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The Ontological Multiplicity of Digital Heritage Models: A Case Study of Yunyan Temple, Sichuan Province, China

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Abstract: This paper investigates the ontological multiplicity of digital heritage objects within the context of a digital twin project focused on Yunyan Temple, Sichuan Province, China—a site threatened by natural disasters. The project employs laser scanning and photogrammetry to generate high-resolution 3D models at varying levels of detail. The study analyzes how these digital objects support diverse analytical tasks ranging from geomorphological analysis to structural assessments and spatial sequence analysis. We present a novel four-layer data integration and service platform architecture designed to manage the complex data relationships arising from this ontological multiplicity. This includes a temporal database to support iterative refinements of conservation strategies based on ongoing monitoring. The findings highlight the dynamic role of digital objects in knowledge production and offer practical implications for database design, data management, and the development of adaptive conservation strategies for cultural heritage.

Keywords: heritage protection; ontological multiplicity; digital objects; knowledge production; Feitian Sutra Cabinet; Yunyan Temple; digital twin

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1. Introduction

The growing integration of digital technologies into cultural heritage management, fueled by initiatives such as the "Digital China" strategy, has led to a significant increase in the use of 3D models and digital twins. The implementation of this strategy is framed within the 'Digital China Overall Layout Plan' (2025–2035), which aims to make substantial advancements in digital infrastructure and services, including those for the preservation and management of cultural heritage.

These technologies offer unprecedented opportunities for precise representation and analysis of heritage sites. A critical aspect of this technological evolution is the integration of digitization tools used to document the existing built environment with those used for health monitoring. This integration is fundamental for the creation of digital twins of buildings, which are essential for their management, maintenance, and preservation over time [1]. These digital twins bridge the gap between the physical and virtual worlds, enabling real-time monitoring and adaptive conservation strategies, especially in the context of buildings and cultural heritage sites [2] at risk from natural disasters.

Despite the significant advances in digital technologies, a critical gap persists in our understanding of the ontological multiplicity of these digital objects and their implications for archaeological [3] and conservation research [4]. In this context, 'ontological multiplicity' refers

to the various forms or 'identities' that digital heritage objects can assume as they are used across various applications and platforms. These objects are dynamic, evolving and interacting with diverse systems, thereby taking on multiple roles and meanings in the process of knowledge production. While existing studies on heritage digital twins [5,6], virtual reality [7,8], deep learning [9], artificial intelligence [10], and the Internet of Things [11] primarily focus on their technical applications, they often overlook the complex epistemological and conceptual issues surrounding the nature and roles of digital heritage objects in shaping knowledge.

This article addresses this gap by focusing on the ontological multiplicity of digital heritage objects, specifically point cloud and photogrammetric models (excluding BIM and derived mesh models) within the context of a case study: the Yunyan Temple project in Douchuan Mountain, Sichuan Province. We define ontological multiplicity as the diverse existential states [12] and attributes exhibited by digital heritage objects [13–15] across different stages, contexts, and applications. This highlights that digital objects are not merely data aggregations but possess multiple identities and roles shaped by complex interactions within various software applications, platforms, and user workflows. This understanding is crucial in highlighting the complexity [16] and fluidity of digital heritage objects and their diverse contributions to knowledge production [17]. The dynamic nature of these objects, particularly within the context of digital twin development, further complicates this understanding. The concept of digital twins introduces the potential for dynamic database construction and intelligent preservation of architectural heritage, with its fluidity and multi-site nature propelling digital heritage objects to play a proactive role in diverse knowledge production endeavors, thereby advancing the process of intelligentization.

Unlike previous research, which has often focused primarily on the technical applications of digital twins for heritage conservation, this study explores the epistemological implications of digital objects across various workflows. It clarifies the concept that "the process of data acquisition is not automatic" and examines how digital objects shape the process of knowledge production, offering new insights into the storage and development of heritage conservation databases. By emphasizing the integration of point cloud and photogrammetric models, this research offers new insights into the storage and development of heritage conservation databases. Unlike the traditional use of Building Information Modeling (BIM) as a unified platform for the integration of all data, our approach creates the necessary data and databases across different workflows, providing a broader reference for achieving data interoperability across disciplines. This offers a more nuanced understanding of digital heritage models and their diverse roles in the knowledge production process.

The study further investigates how these models evolve through various data collection and modeling processes, examining their interactions within the context of a purpose-built database for Yunyan Temple. By leveraging the unique characteristics of digital twins—bridging virtual and physical domains and enabling intelligent functionality—this database facilitates a novel approach to knowledge generation.

The structure of this the paper is outlined as follows: Section 2 details the methods employed in the Yunyan Temple project, emphasizing the multi-method data acquisition and the innovative database design. Section 3 presents the details of the sites. Section 4 presents the results, focusing on the analysis of digital heritage models and the dynamic database generation process. Finally, Sections 5 and 6 discuss the findings, highlighting the ontological multiplicity of digital objects and their contribution to architectural archaeology and heritage conservation.

2. Site Description

The Yunyan Temple, a nationally protected cultural heritage site, has a rich history that spans from its founding in the late Tang Dynasty (AD 618–907) through renova-

tions in the Song (AD 960–1279), Yuan (AD 1271–1368), Ming (AD 1368–1644), and Qing (AD 1636–1912) dynasties. Situated at the foot of Douchuan Mountain, within the Sichuan Jianmen Shudao National Scenic Area and a national geological park, the temple's location adds to its unique culture and historical significance. The national park spans across the cities of Guangyuan, Mianyang, and Deyang in Sichuan (Figure 1).

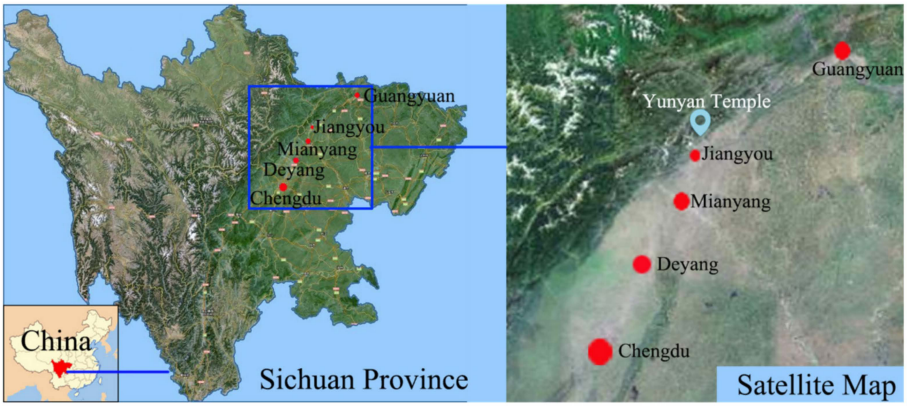


Figure 1. The location of Yunyan Temple.

Douchuan Mountain, itself, is a remarkable geological feature, characterized by three prominent peaks spaced 10–45 m apart with a relative height difference of 53 m. Thes peaks are connected by a series of iron chains forming the "Crossing the Valley", a unique and intangible cultural heritage element (Figure 2). The exposed rock formations of the mountain, featuring typical horn-shaped stone pillars and "one-line-sky" landscapes, are characteristic of conglomerate geological formations. The Guixi Songhualing section of the Ordovician system standard stratum on the mountain offers a record of geological history dating back 410 to 350 million years. The complex geological structure, including three faults within a short distance, along with abundant and well-preserved fossils, further enhances its scientific and educational value.



Figure 2. (**a**) Peak of Douchuan Mountain. (**b**) Crossing the valley on an iron chain.

Yunyan Temple's architectural layout is meticulously planned along a central axis, facing southwest. Key structures include the Temple Gate, Wenwu Hall, Tianwang Hall, and Daxiong Hall, with Dongyue Hall perched atop one of the mountain peaks. The temple's most significant feature is the Feitian Sutra Cabinet (Xingchen Che) [18] (Figure 3), located within Zang Hall. This unique octagonal, 10.8 m tall, 7.5 m diameter structure, crafted from precious nanmu wood and supported by a single central iron pillar (0.5 m in diameter), is the only surviving Song Dynasty Daoist revolving sutra repository in China. Its remarkable functionality—still rotatable by a single person—underscores its exceptional preservation despite being over 800 years old. Yunyan Temple was severely damaged in the 2008 Wenchuan earthquake, and major repairs were launched in 2016. After the restoration, it is in good condition.

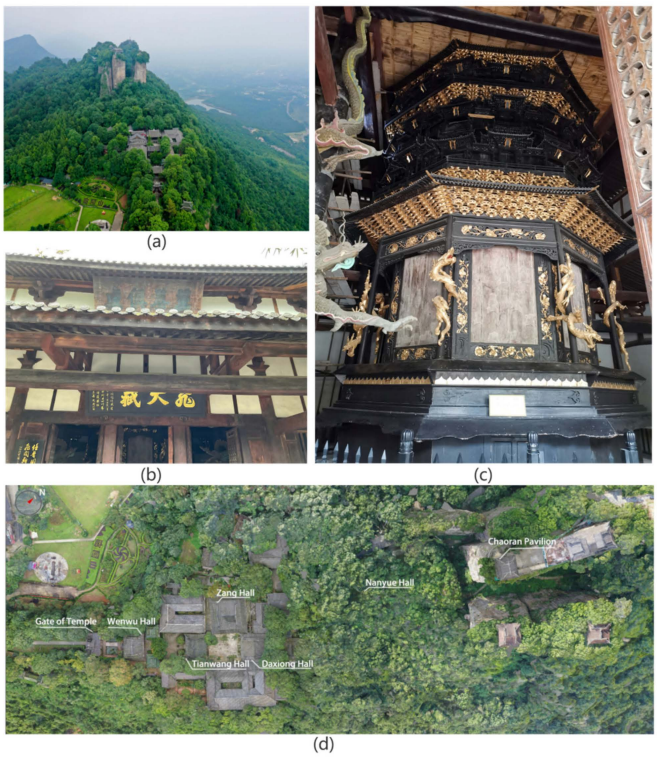


Figure 3. Cultural heritage of Douchuan Mountain: (**a**) Yunyan Temple; (**b**) Zang Hall; (**c**) Feitian Sutra Cabinet; (**d**) site plan of Yunyan Temple.

3. Materials and Methods

This paper centers on the Yunyan Temple project in Douchuan Mountain, Sichuan Province, undertaken between 2022 and 2024. The project aimed to create a digital twin of Yunyan Temple, employing a multi-method approach to data acquisition and a novel database design to manage the resulting complex datasets. This involved the acquisition [2,19] of high-precision real-scene data encompassing [20,21] both the geographical landscape and the architectural heritage of Yunyan Temple. The data acquisition process utilized drone-based photogrammetry, terrestrial laser scanning, and extensive field surveys to capture the temple's historical, cultural, material, and immaterial values. The aim was to acquire precise real-scene data of geographical landscapes and architectural heritages, providing the basis for analyzing the value of cultural heritage and predicting the risks faced by the heritage buildings. The resulting models served diverse purposes, from landscape ecological analysis to detailed architectural assessments, highlighting the inherent flexibility and multifaceted nature of the digital objects. A detailed description of the data acquisition techniques is provided in Section 3.1.

The database design, described in Section 3.2, explicitly addresses the ontological multiplicity of the digital heritage objects. Unlike traditional databases that store primarily processed data, our approach preserves both the raw data and the entire process of interpretation and analysis, enabling a dynamic and iterative knowledge production process. This is crucial because it acknowledges that the "information" contained within the digital objects is not simply "acquired" but actively produced through expert interpretation and analysis. This contrasts with the common misrepresentation in the literature that 3D scanning directly provides all the information needed for heritage protection [22–25]. Our framework moves beyond simply representing the current state of the heritage asset; it enables analysis across multiple time scales and for diverse research purposes.

The selection of point cloud and photogrammetric models, while excluding BIM models, is a conscious choice to focus on the raw data and their direct transformations for a

more detailed analysis of ontological multiplicity. While Heritage Building Information Modeling (HBIM) offers advantages in data management and visualization [26], relying solely on HBIM models for heritage preservation is problematic. The inherent simplification in converting high-resolution 3D scans (point clouds and photogrammetry) to HBIM models inevitably leads to information loss [27]. This loss can compromise accurate assessments of condition, hindering the detection of subtle damage or historical modifications crucial for informed conservation decisions. For example, minor cracks or intricate carvings might be smoothed over, leading to inaccurate measurements and potentially delaying necessary interventions. Therefore, preserving the original high-resolution data alongside any derived HBIM models is essential for comprehensive analysis and the long-term protection of cultural heritage. A multi-model approach ensures that crucial details are not lost, preventing potentially irreversible harm.

The project's methodological framework, which emphasizes knowledge engineering as the bridge between data and virtual models within the digital twin structure (Figure 4), is presented in Figure 5.

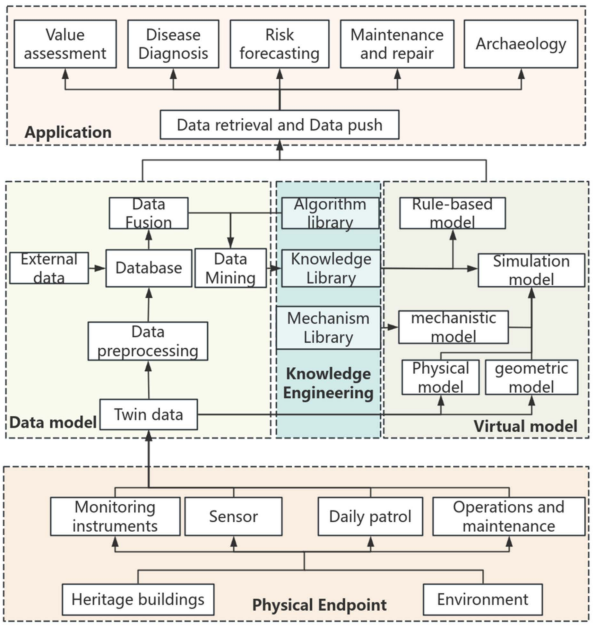


Figure 4. Digital twin framework for heritage preservation.

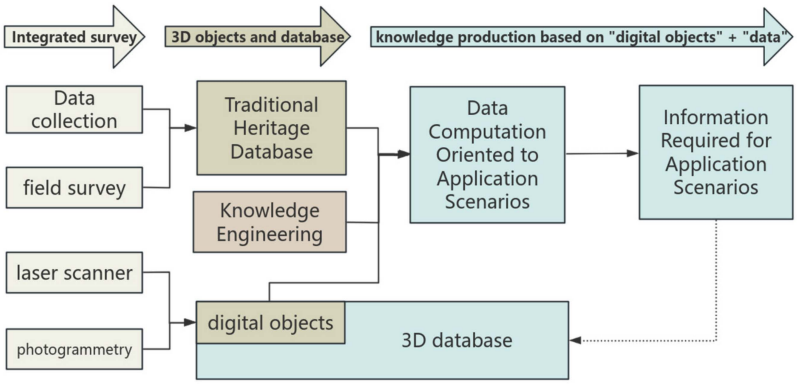


Figure 5. Methodological research approach.

3.1. Three-Dimensional Object Acquisition and Preprocessing

The Yunyan Temple project employed a multi-method approach [28] to acquire high-resolution 3D data, integrating drone-based photogrammetry, terrestrial laser scanning, and detailed field surveys. This integrated strategy aimed to comprehensively capture both

the material and immaterial cultural values of the site, addressing the challenges posed by the mountainous terrain and dense vegetation.

3.1.1. Aerial Data Acquisition

Aerial data acquisition involved the use of a DJI Mavic 2 Pro drone equipped with a camera with a resolution of 12 megapixels. To account for the significant elevation changes in the mountainous environment, a multi-tiered approach to data acquisition was employed. This included establishing oblique photography paths [29,30] for broader contextual capture of the Douchuan Mountain landscape, complemented by close-range [31] helical shooting paths for detailed acquisition of individual buildings. The helical approach was particularly valuable for capturing the intricate details of architectural features (Figure 6).

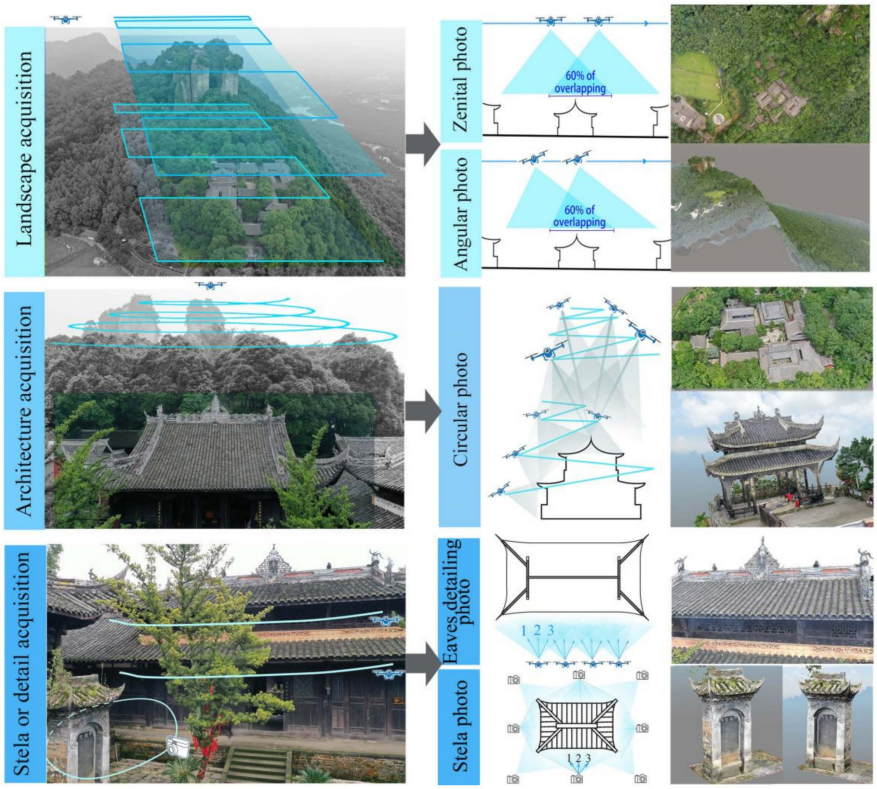


Figure 6. Data acquisition schemes of specially designed photogrammetry at different scales.

3.1.2. Terrestrial Data Acquisition (Laser Scanning)

Terrestrial laser scanning using a FARO three-dimensional laser scanner provided high-accuracy 3D data for the temple's architecture and immediate surroundings. Dense vegetation necessitated careful planning of scan positions to ensure complete coverage. A notable challenge involved scanning the Feitian Sutra Cabinet, a rotating structure. To overcome this, a temporary scaffold was erected to allow for complete scanning of all six sides, including detailed capture of the upper eaves and the internal steel support frame (Figure 7).

3.1.3. Ground Control and Accuracy Enhancement

To optimize the accuracy and registration of both the aerial and terrestrial datasets, a robust ground control network was established. This involved placing clearly identifiable targets (e.g., right-angle signs and grid paper) across the site prior to aerial photography (Figure 8). These ground control points (GCPs), along with target spheres, were also incorporated into the terrestrial laser scanning workflow to ensure precise alignment of the point clouds and the positional accuracy within a tolerance of ± 5 mm.

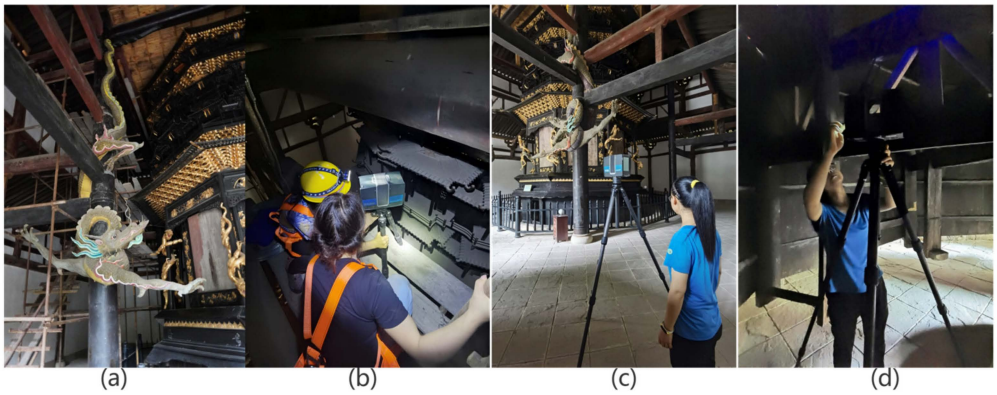


Figure 7. Scanning the Feitian Sutra Cabinet: (**a**) setting up a temporary scaffold; (**b**) scanning the upper part; (**c**) scanning the exterior; (**d**) scanning the interior.

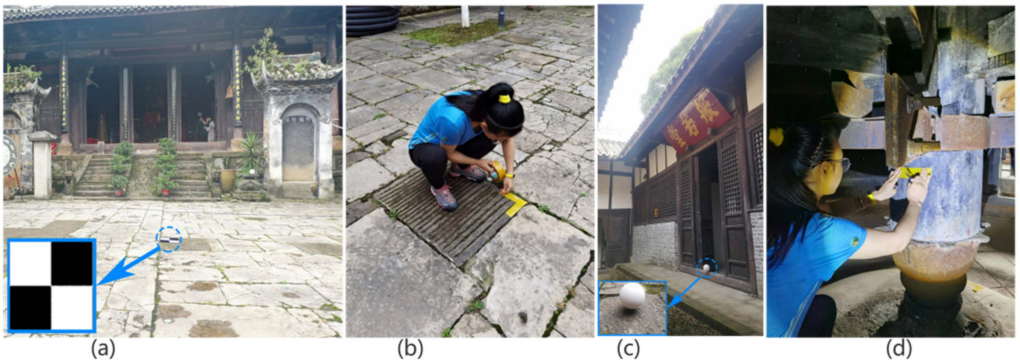


Figure 8. Photogrammetry control points: (**a**) grid paper; (**b**) right-angle signs; 3D laser scanning control points; (**c**) Target ball; (**d**) right-angle signs in the Feitian Sutra Cabinet.

3.1.4. Data Preprocessing

The TLS point clouds were initially processed using FARO Scene 2022 software. This involved noise filtering using a statistical outlier removal algorithm, followed by manual cleaning to eliminate any remaining artifacts or misregistrations. Subsequently, CloudCompare was used for further point cloud processing. This included automated and manual classification of points into distinct categories (e.g., ground, building, and vegetation) to facilitate segmentation and analysis. A voxel-based filtering technique was applied to reduce data density while preserving essential details.

The imagery acquired via drone photogrammetry was processed using ContextCapture software10.15. This involved automatic image orientation, feature extraction, and dense point cloud generation. The generated point cloud was then aligned with the georeferenced TLS point cloud using common tie points identified in both datasets. The accuracy of this alignment was assessed using the root mean square error (RMSE) of the point cloud registration, aiming for an RMSE of less than 1 cm. Finally, textured 3D models were generated from the aligned photogrammetric point cloud, providing a detailed visual representation of the heritage site with high surface detail.

3.2. A Database for Managing Ontological Multiplicity in Digital Heritage

The creation of a robust database for Yunyan Temple necessitates a departure from traditional database paradigms. Understanding the ontological multiplicity of digital heritage objects—their diverse existential states and attributes across different applications and contexts—is paramount. The generated data are not merely raw data [32] but, rather, the raw material for constructing multiple interpretations and generating new knowledge about Yunyan Temple's history, materiality, and significance. This knowledge generation

process is iterative (Figure 9) and involves integrating geometric data, symbolic features, and spatial structures from the digital objects with expert knowledge. Validation against real-world observations ensures the reliability of this new knowledge.

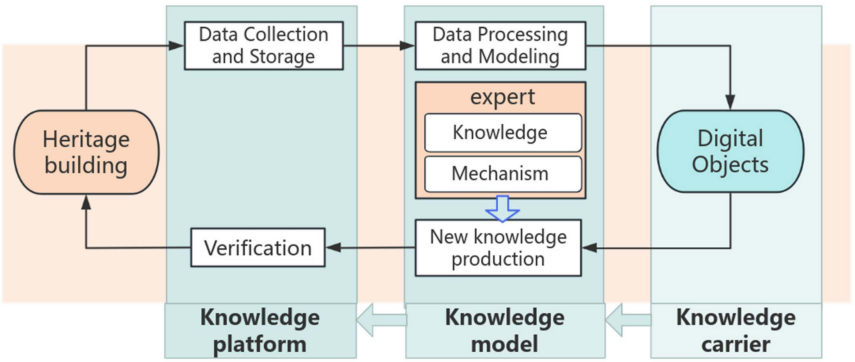


Figure 9. Dynamic process of new knowledge production.

Crucially, this database differs fundamentally from conventional databases (Table 1). Traditional databases primarily store processed and interpreted information, representing knowledge about entities [33]. In contrast, our database preserves both the processed data and the entire process of its generation, including the raw data (point clouds and images) and the various analytical steps. This approach directly addresses the ontological multiplicity of digital objects, recognizing that these objects are not static data points but active instruments for knowledge production [17]. They serve as resources for multifaceted analysis at varying levels of detail, transforming into diverse cognitive datasets relevant to different research questions and conservation needs (e.g., initial condition assessment, historical analysis, and damage detection).

Table 1. Categorization of the data from the processing and analysis of heritage digital objects.

Category	**Content**			
Processing stage	Raw	Intermediate	Analyzed	Published
Generation of data	Raw data	Working data	Outcome data	Publication data
Type of data	Geometric	Material properties	Historical interpretation	
The Methodology employed in data compilation	Index		Metadata	

To manage this complexity and leverage the potential of digital twinning [34], we employ a multi-model approach with varying Levels of Detail (LODs) [35] (Table 2). The foundational model is the high-resolution point cloud, providing a precise geometric representation of the temple. Interpretative data are then linked spatially to this base model, facilitating the integration of diverse data types (measurements, textual descriptions, and metadata) from multiple sources. This multi-source, heterogeneous database allows for flexible and repeatable analysis across various professional domains.

The LOD framework ensures that the required level of detail is matched to the specific analytical task. A high-resolution LOD (LOD3) is crucial for damage assessment, while a lower-resolution LOD (LOD1) might suffice for regional context analysis. This tiered approach avoids overwhelming the database with unnecessary detail while ensuring that critical information is readily accessible for different users and research objectives. The overarching aim is to provide unrestricted access to all relevant information, supporting a continuous cycle of analysis, knowledge generation, and informed decision making in heritage preservation. This approach is inherently linked to the understanding and management of the ontological multiplicity of digital heritage objects.

Table 2. Modeling accuracy.

Level of Model Accuracy		Description of the Object
LOD1	Territorial level	It is used to express the geographical environment of natural and cultural heritage to identify different topographic features, with an accuracy of approximately 0.1 m.
LOD2	Architecture level	It describes the spatial relationships between architectural heritage and natural geography; the spatial combination relationships of architectural heritage; and the overall structure, style, and technical features of buildings. The accuracy is approximately 0.02 m.
LOD3	Element level	It is used to analyze the characteristics of building components, cultural evolution, and the degree of surface deterioration of wooden or stone structures. The accuracy is approximately 0.003 m.

3.3. A Novel Knowledge Production Paradigm: Integrating Digital Objects and Data

This project introduces a new paradigm for knowledge production in heritage studies by leveraging the ontological multiplicity inherent in 3D digital objects and data. The proposed framework (Figure 10) outlines a systematic workflow, illustrating how digital objects transition from raw data to actionable insights and practical applications.

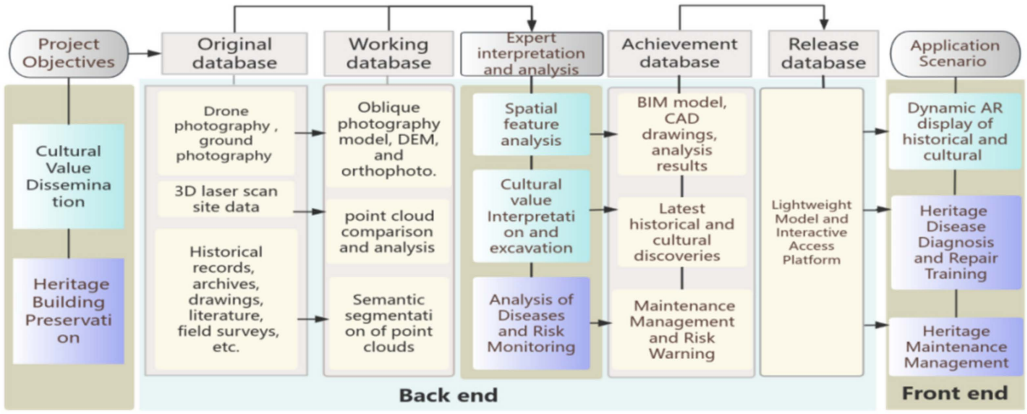


Figure 10. The new workflow and database categorization.

The workflow begins with the Original Database, which consolidates diverse data sources, including drone photography, ground photography, 3D laser scans, and historical records. These raw data form the foundation for subsequent processing. The data are then transitioned into the Working Database, where critical operations such as point cloud comparison, semantic segmentation, and spatial analysis are performed. This stage facilitates expert interpretation and enables the extraction of meaningful insights into cultural value, historical context, and structural risks.

The outputs of these analyses are further refined and stored in the Achievement Database, which contains processed results such as BIM models, CAD drawings, and maintenance plans. These outputs provide a comprehensive understanding of the heritage site's current state and inform preservation strategies. Finally, the Release Database is designed for practical application scenarios, offering lightweight, interactive models and platforms for stakeholders such as heritage managers and the general public to engage with the digital objects effectively.

Unlike traditional approaches that treat digital objects as passive visualization tools, this methodology employs them as active instruments for knowledge generation and decision making. The integration of these databases and processes allows for dynamic interaction between raw data, expert interpretation, and real-world applications, ultimately enabling a more robust and flexible framework for heritage conservation.

This layered approach allows for both the preservation of original data integrity and the efficient management of processed data. The distinction between the front end (user interface) and back end (data management and processing) is crucial. The front

end provides intuitive access to data and visualizations relevant to a specific application, while the back end supports complex data processing and analysis, ensuring the system's stability and scalability. For example, a user might see a simplified digital elevation model on the front end, while the back end contains the detailed Z-coordinate calculations. This framework supports the continuous generation of new knowledge by facilitating iterative analysis and integration of diverse data types.

The rich data contained within 3D digital objects (e.g., photogrammetric models like the Stone Lion model in Figure 11) enable multiple lines of inquiry. For instance, using ContextCapture Viewer, we can extract precise measurements (length, area, and volume), monitor surface changes (moss growth and erosion), create visualizations for historical research, or generate data for 3D printing of cultural artifacts. These diverse applications demonstrate the inherent ontological multiplicity of the digital object—it simultaneously serves as a source of geometric data, a record of material condition, and a tool for creative production. This expands the possibilities of heritage research beyond traditional methods.

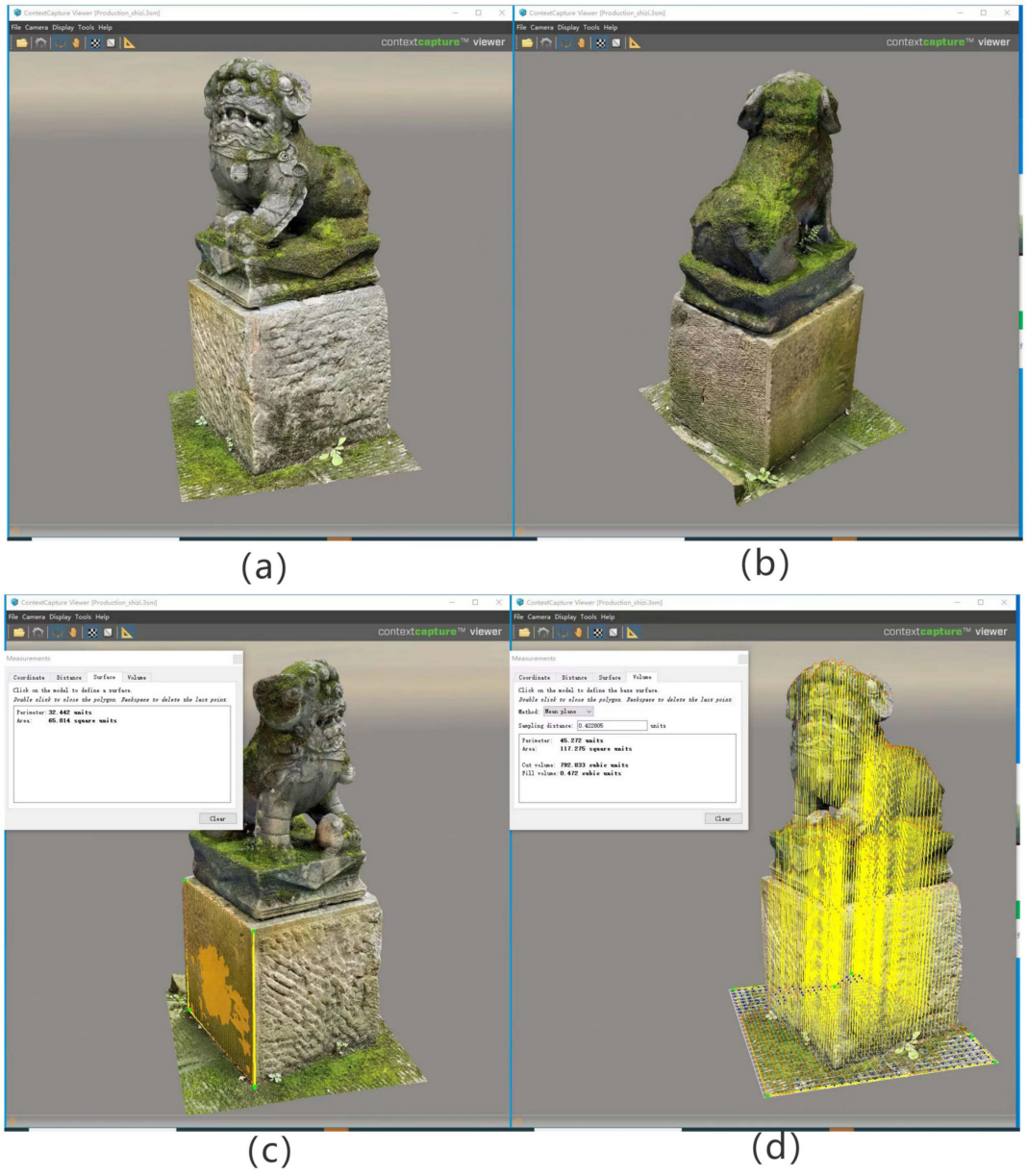


Figure 11. Stone Lion photogrammetry model: (**a**) surface moss on the façade; (**b**) surface moss on the back; (**c**) inquiry about the surface area of one side of the Stone Lion's base; (**d**) volume query of the Stone Lion.

4. Digital Modeling, Analysis, and Data Management of Yunyan Temple

The analysis of Yunyan Temple highlighted the diverse applications of point cloud and photogrammetric data in heritage research. Traditional approaches, relying on the extraction of data to create BIM models as the main data source afterward and serving as an important reference for other studies, often lead to information loss and fail to support multi-disciplinary research. To address this limitation, our approach preserves the original data, along with intermediate and derived data products, thereby supporting a range of analytical needs. The database design reflects this, accommodating the ontological multiplicity of digital heritage objects.

4.1. Heritage Object Generation

A total of 5671 images (4503 oblique and 1246 ground photographs) were acquired for photogrammetric modeling of the Yunyan Temple site and Douchuan Mountain (Figure 12). This comprehensive dataset allowed for the creation of high-resolution 3D models capturing significant details, including the temple's architecture, the Feitian Sutra Cabinet, stone tablets, and intricate carvings.

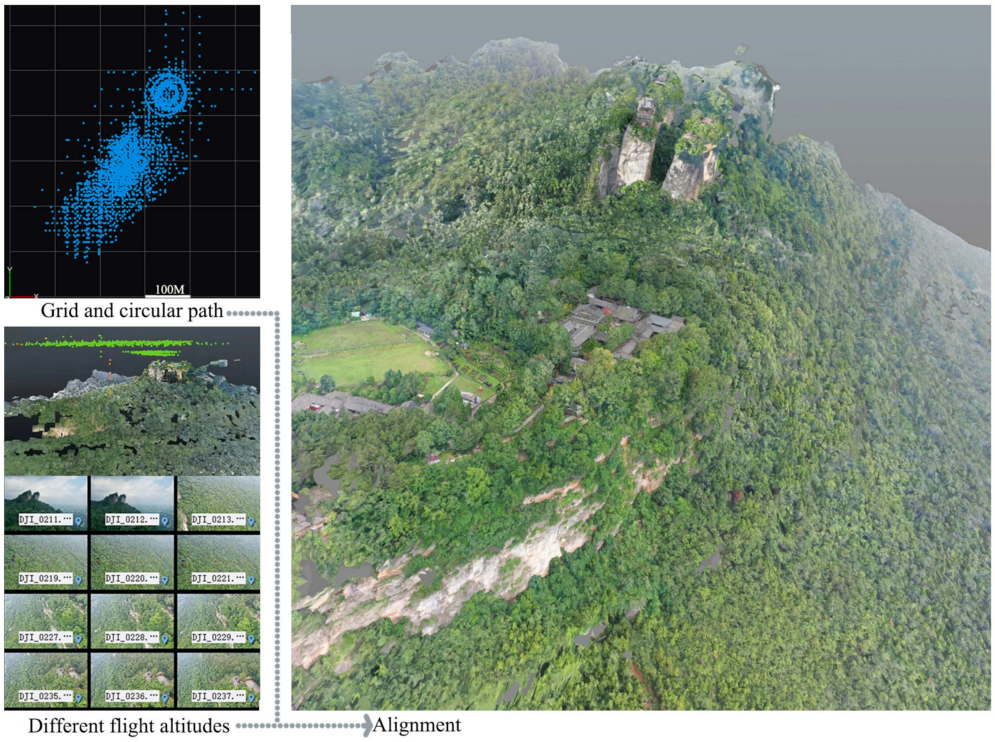


Figure 12. The process of data acquisition and model generation for Douchuan Mountain using a UAV.

The models were generated at varying levels of detail (LODs) to optimize data management and analysis. Higher-resolution models were created for areas requiring detailed analysis (e.g., the Feitian Sutra Cabinet and stone tablets), while lower-resolution models were sufficient for broader contextual understanding (e.g., Douchuan Mountain) (Figure 13).

This approach optimized data management and processing. The use of both drone and ground-based imagery ensured comprehensive coverage and enhanced model accuracy, particularly for complex areas such as Zang Hall (Figure 14). While the point cloud model provided detailed interior and eave features, the photogrammetric model offered a complete representation of the roof. Combining both datasets ensured data completeness.

Similarly, high-resolution point cloud data were collected for the Feitian Sutra Cabinet (Figure 15). Although aligning the individual scans proved challenging, this detailed model provided crucial information.

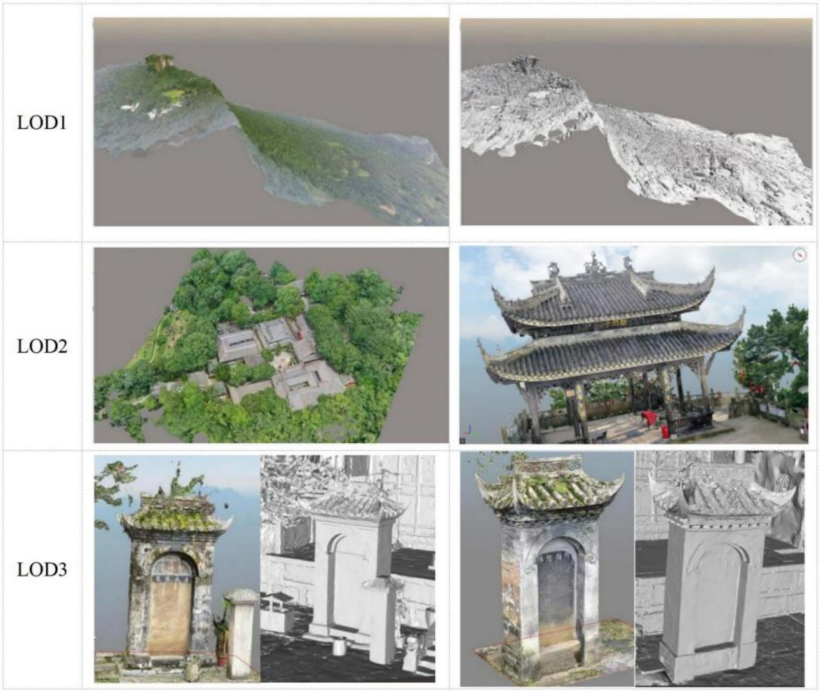


Figure 13. Models of Douchuan Mountain are at the top, the central images are models of Yunyan Temple and Chaoran Pavilion, and below are models of two stone tablets in front of Daxiong Hall.

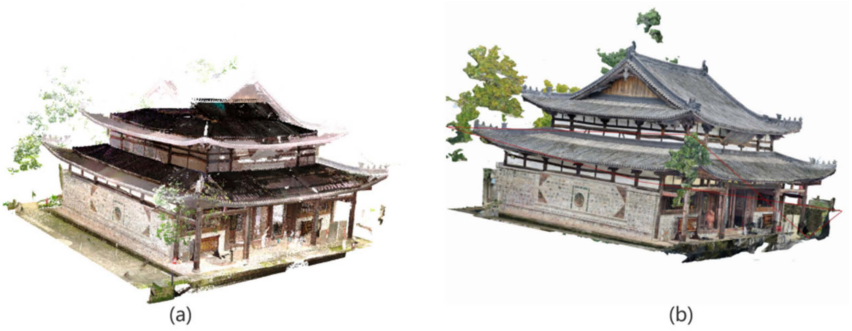


Figure 14. Zang Hall—complementary data representation: (**a**) point cloud model Detailing Interior and eave features; (**b**) photogrammetric model capturing rooftop completeness.

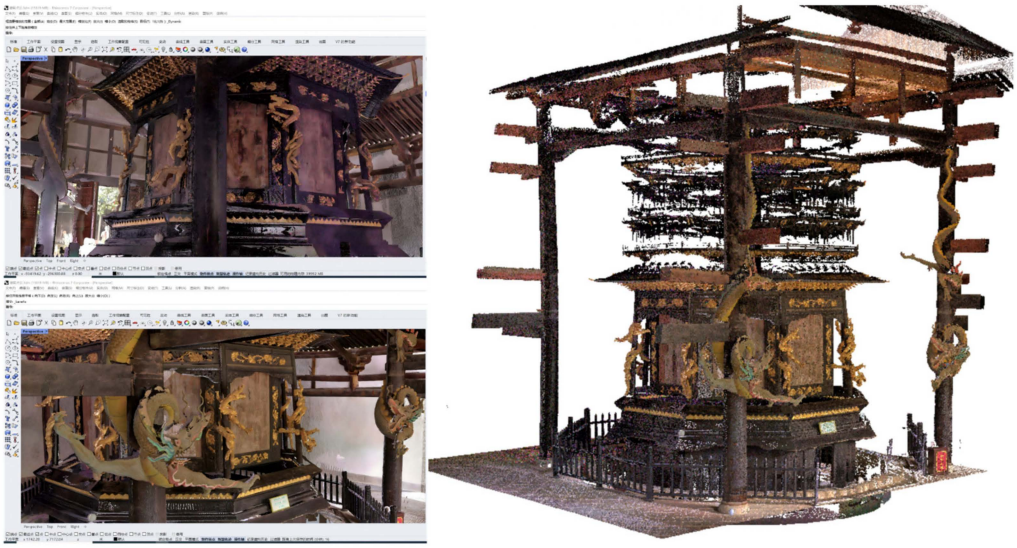


Figure 15. Point cloud model of Feitian Sutra Cabinet.

4.2. Analysis of Digital Heritage Model

4.2.1. Terrain Analysis

Using CloudCompare v2.11 software, a sparse point cloud derived from the photogrammetric model of Douchuan Mountain's geological fault zone facilitated a numerical analysis of elevation changes. This analysis generated topographic heat maps (Figures 16 and 17). These visualizations highlighted areas of significant elevation change, providing crucial context for understanding the temple's location and potential geological influences.

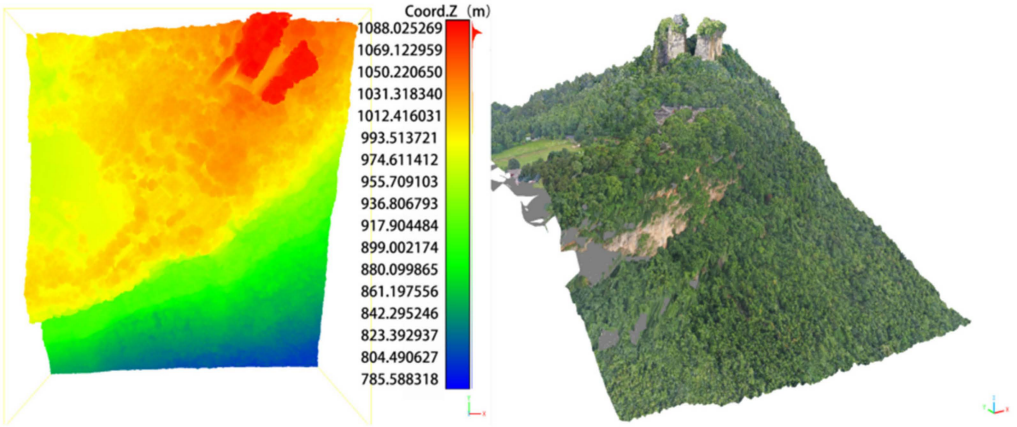


Figure 16. Topographic heat map of Douchuan Mountain's fault zone—elevation changes analyzed using CloudCompare software.

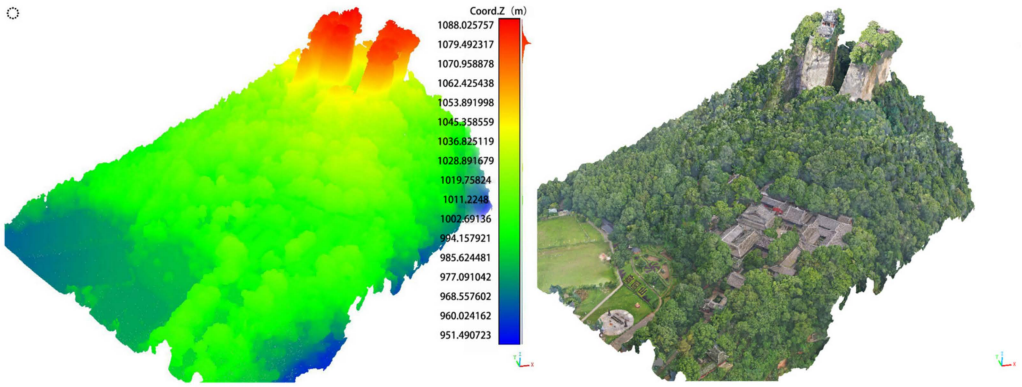


Figure 17. Topographic heat map of Yunyan Temple area—elevation changes analyzed using CloudCompare software.

4.2.2. Structural Deformation Analysis

The analysis of Nanyue Hall using CloudCompare software revealed significant structural issues, including a leaning tendency and visible wall cracking. The deviation visualized in Figure 18 suggests potential structural twisting, which could be attributed to long-term environmental factors such as soil settlement or weathering. Additionally, the presence of cracks along the walls indicates material fatigue and potential stress concentrations. These findings highlight the vulnerability of the structure to further deformation if left unaddressed.

Repeated scanning and deformation monitoring are essential to comprehensively understand these changes over time. Moreover, specific attention should be paid to environmental factors, such as humidity and temperature fluctuations, as well as anthropogenic influences, including tourism or nearby construction activities. Moving forward, this preliminary analysis will be used to inform conservation strategies and prioritize interventions to mitigate risks.

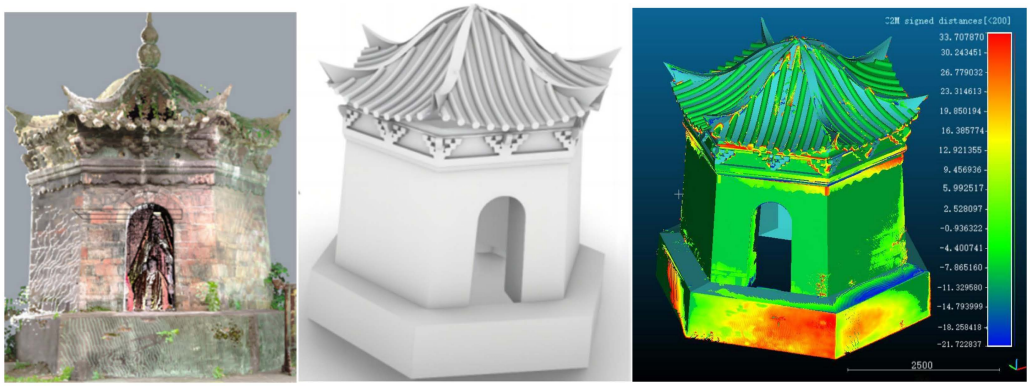


Figure 18. Structural deformation analysis of Nanyue Hall—deviation from ideal model surface (CloudCompare method, initial assessment).

4.2.3. Spatial Sequence Analysis

The spatial sequence of Yunyan Temple, typical of mountain temples, was analyzed using the D/H ratio (length/height of enclosing spaces) and Sky View Factor (SVF) derived from the 3D models (Figure 19). The resulting exponential curve revealed a rhythmic spatial progression along the temple axis, demonstrating the interplay between enclosed and open spaces. Further research using eye tracking could enhance this analysis.

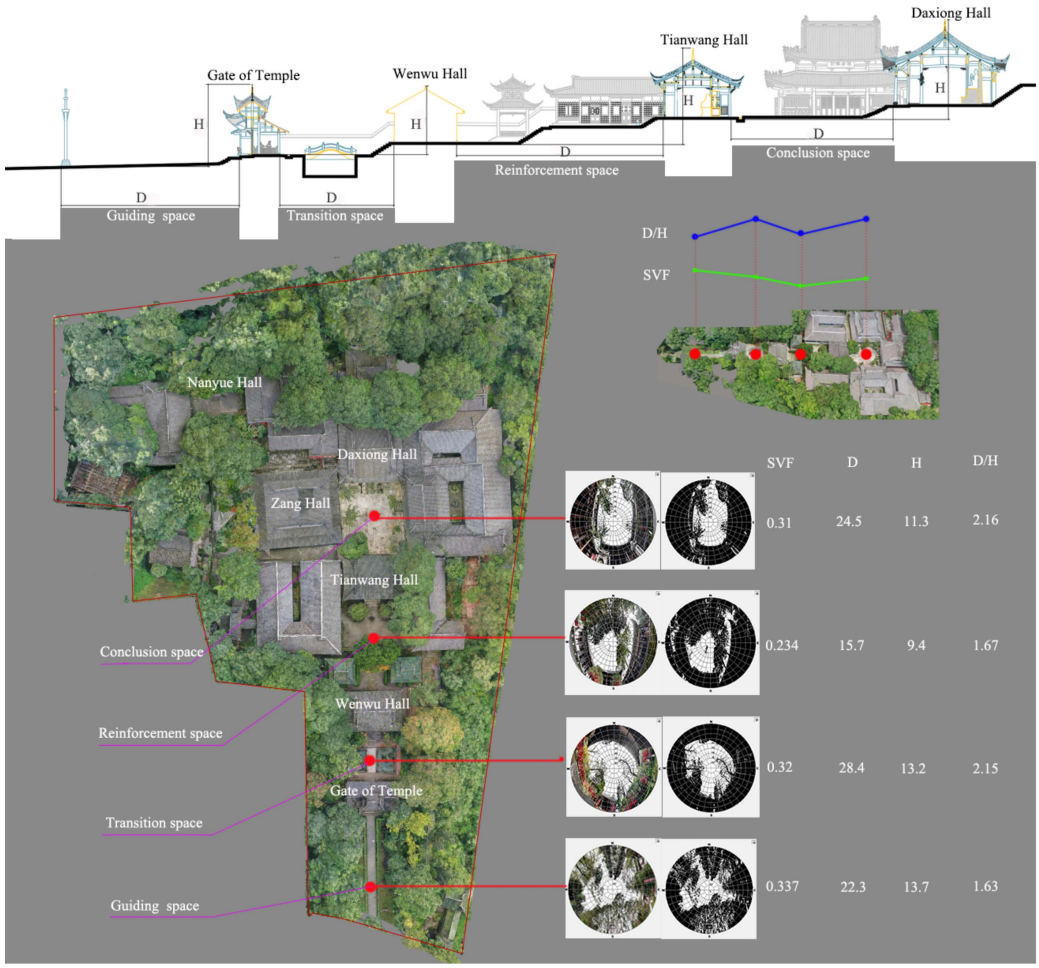


Figure 19. Spatial sequence analysis of Yunyan Temple axis—D/H ratio and sky view factor (SVF) from 3D models.

4.2.4. Semantic Segmentation

A three-level semantic segmentation of the point cloud data was performed, classifying data from landscape to architectural elements (Figure 20). This structured approach facilitates efficient access to specific information, such as historical background, architectural styles, and cultural significance, through linked data tables and multimedia resources.

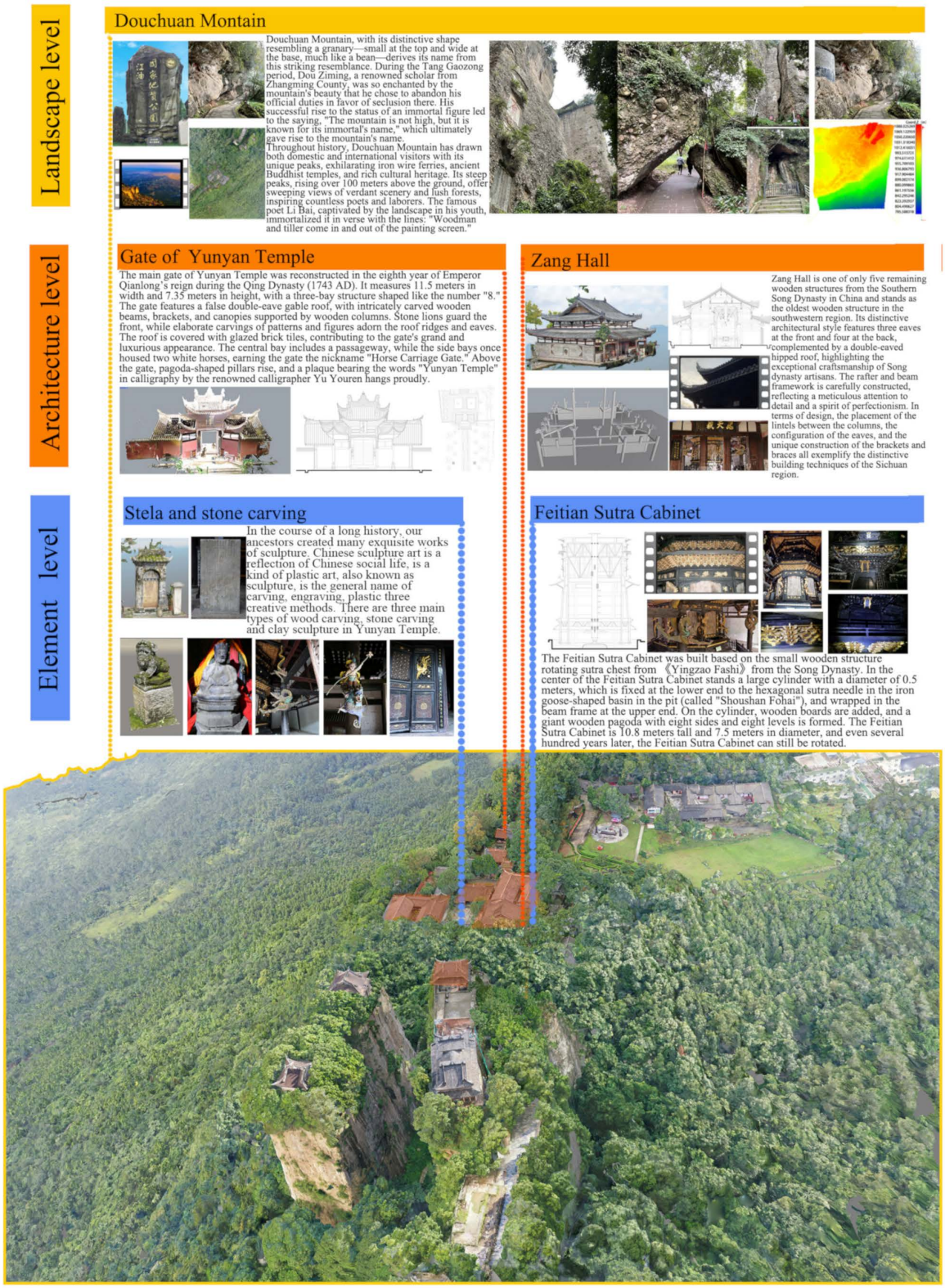


Figure 20. Three-level semantic segmentation of Yunyan Temple point cloud—landscape, architecture, and detail elements with associated information types.

4.3. Platform and Database

To address the ontological multiplicity of digital heritage objects, a flexible and dynamic data management system was essential. The platform was designed to accommodate data storage and access across various stages of processing, supporting diverse research needs while ensuring the prevention of information loss.

4.3.1. Interactive Information Platform

SuperMap, a commercial GIS platform, provides advanced tools for spatial data processing, analysis, and visualization. In this study, SuperMap was utilized to integrate and manage data generated through laser scanning and photogrammetry. The platform was chosen for its ability to handle diverse data types, including point clouds, photogrammetry, and BIM models, along with its robust data exchange features and geographically referenced 3D database (Figure 21). Moreover, its scalability ensures the system can support future expansions, making it a sustainable solution for long-term heritage data management and analysis.

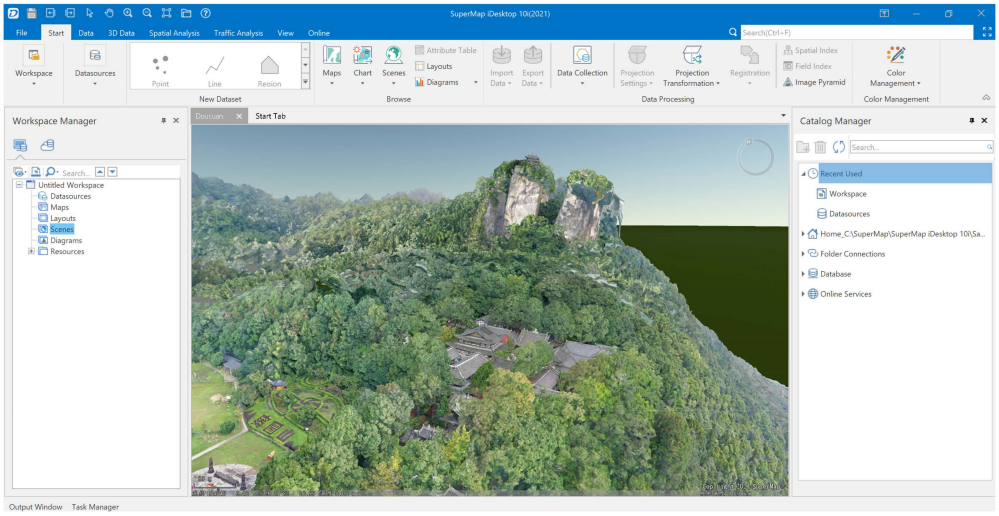


Figure 21. Insertion of the photogrammetric model of the Yunyan Temple into the SuperMap platform.

4.3.2. Dynamic Data Management—Time Series Database

To manage the dynamic data generated throughout the analysis and support iterative refinements of conservation strategies, a temporal database was implemented (Figure 22). This approach is crucial for leveraging ongoing monitoring data to inform decision making. Expert interpretation and analysis of digital objects and associated data are key to generating new knowledge. For example, when developing a heritage conservation maintenance plan, experts analyze all monitoring data collected since the current strategy's implementation, comparing them to historical site data. Positive trends indicate the plan's effectiveness, while negative trends necessitate adjustments. Sufficient historical data allow for the development of predictive models, initially established and then iteratively refined with ongoing data. This data-driven approach enables adaptive strategies that respond to changing site conditions, ensuring the most effective conservation efforts.

4.3.3. Data Integration and Service Platform

The digital twin platform architecture (Figure 23) comprises four layers designed to support diverse analytical and interpretive tasks and to facilitate data assetization. This layered approach addresses the inherent complexity of managing heterogeneous data in architectural heritage projects. The relationship between data and the database mirrors the process by which raw data transform into meaningful information, analogous to the way media scholars view the relationship between images, archives, and meaning making.

Input survey data undergo reorganization, analysis, and presentation to become "heritage cognition"—queryable information for users. While digital objects are not static "cognitions", they possess a multitude of potential applications; however, they are still bounded by the expertise of professionals, software tools, and rendering platforms. For example, digital photographs forming a photogrammetric model become digital objects upon integration into the database, contributing to 3D model generation and animation. Therefore, the database is more than a repository; it is infrastructure supporting various data relationships.

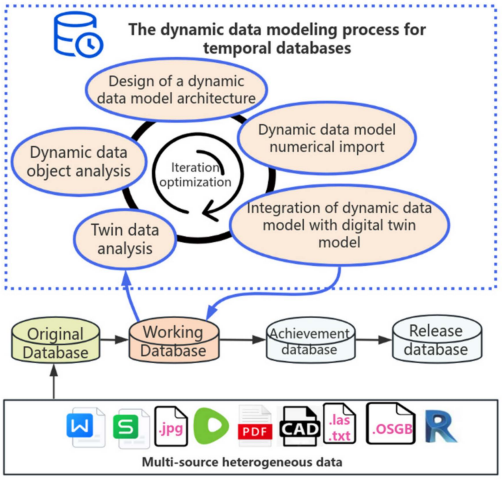


Figure 22. The process of data construction using a temporal database.

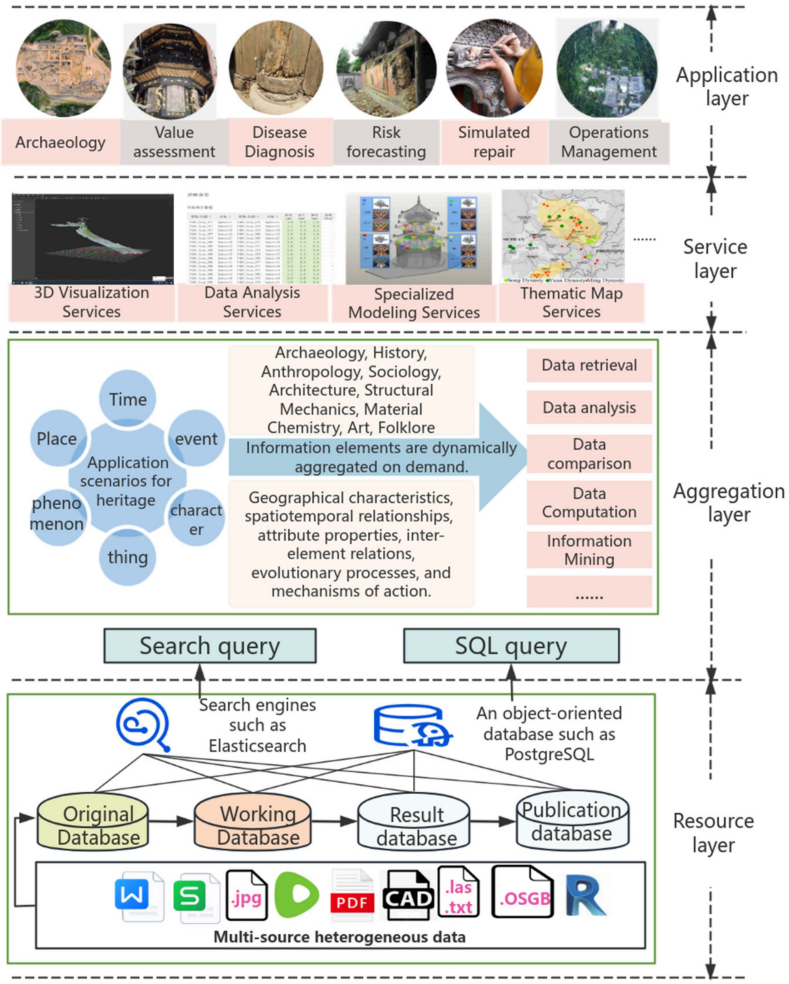


Figure 23. Four-layer architecture of the Yunyan Temple digital twin platform.

The platform's four layers are (1) a resource layer, organizing multi-source heritage survey data into original, working, result, and publication libraries; (2) an aggregation layer, retrieving and integrating data on demand for analysis; (3) a service layer, offering data analysis, thematic modeling, mapping, and visualization; and (4) an application layer, providing specialized tools for tasks such as architectural archaeology, damage assessment, and operational management.

This platform design not only meets the current research needs but also enables data assetization, conserving resources while generating potential revenue. Furthermore, it addresses challenges associated with platform maintenance and operational sustainability.

5. Discussion: Ontological Multiplicity and Its Implications for Heritage Preservation

This research underscores the ontological multiplicity of digital heritage objects, emphasizing their active role in knowledge production and preservation strategies rather than viewing them solely as visualizations. The Yunyan Temple case study exemplifies this by demonstrating how digital models evolve from static data into dynamic tools, facilitating specialized analyses across various disciplines. This iterative development process, driven by expert interpretation and analysis, generates new knowledge relevant to architectural archaeology, structural assessment, and conservation planning. The flexibility and adaptability of these digital objects across different stages of research and preservation are crucial to their effectiveness.

5.1. Practical Implications

The Yunyan Temple project highlights the practical implications of understanding the ontological multiplicity of digital heritage. The "one-to-many" relationship between physical heritage and its digital representations (as seen in the varying levels of detail and data types) allows for the creation of a comprehensive digital twin. This approach, supported by a robust database and platform architecture, enables efficient collaboration, improved workflow, and enhanced heritage value creation by documenting the entire research process in great detail.

5.2. Limitations and Future Directions

While this study demonstrates the potential of digital heritage objects, several limitations must be addressed in order to fully realize their potential. The integration of diverse applications relies on continued advancements in software and platform design. The following areas are particularly important for future research:

- Data Capacity and Management

Managing the large volumes of data generated by laser scanning and photogrammetry, often reaching several terabytes, poses significant challenges. To address this, advanced strategies such as cloud storage, data compression, and workflow-oriented database designs have been adopted. By processing point cloud data according to specific scenario requirements, these methods significantly reduce storage demands while ensuring efficient handling and long-term maintenance of digital twin models, thus enhancing their applicability for heritage research and preservation.

- Interoperability of Digital Tools

Enhancing the interoperability between different digital heritage tools, platforms, and systems is critical for expanding the use of digital twins. Standardizing data formats and improving cross-platform functionality will be key to enabling more widespread adoption of these technologies.

- Ethical Considerations

The digitization of cultural heritage introduces important ethical concerns, particularly regarding privacy, consent, and the representation of cultural identities. As digital archives of heritage sites become more accessible, questions of data ownership and control will need to be addressed, especially when these data are shared internationally. Additionally, privacy concerns may arise if the digital representations include sensitive or personal data related to local traditions or community members.

- Data Privacy, Ownership, and Accessibility

In global contexts, data privacy and ownership are crucial. The sharing of cultural heritage data can expose it to misuse, and the lack of clear ownership frameworks can hinder collaboration. International agreements and standards on data governance are needed to resolve these issues.

- Cost and Scale

While digital heritage preservation offers significant potential, the associated costs can be high, especially for smaller or less developed sites. Future research should focus on developing cost-effective and scalable solutions to make these technologies more accessible across various cultural and financial contexts.

5.3. Application to Other Heritage Sites and Cultural Contexts

The methods discussed in this study are adaptable to a wide range of heritage sites, regardless of their scale or complexity. It resolves the issue in digital twins where large amounts of spatial and monitoring data are merely used for visualization and do not actively participate in heritage research and preservation processes. This study addresses a key challenge by emphasizing the integration of data directly into workflows and knowledge production processes, ensuring that digital heritage models are both comprehensive and practically applicable to ongoing preservation efforts.

By focusing on developing databases closely aligned with specific application scenarios, this approach enhances data utilization and bridges the gap between digital archives and real-world heritage management. The creation of heritage databases is a dynamic process aimed at specific application scenarios and represents a gradual process of gaining deeper understanding of cultural heritage.

6. Conclusions: A Paradigm Shift in Heritage Conservation

This study makes significant contributions to digital heritage conservation by demonstrating that digital twins are not merely passive visualization tools but actively engage in knowledge generation and preservation strategies. The Yunyan Temple case study emphasizes the ontological multiplicity of digital heritage objects, showcasing their ability to serve multiple purposes and exist in various states.

Breaking down the traditional reliance on BIM models for data integration, this research offers a valuable reference for creating architectural heritage databases and encourages the active participation of both the public and researchers in the development of preservation databases. By integrating tools like VR applications, this approach facilitates public engagement with digital heritage models, enhancing awareness and support for heritage preservation. For instance, dynamic VR simulations of historical reconstructions or interactive models of damaged structures can make heritage more accessible to broader audiences.

The proposed layered database architecture efficiently manages the complex relationships inherent in digital heritage, supporting diverse analytical tasks and enabling the development of international standards for managing heritage datasets. This scenario-based

methodology is particularly valuable for heritage sites with limited resources, providing a practical solution for those facing financial or technological constraints.

Moreover, this study's approach has significant implications for heritage preservation policies, particularly in regions prone to natural disasters. By emphasizing the timely documentation and digitalization of historical damage, identification of deterioration causes, and the development of responsive measures, it supports risk mitigation and emergency preparedness. These practices can inform regional or national heritage policies, promoting scalable and adaptable preservation strategies for sites of varying size and technological maturity both in China and globally.

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