Utilization of Geographic Information System Based on Unmanned Aerial Vehicle (UAV) for Detailed Mapping of Sriwedari Cultural Heritage Complex in Surakarta City

Dewi Novita Sari [1]*, Tri Cahyo Utomo [1], Muhammad Doriski [1]

[1] Faculty of Geography, Universitas Muhammadiyah Surakarta, Surakarta, Central Java, Indonesia

e-mail: dns104@ums.ac.id

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Abstract. Sriwedari cultural heritage complex in the City of Surakarta, Middle Java, is one of the buildings from the golden era of Keraton Kesunanan of Surakarta. Sriwedari park was built as a recreation area, entertainment, and recreation place for the Keraton family, which is why it's called "Kebon Rojo" (Park of King). Besides being a park, there are a couple of other cultural heritage buildings like Radya Pustaka museum, Wayang Orang Building, Sriwedari Stadium, and Segaran. According to the Ministry of Education and Culture Republic of Indonesia, Sriwedari has become a kind of cultural heritage in the form of sites. The purpose of this research (1) Utilization of spatial based technology using a Geographic Information System that can map in detail the location of cultural heritage with the data sources from the Unmanned Aerial Vehicle (UAV) complete with the coordinate position and supporting information; (2) 3D Visualization using GIS-based software for distributive functional communication media that is communicative for the people. There are three stages of methods in this research. First, license/permission and collecting coordinate data (Ground Control Point) GCP, data of object distance in the field, and other information related to functions of every building. Second, UAV data processing uses spatial-based software, Agisoft Photoscan, and ArcGIS. Third, 3D and 2D map visualization about the building detail, and function. The specific results including 3D visualization of main gate of the complex, Segaran Reservoir, Graha Wisata Niaga, office, Sriwedari Market, mosque area, and museum. It is better used a combination of double grid and circular mission produce 3D visualization with a flying height of 120 m, 72% overlap, and 75̊ side lap. This research included on the webgis, visitors can understand the contents of the cultural heritage complex and its history.

Keywords: *3D, Cultural Heritage Mapping, GIS, Photogrammetry Application, UAV*

1 INTRODUCTION

Sriwedari Park is a park that accommodates cultural art activities while preserving the history (heritage buildings) in it. In Surakarta City Regional Regulation Number 4 of 2021 Concerning the Spatial Plan for the City of Surakarta 2021-2041 (Peraturan Daerah Kota Surakarta Nomor 4 Tahun 2021 Tentang Rencana Tata Ruang Wilayah Kota Surakarta Tahun 2021-2041, 2021), Sriwedari Park is included in the Cultural Heritage Area and Green Open Space. Within the area of Sriwedari Park are several cultural heritage buildings, including Radya Pustaka Museum, Wayang Orang Building, Sriwedari Stadium, and Segaran (Ami et al., 2012). Sriwedari area as a public space has undergone many spatial and usability changes. Modernization and urban development policy further eliminate the spirit of Sriwedari Park as the king's park that has historical and cultural value for the people of Surakarta. One construction in progress is the construction of the Greater Mosque of Sriwedari Park, which will be built on the land of the former indoor amusement park to the east of Sriwedari Stadium.

In line with this, the people and the government of Surakarta need to know detailed information about the building in Sriwedari Park so that the spirit of cultural heritage conservation balanced with innovation in renewable technology can be realized. The use of Geographic Information Systems (GIS) in Indonesia to map spatial patterns and cultural heritage sites is new (Amin et al., 2023). GIS can map the location of cultural heritage with data sources from unmanned aircraft or Unmanned Aerial Vehicle (UAV), including the coordinates and information related to the cultural heritage (Suhartono, 2007). The use of GIS can also be integrated into the form of visual maps, both 2D and 3D (Fitri & Widartono, 2016), GIS websites, web blogs, and infographics that make it easier for the general public to know information about Sriwedari Cultural Heritage (Utomo et al., 2023).

Objects, buildings, or structures can be categorized as cultural heritage as the criteria in accordance with Undang-Undang Nomor 11 Tahun 2010 pasal 5 (Pemerintah Republik Indonesia, 2010). It can representing a style period of at least 50 (fifty) years old. It has a special meaning for history, science, education, religion, and/or culture, and cultural values for strengthening the nation's personality (Indah Sari, 2015). Generally, the function of building includes residential function, religious function, business function, social and cultural function, and special function. Mapping the cultural heritage complex is important to do considering several aspects of the building's function which can be a reflection of history and culture.

The research gap from previous study in the field of archaeological mapping is 3D visualization which very important for the purposes of recording, documenting, and reconstructing, in order to protect and manage cultural assets (Kadobayashi et al., 2002; Grussenmeyer et al., 2008). The most practical and most accurate approach in recording, modeling, and visualizing (Sari et al., 2024) historical and archaeological sites is by combining 3D laser scanning and digital photogrammetry (Suhartono, 2007; Beraldin et al., 2000). Several related studies regarding GIS-based cultural heritage mapping have been carried out, including to identify the function of group A cultural heritage buildings in Semarang City (Indah Sari, 2015); 3D visualization of cultural heritage areas using Cityengine with Quadcopter rides (Fitri & Widartono, 2016); and the use of GIS for the preservation of sites around Borobudur Temple (Suhartono, 2007).

Traditional mapping methods typically rely on manual surveying techniques such as total station surveys, plane table surveys, or handheld GPS devices. These methods require skilled personnel to collect data in the field, which can be time-consuming, labor-intensive, and prone to human error. Traditional mapping methods also only produce standalone datasets that are difficult to integrate with other geospatial data sources or analyze using modern GIS tools. Lack of interoperability and compatibility can hinder data sharing, collaboration, and holistic analysis of cultural heritage sites.

This research addresses how to utilize the Geographic Information System (GIS) integrated with Unmanned Aerial Vehicle (UAV) for detailed mapping of the Sriwedari Cultural Heritage Complex, Surakarta City, Indonesia. This study aims to map the details of buildings, functions, and information in Sriwedari Cultural Heritage Complex using the help of the Geographic Information System and Unmanned Aerial Vehicle (UAV) and produce 3D visualization of the Sriwedari Cultural Heritage Complex. Therefore, the extent to which Unmanned Aerial Vehicle (UAV) can be processed into a detailed map of Sriwedari Cultural Heritage Complex, Surakarta City, can be identified, which will be presented in the form of 3D interactive visualizations (Sugumaran et al., 2011).

2 MATERIALS AND METHODOLOGY

2.1 Tools and Materials

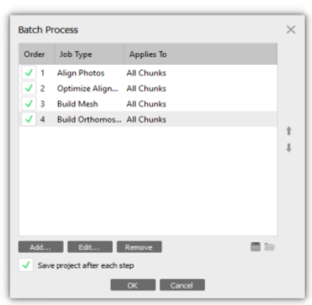
The tools and materials used in this study included DJI Mavic 2 Pro for aerial photo taking, iPhone 11 for data storage and remote photo taking, GPS for coordinate selection, Canon D3200 camera for documentation, Agisoft Photoscan for orthomolecular data processing, ArcGIS for spatial data processing, Pix4Dpictures for determination of flight trajectory, Acer Swift 3 Core i7 Gen 10th 8 GB RAM laptop for data processing.

The selection of aerial photography using DJI Mavic 2 Pro certainly considers the quality of the resulting photos, which is good because it utilizes Superior Image quality with Hasselblad. Excellent light and color performance make it an ideal choice, with the Dlog-M 10-bit color profile allowing for higher color capture levels and an adjustable aperture from f/2.8 to f/11, providing better control in various lighting conditions. The drone's sufficient flying quality also assists aerial capture; the Mavic 2 Pro has an optimal flight time of up to 30 minutes.

Certainly, during aerial photography, the visual display during flight and the photo results are supported by the smartphone, the iPhone 11, which is already connected to the Pix4Dmapper application.

The aerial photography was conducted using a mission or project path so that the drone's mission path entirely encompassed the coverage of the area. The drone systematically flew following the mission or project path, with settings of 120 m altitude, 72% front overlap, 75% side overlap, and double grid, resulting in 207 photos and a flight duration of 30 minutes, with an additional 19 minutes allocated for returning to the "going home" point. The front and side overlap was set at 70% or higher because the photos were neither too far nor too close during the photo stitching process, with a tie point setting of 80,000.

The aerial photo results are processed using Agisoft with the highest quality settings, with tie point limit and key point limit set to 80,000, optimized alignment, aggressive depth filtering in mesh building, and then the surface mesh is turned into an orthomosaic. With these settings, maximum results have been achieved and can be consumed by the community. Certainly, processing data and rendering require a laptop or computer specification that meets the standards of an Acer Swift 3 Core i7 10th Gen with 8 GB of RAM to produce good quality orthomosaics and 3D models, also with settings as follows:



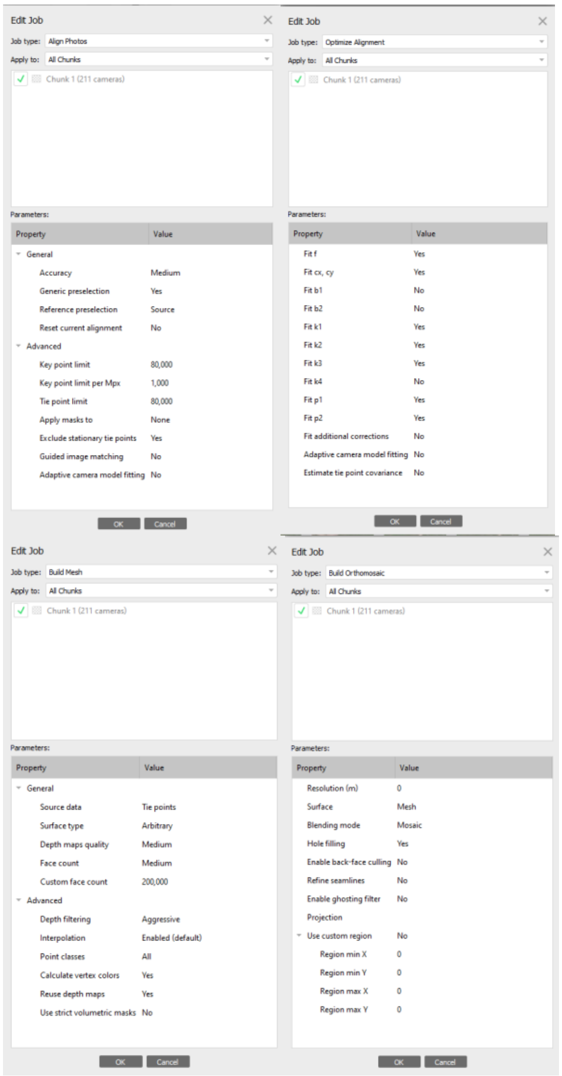


Figure 2-1: Agisoft Data Processing Settings

From these results, the final stage involves finishing by providing a layout on the orthomosaic map and digitizing the areas of the orthomosaic for use and consumption by the general public, such as providing legends and explanations of the areas.

2.2 Methods

There were three stages in this study. The first stage was processing the permit and collecting the data in the form of coordinate data, Ground Control Point (GCP), object distance data in the field, and other information related to the function of each building in the Sriwedari Cultural Heritage Complex (Sari et al., 2022). The data acquisition using drone requires clear weather (Rohman & Prasetya, 2019). At this stage, aerial photography was carried out using a drone (Danardono et al., 2023). The second stage was processing aerial photo data with the camera's upright position with a shooting area of ±1 ha. The third stage was the visualization of advanced website-based data processing results. The online output stage of this map is in the form of 3D visualization and scientific journal articles as a form of information for the public. Additional information obtained from informants in the field related to cultural heritage buildings in Sriwedari was written into an online-based article so that website visitors can understand the inside of the cultural heritage complex and its history and can be teaching materials to the public and academics. The complete research flow can be seen in the following flowchart.

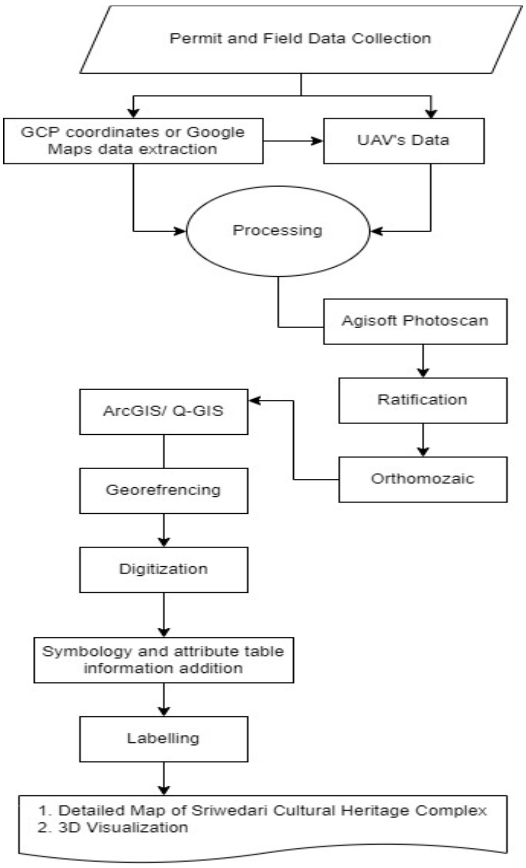


Figure 2-2: Research Flowchart

Some of the stages of data collection in the field included:

1. Field survey. The field survey is intended to determine the condition of the location in order to maximize the planning of what is developed in the area of Sriwedari Park. Application for permit was addressed to the Regional Development and Research Agency of Surakarta City. It was followed by collecting information on the inside of the cultural heritage area from the manager of the Radyapustaka Museum.
2. Ground Control Point (GCP). The boundaries of the area of Sriwedari Park, which became the research object, were used as Ground Control Point (GCP). This point became a drone flight control point using an autopilot with a grid model, which required four angles as GCP. The GCP point data in the field is in a geographic coordinate system that has x and y coordinates as follows:

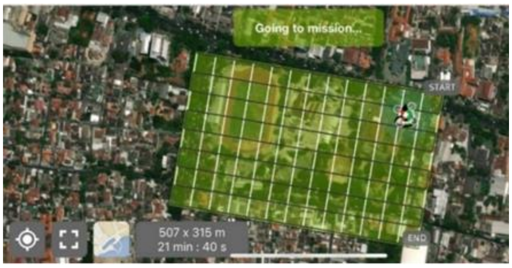
Table 2-1: GCP coordinates created for each flying mission

Mission Type	Longitude	Latitude	Dimension (m)	Camera Angle
Grid	-7.568775°	110.813345°	682 m x 475	70°
Double Grid	-7.568675°	110.812875°	484 m x 318	75°
Circular Mission	-7.568763°	110.812473°	652 m x 408	10°

3. UAV aerial photo. UAV aerial photo was taken using auto pilot after setting the GCP in pix4Dpictures used as flight trajectories automatically follow the grid. Application used when creating automatic flying trajectories was Pix4DPictures. The aerial photo taking used grid mission, double grid mission, and circular mission. The number of photos taken from the grid mission trajectory is 207 photos, double grid is 313 photos, and circular is 177 photos. The aerial photo taking started in the morning from 09.00 to 12.00.
4. GCP binding with aerial photos. GCP dot binding to produce 3D shapes was carried out with a combination of double grid and circular mission. The method used was Block Bundle Adjustment which can restore the position of the aerial photo coordinates on the ground coordinates (geographical surface of the ground) and produce a more stereo-vision display (Eisenbei, 2009). The following is the creation of the mission of this study.

(A) Double Grid Mission

(B) Circular Mission



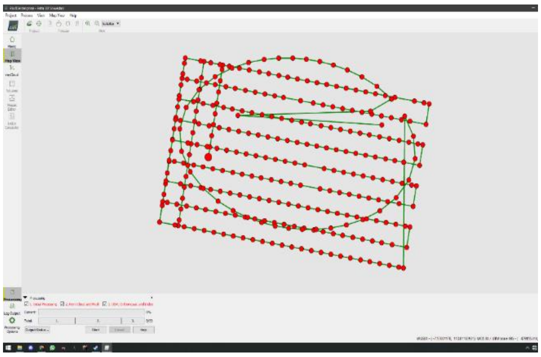
(C) Going to Mission

Figure 2-3 : GCP binding with aerial photos according to the flying missions (A) double grid mission; (B) circular mission; (C) going mission.

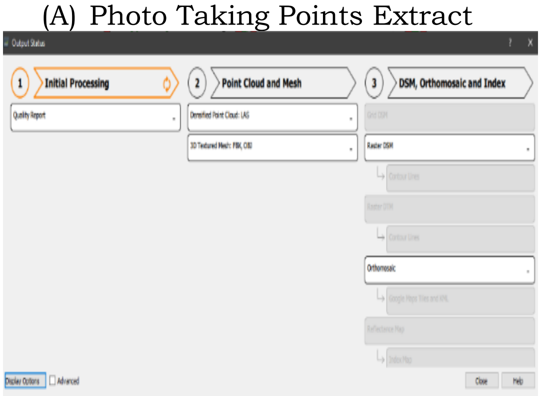
UAV data processing. After taking photos using a drone, the image was processed with Agisoft and Pix4Dpictures software's. This software is efficient and has the ability to reconstruct 3D data (Malawani et al., 2020). All photos were combined into one in the form of DSM and ortho-mosaic. The processing into DSM used the components from merging align photos source data: tie point, type WGS 84 (EPSG: 4326). Ortho-mosaic result used the surface from DSM processed with default blending mode, geographic type.

In the final stage of processing data visualization to form 3D and 2D for giving information to the public, the following stages of data visualization were carried out:

1. The creation of a detailed map of the building. The creation of a map was carried out using ArGIS software by digitizing the buildings in Sriwedari Cultural Heritage Complex. Additional building information was included in the table attributes.
2. 3D Visualization. One of the easiest approaches in 3D modeling is to extract the cloud point object photo data using elevation data (Zhao et al., 2018). The cloud points with high accuracy is usually obtained from LiDAR data. To overcome the limitations of the method, a 3D building model was made through UAV acquisition. The Build Dense Cloud step was employed in the Pix4Dpictures software to obtain DSM data. Creating a detailed map of the building using the Build Mesh feature by including source data tie points, Surface Arbitrary (3D), and face count high (90,000). Figures 4 and 5 are examples of Build Dense Cloud with Pix4Dpictures.
3. Ground truthing involves comparing UAV-derived data with ground-based measurements or existing datasets to verify accuracy. This study conduct on-site surveys or use reference points to validate the spatial accuracy of UAV imagery and models.



(A) Photo Taking Points Extract



(B) Stage Process on Pix4Dpictures

Figure 2-4 : (A) and (B) the sequence of stages of processing aerial photo data into DSM on Pix4Dpictures.

The challenges encountered during the study were factors such as sensor calibration, image resolution, and environmental conditions which influence the precision of data captured by UAVs. Navigating the regulatory landscape to obtain necessary permits and permissions for UAV flights over Sriwedari heritage sites can be time-consuming. It is not permitted to operate at a height of more than 500 ft (150 m) in airspace areas that have been designated as having air traffic lanes.

3 RESULTS AND DISCUSSION

The UAV aerial photo taking produced 489 aerial photos. The number of UAV aerial photos produced was influenced by the parameters inputted before the UAV took off, including sidelap, overlap, altitude, and survey area shape (Albeni et al., 2018). The area of Sriwedari Cultural Heritage Complex and its surroundings is ±1 ha. The flying height is 120 m, with 72% overlap and 75% sidelap. The results of the information obtained from the creation of detailed maps include the main gate of the complex, Segaran Reservoir, Graha Wisata Niaga, office, Sriwedari Market, mosque area, and museum. Existing facilities in Sriwedari Complex are still operating, such as museums, offices, and Graha Wisata Niaga. However, several parts of the complex, such as the Segaran Reservoir, a cultural heritage, are no longer operated. Several buildings in the southern part of the complex directly adjacent to Sriwedari Market have quiet slums and adjacent areas that can be a concentration of sustainable land management.

It can be observed from the results in Figure 6 that the footprint of the building is well-recorded. The difference between building objects, vegetation, road, and water can be distinguished well. The building pattern is quite regular with low density, which allows the Sriwedari Cultural Heritage Complex to be used as a tourist attraction with a capacity of >7,000 people. Interpretation to determine objects based on the elements of image interpretation on UAV does not have to use nine elements of interpretation but simply looks at primary essential elements such as hue/ color, secondary elements, namely shape, texture, height, site/ situation/ association, and convergence of evidence.

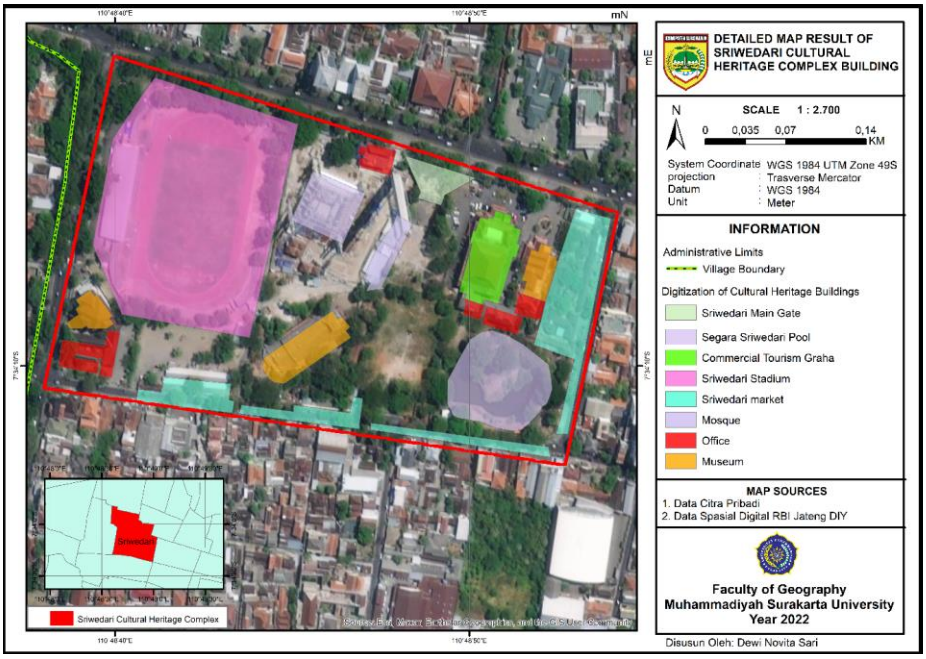


Figure 3-1 : Detailed map result of Sriwedari Cultural Heritage Complex building

The results obtained for 3D visualization obtained from DJI Mavic 2 Pro are good enough to do landscape mapping of cultural heritage buildings. This can more accurately identify existing buildings in Sriwedari Cultural Heritage Complex. The 3D model was not tested for accuracy because the purpose of the study was only to obtain the detailed aspects of the complex using the combined flight trajectory method. Detailed information on the name of the cultural heritage sites within the complex also adequately describes the original appearance in the field. The following are the results of 3D modeling of the cultural heritage complex.

Figure 3-2 : 3D Visualization Result of Sriwedari Cultural Heritage Complex

In making dense cloud, there were two constructions that could optimize the data set. The type used in this study is arbitrary (Figure 6). Build Mesh Arbitrary was chosen because the researchers wanted to highlight the shape of the building compared to objects captured from the ground. Build Mesh Arbitrary can be used to process data sets containing up to several hundred photos, but the results of the process usually take much less memory. In general, the creation of detailed maps and 3D visualization of landmarks of cultural heritage complex buildings is very effective when using data sources derived from UAVs. The texture of the building from the roof to the ground area will be more detailed when zooming in on the model. Software's that can be used for building 3D visualization include Agisoft Photoscan and Pix4Dpictures.

The selection of side-lap, overlap, altitude, and survey area shape greatly affect the results obtained for 3D visualization. The higher the overlap and darker the value, the more photos are produced. Meanwhile, the higher the altitude value used; the fewer photos produced. In this study, the combined flight trajectory was used, which made the results less optimal. The flight trajectory was chosen using a double grid or circular. This is because the researchers' hypothesis regarding overlapping or patching the flight trajectory would be better when using a stereo model to produce stereoscopic observation. This stereoscopic process is necessary because, according to the basic concept of photogrammetry, when the left eye looks at the object in the left photo and the right eye sees the object in the right photo, a better 3D impression will be produced (Negara & Harintaka, 2021). However, the results obtained were considered less optimal and could not provide a more vivid 3D shape of the buildings.

Meanwhile traditional mapping methods such as manual survey for preservation (Suhartono, 2007) and participatory mapping by the community can catalog its heritage resources and determine their value (Frenierre, 2020). It have been valuable for documenting cultural heritage sites, UAV and GIS technology offer significant advantages in terms of data accuracy, efficiency, accessibility, and analysis capabilities.

The involvement of the public and its benefits through the processing of orthomosaic and 3D data enable the community to better understand local history, identify the distribution of cultural heritage sites, and contribute to efforts to preserve culture (Fitria et al., 2023).

4 CONCLUSION

From the activities that were carried out, several conclusions were obtained, including the following: the presentation of detailed map of Sriwedari Cultural Heritage Complex buildings can be done using unmanned aircraft or Unmanned Aerial Vehicle (UAV). Within the complex, there are the main gate of the complex, Segaran Reservoir, Graha Wisata Niaga, office, Sriwedari Market, mosque area, and museum. It is necessary to select a UAV data collection method to produce better 3D visualization. 3D model visualization used a combination of double grid and circular mission. The method used was block bundle adjustment. Cloud point processing is a crucial step in obtaining building height information. The results of the 3D landscape of the buildings obtained are good enough for a complex area of ±1 ha with a flying height of 120 m, 72% overlap, and 75° side lap.

Specific recommendations for future research, such as exploring the integration of other technologies (e.g., LiDAR, augmented reality) with different mission methodologies to other cultural heritage sites. One of the potential policy implications involves fostering collaboration and partnership with the Ministry of Education and Culture of the Republic of Indonesia, along with relevant stakeholders, to integrate study findings into a valuable WebGIS platform. This platform would serve as a comprehensive tool for cultural heritage preservation efforts. By leveraging the expertise and resources of the Ministry and stakeholders, as well as incorporating research outcomes, the WebGIS can effectively catalog, map, and monitor cultural heritage sites across Indonesia.

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