection of altitude data using the total station are as follows:

Vertical Angle : 78°41'59"
Oblique Distance : 42,441 m
Height Equipment : 1,103 m

So that it can be searched with trigonometric formulas in the following way: (see Figure 7)

Cos 78°41'59" x 42.441 m = Tinggi +1.103 m
8.316 m = Height + 1.103 m
Height = 8.316 m + 1.103 m
Height = 9.419 m

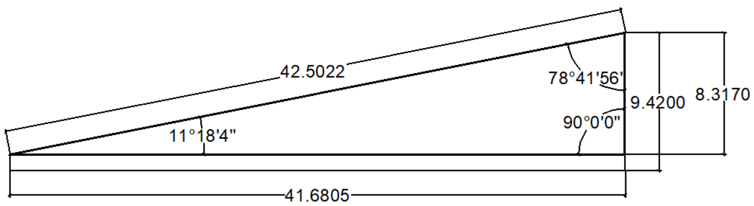

Figure 7 Angle calculation sketch

The results of height measurement conducted in the Agisoft Metashape can be seen in Figure 8.

Figure 8 Height measurement results in the Agisoft Metashape

Measurements with total stations were carried out at 2 points as a comparative analysis in the Field with the results of Aerial Photography, namely at points 6 and 7, with a comparison of accuracy summarized in Table 6, indicating that the physical building heights measured using a total station has an average difference of 0.03 cm.

Table 6 Altitude comparison measurement results at points 6 and 7

NO	Orthophoto (m)	Field (m)	
		Total Station	Tap Measure (manual)
1	9,55	9,462	9,45
2	9,43	9,420	9,42

3.7. Analysis of the Result of Import Point Clouds to BIM

A total of 272 photos taken at Wisma Sri Mahkota were processed with Agisoft Metashape. The point clouds generated by the Software were integrated into the BIM application using Autodesk Revit through the help of the Autodesk Revit Recap program (see Figure 9).

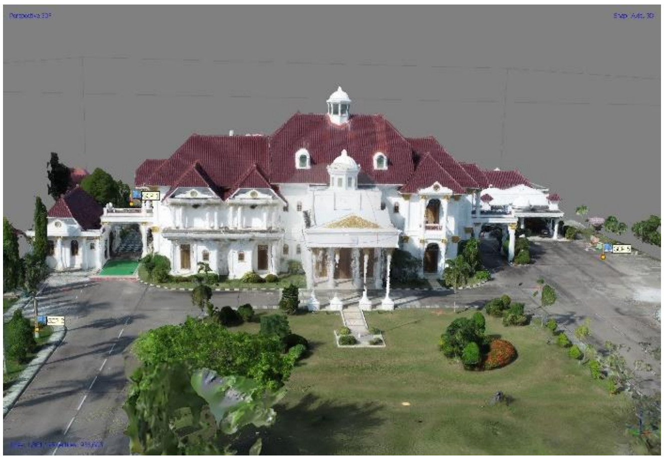

Figure 9 The 3D model of the case study

The modeling developed in Autodesk Revit provides sufficient information to be used as a reference for building reconstruction because the information obtained is in the form of color, height, etc. Figure 10 shows the results of the 3D point cloud model from Agisoft MetaShape Pro, and the 3D BIM Model imported by Autodesk Revit can be seen in Figure 11.

Figure 10 Point clouds 3D model from Agisoft Metashape Pro

Figure 11 3D BIM model imported from Autodesk Revit

4. CONCLUSION

Based on the study conducted on the Wisma Sri Mahkota Bengkalis building, the application of UAV aerial photography for 3D modeling can be utilized by taking into account several aspects, such as horizontal accuracy and distance accuracy. Furthermore, the requirements errors not exceeding the required conditions for aerial photography should be considered. From the results of this study, it can also be concluded that 3D modeling using Point Clouds as a result of processing UAV Aerial Photos can be integrated with BIM, where the integration can be seen in the form of color, coordinates, building height, and 3D points.

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