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Review

Digital Technologies Enabling Rural Revitalization: The Practice of AI and BIM in the Adaptive Reuse of Historic Buildings

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Abstract: The integration of artificial intelligence (AI) and Building Information Modeling (BIM) has emerged as a transformative approach to the adaptive reuse of historical buildings. This study examines the synergistic role of AI and BIM in enhancing component identification, 3D modeling, design scheme generation, and intelligent manufacturing. By leveraging data-driven methodologies, this research aims to establish a comprehensive and systematic framework for the efficient reuse of historical buildings. Furthermore, this study examines how the integration of AI and BIM can optimize digital workflows, improve the management of building renovations, and facilitate their transition to sustainable construction practices. Ultimately, the findings of this research contribute to the broader discourse on intelligent, technology-driven heritage conservation and inform future advancements in the field.

Keywords: digital technology; artificial intelligence; building information modeling; historical buildings; adaptive reuse

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1. Introduction

With the implementation of the rural revitalization strategy, historical buildings — serving as both cultural assets and spatial resources — have increasingly gained attention in the context of adaptive reuse. However, traditional restoration approaches often face challenges related to efficiency, precision, and refined management. The emergence of artificial intelligence (AI), Building Information Modeling (BIM), and other digital technologies has created new opportunities for the intelligent identification, spatial optimization, and life-cycle management of historical building restoration.

This study explores the integrated application of AI and BIM in the adaptive reuse of historical buildings, examining key technical methodologies, implementation strategies, and operational frameworks. Furthermore, it discusses future development trends, aiming to establish a data-driven digital transformation model. By leveraging big data, this approach seeks to enhance the efficiency, sustainability, and environmental responsibility of rural historical building conservation and redevelopment [1].

2. Key Technologies for Promoting Adaptive Reuse of Historical Buildings in Collaboration with AI and BIM

2.1. Historical Building Component Extraction and Semantic Analysis Based on AI Recognition

Historical buildings often pose challenges due to limited documentation and structural complexity, rendering traditional identification methods insufficient for adaptive reuse. Artificial intelligence (AI) offers a powerful solution by leveraging computer vision and deep learning to automatically analyze images, videos, and 3D scans. This enables accurate identification of architectural components such as walls, doors, windows, roofs, and other structural elements. Furthermore, AI-driven semantic analysis algorithms can label the functional and aesthetic characteristics of each component, ensuring a detailed understanding of the building's structure and design. AI also plays a critical role in data collection, predictive analysis, and automated design optimization, making it indispensable in architectural preservation. The high accuracy and efficiency of AI-driven identification led to the creation of precise BIM models, enhancing both the quality and feasibility of adaptive reuse projects [2].

Figure 1 illustrates this AI-BIM Framework for Historic Structure Diagnosis and Restoration:

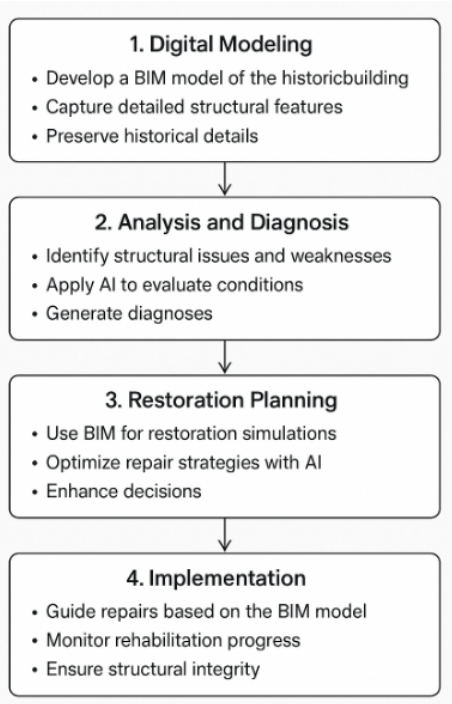

Figure 1. AI-BIM Framework for Historic Structure Diagnosis and Restoration.

2.2 The Role of BIM in Building Reuse

In the transformation of historical buildings, BIM technology can be used to establish accurate digital building models and describe in detail the structural characteristics, component information and historical background of historical buildings, so as to formulate scientific transformation plans and provide strong data support. Due to the parametric modeling and information integration functions of BIM, the real situation of contemporary historical buildings can be highly restored, and on the basis of not changing the original cultural value, designers can be assisted to develop multiple sets of transformation methods and adjust them to improve the scientific nature of transformation. BIM combined with AI can also conduct intelligent simulation and real-time debugging during the construction process, accurately simulate the construction process and sequence, and predict possible contradictions or risk factors, which can greatly improve the management level and safety of the construction site. As a database that covers the entire life of the building, BIM can also record and predict the operation of the historical building according to the use and management of the historical building after the completion of the project to extend its service life, reduce long-term management costs, and comprehensively help the historical and cultural buildings of rural revitalization [3]. Figure 2 below is the historical building construction simulation drawing achieved by BIM:

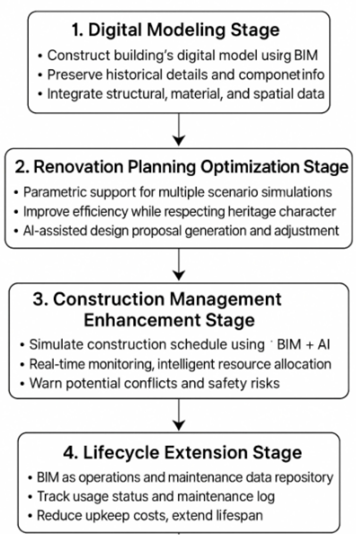

Figure 2. BIM-AI Synergy in Heritage Architecture Revitalization.

3. Collaborative Application of AI and BIM in Adaptive Reuse of Historical Buildings

3.1. Parametric Generation for Spatial Reconstruction and Enhanced Adaptability

Generative design has increasingly demonstrated its pivotal role in the restoration and transformation of historical buildings. This methodology leverages artificial intelligence and parametric modeling to generate multiple design iterations based on predefined parameters, such as spatial dimensions, structural constraints, and lighting requirements. These iterations are subsequently refined through intelligent optimization algorithms, wherein computational models iteratively adjust design solutions toward optimal outcomes based on targeted criteria such as cost efficiency, carbon emissions, and spatial density.

A key advantage of generative design lies in its ability to integrate self-learning mechanisms that respond to dynamic environmental variables, including precipitation levels, wind direction, seismic intensity, and frequency. By incorporating these adaptive capabilities, historical buildings can undergo morphological transformations, ensuring structural resilience and functionality across diverse environmental conditions [4].

The integration of generative design with Building Information Modeling (BIM) further expands the potential for adaptive reuse. The BIM platform enables designers to synthesize AI-driven data and represent it through graphical visualization, facilitating the assessment of design feasibility and contextual appropriateness. This collaborative framework significantly enhances design efficiency while promoting greater flexibility and creativity in transformation strategies [5]. Table 1 presents statistical data on the application of generative design in the adaptive reuse and reconstruction of historical buildings in recent years.

Table 1. Application statistics of generative design in the reuse of historical buildings.

Year	Number of items	Proportion of total renovation projects (%)
2018	15	10
2019	25	15
2020	40	20
2021	60	30
2022	90	45

Note: Data source "2022 Architectural Design Technology Application Report".

As can be seen from Table 1, the number of applications of generative design in adaptive reuse of historical buildings has increased rapidly, from 15 cases in 2018 to 90 cases in 2022, and the proportion has increased from 10% to 45%.

3.2. Conceptual Modeling Integrating Style Recognition to Enhance Semantic Expression

In the adaptive reuse of historical buildings, AI-assisted conceptual modeling plays a crucial role in enhancing design expression and ensuring stylistic coherence. By leveraging text-based architectural descriptions, designers can efficiently generate conceptual sketches or 3D models that align with specific stylistic intentions. This process facilitates the seamless transformation of textual input into spatial forms, enabling a more effective exploration of the interplay between function and cultural identity while preserving historical continuity. Moreover, as a methodological approach to style transfer, AI enables the extrapolation and application of diverse architectural styles across historical, contemporary, and even speculative future contexts. This capability fosters the integration of traditional aesthetics with modern functionality, ensuring a coherent and contextually sensitive architectural expression.

Furthermore, the implementation of intelligent technologies and case-based knowledge systems allows for the rapid generation of multiple renovation schemes, significantly reducing the time and labor costs associated with manual iterations. Simultaneously, the advanced three-dimensional visualization capabilities of the BIM platform optimize design consistency with historical architectural elements, thereby enhancing spatial coherence in functional adaptation. Ultimately, this integrative approach aims to improve the efficiency of secondary utilization while elevating the aesthetic quality of architectural heritage conservation and transformation.

Figure 3 presents a statistical analysis of the application of AI-assisted conceptual design in the adaptive reuse of historical buildings in recent years.

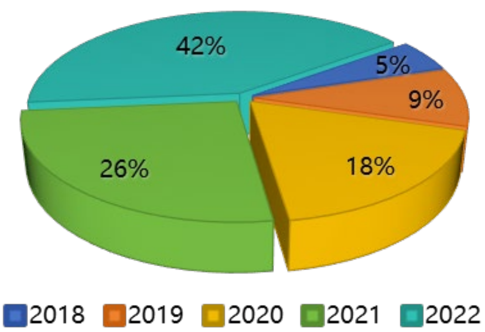

Figure 3. Statistical Analysis Charts.

Note: Data source "2022 Architectural Design Technology Application Report".

3.3. 3D Reconstruction Supports State Recognition to Achieve Intervention Accuracy

In the transformation process of historical buildings, through the combination of three-dimensional scanning, artificial intelligence algorithms and other ways, we can quickly build a high-precision model to reflect the current situation, including the overall building framework, component details and surface information. At present, the most common way is to use laser point cloud scanning and oblique photography, which is very suitable for historic buildings containing complex spatial layout, information missing or missing. After modeling, artificial intelligence can analyze the building structure according to the scanning data, extract the cracks, deformation, fall off, etc., of the key damaged parts, and put forward improvement suggestions according to the historical building type and material characteristics. Compared to traditional manual work using drawings, 3D restoration can be distinguished by faster speed, lower error rate, and real-time updated data. At the same time, the resulting digital twin model can also be used as a reference comparison for design simulation and result improvement, which can enhance the improvement effect while protecting culture and heritage. Table 2 below shows the actual application data of AI and 3D scanning technology in related projects:

Table 2. Application statistics of AI and 3D scanning technology in the reuse of historical buildings.

A given year	Number of items	Proportion of total renovation projects (%)
2018	12	9
2019	22	14
2020	38	19
2021	55	28
2022	85	42

Note: Data source: China Smart Building Annual Development Report (2022), Research Review on Intelligent Building and 3D Modeling.

As shown in Table 2, the application rate of AI and 3D scanning technology in the adaptive reuse of historic buildings increased from 9% in 2018 to 42% in 2022, and the number of projects increased more than seven times.

3.4. Information Construction: Integrating AI and BIM for Enhanced Construction Process Management

The integration of AI and BIM enhances data consistency and workflow efficiency across the entire lifecycle of a project, including design, construction, and operation.

In the design phase, AI can automatically generate an initial 3D model framework by extracting and analyzing scanned data from the building's foundation or existing drawings, enabling rapid model creation. When combined with BIM technology, this data is structured into an organized format, serving as a reference for workspace planning and component classification.

During the construction phase, AI leverages the BIM model's structural elements and their interrelationships to identify potential issues in advance and simulate the actual construction process. By integrating with scheduling tools and resource databases, AI enables real-time route optimization, improving material utilization and minimizing wasted time and resources.

In the operational phase, the BIM model serves as a comprehensive repository of facility data, while AI processes real-time sensor inputs to predict maintenance needs. This proactive approach reduces the likelihood of equipment failures and extends the effective service life of building systems. Figure 4 illustrates the application of AI and BIM technology in construction management:

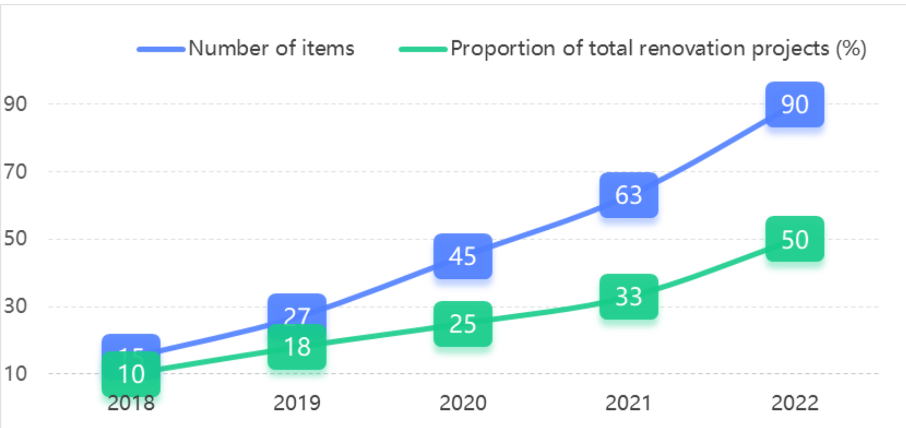

Figure 4. Illustrates the Application of AI and BIM Technology in Construction Management.

4. AI and BIM Integration: Advancing Intelligence in the Reuse of Historic Buildings

4.1. Advancing AI-Driven Design and Robotic Construction for Intelligent Restoration of Historic Buildings

The renovation of historic buildings often presents challenges such as irregular structures, spatial constraints, and delicate materials, making it difficult for traditional construction methods to balance quality, safety, and efficiency. However, the integration of AI and robotics enables high adaptability and rapid response throughout the entire process, from design to construction.

AI systems can analyze scanned images, 3D point clouds, or BIM models to interpret the building's form, structure, and component relationships, automatically generating design strategies that align with both functional requirements and heritage preservation. Robotic construction systems, guided by AI-generated commands, can precisely position and assemble components, making them particularly suitable for small, intricate, or high-risk construction areas.

In practice, AI continuously optimizes design outcomes and decomposes them into executable instructions, while BIM technology translates these into construction route and node control parameters. Furthermore, by integrating automated guidance systems and sensor data, robotic systems can execute tasks autonomously and correct errors in real time.

The operational framework of the intelligent construction system can be summarized as follows:

$$S = \sum_{i=1}^{n}(D_i \cdot C_i \cdot Q_i) \quad (1)$$

In this model, the total function of the historical building construction system is represented by S, the i-th design element generated by AI design is D_i , C_i is the implementation result of related construction operations, and Q_i is the information feedback quality of each task.

4.2. Developing an Adaptive Intelligent System for Enhancing Built Environment Resilience and Adaptability

As historic buildings undergo adaptive reuse and restoration, they often struggle to meet modern requirements for comfort and energy efficiency due to their structural constraints, aging facilities, and preservation limitations. To address this, adaptive intelligent systems are implemented. Utilizing AI algorithms and multi-dimensional data collection, these systems continuously monitor and adjust environmental conditions in real-time. Without altering the original architectural layout, they enhance thermal comfort, improve air circulation, and optimize natural lighting — making them particularly suitable for minimal-intervention revitalization of heritage buildings such as traditional courtyards, auditoriums, and ancestral halls.

The responsive control process involves the collection and analysis of environmental data, including temperature, humidity, illumination, and wind speed. AI-driven algorithms assess the current environmental state and determine the optimal response strategy. Execution involves adjusting controllable building elements such as operable windows, sunshades, and ventilation systems. The system's calculation formula is expressed as follows:

$$E = \frac{\sum_{i=1}^{n}(w_i \cdot \Delta P_i)}{T_{res}} \quad (2)$$

In the formula, E is the coefficient of adjustment ability, and w_i represents the AI reaction weight of the i-th environmental factor (such as sensitivity to temperature and humidity). ΔP_i signifies the deviation of i-th parameter from ideal condition, and T_{res} represents the system's required response time.

4.3. Integration of Multi-Source Data for Visual Management of the Entire Process

With the continuous development of building information processing technologies, data has gradually become the primary driver of the building lifecycle. In the context of historical building reuse, where decision-making involves multiple stages, diverse stakeholders, and various situational factors, developing a system that can aggregate rich datasets with dynamic visualization capabilities has become essential for enhancing task execution efficiency and management transparency.

The integration of artificial intelligence (AI) technologies within the BIM platform facilitates the continuous and shared flow of building information from design to operation and maintenance, overcoming the traditional challenges of data fragmentation and information silos. The comprehensive data includes geometric model parameters and semantic identifiers generated during the design phase, key updates and resource flow data during the construction phase, as well as sensor data — such as temperature, humidity, energy consumption, and component pressure — during the usage phase, and inspection records and customer feedback during the repair phase. All data are embedded into the BIM platform following standardized data construction and interface protocols, with the AI system identifying, connecting, and analyzing these datasets in chronological order. This approach enables the provision of accurate and real-time assessments of building operations for decision-makers.

Based on this premise, a model of the entire visual review process is constructed, and the data processing power and output speed can be calculated by the following formula:

$$V = \frac{\sum_{j=1}^{m}(R_j \cdot C_j)}{L+D} \tag{3}$$

In the formula, V is the system visibility response speed index, R_j is the information timeliness index of class j sources, C_j is the correlation degree of this kind of information to management, L is the data processing time index, and D is the loss of data exchange between different types of platforms in the system data processing.

4.4. Optimizing Modular Construction and Intelligent Manufacturing to Promote Green and Efficient Reuse

In recent years, with the rapid development of intelligent manufacturing concepts in the construction industry, modular construction methods have shown significant advantages in accelerating construction progress, reducing energy consumption and achieving green building standards. Given the structural complexity during the secondary use of existing buildings, site constraints, and preservation requirements, it is essential to integrate AI-driven optimization design, precise BIM-based modeling, and modular pretreatment technologies to formulate a strategic approach for rapid, damage-free reconstruction.

Modular construction involves decomposing building elements into standardized components or partial components, which are then managed and designed through digital models for precise component management, node design, and functional integration. Artificial intelligence can efficiently combine and optimize these modules, adjusting their size and connection forms in real-time based on the building's spatial layout and structural characteristics to enhance compatibility. Components can be mechanized during production, prefabricated, and transported to the site for rapid assembly, reducing construction time and minimizing the structural load on existing buildings. The system's performance can be expressed using the following module productivity formula:

$$Meff = \frac{Q \cdot S}{T+E} \tag{4}$$

Among them, M_{eff} represents the efficiency of module design and production, Q represents the degree of standardization of unit component design, S represents the assembly efficiency of the construction site, T represents the factory production time, and E represents the resources invested in transportation and assembly time.

5. Conclusion

The integration of artificial intelligence (AI) and Building Information Modeling (BIM) offers an efficient, intelligent, and resource-efficient approach to the adaptive reuse of historical buildings. This synergy enables comprehensive information support across various stages, including planning, construction, environmental analysis, and data integration. As technological advancements continue to evolve, the deepening integration of AI and BIM will further facilitate the seamless convergence of historical building preservation with modern functionality, playing a pivotal role in the sustainable development of rural revitalization.

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