3D Scan and HBIM of Thai Hoa Hall for the Conservation of Hue's Cultural Heritage

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Abstract

This study presents a Scan-to-HBIM workflow applied to Thái Hòa Hall, one of the most prominent cultural heritage structures within the Imperial City of Huế, Vietnam. The proposed methodology integrates terrestrial LiDAR scanning, high-resolution photogrammetry, and semantic-based HBIM modeling to construct a comprehensive digital representation of the site.
The project introduces a classification system informed by on-site restoration practices and develops an HBIM model encompassing metadata on materials, structural functions, and repair history. This approach enables the documentation of both structural precision and symbolic elements, resulting in a multi-layered digital record that supports long-term preservation.
The resulting HBIM model serves multiple purposes, including restoration planning, archival conservation, and public visualization. As the first fully implemented HBIM project within the Huế Monuments Complex, it also offers a valuable template for integrating digital technologies with traditional craftsmanship in the context of heritage conservation.

1. Introduction

Located at the heart of the Imperial City of Huế, the Thái Hòa Hall stands as a powerful architectural symbol of political authority, royal legitimacy, and ceremonial tradition during the Nguyễn Dynasty of Vietnam. Serving as the venue for imperial enthronements, receptions of foreign envoys, and major state rituals, the hall embodies both architectural sophistication and profound cultural significance. Originally constructed in 1805 and later reconstructed under Emperor Minh Mạng in 1833, the hall reflects the political and artistic aspirations of successive Nguyễn rulers through multiple phases of renovation. Among these, the most notable transformation occurred in 1923, when Emperor Khải Định commissioned structural and decorative enhancements to commemorate his 40th birthday. This included the introduction of reinforced concrete columns and elaborate ornamental details, while preserving the traditional timber framework and tiled roof - exemplifying a deliberate fusion of modern and classical architectural elements.

Despite its historical and cultural significance, the hall has undergone more than 30 restoration interventions over its 200-year history, with limited systematic documentation or digital archiving of its physical and material transformations. The absence of such integrated records presents significant challenges to long-term preservation, risk assessment, and the transmission of knowledge across generations.

This study proposes a high-resolution digital documentation and Historic Building Information Modeling (HBIM) workflow as a foundation for the preservation and management of the Thái Hòa Hall. By integrating terrestrial LiDAR scanning with photogrammetry, the workflow captures the hall's complex architectural geometry and ornamental features in digital form. The resulting dataset not only serves as an accurate physical record but also enables semantic modeling of structural components, materials, and restoration history within a BIM environment.

As the first full-scale implementation of HBIM within the Huế heritage complex, this project sets a critical precedent for the broader application of digital preservation frameworks to other traditional timber structures in the imperial enclosure, such as the Thái Miếu Ancestral Temple, royal tombs, and ceremonial pavilions. Beyond its technical contributions, the project serves as a methodological bridge between embodied traditional knowledge and contemporary digital workflows, shedding light on the potential of HBIM to capture and manage the layered material transformations inherent in living heritage sites.

2. Research Methodology

Thái Hòa Hall exhibits a high degree of architectural complexity in both its structural and ornamental dimensions. Designed in the traditional *chongcham deokok* style characterized by overlapping double-eaved roofs, the structure comprises a front hall (seven bays, two aisles) and a main hall (five bays, two aisles), which are organically linked through an intricate roof system. The building's load-bearing framework is a hybrid system supported by 80 gilded timber columns (*geumgangmok*) and 16 reinforced concrete columns, reflecting a sophisticated interplay of traditional craftsmanship and modern materials. The roof is clad with yellow-glazed tiles, and the building's façade is adorned with intricate decorative elements, including grand relief carvings of dragons and clouds, vivid enamel ornamentation, and the *"one poem, one painting"* inscriptional system. These richly layered artistic features, combined with the structure's formal symmetry and symbolic expression, exemplify the architectural synthesis of structural rigor and aesthetic sophistication. As a concentrated embodiment of royal construction techniques, the

hall represents a cultural asset of exceptional heritage value and poses significant challenges for accurate restoration.

The process of converting traditional timber architecture into a BIM environment presents a range of technical challenges. In particular, it requires the reconstruction of non-standard structural elements, many of which exhibit complex and non-repetitive geometries that resist conventional quantification. Achieving a faithful representation of such components - both in form and in detail - demands advanced technical expertise and substantial time investment, especially when striving to align with the formal logic and aesthetic sensibilities of traditional architectural styles.

To address existing limitations, this study employed a hybrid workflow integrating terrestrial LiDAR scanning and photogrammetry. Data acquisition and modeling were carried out in two stages between 2024 and 2025, with the primary aim of producing a foundational dataset for HBIM-based heritage preservation. The HBIM model was developed not only to capture geometric accuracy but also to support structural and architectural analysis of Thái Hòa Hall, focusing on key design features. This approach contributes to the quantitative and visual documentation of traditional timber architecture, including spatial organization, design logic, and decorative systems.

2.1 Data Acquisition: LiDAR and Photogrammetry

In the 3D scanning of traditional timber architecture, certain limitations arise due to the structural complexity and restricted accessibility of concealed areas - such as inner roof spaces, connecting beams, interlocking joints, and ceiling interiors - where shadowing effects hinder the physical reach of scanning equipment. These constraints often result in the omission of critical structural elements and reduce the overall completeness of the model.To mitigate these issues, the research incorporated a combination of historical drawing analysis, expert consultation, and on-site investigation of the ongoing restoration work at Thái Hòa Hall. This enabled the supplementary photographic documentation of interior roof structures, enhancing both the accuracy and integrity of the HBIM dataset.

High-density point cloud data - with a point spacing of less than 6 mm - was acquired using the Leica RTC360 terrestrial LiDAR scanner. A total of 254 scanning stations were established across both interior and exterior spaces, ensuring comprehensive coverage of complex features such as timber columns, roof structures, and decorative elements. In parallel, over 44,500 high-resolution images were captured using Sony A7R IV/V cameras and the DJI Mavic 3 Pro drone. These images were utilized for the generation of richly textured meshes and orthophotos, complementing the geometric dataset and enhancing visual fidelity in the HBIM model.

Equipment	Specifications
LiDAR	Leica RTC360
DSLR Camera	Sony A7R5, Sony A7R4
Drone	DJI Mavic 3 Pro

Table 1. 3D Scanning and Photogrammetry Equipment Utilized for Thái Hòa Hall

RTC360 Specification	Details
Distance Measurement Accuracy	±1.0 mm @ 10 m ±2.0 mm @ 20 m
Angular Accuracy	Horizontal: 18 arcsec Vertical: 18 arcsec
Measurement Range	Up to 130 m (under standard reflectivity conditions)
Scanning Speed	Up to 2,000,000 points per second
3D Point Accuracy (System-Level)	Up to 2,000,000 points per second
Positioning Accuracy (without RTK)	Approx. ±5 cm using Visual Inertial System (VIS)-based tracking
Positional Drift (VIS only, average)	Less than ±5 cm (average over continuous operation)

Table 2. Technical Specifications of the Leica RTC360 Terrestrial Laser Scanner

Figure 1. Extended 3D Scanning and High-Resolution Image Acquisition at Thái Hòa Hall(Under restoration)

Figure 2. Extended 3D Scanning and High-Resolution Image Acquisition at Thái Hòa Hall(After Restoration)

Figure 3. Extended 3D Scanning and High-Resolution Image Acquisition at Thái Hòa Hall(After Restoration)

Figure 4. Field Operations during the Second Scanning Phase at Thái Hòa(After Restoration)

2.2 Data Processing and Alignment

The point cloud and photogrammetric datasets were processed using a combination of Leica Cyclone, RealityCapture, and Agisoft Metashape, with software selection tailored to the complexity and characteristics of specific architectural elements. Point cloud registration was conducted with high precision based on fixed targets and overlapping scan positions. Meanwhile, the photogrammetric models were meticulously calibrated and merged to produce high-resolution textured meshes, ensuring both geometric accuracy and visual fidelity across diverse spatial conditions.

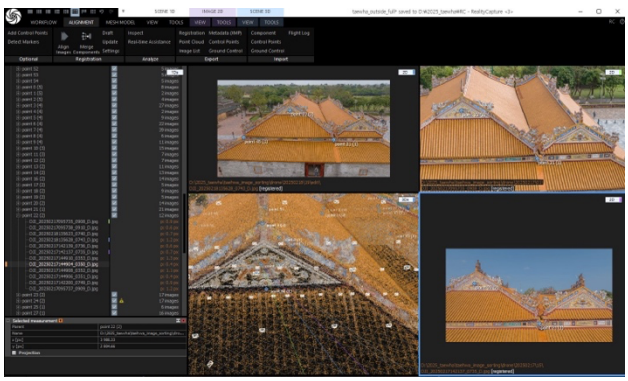

Figure 5. Post-Processing Workflow of Photogrammetry Data from the Thái Hòa Hall

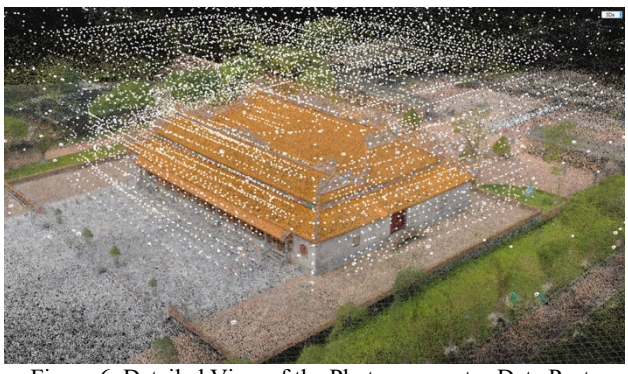

Figure 6. Detailed View of the Photogrammetry Data Post-Processing Workflow - Thái Hòa Hall

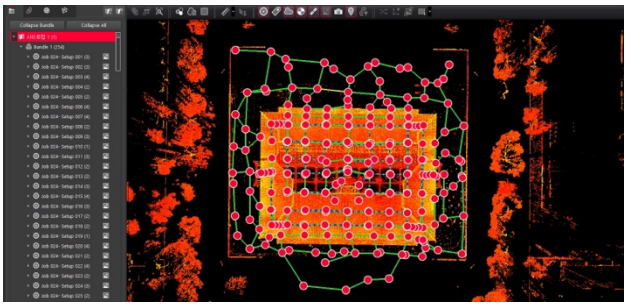

Figure 7. Top-View Perspective of the 3D Scan Data Post-Processing Workflow - Thái Hòa Hall

2.3 Classification Framework and Semantic Structuring

When employing HBIM as a heritage management tool, the establishment of a systematic classification framework is essential. Despite the fact that East Asian traditional timber architecture shares common principles in structural typologies, component nomenclature, construction sequences, and restoration practices, existing HBIM implementations often lack classification systems that adequately reflect these cultural and technical specificities.

East Asian countries - including China, Korea, Japan, and Vietnam - share a set of analogous structural principles in their traditional timber architecture. These include the use of non-fastening interlocking joinery techniques, frame structures that distribute and transfer roof loads, and modular design systems that divide space according to standardized dimensions (e.g., Japan’s *Ken* unit or Korea’s *Kan* system). The classification of architectural components is closely tied to traditional construction workflows and functional units, with specialized artisan groups (or work guilds) organized according to these phases. Such structural and procedural characteristics can be effectively incorporated into the design of HBIM classification systems, providing a foundation for adopting shared classification standards across regions with similar architectural heritage.

As demonstrated in the restoration project of Thái Hòa Hall, the conservation workflow of traditional architecture in Huế, Vietnam typically unfolds in three main stages: (1) processing and fabrication of timber structural components, (2) assembly of the framework and roof, and (3) restoration of interior finishes and decorative elements. Correspondingly, the artisan teams involved are divided into carpentry/ornamental groups and masonry teams. This workflow aligns closely with the higher-level classification system used in HBIM modeling and attribute assignment, offering a culturally grounded structure for data organization.

To adequately reflect the complex architectural characteristics of Thái Hòa Hall and address the nuanced requirements of its conservation and restoration, this study proposes a newly designed semantic classification system within the HBIM (Historic Building Information Modeling) framework. The classification was developed based on empirical field data, ensuring contextual relevance and structural fidelity throughout the modeling process.

Rather than mechanically adopting existing commercial BIM classification systems (such as Omniclass or Uniclass), this framework employs a hybrid approach that organically integrates the actual restoration workflow of Thái Hòa Hall with the

functional structure of traditional artisan teams. By aligning the classification with context-specific construction phases and craft-based operational units, the system enhances both cultural fidelity and practical applicability in HBIM development.

This approach enables more precise data management and information integration for both structural and decorative elements of Thái Hòa Hall. Consequently, the applicability of HBIM is extended beyond restoration design to encompass conservation monitoring, educational programming, and exhibition curation, broadening its utility across multiple domains of heritage practice.

2.3.1 Development of the Classification System

Architectural components were defined according to six primary categories, grounded in both structural logic and the operational framework of the restoration team.

Classification Code	Examples of Components
Basic Structure (BS)	Foundation stones, base platforms, alignment stones
Framing Structure (ST)	Columns, beams, lintels, brackets
Roof Structure (RF)	Ridge beam, rafters, bargeboards, decorative tiles
Interior Finishes (IF)	Floor, ceiling, doors, partitions
Decorative Features (DF)	Carved panels, ornamentation, inscription boards
Electrical, others (EL)	Electrical equipment, etc.

Table 3. Draft Classification Scheme of HBIM Components for Thái Hòa Hall

This classification system holistically integrates the functional roles, sequential construction processes, and the component framework of traditional timber architecture. Moreover, it is optimized not only for the input of 3D geometric data but also for encoding a wide range of metadata, including material properties, joinery techniques, repair history, and artisan attribution. As such, the HBIM model is designed to transcend the limitations of a mere geometric library, serving instead as a comprehensive information system that encapsulates both the structural logic and conservation practices inherent to cultural heritage.

Such a classification framework enables the HBIM model to function beyond a mere repository of geometric information. It provides a foundation for long-term maintenance planning, accumulation of repair histories, informed decision-making on component replacement, and the formulation of preservation strategies based on digital twin technologies. Furthermore, by applying this unified classification system to other traditional structures within the Huế Imperial Citadel - such as the Imperial Ancestral Temple (Thái Miếu), Diên Thọ Palace, and Tổ Miếu - the groundwork is laid for establishing an integrated and coherent heritage management platform.

Figure 8. Draft Classification Scheme of HBIM Components for Thái Hòa Hall

2.3.2 Metadata Architecture

For each component category, metadata fields have been systematically designed to support long-term preservation and comparative analysis:

1) Component Typologies and Material Specifications: Central axial columns - *Lim* wood (*Erythrophleum fordii*), principal beams - *Lim* wood, exterior walls - traditional hand-made brick combined with lime-based plaster finish, roof - imperial yellow-glazed yin-yang roof tiles

2) Chronology of Construction and Restoration: Original construction: 1805 - during the reign of Emperor Gia Long; major reconstruction: 1833 - under Emperor Minh Mạng; maintenance record: 1923 - under Emperor Khải Định; recent full-scale restoration: 1993, and 2021 ~ 2024 - as part of the comprehensive heritage conservation project

3) Structural and Symbolic Functions: Joint technique – traditional timber joinery using interlocking mortise and tenon, without nails; central columns and main trusses – primary load-bearing structural framework; main gate – aligned with the *Shinto* axis: ritual function and imperial authority symbol; roof ornaments – ridge-end decorations featuring dragons and phoenixes: symbols of royal authority; flooring – base platform: supports ceremonial and reception spaces

4) Physical Condition Assessment: Condition as of scanning date - 2025: recently restored; no visible damage

Where necessary, the metadata structure has been designed to enable multilayered traceability of restoration history by allowing links to original sources such as historical drawings, restoration reports, and archival photographs.

Metadata	Contents (Example)
Maintenance Cycle	5 years
Structural Function	Door
Special Value	Symbol of imperial authority
Surface Finish	Gilded lacquer – protective layer deteriorated
Related Documents	JPG image, original drawings, 3D scan, survey documents
Recommended Action	Preserve original state – tight-fitting joints – no new intervention
Construction Technique	Traditional mortise & tenon – precise wood joining
Structural Type	Wooden door – 2 panels – mortise & tenon – interlocked
Material Type	Lim wood (native)
Usage History	Used 1993–2003 – restored 2003; 2021: laser scanned for documentation
Material Source	Đông – Huế Forest
Last Inspection Date	2021 – Center for Conservation of Huế Monuments
Construction Period	Approx. 1833 – under Emperor Minh Mạng
Component Code	D4 Door – Front axis – South-facing
Original Condition	Reused timber – some hinges replaced in 2003

Current Condition	Worn lacquer, cracks, delamination – needs inspection
Inspection Unit	TTBTDTCĐ Huế / Central Institute for Humanities and Social Sciences (CIHSS Central Region)

Table 4. Proposed Metadata Structure for the Thái Hòa Hall

2.4 HBIM Modeling & Data Integration

Following the design of the semantic structure, the HBIM model of Thái Hòa Hall was developed within the Autodesk Revit environment. Based on the geometric and attribute data acquired during the scanning phase, over 5,241 architectural components were segmented and modeled. These components were systematically categorized according to the previously defined semantic classifications.

2.4.1 Geometric Modeling

The foundational geometry was constructed with reference to both point cloud and textured mesh data. Parametric objects in Revit were used to model key wooden components such as columns, beams, walls, and interior finishes. Irregular elements—such as asymmetrical dragon heads—were modeled separately as custom families, based on mesh data processed through RealityCapture.

Figure 9. Dragon head modeled in 3D through photogrammetry

2.4.2 Integration of Information Layers

Each modeled component was assigned the following metadata parameters:

1) Material Information : e.g., *Lim* wood - dense tropical hardwood; *hoàng lưu ly* tiles - glazed imperial yellow roof tiles; *Bát Tràng* bricks - traditionally handcrafted bricks; *cheongseok* - natural blue stone

2) Construction and Restoration Timeline : Initial construction in 1805 - during the reign of Emperor Gia Long; major restoration in 1833 - under Emperor Minh Mạng, including full roof replacement; maintenance history in 1923, 1993; comprehensive restoration project: 2021 ~ 2024

3) Condition Assessment and Classification : Original components preserved - approximately 70–80% of structural elements remain intact; Damaged areas: lower sections of columns showing decay, termite damage, signs of foundation settlement; Replaced components: roof structures and door hinges replaced during the 1993 restoration; Missing elements: decorative *long–phụng* (dragon–phoenix) motifs, broken roof tiles

4) Restoration Stakeholders and Responsible Teams : Huế Monuments Conservation Centre; Vietnam Association for Cultural Heritage; Huế Cultural Heritage Conservation JSC

Leveraging Revit's shared parameter and schedule functionalities, this metadata was directly embedded within the model itself. The structure was intentionally designed to facilitate future integration with digital archives and asset management systems.

2.4.3 Interoperability and Data Format Conversion

The finalized HBIM model was exported in multiple formats to accommodate the diverse needs of various stakeholders:

1) .IFC : for long-term preservation and interoperability with GIS and document management systems;
2) .GLB / .gITF : for web-based visualization and AR/VR content development;
3) .RVT : as an internal format for use in restoration sites and facility management.

These formats facilitate data reuse and scalability across a range of future applications, including subsequent restoration workflows, comparative heritage studies, and the development of educational content.

2.5 Archival Integration and Visualization

The finalized HBIM model was exported into multiple formats - such as .IFC, .RVT, and .GLB - to ensure interoperability across platforms. Additionally, a digital archive structure was established, enabling the model to serve as a foundational dataset for future applications in various domains.

1) Development of scheduled maintenance plans
2) Damage simulation and structural analysis
3) Educational VR/AR content production
4) Web-based public access and dissemination services

To ensure systematic preservation and facilitate broader accessibility, a digital archive platform is being developed to comprehensively organize the acquired 3D scan and BIM datasets. This platform is designed to support both academic research and public engagement by enabling seamless access to structured heritage information. By integrating advanced digital documentation into heritage stewardship, the archive is expected to serve not only as a foundation for education, research, and exhibition but also as a catalyst for reinforcing the societal value of cultural heritage in the digital age.

3. Result

3.1 Summary of High-Precision Scanning Results

Through the integration of LiDAR and photogrammetry-based scanning, a high-density point cloud comprising approximately 8.167 billion points was generated for the Taehwa-jeon Hall. A total of 254 scan stations were established to capture both interior and exterior geometries, resulting in an average geometric accuracy of ±2 mm. Particularly, structurally critical elements such as timber columns and beams were documented at sub-millimeter resolution, ensuring precise representation of their physical conditions.

Concurrently, over 44,500 high-resolution images - each approximately 20 megapixels - were captured using Sony A7R5/A7R4 cameras and a DJI Mavic 3 Pro drone. These images were processed to generate orthophotos and detailed mesh models. The resulting dataset proved especially effective for the precise documentation of complex architectural features, such as asymmetrical eaves structures and non-repetitive ornamental elements.

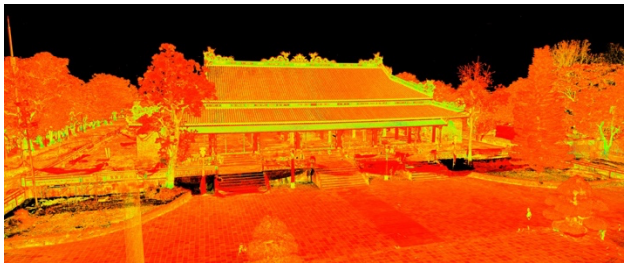

Figure 10. Exterior 3D Scanning of Thái Hòa Hall (Under restoration)

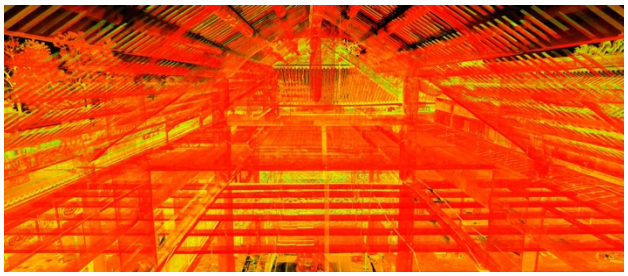

Figure 11. Interior 3D Scanning of Thái Hòa Hall (Under restoration)

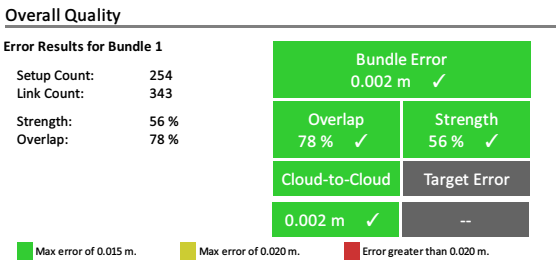

Figure 12. 3D Scanning Report of Thái Hòa Hall

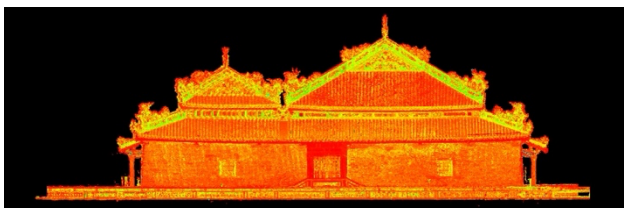

Figure 13. Exterior 3D Scanning of Thái Hòa Hall (After Restoration)

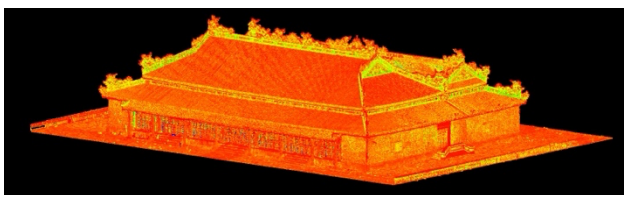

Figure 14. Exterior 3D Scanning of Thái Hòa Hall (After Restoration)

3.2 Modeling of HBIM Components

Based on the semantic classification system defined in Section 2.3, a total of 5,251 architectural components were modeled in Autodesk Revit. The modeled components are categorized as follows:

1) Foundation and Substructure: 32 components
2) Timber Structural Framework: 188 components
3) Roof Assemblies: 231 components
4) Interior Finishing Elements: 464 components
5) Ornamental Features: 4,267 components
6) Mechanical and Electrical Systems: 2 components

Approximately 90% of the architectural components required custom modeling, primarily due to the presence of manually carved or irregularly shaped timber elements. The remaining components were constructed using parametric families, offering high potential for reuse in future projects with similar structural characteristics.

Each object was embedded with the following metadata:
1) Restoration Period (linked to restoration history documentation)
2) Structural Function (distinction between load-bearing and ornamental elements)
3) Current Condition (categorized as original, damaged, or replaced)

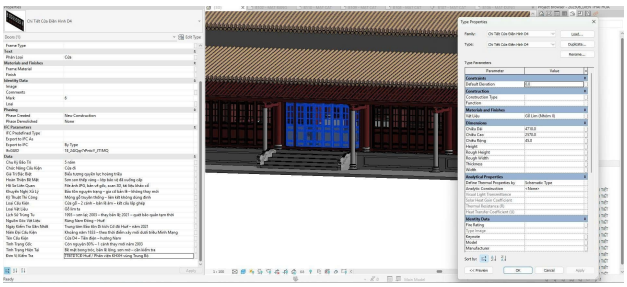

Figure 15. HBIM Metadata of Thái Hòa Hall (Revit)

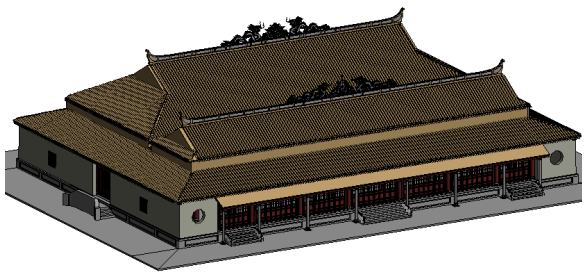

Figure 16. Thái Hòa Hall HBIM 3D Model (Revit)

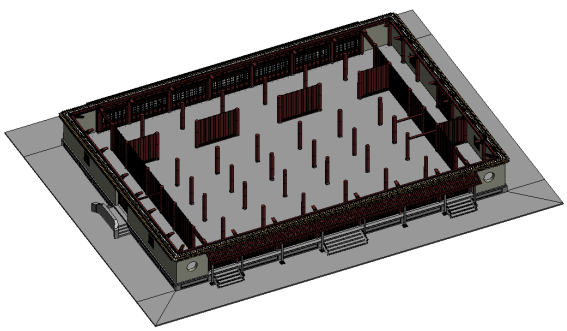

Figure 17. Sectional View Showing Column Structure, Wall, Multi-level Steps in the Thái Hòa Hall HBIM 3D Model (Revit)

3.3 Visualization Outputs and Applications

The HBIM model was exported in multiple formats to accommodate various stakeholders and application contexts:
1) **.RVT**: For use in HBIM workflows and restoration planning
2) **.IFC**: For integration with GIS, conservation documentation systems, and for archival purposes

3) **.GLB**: For web-based 3D visualization and immersive VR/AR applications

Additional deliverables included the following:
1) Orthophoto-based floor plans and sectional drawings
2) Point cloud intensity maps

These materials are scheduled to be utilized in the presentation of the Scan-to-HBIM digitization outcomes of Thái Hòa Hall at the end of 2025, and may subsequently serve as part of the digital archiving dataset for the Complex of Hué Monuments in Vietnam.

This study conducted 3D scan-based digital documentation of Thái Hòa Hall, a UNESCO World Cultural Heritage site in Huế, Vietnam, and proposed a direction for establishing a future cultural heritage management system based on Historic Building Information Modeling (HBIM). The 3D scanning, carried out in practice, accurately recorded the structural characteristics and decorative elements of traditional wooden architecture in high resolution, thereby providing essential foundational data for long-term preservation and subsequent analysis.

Although the HBIM model has not yet been fully completed at this stage, the 3D scan data contains structural information that can later be converted into BIM components. The application of an HBIM framework based on this data is expected to make a tangible contribution to improving preservation efficiency and integrated management of structural information. In particular, integrating historical data such as repair records, material information, and damage areas into the BIM system is anticipated to support the development of conservation plans and enable proactive responses to potential risks.

In addition, the establishment of a digital archive platform can enhance the educational and research utilization of 3D scan and HBIM data by making them accessible to general researchers and the public, thereby contributing to the dissemination of cultural heritage value. The Thái Hòa Hall case can serve as a testbed for the potential expansion of such technology to similar traditional structures within the Huế Monuments Complex (e.g., Thế Miếu, Hưng Miếu, Diên Thọ Residence). This attempt holds significance as an empirical demonstration of a comprehensive digital technology–based approach to the preservation of traditional Vietnamese wooden architecture.

Future research will expand into the practical implementation of HBIM, enhancement of user experience on the digital platform, and automation of structural analysis. It also aims to explore the broader application of Scan-to-BIM technology across the entire Huế Imperial City and adjacent heritage sites.

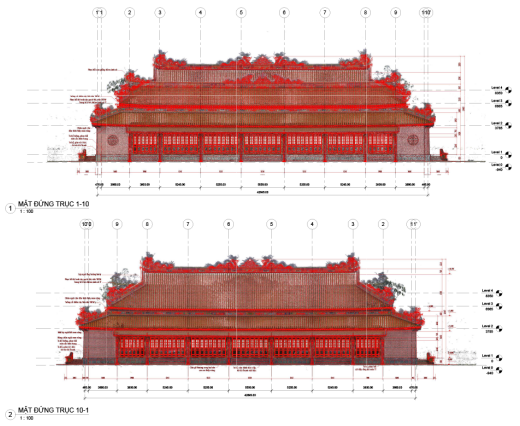

Figure 18. Drawings Generated from 3D Scanning Outputs

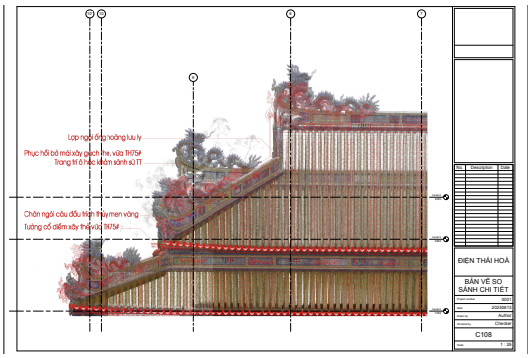

Figure 19. Drawings Generated from 3D Scanning Outputs

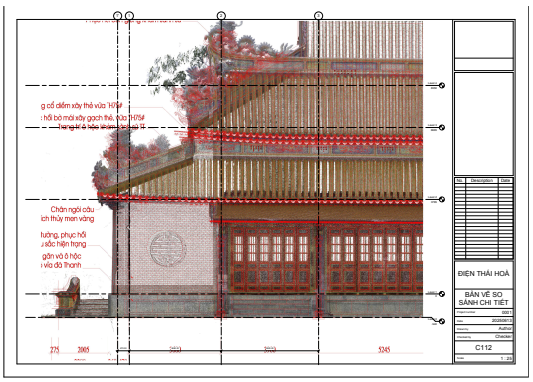

Figure 20. Drawings Generated from 3D Scanning Outputs

4. Discussion

4.1 Technical Challenges of Applying HBIM to the Complexity of Traditional Architecture

In the case of Thái Hòa Hall, the process of applying HBIM revealed a structural tension between the standardized principles of BIM and the irregular geometry and symbolism inherent in traditional timber architecture. The main technical challenges were as follows:

1) Difficulty in Semantic Segmentation of Decorative Elements: Components such as poetic inscriptions paired with paintings (*Il-si-il-hwa*) and dragon motifs required mostly manual segmentation due to their irregular shapes and overlapping patterns.
2) Burden of Custom Family Creation: Approximately 90% of all components required mesh-based custom modeling, which significantly increased the workload in terms of modeling time and human resources.
3) Composite Material Structure: Due to the coexistence of reinforced concrete and traditional timber structures, the classification logic and metadata structure had to be designed in a dual-layered format. These challenges highlight the need to develop a flexible HBIM template capable of accommodating non-standard elements and symbolic features.

4.2 Insights into Conservation Practice

Despite the aforementioned technical challenges, this project has offered meaningful insights into the practical field of cultural heritage conservation and research. Deviations in column positioning and misalignments - previously undocumented - were identified through the HBIM model and subsequently verified via high-precision on-site 3D scanning.

The integration of restoration chronology and material replacement history into a unified, visual timeline significantly improved communication efficiency between designers and heritage managers. The developed semantic classification system also demonstrates potential for adaptation into a modular information design template, suitable for application in other traditional timber structures within the Huế Imperial Citadel.
Moreover, by embedding historical records and restoration documentation within the HBIM model itself, the project lays a foundation for enhanced collaboration among architects, heritage conservationists, and local stakeholders.

4.3 Applicability to Cultural Heritage Conservation Workflows

This project represents the first field-based implementation of HBIM within the Huế Monument Complex and serves as a technical framework for future applications to analogous structures such as the Thế Miếu (Ancestral Temple), flanking pavilions, and ritual spaces. It further demonstrates the feasibility of integrating traditional artisan workflows into the BIM structure while preserving their culturally specific meanings.

For future development, the following directions are proposed:

1) Integration of AI-driven semantic classification automation
2) Optimization of the Scan-to-BIM process for nested and overlapping ornamental structures
3) Design of user-centered digital archive interfaces to enhance public accessibility and engagement

5. Conclusions

This study proposes and validates a Scan-to-HBIM workflow by integrating terrestrial LiDAR scanning, high-resolution photogrammetry, and semantic-based HBIM modeling for the Thái Hòa Hall, a representative example of traditional timber architecture within the Imperial Citadel of Huế, Vietnam. The research demonstrates the feasibility of constructing a multilayered digital archive that captures both geometric precision and cultural context.

This project demonstrated the practical applicability of HBIM in real-world heritage contexts, particularly affirming its effectiveness even in traditional timber structures characterized by a complex interplay of historical interventions, symbolic ornamentation, and non-standardized geometries.

This study proposed a reusable semantic classification system based on site-specific restoration workflows and developed a multilayered HBIM model integrating structural, material, and historical information. The outcomes demonstrate the potential of such models to generate visualization data that is meaningful and accessible for both conservation experts and the general public.

Despite remaining technical limitations - such as the automatic segmentation of decorative elements and the handling of mixed-material conditions - this study reaffirmed the value of HBIM as a practical interface between traditional artisanal knowledge and contemporary digital technologies.

The workflow and data structure developed through this study are currently being applied to similar architectural structures within the Huế monument complex, including Thế Miếu, Diên Thọ Palace, and the Left-Right Pavilions. Looking ahead, the integration of VR/AR applications and AI-based semantic automation is expected to further enhance the sustainability, accessibility, and interpretability of cultural heritage information.

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Appendix

Year	Restoration Details
1805, 1819	Emperor Gia Long commissioned the original construction of Thái Hòa Hall in the Đại Cung Môn area and later conducted repairs
1833	Emperor Minh Mạng restructured its architectural layout, relocated the hall to its current location, and expanded it through major reconstruction
1846, 1847	Renovations were carried out during the reign of Emperor Thiệu Trị
1868, 1878, 1879	Renovations were carried out during the reign of Emperor Tự Đức
1891, 1899, 1900, 1904, 1906	Renovations were carried out during the reign of Emperor Thành Thái
1907, 1910, 1914	Renovations were carried out during the reign of Emperor Duy Tân
1922, 1923, 1924	Renovations were carried out during the reign of Emperor Khải Định
1939, 1943	Renovations were carried out during the reign of Emperor Bảo Đại
1945	Repair
1978	After a partial and inaccurate restoration in 1968, the pavilion was severely damaged by Typhoon Hester in 1971 and a bombing in 1972 that destroyed its central roof
1994	Reinforced the front roof with tiles
1997	Restored gilded wooden components
1998	Restored gilded wooden box
1999	Rear roof severely damaged by flood and storm; repair conducted
2016	Warped and sagging timber in east and west wings reinforced with steel structure
2020	Severe damage to east and west wings due to 2017 flood and typhoon; emergency restoration planned
Early 2022	Thừa Thiên Huế Province approved the Comprehensive Preservation and Restoration Project (2021). HMCC initiated the project with full investment funding.
November 23, 2024	The People's Committee of Thừa Thiên Huế Province officially announced the completion of the Preservation and Comprehensive Restoration Project of the Thái Hòa Hall relic and opened it to visi-tors.

Table 5. Restoration and Repair History of Thái Hòa Hall