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Article

Digital reconstruction of historical monuments with drones and 3D Photogrammetry: An ICT application for heritage management

Reconstrucción digital de monumentos históricos con drones y fotogrametría 3D: Una Aplicación de TICs para la gestión del patrimonio

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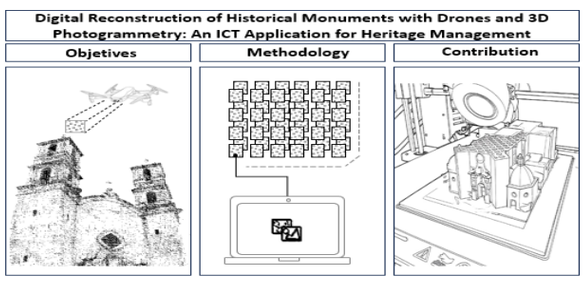
Abstract

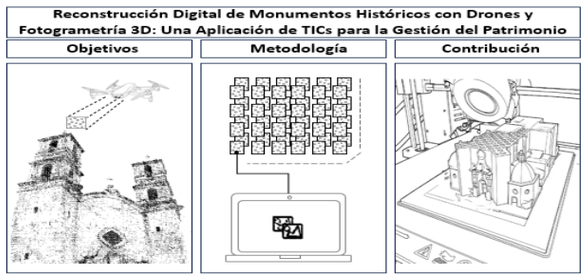
This study presents a technological alternative for the digital representation of historical buildings, leveraging drones and aerial photogrammetry. The research was conducted on the Parish of San Jerónimo, located in Huandacareo, Michoacán, to construct a detailed three-dimensional model to support structural analysis and heritage documentation. The methodological process included flight path planning, systematic image acquisition using a DJI Mini 2 SE drone, and subsequent processing in Agisoft Metashape. This workflow enabled the generation of accurate 3D models derived from point clouds and digital meshes. The resulting model was validated by comparing its dimensions with real-world measurements, achieving high fidelity with a maximum deviation of ±0.15 cm per meter. The main contribution of this work is to demonstrate that accessible technological tools can effectively support the conservation and documentation of heritage structures, while reducing costs and minimising fieldwork risks.

Resumen

Este trabajo presenta una alternativa tecnológica para la representación digital de edificaciones históricas mediante la implementación de drones y técnicas de fotogrametría aérea. El estudio se desarrolló en torno a la Parroquia de San Jerónimo, ubicada en Huandacareo, Michoacán, para elaborar un modelo tridimensional que permita el análisis estructural y el registro patrimonial. El proceso metodológico incluyó la planificación de rutas de vuelo, la captura sistemática de imágenes con un dron DJI Mini 2 SE y su posterior procesamiento en la plataforma Agisoft Metashape, para generar modelos 3D precisos a partir de nubes de puntos y mallas digitales. La evaluación del modelo generado se validó contrastándolo con las dimensiones de mediciones reales. El resultado fue un modelo de alta fidelidad, con una variación máxima de ±0.15 cm por metro. La herramienta tecnológica apoya eficazmente la documentación de construcciones patrimoniales, reduciendo costos y riesgos asociados al trabajo de campo.



Drone, 3D modelling, Photogrammetry.



Dron, Modelado 3D, Fotogrametría.

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

Safeguarding historical monuments is not only a technical challenge but also a cultural responsibility, as these sites carry society's memory, identity, and traditions. In Mexico, their preservation is overseen by the National Institute of Anthropology and History [INAH] through the National Coordination of Historical Monuments [CNMH]. According to the Federal Law on Archaeological, Artistic and Historical Monuments and Zones, any intervention in these buildings must be authorised and supervised by the INAH to guarantee their conservation. While this regulatory framework establishes the basis for protection, it also highlights the need for innovative methods to document and analyse heritage in efficient, accurate, and non-invasive ways.

Recent advances in information and communication technologies have introduced new possibilities for heritage management. Among them, drones combined with aerial photogrammetry stand out as a versatile alternative to traditional surveying techniques. Unlike conventional approaches, which often require significant resources and may even put fragile structures at risk, drone-based photogrammetry enables rapid data collection, high-resolution imagery, and the creation of reliable 3D models. These models offer more than visual records; they provide measurable information that can support structural assessments, help track deterioration over time, and preserve digital evidence for future restoration projects.

The problem this study addresses is the limited availability of methodologies that are both accessible and precise for the systematic documentation of historical buildings. Traditional practices can be slow, expensive, or difficult to replicate across different contexts.

This research proposes that integrating drones with photogrammetric techniques can fill that gap by delivering accurate 3D reconstructions validated against on-site measurements.

The central hypothesis is that this approach can strengthen both the technical evaluation and the cultural safeguarding of heritage monuments.

Rather than presenting the study as a set of rigid sections, it is worth noting that this work begins with a brief discussion of the background and theoretical principles that frame the use of drones and photogrammetry in heritage conservation. It then moves into the methodological approach applied to the San Jerónimo Parish in Huandacareo, where the combination of aerial imagery and digital processing was put into practice. The results obtained from this case illustrate not only the accuracy of the 3D reconstruction but also its potential to support preservation strategies. From there, the discussion naturally opens up to the advantages and challenges of adopting these technologies, leading to broader reflections on how digital tools may shape the future of cultural heritage management.

Methodology

The methodological design of this research integrates aerial photogrammetry and drone technology to achieve precise three-dimensional documentation of historical monuments. The process begins with identifying key variables that directly influence the quality of the photogrammetric model: flight altitude, ground sample distance [GSD], image overlap, camera resolution, and the number and distribution of ground control points [GCPs]. Each of these factors has been widely recognised in recent studies as decisive for ensuring the geometric accuracy of digital reconstructions [Bolognesi, 2023], [Hinge, 2019].

The first stage involved planning the flight mission, during which the DJI Mini 2 SE was configured to operate at a safe, consistent altitude. Parameters such as speed, orbital patterns, and photo-capture intervals were adjusted to ensure systematic coverage of San Jerónimo Parish [Figure 1]. The advantage of using drones lies in their ability to access complex angles and minimise risks to operators, compared with traditional scaffolding-based surveys or total station scanning, which can be more invasive and less efficient [Carvajal-Ramírez, 2019].

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Box 1

[a]

[b]

Figure 1

Perspectives of modelled architecture

Source: Own work

Once the flight plan was executed, the images were collected with careful attention to overlap [front: 80%; side: 70%], as recommended in recent guidelines for heritage documentation [Zhang, 2025]. The dataset was then processed in Agisoft Metashape, with the workflow including photo alignment, dense point cloud generation, mesh reconstruction, and texturing. The digital model was georeferenced using ground control points to ensure consistency with real-world coordinates.

A critical step in this methodology was comparing the reconstructed model with actual field measurements. This validation, performed using on-site physical dimensions, confirmed the accuracy of the 3D model to within ±0.15 cm per meter. Such precision demonstrates the reliability of photogrammetry as an alternative to laser scanning, which, although highly accurate, often entails higher costs and specialised equipment [Zakaria, 2025].

The methodological approach adopted here not only emphasises the technical rigour of data acquisition and processing but also highlights its replicability. By combining accessible drone technology with advanced photogrammetric software, this study proposes a sustainable framework that cultural institutions can replicate for the documentation and conservation of heritage sites.

Results

The case study focused on the Parish of San Jerónimo in Huandacareo, Michoacán, where more than 800 aerial photographs were captured using a DJI Mini 2 SE drone.

These images provided the raw dataset for photogrammetric processing. The flight plan ensured systematic coverage with adequate overlap, allowing for precise reconstruction of the building's geometry. This stage alone demonstrated the potential of drones to document historical sites without exposing them to physical risks, an advantage over conventional surveying techniques [Bagnolo, 2019].

The collected images were processed in Agisoft Metashape, where alignment, dense point cloud generation, and mesh reconstruction were performed.

Box 2

Figure 2

Start of image construction in Agisoft Metashape.

Source: Own work

The software enabled the extraction of geometric and textural information, producing a highly detailed digital twin of the monument.

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This process required several hours of computational work, yielding a scalable 3D dataset that could be reused for diverse applications, from conservation to virtual dissemination [Wahbeh, 2017].

Around the object, extraneous elements were identified; therefore, the scene was refined to prevent these parts from being processed and incorporated into the 3D model. For this task, the freeform selection tool was employed as shown in Figure 3.

Box 3

Figure 3
Construction of the 3D model.
Source: Own work

To assess the model's reliability, the dimensions derived from the 3D reconstruction were compared with field measurements. The analysis confirmed a mean accuracy of ±0.15 cm/m, consistent with international standards for architectural photogrammetry. Subsequently, the building was printed as shown in Figure 4.

Box 3

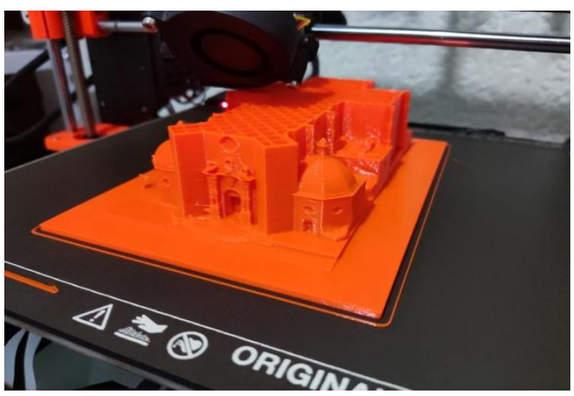

Figure 3
3D printing process.
Source: Own work

This degree of precision highlights the capacity of UAV-based photogrammetry to serve as a viable alternative to terrestrial laser scanning, while maintaining lower costs and easier deployment [Zakaria, 2025].

The resulting 3D model of the Parish not only documents the building's current condition but also serves as a reference for preventive conservation. Stored in digital repositories, the images and models enable periodic comparisons to monitor deterioration, evaluate previous restoration works, and plan new interventions.

Beyond technical documentation, the digital twin also supports educational and outreach initiatives by enabling communities and institutions to visualise and interact with cultural heritage in new ways [Hermon, 2022].

Conclusions

a. This research demonstrated that drone-based photogrammetry is not only a viable tool for documenting historical monuments but also a transformative approach that redefines how heritage inspections are carried out. Traditionally, assessing buildings such as the San Jerónimo Parish required manual surveys, scaffolding, or direct physical access to fragile structures—methods that were often time-consuming and expensive and posed significant safety risks to inspectors. By contrast, the methodology presented here enabled the generation of a highly accurate 3D model, validated to ±0.15 cm per meter, without exposing personnel to hazardous conditions.

b. The impact of this approach is twofold. On the one hand, it provides cultural institutions, such as the National Institute of Anthropology and History [INAH], with reliable digital records that support preventive conservation, restoration planning, and long-term monitoring of deterioration. On the other hand, it democratises access to technology, showing that even with affordable drones and accessible software, it is possible to achieve results comparable to those from more expensive, specialised equipment. This not only reduces costs but also makes the methodology replicable for smaller municipalities and communities seeking to safeguard their cultural heritage.

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c. Nevertheless, there is room for improvement. Future research should explore integrating photogrammetry with Building Information Modelling [BIM] systems and artificial intelligence algorithms to detect cracks, deformations, or material decay automatically. In addition, combining drone imagery with thermal or multispectral sensors could provide deeper insights into structural health beyond what the human eye can see.

d. In essence, this study shows that what was once a rudimentary and risky task can now be performed with precision, safety, and efficiency. By embracing technology, heritage management shifts from a reactive process to a proactive, preventive strategy, ensuring that monuments like San Jerónimo Parish are preserved, understood and appreciated for their full historical and cultural significance.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Vega-Flores, María Yaneth, Sánchez-Hernández, Miriam Zulma and Téllez-Martínez, Jorge Sergio: Contributed to the project idea, research method and technique.

Fernández-Flores Víctor Delfino: He was responsible for the project.

Availability of data and materials

The data obtained and the materials used for the modelling form are the property of the cultural conservation institutions; therefore, they are not available to any particular external interest.

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Abbreviations

INAH National Institute of Anthropology and History
CNMH National Coordination of Historical Monuments
GSD Ground Sample Distance
GCP Ground Control Points
UAV Unmanned Aerial Vehicle
BIM Building Information Modelling

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