 e-ISSN 2682-7727 https://doi.org/10.17576/geo-2026-2202-01

UAV-Based photogrammetry for cultural heritage mapping and 3D modelling of Kota Lama Duyong, Terengganu

Lam Kuok Choy[1], Nor Haslina Ja'afar[2], Mohd Iskandar Abdul Malek[2], Nor Zalina Harun[3], Alisa Abdul Wahab[4], Khalilah Zakariya[5], Aajirah Hanim[1], Farah Nuralissa Muhammad[1]

[1]Geography Program, Faculty of Social Sciences and Humanities,
Universiti Kebangsaan Malaysia
[2]Department of Architecture and Built Environment,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
[3]Institute of The Malay World and Civilization (ATMA), Universiti Kebangsaan Malaysia
[4]Lembaga Muzium Negeri Terengganu, Bukit Losong, Kuala Terengganu
[5]Kulliyyah of Architecture and Environmental Design,
International Islamic University of Malaysia

Corresponding author: Lam Kuok Choy (email: lam@ukm.edu.my)

Received: 22 August 2024; Accepted: 18 September 2025; Published: 21 May 2026

Abstract

Cultural heritage buildings are increasingly exposed to environmental degradation, urban development and inadequate documentation, creating an urgent need for efficient and accurate digital preservation approaches. This study examines the application of Unmanned Aerial Vehicle (UAV) based photogrammetry for three-dimensional (3D) documentation and visualization of Kota Lama Duyong, a historically significant heritage structure located in Kuala Terengganu, Malaysia. UAV image acquisition was carried out using a DJI Mavic 2 Pro through automated double grid and circular flight missions to ensure sufficient image overlap and comprehensive façade coverage in a spatially constrained environment. A total of 180 aerial images were processed using Agisoft Metashape Professional, employing Structure-from-Motion (SfM) and Multi-View Stereo (MVS) techniques to generate sparse and dense point clouds, polygonal mesh models, textured 3D surfaces and orthoimages. The results demonstrate that UAV-based photogrammetry can produce geometrically coherent and visually detailed 3D models suitable for cultural heritage documentation, visualization and digital archiving, even under challenging site conditions. Minor geometric distortions were observed in areas affected by vegetation and infrastructural obstructions; however, the overall model quality remains adequate for heritage recording purposes. This study confirms that UAV photogrammetry represents a cost-effective, flexible and practical solution for heritage digitization and contributes region-specific empirical evidence to support the integration of UAV-derived 3D models into GIS-based cultural heritage management and conservation frameworks.

Keywords: GIS, heritage building, Kota Lama Duyong, photogrammetry, UAV mapping

Introduction

Cultural heritage assets, including monuments and historic buildings, represent significant historical, architectural and socio-cultural values and serve as tangible expressions of national identity. These assets embody both intrinsic and economic value through their architectural aesthetics, construction techniques, craftsmanship and embedded cultural philosophies (Sabzali Khan et al., 2011; Ergun, Sahin & Bilucan, 2023). Owing to their uniqueness and irreplaceable nature, historic buildings require systematic preservation and conservation to safeguard their cultural significance and ensure their continued contribution to society and future generations.

Beyond their cultural importance, heritage buildings contribute substantially to tourism, education and local economic development. In Malaysia, the tourism sector was reported as the third-largest income-generating industry, contributing RM21.4 billion in 2011 (Samsudin, 2013) and increased to RM291.9 billion, contributing 15.1% to the national Gross Domestic Product, in 2024 (Department of Statistics Malaysia, 2025). Consequently, effective heritage management plays a critical role in sustaining tourism-driven economic growth while reinforcing cultural identity.

Despite their importance, cultural heritage sites worldwide face increasing threats from natural hazards, human activities, environmental degradation and aging-related deterioration. These challenges are often exacerbated by insufficient documentation, lack of awareness and inadequate management frameworks, which hinder effective conservation efforts (Ghafar Ahmad, 2009). The absence of comprehensive and standardized heritage records frequently results in persistent maintenance and conservation issues. Therefore, the development of systematic documentation approaches aligned with established conservation principles is essential to support long-term heritage preservation.

Recent advances in digital technologies have significantly transformed heritage documentation and management practices. Digital recording techniques, often is the first steps of digitization, enable accurate capture, storage and dissemination of physical and structural information, enhancing conservation planning and public accessibility (Khoshelham, 2018). Multimodal and interactive technologies have been recognized as critical tools for documenting, preserving and communicating cultural heritage assets (Portalés, 2018). Such digital approaches also strengthen the role of museums and heritage institutions as educational platforms and tourism assets.

In recent years, drone-based photogrammetry has emerged as a widely adopted technique for generating accurate 3D models of cultural heritage sites. Unmanned Aerial Vehicles (UAVs) enable efficient acquisition of high-resolution imagery from flexible viewpoints, allowing detailed documentation of complex structures that are difficult to survey using conventional terrestrial methods (Dore & Murphy, 2012). The increasing adoption of UAV platforms is largely attributed to their ability to operate at low altitudes and deploy diverse sensors, including digital and single-lens reflex (SLR) cameras, as well as GNSS/INS systems for navigation, acquisition planning and direct georeferencing (Nex & Remondino, 2014).

Compared with traditional field survey techniques, UAV-based photogrammetry offers several advantages, including improved spatial accuracy, higher data completeness, faster acquisition, cost efficiency, reduced site disturbance and enhanced accessibility to hazardous or constrained environments (Lorenzo et al., 2019). Moreover, UAV-derived imagery supports both visually realistic representations and metrically accurate datasets suitable for conservation, monitoring and restoration applications (Febro, 2020; Alsadik, 2020).

In parallel, Geographic Information Systems (GIS) have evolved as essential platforms for storing, visualizing, analyzing and managing spatial heritage data. Modern GIS architecture integrates data management, spatial analysis and visualization within modular environments, supporting multidisciplinary heritage workflows. Additionally, planning and design codes established by local authorities can be incorporated into GIS-based heritage databases to support informed decision-making in conservation and urban planning contexts (Foster, 2020; Aljohani et al., 2021).

Traditionally, GIS applications focused primarily on two-dimensional (2D) spatial representations. However, recent technological developments have enabled the integration of three-dimensional (3D) spatial data, facilitating advanced visualization, analysis and documentation of complex heritage structures (Dore & Murphy, 2012). The integration of 3D digital models within GIS environments provides comprehensive digital repositories that combine geometric, spatial and historical information, along with metadata on data provenance and reliability. Such integrated systems offer robust platforms for long-term archiving, analysis and management of cultural heritage assets (Portalés, 2018).

The primary objective of this study is to develop a high-resolution 3D digital model of the heritage building Kota Lama Duyong using UAV-based photogrammetry. Specifically, the study aims to evaluate the effectiveness of UAV image acquisition and photogrammetric processing techniques in capturing accurate geometric and visual information of a culturally significant structure within a spatially constrained environment. Additionally, this research seeks to demonstrate the applicability of integrating UAV-derived 3D outputs with GIS platforms to support cultural heritage documentation, visualization and long-term conservation planning.

Study area and method

Study area

The selected case study is the Kota Lama Duyong (approximately 5°20′10″ N and 103°07′38″ E), located on Duyong island at the mouth of Terengganu River in the state of Terengganu, Malaysia. The site occupies an area of approximately 400 m² (Figure 1). Locally known as Kota Tok Hakim, the structure was commissioned by Dato’ Biji Sura (Nik Mohamad bin Hitam) in 1919 and completed in 1920. Kota Lama Duyong represents a distinctive example of traditional Malay architectural heritage, characterized by unique construction techniques and intricate wood and stone carvings. The structure exhibits architectural significance through its craftsmanship and symbolic design elements, making it an important cultural and historical landmark.

Geografia-Malaysian Journal of Society and Space 22 issue 2 (1-15)
© 2026, e-ISSN 2682-7727 https://doi.org/10.17576/geo-2026-2202-01

Figure 1. Location of the Kota Lama Duyong

In 1996, a reconstruction initiative was undertaken by the Ministry of Culture and Arts to repair extensive damage caused by severe flooding in 1986. The restoration was completed in September 1999 and adhered closely to the original architectural design. However, despite these efforts, the structure has since experienced renewed deterioration. Architecturally, the building resembles a small Malay royal palace and incorporates foreign stylistic influences, including Corinthian and Egyptian elements, particularly evident in its columns and stone wall detailing (Figure 2).

Figure 2. Kota Lama Duyong

Methodological framework

The application of Unmanned Aerial Vehicle (UAV)-based photogrammetry represents a key digital documentation approach employed in this study to demonstrate the applicability of advanced geospatial technologies in cultural heritage preservation. Digital 3D documentation of heritage sites requires an integrated workflow comprising data acquisition, data processing and data representation. The overall methodological framework adopted in this study is illustrated in Figure 3.

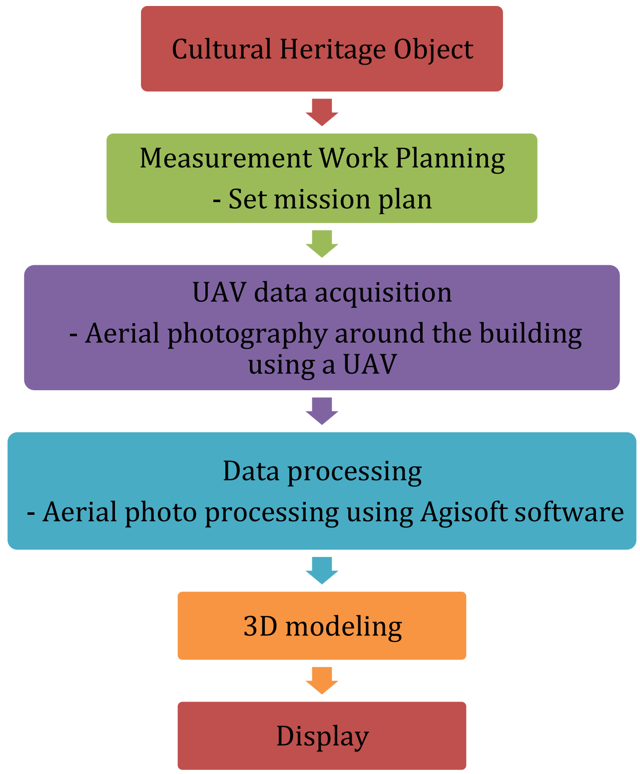


Figure 3. Workflow overview

Data acquisition

Data acquisition was conducted using a DJI Mavic 2 Pro quadcopter UAV equipped with a high-resolution onboard camera suitable for small-scale mapping and documentation tasks (Table 1). The Mavic 2 Pro is a compact, foldable UAV capable of horizontal flight distances of up to 8 km under unobstructed, line-of-sight conditions using the DJI GO 4 application (Vellemu et al., 2021). The UAV integrates Global Navigation Satellite System (GNSS) technologies, enabling precise navigation, waypoint control, obstacle avoidance and automated return-to-home functionality. These features are critical for ensuring flight stability, accurate image acquisition and safe landing during data collection.

 e-ISSN 2682-7727 https://doi.org/10.17576/geo-2026-2202-01

Table 1. Technical specifications of the DJI Mavic 2 Pro and camera system

Parameter	Value
Weight	907 g
Maximum take-off altitude	6000 m
Maximum flight time	31 minutes (at 25 km/h)
Maximum flight distance	18 km (at 50 km/h)
Tilt angle	35° (S-mode), 25° (P-mode)
Sensor	1-inch CMOS (12 MP)
Field of view	~77°
Focal length	35 mm
Aperture	f/2.8–f/11
Video resolution	3840 × 2160 pixels

Source: DJI Official Website, 2025

Flight planning and mission execution were carried out using the PIX4Dcapture platform (www.pix4d.com), which supports automated mission planning and pre-flight checks. This software provides multiple mission planning options to ensure consistent image overlap and flight stability. Flight parameters were predefined prior to deployment to ensure consistency and operational safety. Two complementary flight missions were executed: a double grid mission to capture nadir and oblique imagery over the study area and a circular mission to acquire detailed façade imagery around the heritage structure. The combined use of these missions enhanced image redundancy and façade coverage, which are critical for high-quality 3D reconstruction. Table 2 summarizes the key parameters and outcomes of both flight missions.

Table 2. Summary of UAV mission parameters and observations

Parameter	Double Grid	Circular
Flight time	8 min 44 s	4 min 14 s
Coverage area	61 m × 69 m	64 m × 70 m
Image overlap	70% × 70%	–
Camera angle	45°	15°
Flight altitude	25 m	25 m
Flight path length	942 m	172 m
Images captured	156	24

For this study, a combination of double grid mission and circular mission flight patterns was employed (Figures 4c). The double grid mission consists of parallel and cross-directional flight paths and is particularly effective for capturing large areas and generating high-quality 3D reconstructions (Figure 4a). Camera tilt angles ranging between 15° and 45° with 70% forward and 70% side overlap were applied to enhance facade coverage and minimize occlusions. Whereas the circular mission was utilized to capture oblique imagery around the structure by flying the UAV along a circular trajectory centered on the building (Figure 4b). This mission involves straight flight segments combined with 90° turning manoeuvres and is especially effective for documenting vertical architectural elements and complex structural geometries. The integration of both mission types ensured comprehensive image coverage suitable for accurate 3D modelling. A

© 2026, e-ISSN 2682-7727 https://doi.org/10.17576/geo-2026-2202-01

total of 180 images were captured across both missions and subsequently combined during photogrammetric processing in Agisoft Metashape Professional (Figure 5).

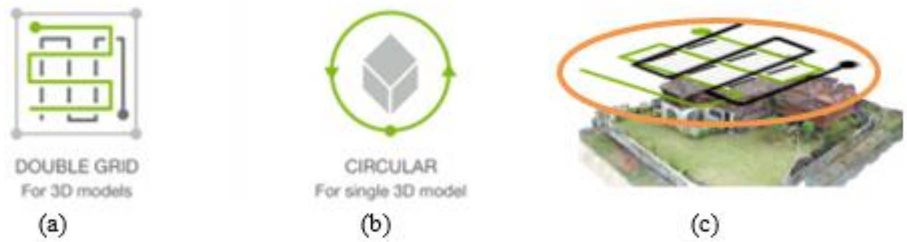


Figure 4. (a) Double grid mission, (b) Circular mission, (c) illustration of combined mission flight path over the heritage building

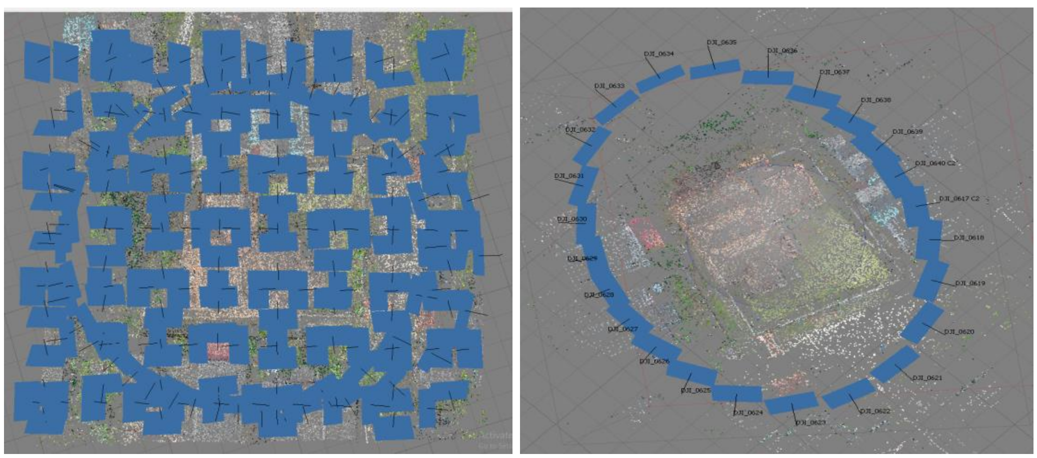


Figure 5. Camera position by combination of two mission during photography

Data processing

The UAV-acquired imagery was processed using Agisoft Metashape Professional (Agisoft LLC), a standalone photogrammetry software widely applied in GIS, cultural heritage documentation and 3D spatial modelling applications (Agisoft, 2025; Kingsland, 2020). The automated photogrammetric data processing workflow was designed to transform the UAV-acquired imagery from overlapping digital images into accurate and georeferenced three-dimensional (3D) models suitable for cultural heritage documentation and spatial analysis. Figure 6 illustrates the overall photogrammetric processing workflow from image import to final model generation.

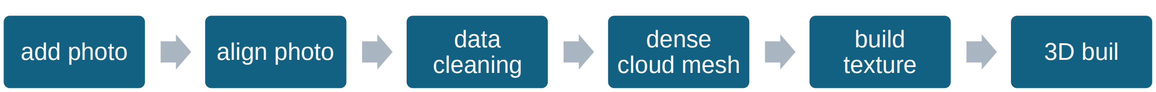


Figure 6. Stages in UAV image processing using Agisoft Metashape Professional software to produce orthophoto and 3D models

The data processing workflow consists of several sequential stages, including image pre-processing, image alignment and camera calibration, sparse point cloud generation, dense point cloud reconstruction, mesh generation and texture mapping. Initially, through the Structure-from-Motion (SfM) processing, the software recovered camera positions and orientations through homologous feature points matching across all the overlapping images. This process enabled the estimation of internal and external camera parameters, resulting in the generation of a sparse point cloud that defined the basic geometry of the structure. This was followed by dense point cloud generation using Multi-View Stereo (MVS) algorithms, which enhanced the geometric detail and spatial resolution of the reconstructed model. The dense point cloud provided a high-resolution representation of the architectural elements, including façades, columns, roofs and decorative components. Noise filtering and point classification were applied to remove outliers and improve surface continuity.

Subsequently, a polygonal mesh was generated from the dense point cloud to represent the surface geometry of the heritage structure. High-resolution texture mapping was then applied by projecting the original UAV imagery onto the mesh surface, producing a photorealistic 3D model. This textured model preserved both geometric accuracy and visual detail, making it suitable for documentation, visualization and heritage analysis. The final 3D products, including the dense point cloud, textured mesh and orthophoto outputs, were exported in standard formats such as .OBJ, .BLEND, .FBX, .GLTF and .GLB, allowing full-scene visualization, interoperability with 3D platforms and integration into GIS-based heritage management systems. These outputs form the basis for heritage building condition assessment, spatial visualization and long-term digital archiving.

Results

Output of the image processing workflow

Kota Lama Duyong was surveyed to acquire high-resolution image data for cultural heritage documentation using UAV-based photogrammetry. The site presented several operational challenges due to its dense surrounding residential development, vegetation cover and limited accessibility. These constraints required careful flight planning and mission execution to ensure sufficient image coverage and overlap. Consequently, two flight missions were executed: a double grid mission to capture nadir and oblique imagery over the study area and a circular mission to acquire detailed façade imagery around the heritage structure. The combined use of these missions enhanced image redundancy and façade coverage, which are critical for high-quality 3D reconstruction

a) Image alignment

In the initial stage, all images were aligned based on feature point detection using Structure-from-Motion (SfM) algorithms. This process refined camera positions and orientations while generating a sparse point cloud representing the overall geometry of the structure (Figure 7a). To balance processing efficiency and model accuracy, the alignment accuracy was set to *medium*, considering the large dataset and hardware limitations. Although higher accuracy settings can improve geometric precision, they often result in longer processing times and increased risk of computational errors (Andrei et al., 2018). This stage is critical, as it directly influences the resolution and spatial accuracy of the final 3D model.

b) Dense point cloud generation

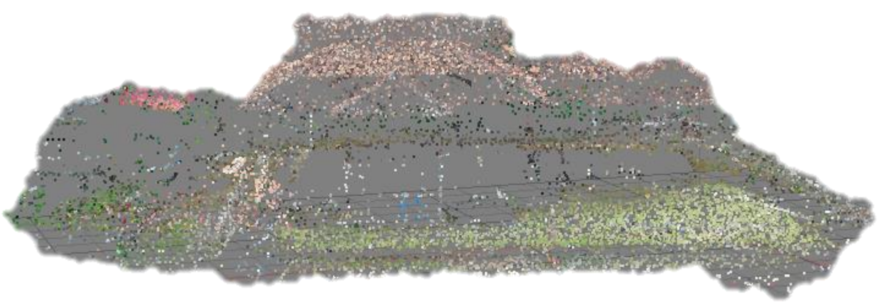
Following successful alignment, a dense point cloud was generated using Multi-View Stereo (MVS) techniques. The quality parameter was again set to *medium* to ensure manageable processing time while maintaining sufficient detail. Manual editing was conducted to remove noise, erroneous points and irrelevant objects outside the area of interest. The resulting dense point cloud provided a detailed spatial representation of the building's architectural features (Figure 7b).

c) Mesh generation

The cleaned dense point cloud was then converted into a polygonal surface through the mesh generation process. Using dense cloud geometry, camera parameters and viewing angles, an untextured 3D mesh model was produced (Figure 7c). This stage required additional manual refinement, including gap filling, removal of unwanted faces and surface smoothing to improve model continuity and structural integrity.

d) Texture mapping and rendering

In the final modelling stage, texture mapping was applied to the mesh surface by projecting high-resolution image data onto the polygonal model. Both procedural and file-based textures were used to accurately reproduce the visual appearance of the building's surface materials, following recommended texturing practices (Setiawan, 2017). The resulting textured model exhibits realistic surface color and detail, as shown in Figure 7d.



(a)

(b)

Geografia-Malaysian Journal of Society and Space 22 issue 2 (1-15)
© 2026, e-ISSN 2682-7727 https://doi.org/10.17576/geo-2026-2202-01

(c)

(d)

Figure 7. (a) Tie Point, (b) Dense Cloud, (c) Mesh, (d) Texture

e) Othoimage and 3D modelling of Kota Lama Duyong

Following 3D model completion, orthoimages of the building exterior were generated to provide a geometrically corrected, scale-accurate representation of the structure. Figure 8 presents the orthoimage produced in this study. The orthophoto is georeferenced to WGS84 (World Geodetic System 1984) datum with Universal Transverse Mercator (UTM Zone 47N) projection and with a ground resolution of 4cm/pixel.

Figure 8. Orthophoto illustrates the typical UAV flight coverage of the heritage site

However, the presence of physical obstacles such as electrical cables and surrounding trees limited image acquisition at the rear sections of the building. These occlusions resulted in localized distortions in the final orthoimage and minor geometric inconsistencies in certain façade areas. Consequently, while the reconstructed model closely represents the real structure, some areas exhibit reduced completeness due to unavoidable site constraints. The last process is orthoimages of the building (exterior) were generated. Figure 9 shows some of the final results obtained in this study for the production of a 3D model of the Kota Lama Duyong building.

Figure 9. Examples of UAV captured photos of Kota Lama Duyong

Three-dimensional visualization and display

The finalized 3D models were exported in widely supported formats, including .OBJ, .BLEND, .FBX, .GLTF and .GLB, enabling interoperability across various visualization, web-based and GIS platforms. These formats facilitate interactive viewing, archival storage and dissemination of cultural heritage information. Representative screenshots of the interactive 3D visualization are presented in Figure 10. Through 3D visualization, the digital reconstruction enables users to explore the heritage structure virtually, providing an immersive experience that closely resembles on-site observation. This digital output can be utilised to support heritage conservation, educational dissemination and public engagement, while also serving as a long-term digital archive of the site. The 3D model of Kota Lama Duyong has been published on an online visualization platform and can be accessed at: https://skfb.ly/oBHDQ

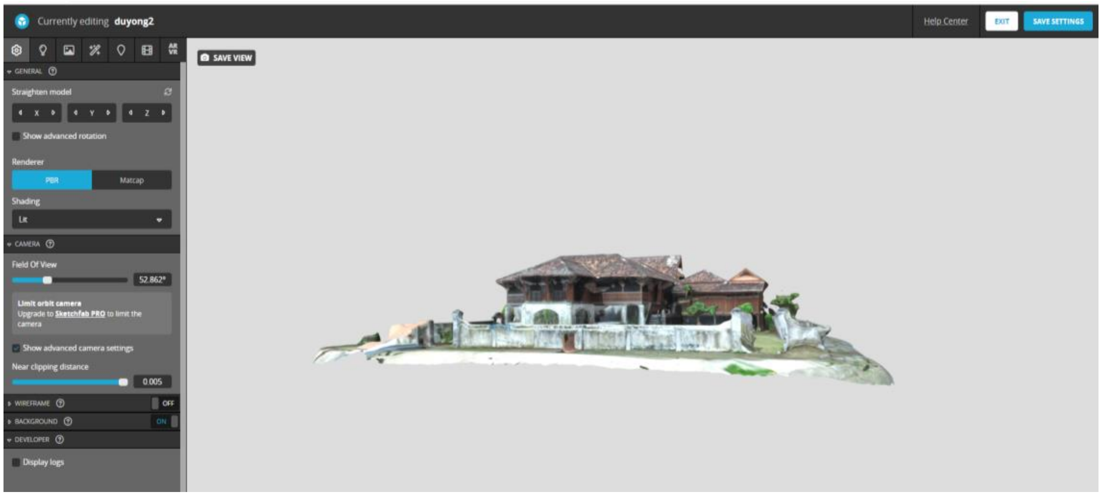


Figure 10. 3D modelling output of Kota Lama Duyong

Discussion

Cultural heritage documentation represents one of the primary application domains of UAV systems, largely due to their cost-effectiveness, operational flexibility, accessibility and rapid deployment capabilities (Achille et al., 2015). This study successfully produced a high-resolution three-dimensional digital replica of Kota Lama Duyong using UAV-based photogrammetry, demonstrating the effectiveness of drone technology for cultural heritage documentation and preservation. The resulting 3D model captures the architectural form, structural details and decorative elements of the heritage building, providing a comprehensive digital record that can support conservation, visualization and management efforts.

Numerous studies have reported that UAV platforms provide an efficient and accurate means of capturing detailed spatial data for heritage structures, particularly in environments where conventional terrestrial surveys are constrained by accessibility or safety limitations (Bakirman et al., 2020; Xu et al., 2014; Achille et al., 2015). For instance, Dore and Murphy (2012) and Nex and Remondino (2014) highlighted the advantages of UAV photogrammetry in recording complex architectural forms, emphasizing its ability to capture oblique perspectives and vertical façades that are difficult to document using ground-based methods. Similarly, the results obtained for Kota Lama Duyong show that UAV-derived imagery, when combined with appropriate flight planning and photogrammetric processing, can produce detailed and geometrically coherent 3D models of heritage buildings with complex structural and decorative elements.

The ability of UAVs to operate in hard-to-access or constrained environments makes them particularly suitable for heritage sites where traditional surveying methods are limited or impractical. In terms of environmental constraints, Febro (2020) emphasized the importance of careful flight planning in densely built or spatially restricted environments. In this study, the UAV platform enabled efficient data acquisition despite spatial constraints and environmental challenges. The Kota Lama Duyong site is surrounded by residential structures, which restricts accessibility and limits optimal ground-based survey viewpoints. These environmental constraints necessitated careful flight planning to ensure sufficient image overlap, appropriate viewing angles and safe UAV operation. Pre-flight site assessment and strategic selection of take-off and landing zones were therefore critical to the success of the data acquisition process. As highlighted by Febro (2020), effective flight planning is essential in complex environments, particularly when surveying large or architecturally intricate structures. The successful reconstruction obtained in this study reinforces the conclusion that UAV photogrammetry remains viable even under challenging site conditions when supported by systematic planning and suitable mission design.

From a data processing perspective, the use of Structure-from-Motion (SfM) and Multi-View Stereo (MVS) techniques implemented in Agisoft Metashape Professional aligns with workflows adopted in recent heritage documentation studies (Markiewicz et al., 2024; Portalés, 2018). Image quality was a decisive factor influencing the accuracy and visual fidelity of the photogrammetric reconstruction. The use of a suitable UAV platform equipped with a high-resolution camera ensured adequate image sharpness, exposure consistency and spatial coverage that contributed to the generation of a dense point cloud and a detailed textured mesh, which accurately represents the geometry and surface characteristics of the heritage structure. These studies emphasize that the integration of dense point clouds and textured mesh models enables not only accurate geometric representation but also enhanced visual interpretation of heritage features. The high level of detail achieved in the 3D model of Kota Lama Duyong corroborates these findings and demonstrates the robustness of the adopted workflow.

Furthermore, when compared with traditional terrestrial surveying and laser scanning approaches, UAV-based photogrammetry offers greater flexibility and lower operational complexity, particularly for sites with limited access or budgetary constraints. While terrestrial laser scanning (TLS) may provide higher geometric accuracy in certain contexts, several authors have noted that UAV photogrammetry offers sufficient accuracy for documentation, monitoring and visualization purposes in heritage conservation projects (Nex & Remondino, 2014).

Overall, the results demonstrate that UAV-based photogrammetry is a reliable and practical approach for digitally preserving cultural heritage sites, particularly in environments with limited accessibility. The generated 3D model provides a valuable digital archive that can support future conservation planning, structural assessment and public dissemination, thereby contributing to the sustainable management of heritage assets.

Conclusion

This study demonstrates the effective application of UAV-based photogrammetry for the digital documentation and 3D modelling of Kota Lama Duyong, a culturally significant heritage structure in Kuala Terengganu, Malaysia. By integrating structured flight planning, automated image acquisition and photogrammetric processing, a high-resolution 3D model and orthoimage products were successfully generated, capturing both the geometric form and visual characteristics of the heritage building.

The results confirm that UAV photogrammetry provides a practical, cost-effective and flexible solution for heritage documentation, particularly in spatially constrained and difficult-to-access environments. The combination of double grid and circular flight missions enabled comprehensive image coverage and enhanced façade representation, contributing to a detailed and visually coherent 3D reconstruction. Integration of the photogrammetric outputs with standard 3D formats further supports interoperability, visualization and potential incorporation into GIS-based heritage management systems. Despite the overall success of the approach, certain limitations were observed, primarily related to environmental obstructions such as vegetation and overhead utilities, which resulted in localized occlusions and minor geometric distortions. These constraints highlight the importance of site-specific flight planning and suggest that future studies may benefit from the integration of complementary data sources, such as terrestrial photogrammetry or laser scanning, to improve completeness in obstructed areas.

From a broader perspective, this study contributes empirical evidence supporting the use of UAV-based photogrammetry for cultural heritage preservation in Southeast Asia, a region where digital heritage documentation remains relatively underrepresented in the literature. The developed 3D model provides a valuable digital archive that can support conservation planning, structural assessment, public dissemination and long-term heritage monitoring. Future research should focus on incorporating quantitative accuracy assessments using ground control points, integrating Terrestrial Laser Scanner and developing GIS-enabled analytical frameworks for condition monitoring and change detection. Such advancements would further enhance the role of UAV photogrammetry as a core technology in sustainable cultural heritage management.

Acknowledgement

The authors gratefully acknowledge Universiti Kebangsaan Malaysia for funding this research under Grant No. UKM-TR-017. The authors also extend their appreciation to Muzium Negeri Terengganu (Terengganu State Museum) for providing partial funding and research collaboration support.

Reference

Achille, C., Adami, A., Chiarini, S., Cremonesi, S., Fassi, F., Fregonese, L., & Taffurelli, L. (2015). UAV-based photogrammetry and integrated technologies for architectural applications-Methodological strategies for the after-quake survey of vertical structures in Mantua (Italy). *Sensors, 15*(7), 15520-15539.

Agisoft Metadatshape. (2025). How to document historical buildings with Agisoft Metashape: Field to archive. https://www.agisoftmetashape.com/how-to-document-historical-buildings-with-agisoft-metashape-field-to-archive/?srsltid=AfmBOoo6dqyyEtqVeG9vIbsqERYsswQoBP1g8qlmZiLJCIBipZNVZPyq

Aljohani, N. M., Jaafar, M., & Choy, L. K. (2021). Urban planning in Al-Madinah Al-Munawarah using new green spaces modelling through GIS application. *Indonesian Journal of Geography, 53*(3), 340-347.

Alsadik, B., (2020). Crowdsource drone imagery–A powerful source for the 3D documentation of cultural heritage at risk. *International Journal of Architectural Heritage, 16*, 977-987.

Andrei, E., Marina, I., Constantin,S. C., Adrian, U., & Gheorghe, R. (2018). The drone - A methodological tool for generating base layers in GIS. Proceedings of the 4th International Scientific Conference Geobalcanica.

Bakirman, T., Bayram, B., Akpinar, B., Karabulut, M. F., Bayrak, O. C., Yigitoglu, A., & Seker, D. Z. (2020). Implementation of ultra-light UAV systems for cultural heritage documentation. *Journal of CulturalHeritage, 44*, 174–84.

Department of Statistics Malaysia. (2025). Tourism Satellite Account, 2024. https://www.dosm.gov.my/uploads/release-content/file_20250911100857.pdf

DJI Official Website (2025). https://www.dji.com/global

Dore, C., & Murphy, M. (2012, September 2-5). Integration of historic building information modelling and 3D GIS for recording and managing cultural heritage sites. 18th International Conference on Virtual Systems and Multimedia: Virtual Systems in the Information Society, Milan, Italy.

Ergun, B., Sahin, C., & Bilucan, F. (2023) Level of detail (LoD) geometric analysis of relief mapping employing 3D modeling via UAV images in cultural heritage studies. *Heritage Science*, *11*, 194.

Febro, J. D. (2020). 3D documentation of cultural heritage sites using drone and photogrammetry: A case study of Philippine Unesco-recognized Baroque Churches. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 11*(8), 1-14.

Foster, G. (2020). Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts. *Resources, Conservation and Recycling*, *152*, 104507.

Ghafar Ahmad, A. (2009, July 17-19). Treatment of rising damp and replastering at heritage buildings. Bengkel Bersiri 2009 Konservasi Bangunan Warisan Siri 2: Lepaan Kapur, Perak. Dewan Pusat Pelancongan Negeri Perak, Ipoh.

Khoshelham, K. (2018). Smart heritage: Challenges in digitisation and spatial information modelling of historical buildings. In Alberto Belussi, Roland Billen, Pierre Hallot, & Sara Migliorini (Eds.), Proceedings of the 2nd Workshop on Computing Techniques for Spatio-Temporal Data in Archaeology and Cultural Heritage (p. 7–12). University of Melbourne.

Kingsland, K. (2020). Comparative analysis of digital photogrammetry software for cultural heritage. *Digital Applications in Archaeology and Cultural Heritage*, *18*, e00157.

Lorenzo, C., Lorenzo, E., & Chamorro, E. (2019). Using drones, 3D modeling and digital fabrication technologies to promote architectural heritage: A case study. ICERI2019 Proceedings, 3565-3571.

Markiewicz, J., Karwel1, K., & Murtiyoso, A. (2024). The critical evaluation of multi-view stereo approaches in 3D dense reconstruction for cultural heritage objects. *Journal of Modern Technologies for Cultural Heritage Preservation*, *3*(1).

Nex, F. C., & Remondino, F. (2014). UAV for 3D mapping applications: A review. *Applied Geomatics*, 6(1).

Portalés, C., Rodrigues, J. M. F., Rodrigues Gonçalves, A., Alba, E., & Sebastián, J. (2018). Digital Cultural Heritage. *Multimodal Technologies and Interaction, 2*(3), 58.

Sabzali Musa Kahn, Effendi Shamsuddin, & Nik Nairan Abdullah. (2011). Mendepani seni warisan dan kreatif dalam mencapai satu gagasan melayu di Nusantara. Kertas kerja seminar Universiti Islam Negeri Sunan, Gunung Djati, Bandung.

Samsudin, M., & Mohamad, S. (2013). Pengaruh warisan sejarah dalam industri pelancongan Langkawi. *Internationl Journal of Malay World Civilis, 1*(1), 99-109.

Vellemu, E.C., Katonda, V., Yapuwa, H., Msuku, G., Nkhoma, S., Makwakwa, C., Safuya, K., & Maluwa, A. (2021). Using the Mavic 2 Pro drone for basic water quality assessment. *Scientific African, 14,* e00979.

Xu, Z., Wu, L., Shen, Y., Li, F., Wang, Q., & Wang, R. (2014). Tridimensional reconstruction applied to cultural heritage with the use of camera-equipped UAV and terrestrial laser scanner. *Remote Sensing, 6*(11), 10413-10434.