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Use of BIM Technologies In Managing the Refurbishment of Residential and Commercial Properties

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Abstract: This article examines the potential of building information modeling (BIM) technologies in managing the reconstruction of residential and commercial properties, with a focus on cultural heritage preservation. The theoretical foundation includes an analysis of BIM technologies, generative design, and digital twins, as well as their integration for precise digital modeling, optimization of design solutions, and dynamic monitoring of operational parameters. A case study of the reconstruction of the former Santa Barbara cinema in Paternò demonstrates that the comprehensive application of these technologies significantly enhances design accuracy, improves energy efficiency, optimizes operational performance, and preserves the historical integrity of the structure. The findings confirm the hypothesis that integrating BIM with modern digital tools is an effective approach for managing reconstruction projects, providing substantial practical value for professionals in architecture, construction, and real estate management. The article also presents recommendations for further research aimed at improving generative design algorithms and enhancing the reliability of digital twins. The topic of BIM technology application in reconstruction management will be of interest to leading specialists in architectural and engineering design, strategic construction project management, and urban studies, as it offers an innovative methodological framework for integrating digital tools to optimize reconstruction processes, minimize technological risks, and ensure the sustainability of urban infrastructure.

Keywords: BIM, generative design, digital twin, building reconstruction, cultural heritage preservation, automation, IoT, energy efficiency.

Introduction: The reconstruction of residential and commercial properties is one of the key challenges in the modern construction industry, driven by the need to enhance energy efficiency, ensure urban sustainability, and preserve cultural heritage. Traditional methods of design and reconstruction management often fail to account for the complex interplay of factors such as structural integrity, operational performance, and historical value. In this context, the adoption of digital technologies has become essential. Building Information Modeling (BIM) plays a particularly significant role, as it enables the creation of comprehensive digital models throughout the entire lifecycle of a building, significantly improving the accuracy of design solutions and enhancing coordination among all project participants. Additionally, modern generative design methodologies and the use of digital twins, combined with Internet of Things (IoT) systems, open new possibilities for dynamic monitoring and management of reconstructed buildings.

Azhar S. and Brown J. [2] highlight BIM's potential as a tool for conducting detailed environmental assessments and optimizing building lifecycles. The study by Cascone S., Parisi G., and Caponetto R. [1] also presents an example of BIM application in the design of the Santa Barbara cinema. Similarly, Pereira V. et al. [6] conduct a systematic and scientometric analysis of BIM implementation for improving energy efficiency, emphasizing the need for an integrated approach to incorporating digital tools into the management of building performance.

Furthermore, Ajtayné Károlyfi K. and Szép J. [3] propose a parametric BIM framework for conceptual structural design aimed at evaluating embodied environmental impact, addressing an existing research gap in early-stage design with a focus on sustainability metrics. Liberotti R. and Gusella V. [4] demonstrate how parametric modeling can be integrated into design processes to support sustainable restoration of historic buildings. Meanwhile, Gigliarelli E., Calcerano F., and Cessari L. [5] combine heritage BIM, numerical modeling, and decision-support systems to optimize renovation processes. However, their research often lacks a comprehensive approach to reconstruction management during project implementation, highlighting a gap in the integration of theoretical models with practical solutions.

Sun Y. and Dogan T. [7] propose generative methods for rapidly exploring solution spaces in urban design, significantly accelerating the development of optimal urban planning concepts. Similarly, Qian C., Tan R. K., and Ye W. [8] employ adaptive algorithms based on artificial neural networks for generative layout design, while Ghannad P. and Lee Y. C. [9] present an automated approach to modular residential design using configuration algorithms and generative adversarial networks (CoGAN). These studies emphasize the drive toward automation and adaptability in design solutions; however, they often do not account for the specific requirements of reconstructing buildings with historical or cultural significance.

Summarizing the analysis, the identified research gap lies in the insufficient integration of BIM technologies with modern generative methods and artificial intelligence algorithms for comprehensive reconstruction management. Such integration should simultaneously meet the requirements of energy efficiency, sustainable development, and cultural heritage preservation.

The objective of this study is to analyze the potential of BIM technologies in managing the reconstruction of residential and commercial properties. This includes the integration of generative design and digital twins to enhance the accuracy of design solutions, improve operational performance, and ensure compliance with modern energy efficiency and sustainability standards.

The study's scientific novelty is determined by the synthesis of research perspectives on BIM technologies with generative design methods and environmental assessments.

The research hypothesis suggests that the implementation of BIM technologies combined with generative design methods and digital twins significantly improves the building reconstruction process. This improvement is reflected in enhanced modeling accuracy, optimized engineering solutions, reduced energy consumption, improved user comfort, and the preservation of the cultural identity of historic structures.

The methodological framework of this study is based on a comparative analysis of scientific articles by other researchers.

Theoretical framework: BIM, generative design, and digital twins in building reconstruction

In modern conditions, the reconstruction of both residential and commercial buildings requires a comprehensive approach that not only restores the physical structure but also ensures high energy efficiency, optimizes operational performance, and preserves cultural heritage. In this context, the application of digital technologies has become an integral part of management processes. This section provides a theoretical foundation for three key areas: Building Information Modeling (BIM), generative design, and digital twins, which enable the integration of these approaches into comprehensive reconstruction management.

Building Information Modeling (BIM) is the process of creating and managing a digital representation of a building's physical and functional characteristics throughout its entire lifecycle. The use of BIM enables the development of detailed parametric models that integrate architectural, structural, and engineering data, significantly improving design accuracy and interdisciplinary collaboration. The main advantages of BIM include:

● Creation of a unified information model: Consolidating data from various specialists (architects, engineers, contractors) within a single digital environment helps minimize errors and improve the quality of the final project.

● Parametric modeling: The ability to dynamically adjust model parameters allows for rapid responses to changes in project requirements and reconstruction conditions.

● Compliance with standards and data exchange: The use of IFC formats and relevant standards (such as UNI 11337) ensures compatibility and transparency in project documentation.

Generative design relies on algorithmic methods and computational models to automate the creation of multiple design options based on predefined parameters and constraints. This method enables iterative modeling, which is particularly important in the reconstruction of historically significant buildings, where both structural constraints and aesthetic considerations must be taken into account [8]. The key capabilities of generative design include:

● Iterative analysis of design solutions: Automatic generation and evaluation of multiple options allow for the selection of the most optimal solution based on spatial efficiency, structural stability, and energy performance.

● Parameter optimization: Algorithms can consider numerous variables, ensuring the adaptation of the model to the specific requirements of reconstruction.

● Reduction of development time: Automation significantly reduces the time required compared to traditional manual design methods.

A digital twin is a virtual representation of a physical object that synchronizes with the real state of a building through data collected from Internet of Things (IoT) sensors. This technology enables real-time monitoring of operational performance, failure prediction, and optimization of engineering system functionality [7, 8].

The comprehensive application of these technologies creates a synergistic effect, improving the quality of reconstruction projects by integrating the precision of digital modeling, the flexibility of algorithmic solutions, and real-time monitoring of operational parameters. The integration of BIM with generative design facilitates the creation of optimized design solutions, which can then be dynamically adjusted based on data received through the digital twin [2, 5].

For a clearer understanding of the key characteristics and interrelation of these technologies, the table below is presented.

Table 1. Comparative characteristics of BIM, generative design, and digital twins (compiled by the author based on the analysis of the source [1]).

Technology	Key Capabilities	Advantages	Limitations
BIM	• Creation of detailed digital models • Integration of architectural, structural, and engineering data • Support for parametric modeling	• Improved design accuracy • Enhanced interdisciplinary collaboration • Reduction of errors and project execution	• High qualification requirements for specialists • Dependency on specific software

		time	
Generative Design	• Automated generation of multiple design variants • Iterative optimization based on predefined criteria (spatial efficiency, structural stability, etc.)	• Rapid creation and evaluation of design solutions • Flexible model adaptation • Reduced development time	• Requires significant computational resources • Complexity in setting up algorithms and parameters when multiple constraints exist
Digital Twins	• Virtual representation of an object synchronized with real-world conditions • Real-time monitoring of operational performance	• Predictive maintenance and failure prevention • Dynamic management of engineering systems • Improved user comfort	• Dependence on the accuracy and stability of IoT sensors • Need for a reliable connection to information systems

The combined use of these technologies enables detailed digital modeling, flexible optimization of design solutions, and dynamic monitoring of operational parameters, which is particularly important for projects involving historically and culturally significant buildings. This approach lays the foundation for creating sustainable, energy-efficient, and functional reconstructed spaces that meet modern standards in construction and real estate management.

Methodological approach to reconstruction management using BIM technologies

The methodology for implementing reconstruction projects using BIM technologies includes the following key stages:

- BIM modeling. At the initial stage, an integrated digital model of the building is created, encompassing architectural, structural, and engineering systems. The use of specialized software (such as Autodesk Revit) enables the development of parametric families, ensuring dynamic updates to the model when design changes are made. The application of data exchange standards (such as the IFC format) and national requirements (e.g., UNI 11337) guarantees high accuracy and interoperability of the model among different project stakeholders [6, 9].
- Implementation of generative design. The creation of multiple alternative design solutions is carried out using visual programming algorithms (such as Dynamo). This stage allows for the automatic generation and evaluation of various options based on predefined criteria, including spatial efficiency, structural stability, and energy performance. Generative design significantly accelerates the optimization process and reduces the time required compared to traditional manual design methods.
- Integration of monitoring and management systems. The next stage involves the deployment of monitoring and control systems based on data received from Internet of Things (IoT) sensors, as well as the use of digital twins. Real-time data is integrated into the BIM model, allowing for automatic adjustments to engineering systems (heating, ventilation, air conditioning, lighting, and shading) and facilitating preventive maintenance. This approach contributes to reduced energy consumption, improved user comfort, and the timely resolution of system failures.
- Use of a common digital platform (CDE). To ensure efficient information exchange between architects, engineers, contractors, and clients, a unified digital platform is implemented. This enables real-time updates to project documentation, minimizes errors, and facilitates the coordination of design changes, which is particularly crucial for the reconstruction of historically significant buildings [1, 8].

For a more in-depth understanding of the interrelations between the stages of this methodology, Table 2 is presented below.

Table 2. The stages of the methodological approach to reconstruction management using BIM technologies Compiled by the author based on the analysis of the source [1].

Stage	Description	Tools/Technologies	Advantages	Limitations
BIM Modeling	Creation of a detailed, integrated digital model of the object, including architectural, structural, and engineering components	Autodesk Revit, IFC formats, parametric families	High modeling accuracy, real-time data updates, compliance with international standards	Requires specialized skills, significant time and financial investment for software implementation
Generative Design	Iterative creation of multiple design options based on visual programming algorithms, optimized according to predefined criteria	Dynamo, optimization algorithms, computational platforms	Rapid generation of alternative solutions, adaptive optimization, reduced development time	High computational resource requirements, need for precise algorithm configuration
Integration of Automated Management Systems	Implementation of monitoring and management systems using IoT and digital twins integrated into the BIM model	IoT sensors, digital twins, automation scenarios (based on Dynamo)	Real-time monitoring of operational parameters, reduced energy consumption, preventive maintenance	Dependence on data quality, integration complexities with existing systems
Coordination and Collaboration	Organization of joint work among all project participants through a unified digital platform, real-time information exchange	CDE platforms, cloud services, project management systems	Improved communication, reduced errors, faster decision-making	Challenges in standardization alignment, need for continuous interaction among participants

The comprehensive integration of these stages enables the creation of a flexible and adaptive reconstruction management system. The developed BIM model serves as a foundation for subsequent generative design, where iterative optimization produces solutions that meet the functional and energy requirements of reconstruction. The implementation of automated management systems integrated with digital twins ensures continuous monitoring of the building’s operational characteristics and allows for prompt responses to changes in external and internal conditions. Overall, coordination and information exchange among project participants contribute to risk reduction, lower time and financial costs, and improved quality in reconstruction projects.

Case study: application of BIM technologies in reconstruction using a specific object

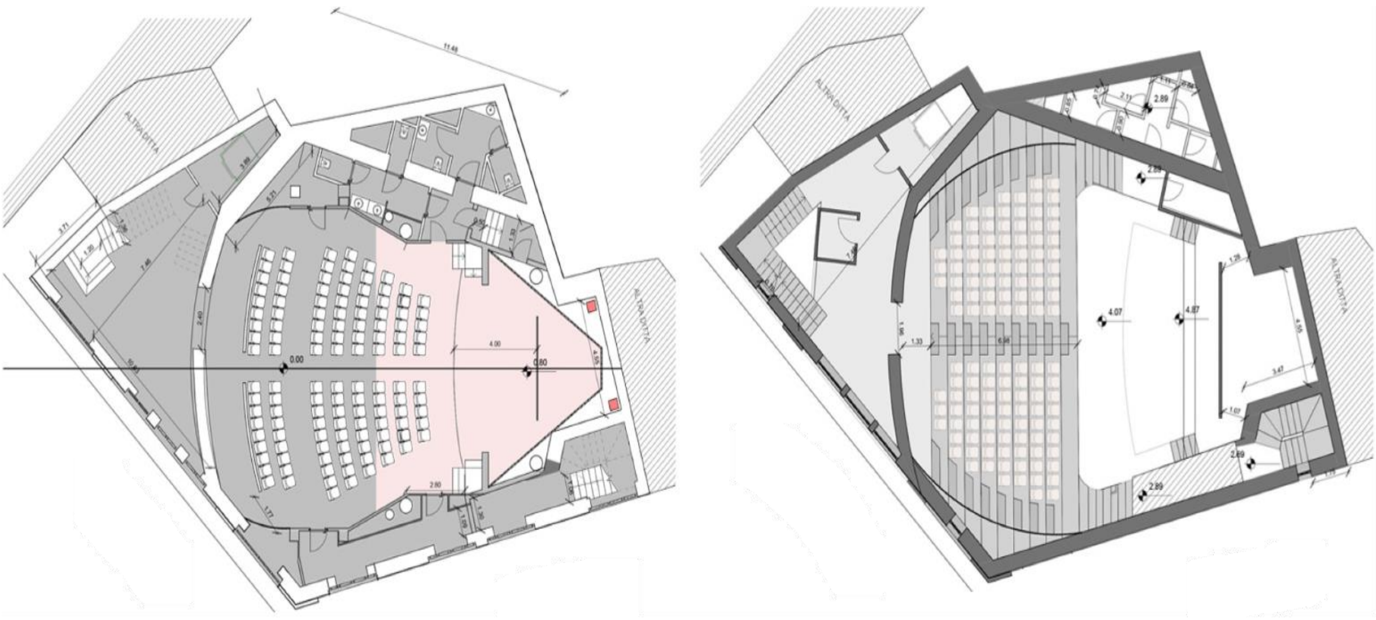
This section provides a detailed analysis of the application of BIM technologies in the reconstruction process of a specific site—the former Santa Barbara cinema in Paternò. This building, possessing significant historical and cultural value, serves as a unique example of combining heritage preservation with the implementation of modern digital technologies to optimize design solutions and improve the operational characteristics of the reconstructed structure.

The former Santa Barbara cinema was established in the early 20th century and for many years served as a cultural hub for the city, hosting film screenings, theatrical performances, and public events. Over time, due to changing socio-economic conditions and the emergence of alternative entertainment formats, the building fell into decline, leading to the deterioration of its architectural appearance and functional characteristics.

The primary objective of the cinema's reconstruction is to preserve the building’s historical identity while modernizing its engineering systems and enhancing operational performance. To achieve this goal, the project defined the following key tasks:

- Preservation of historical appearance. Restoration and conservation of original architectural elements to maintain the cultural identity of the structure.
- Structural reinforcement. Implementation of repair work aimed at restoring load-bearing elements and eliminating structural defects.
- Modernization of engineering systems. Replacement of outdated heating, ventilation, air conditioning, electrical, and plumbing systems with the integration of energy-efficient technologies.
- Integration of automated management systems. Deployment of a digital twin and IoT sensors to enable real-time monitoring and management of operational parameters [1, 6].

During the design phase, a detailed BIM model of the building was created using Autodesk Revit, incorporating architectural, structural, and engineering data. The use of parametric modeling allowed for the consideration of historical construction features and the preservation of original elements while integrating modern engineering solutions (Fig. 1).



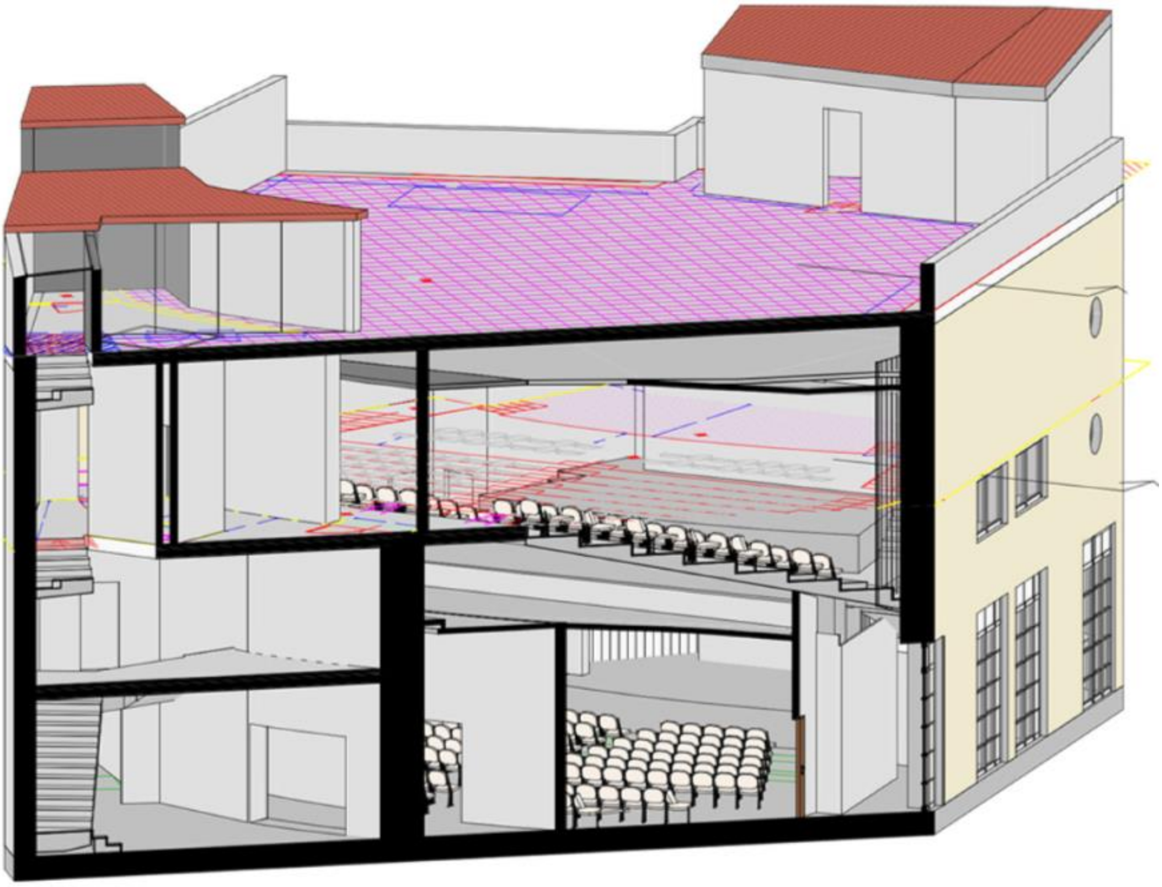


Fig. 1. Current state of the "Ex Cinema Santa Barbara" derived from the BIM model [1]

The iterative process of creating alternative options made it possible to evaluate design solutions based on criteria such as structural stability, energy efficiency, and compliance with aesthetic requirements, ensuring an optimal balance between preserving historical appearance and meeting modern functional needs [4, 5].

One of the key stages of the project was the implementation of automated management systems based on the integration of digital twins and IoT sensors [1, 3].

For a deeper understanding of the project's implementation stages, Table 3 presents the main activities, applied technologies, and achieved results.

Table 3. The main stages and results of the reconstruction of the former cinema "Santa Barbara" Compiled by the author based on the analysis of the source [1].

Project Stage	Main Activities	Applied Technologies	Key Results
Historical Assessment and Diagnostics	Comprehensive diagnostics, including laser scanning, non-destructive testing, evaluation of structural and engineering system conditions, and analysis of historical element preservation	Laser scanning, HBIM	Identification of structural defects, façade damage, and engineering system deterioration, defining restoration directions
BIM	Creation of a detailed BIM model of the	Autodesk	Development of an

Modeling	building, incorporating architectural, structural, and engineering components, using parametric families and data exchange standards (IFC)	Revit, IFC, parametric families	accurate digital model providing a foundation for design optimization and project coordination
Generative Design	Automated generation of alternative reconstruction solutions based on energy efficiency, structural stability, and historical preservation criteria	Dynamo, optimization algorithms	Identification of optimal design solutions that maintain historical integrity while incorporating modern engineering systems
Integration of Automated Systems	Implementation of IoT sensors and a digital twin for monitoring and managing HVAC, lighting, and shading systems; development of automation scenarios for parameter adjustments	IoT, digital twin, automation scenarios (Dynamo)	Real-time monitoring, reduced energy consumption, and enhanced user comfort
Coordination and Project Execution	Establishment of a unified digital platform for data exchange among project participants, real-time updates of the BIM model, and coordination of design changes	CDE platforms, cloud services	Improved communication, reduced errors, and timely decision-making

The implementation of the reconstruction project for the former Santa Barbara cinema demonstrated the high efficiency of applying BIM technologies in managing the restoration of historically significant structures. The key achievements of the project include:

- Increased accuracy of design solutions. The developed BIM model enabled a detailed analysis of the building's structural and engineering features, minimizing errors and facilitating real-time modifications.
- Optimization of engineering systems. Iterative generative design contributed to selecting optimal solutions that balanced modern energy efficiency requirements with the preservation of the building's historical appearance.
- Dynamic management of operational parameters. The integration of digital twins and IoT sensors allowed real-time monitoring, automated control of engineering systems, and reduced energy consumption, improving overall user comfort.
- Improved interdisciplinary collaboration. A unified digital platform for project coordination ensured timely information exchange, significantly reducing risks and project implementation time.

This case serves as a clear example of successfully combining cultural heritage preservation with the adoption of modern engineering solutions, providing significant practical value for future reconstruction initiatives.

CONCLUSION

The application of BIM technologies, complemented by generative design methods and the integration of digital twins, enables the development of an efficient building reconstruction management system that meets modern energy efficiency requirements while preserving cultural heritage. The case study of the reconstruction of the former Santa Barbara cinema in Paternò demonstrated that creating a detailed BIM model, automatically generating optimal design solutions, and implementing real-time monitoring systems significantly enhance the accuracy of design decisions and the operational performance of the building.

The results confirm the proposed hypothesis that the comprehensive application of modern digital technologies serves as a powerful tool for managing reconstruction projects, contributing not only to the optimization of engineering solutions but also to the preservation of the historical identity of buildings. This study provides practical recommendations for professionals in architecture and construction, as well as outlines promising directions for further research. These include the advancement of generative design algorithms, improving the reliability of digital twins, and integrating artificial intelligence methods for predicting the operational characteristics of buildings.

This research contributes to the development of digital technologies in the construction industry and confirms their significance for the comprehensive reconstruction of buildings while preserving cultural heritage.

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