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Orginal Article

Directions for the formation of «City Intelligent models» using artificial intelligence for the post-war reconstruction of historical buildings

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Abstract: Addressing the limitations of current digital simulations for historical buildings, this paper suggests a specific technical task for the development of a simulation analysis platform based on City Intelligent Modelling (CIM). The objective is to establish a systematic approach for digitally maintaining and managing historical dwellings. The technique presented in this paper focuses on constructing sophisticated parametric models that offer numerous modelling benefits, allowing for convenient updates to the Historic Building Information Modelling (HBIM). The text discusses various applications and integrations of Building Information Modelling (BIM) in urban planning, construction projects, and historic building renovations. CIM is presented as a comprehensive digital platform that visually represents cities, aiding urban planners in decision-making for sustainable development. The text delves into the use of advanced analytical tools within CIM for diverse data analysis, predictive modelling, and simulation to forecast trends. The focus shifts to the evolution of BIM, progressing from 3D to 5D models, influencing construction project management and cost estimation. The integration of BIM in historic building projects is explored, emphasising the challenges and proposing innovative solutions using HBIM. The paper also introduces the concept of Infrastructural Building Information Modelling (InfraBIM) in construction management, incorporating Virtual and Augmented Reality for enhanced visualisation.

Keywords: CIM, post-war reconstruction, artificial intelligence, historical buildings, BIM

1. Introduction

War constantly puts significant pressure on a country, serving as an indicator of the effectiveness of its state institutions in ensuring security. Moreover, war serves as a catalyst for the development of new, pragmatic strategies aimed at protecting the nation and its citizens from the ravages of war. Many of these innovative solutions will take shape during the renovation phase. However, in this context, there is still a zone of development and room for more. It is already worth thinking about the programme of rebuilding Ukraine after the war, considering all the previous plans for the implementation of the principles of sustainable development in Ukraine. The speed imperative at an early stage of reconstruction affects the management organisation and resource allocation methods. The basis of this transformation is the principle of post-war reconstruction: "to rebuild better than it was".

Historic buildings should be considered as an integral component of the sociocultural entity, encompassing the values and communities that reside in or use them, in addition to the architectural structure consisting of physical elements such as walls, floors, ceilings, windows, doors, and stairs. These buildings undergo transformations influenced by user actions and conservation efforts [6]. Research shows that an original appearance not only enhances the visual appeal of a building but also contributes to the tranquillity of the environment and the overall satisfaction of the building's occupants [6].

Historic buildings are related to many challenges, including subpar comfort, safety deficiencies, and excessive energy consumption. One of the main objectives of this research is to improve the energy efficiency of a building by exploring alternative architectural and technical solutions in the case of the inevitable need to retrofit historic buildings most vulnerable during war damage. The aim is to seamlessly integrate these solutions into the modernisation process. As a result, strategies are formulated, and various BIM software packages are used to model the energy consumption of the building. This approach leads to a reduction in energy consumption and extends the life of the building, which is achieved by selecting an appropriate retrofit method. The effectiveness of BIM technologies is evident in their ability to meet modern requirements, reducing both design time and cost. Moreover, they enable design optimisation by applying lessons learned from the design of new structures. In addition, BIM provides indispensable information to support an investment project throughout its lifecycle [1]. BIM is not only a technological tool but also a collaborative methodology that can potentially improve project quality, as shown in Table 1 [5].

Table 1. The potential benefits of BIM integration in the City Intelligent Modelling

Benefits of BIM adoption			
Process efficiency	Communication effectiveness	Efficiency of project progress monitoring	Improved construction planning
BIM's ability to unite all stakeholders involved in a project, promoting the exchange of information, and supporting decision-making from project initiation to completion	The capability of BIM to offer a more streamlined communication system and facilitate smoother interactions among involved parties.	BIM's ability to enable direct visual tracking of completed tasks and the outstanding work that needs to be done	BIM streamlines the project's planning phase by introducing the concept of visualising project activities and execution

City Intelligent Modelling (CIM) involves the creation of an extensive information model of a digital city, considering data about historical buildings. This is achieved by combining a wide range of data sources using technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS), Internet of Things (IoT), and related tools. This innovative approach holds significant promise for effectively managing and upgrading reconstruction areas. This paper outlines a new version of the automated construction management system capable of efficiently maintaining historical residential buildings with minimal intrusion while ensuring precision and productivity. A novel concept, "Community Intelligent Modelling," is introduced, highlighting the platform's suitability for reconstructing residential structures [10]. Moreover, this simulation platform can serve as a crucial link between buildings and digital environmental analysis software, further enhancing the optimisation of residential areas.

In the evolving landscape of building industrialisation, Building Information Modelling (BIM) has become a widespread tool used throughout the building management lifecycle. BIM is valued for its ability to gather and retain static data and its visual, tangible, controllable, manageable, simulated, and predictable features. This makes it highly applicable in the management of residential buildings. However, there are areas for improvement in monitoring time-series data with BIM. To address these challenges, researchers are using Internet of Things (IoT) technologies, such as sensors and radio frequency identification (RFID), to monitor the microenvironment and dwelling components, effectively mitigating these limitations.

In addition, Geographic Information System (GIS), which encompasses meteorological and ecosystem data, plays a crucial role in macro-information management. Time series data can be collected and stored in a Building Information Modelling (BIM) platform, which allows visualisation, analysis, and modification of models using techniques such as finite element analysis [12].

City Intelligent Modelling (CIM) incorporates geospatial data to represent the physical layout of a city, including structures, roads, topography, and infrastructure. Geographic Information Systems (GIS) prove indispensable for organising and visualising this vast data set, including data on historic buildings. Monitoring data help to refine boundary conditions for analytical tools such as finite element analysis and computational fluid dynamics (CFD), ultimately facilitating environmental modelling and prediction, even with limited data.

In addition, research is underway to integrate BIM, IoT, and GIS technologies to provide intelligent management throughout the building lifecycle. The integration of IoT devices and sensors within CIM greatly enhances data collection capabilities and enables real-time monitoring of urban systems. This data contributes to the accuracy of the model and allows it to be dynamically adjusted to real-world conditions.

In the design phase, BIM-GIS-IoT integration is based on the Precinct Information Modelling (PIM) concept, which serves as a guide for architects and planners to smoothly transition from BIM to broader City Intelligent Modelling (CIM). During the construction phase, the integration of BIM, GIS, and IoT technologies serves as a complement to the intelligent construction site system [11].

Nevertheless, there are numerous incompatibilities between BIM and GIS systems across various dimensions, as highlighted in [7]. BIM places its emphasis on the indoor environment, concentrating on intricate details and primarily addressing buildings. In contrast, GIS is primarily concerned with the outdoor environment, lacking the same level of detail and relying on information related to existing objects with geospatial references. BIM tends to focus on buildings and their attributes, whereas GIS encompasses entire cities and urban areas, maintaining a predominantly 2D nature compared to the 3D orientation of BIM.it is worth noting that for traditional rural housing, most research still relies on individual technologies to monitor and analise specific influencing factors. Few studies focus on the holistic maintenance and management of the entire housing estate and its immediate surroundings. One notable gap in existing research is the lack of reliable connections and linkages between different data sources. This limitation may compromise the scientific rigour and applicability of the results, which often have a narrow focus on single aspects [2]. CIM, which functions as a multi-source heterogeneous data model based on BIM, aims to create a three-dimensional digital city information system. This is achieved by integrating data from multidimensional information models and city infrastructure. Like BIM, CIM has such characteristics as visualisation, interactivity, and predictive capabilities.

The aim of the study is to create a technical task for a CIM system that not only efficiently manages historical residential buildings but also serves as a dynamic platform for data collection, real-time monitoring, and informed decision-making throughout the building lifecycle. This initiative seeks to bridge the gap in existing research, establishing reliable connections between various data sources and promoting a holistic approach to the maintenance and management of rural housing estates and their surroundings, ultimately contributing to the resilience and well-being of the affected communities.

2. Methodology

2.1. CIM and dimensional modelling

City Intelligent Modelling (CIM) is a comprehensive and advanced approach using digital technologies to visually represent a city or urban area. This model integrates various aspects of the city, including its physical, social, economic, and environmental dimensions, into a cohesive and dynamic digital platform. The goal is to provide a holistic and interactive city simulation, aiding urban planners, policymakers, and stakeholders in decision-making processes and sustainable urban development. CIM facilitates the integration of smart infrastructure and services, such as smart energy grids, intelligent transportation systems, and waste management solutions, ensuring efficient resource utilisation and improved quality of life for city residents.

Complex intellectual models refer to advanced frameworks, algorithms, or systems designed to replicate, simulate, or model various aspects of human intelligence and decision-making. These models often encompass a combination of artificial intelligence (AI), machine learning (ML), deep learning, and other computational techniques to comprehend, learn, reason, and make informed decisions. They aim to achieve a deeper understanding and representation of complex phenomena, solve intricate problems, and support advanced applications across various domains.

Developing complex intellectual models involves creating sophisticated frameworks, algorithms, or systems that replicate or simulate aspects of human intelligence or decision-making. These models often draw upon artificial intelligence (AI), machine learning (ML), deep learning, and related technologies. They hold great potential for driving innovation, automation, and decision-making in a wide range of real-world applications [13]. Advanced analytical tools within CIM enable the analysis of diverse data sets, such as demographics, traffic patterns, energy consumption, and environmental factors. Predictive modelling and simulation can forecast trends and evaluate potential outcomes of reconstruction projects.

The comprehensive approach of CIM, utilizing digital technologies to visually represent a city, integrates various dimensions, including physical, social, economic, and environmental aspects. This platform aids urban planners, policymakers, and stakeholders in decision-making processes for sustainable urban development. CIM facilitates the integration of smart infrastructure and services, such as smart energy grids, intelligent transportation systems, and waste management solutions. This not only ensures efficient resource utilisation but also contributes to an improved quality of life for city residents. Advanced analytical tools within CIM enable the analysis of diverse data sets, allowing for predictive modelling and simulation to forecast trends and evaluate potential outcomes of reconstruction projects.

In the initial stages of Construction Projects (CPs), 3D BIM provides a powerful tool for visualising the design. The 3D model encompasses data regarding the geometry of its elements. Integrating the BIM concept into this model facilitates the generation of an information data set and current documentation, valuable for future maintenance and restoration efforts on the building. Moreover, this model holds potential for diverse analyses in the future, such as structural stability assessments, particularly in consideration of the nearby railway line [14]. It offers a clear and concise representation of building models in three dimensions, allowing stakeholders to better understand the design. Additionally, 3D models serve the crucial purpose of clash detection, identifying and resolving interferences or conflicts between various building components before reconstruction begins [3]. When time is integrated into 3D BIM models, it transforms into 4D BIM, enabling time simulation of CPs (Fig. 1). This dynamic visualisation offers a comprehensive understanding of the project's progress over time. The integration of 4D represents a natural progression. This advancement is facilitated by the presence of specific information, enabling the formulation of a construction schedule. Essentially, it involves establishing the sequential order for the gradual assembly of building elements in the real-world construction process [14]. The aim of the 4D BIM model is to scrutinise and validate the construction work plan, identifying potential discrepancies and contradictions. During this phase, various data points are gathered, including projected deadlines, activity sequences, critical activity definitions, equipment specifications, work teams, and their employment arrangements. Additionally, relevant documents such as site logistics studies and architectural blueprints are acquired. The site logistics study examines crucial aspects, including material storage determination, equipment and machinery selection, construction work approach, integration of communal areas, and transportation logistics. This analysis facilitates the identification and characterisation of the forthcoming site planning process, enabling the formulation of an enhanced process model that can be replicated across diverse construction projects [9]. The use of 4D models allows for fine-tuning of the project schedule by synchronising daily resource requirements, including equipment, labour, materials, and time. This optimisation is a fundamental aspect of effective project management and on-time delivery. When cost information is incorporated into a 4D model, it transforms into a 5D BIM model, providing a transparent, accurate, and quick assessment of the various costs associated with construction projects (CPs). This comprehensive financial perspective of a project helps to find real cost and time savings, especially given the expanded scope of work for the renovation of historic buildings and the correspondingly increased scope of work. The 5D BIM model simplifies the process of assessing changes and irregularities in a project, ensuring that they are in line with budgetary constraints and cost-saving strategies [3].

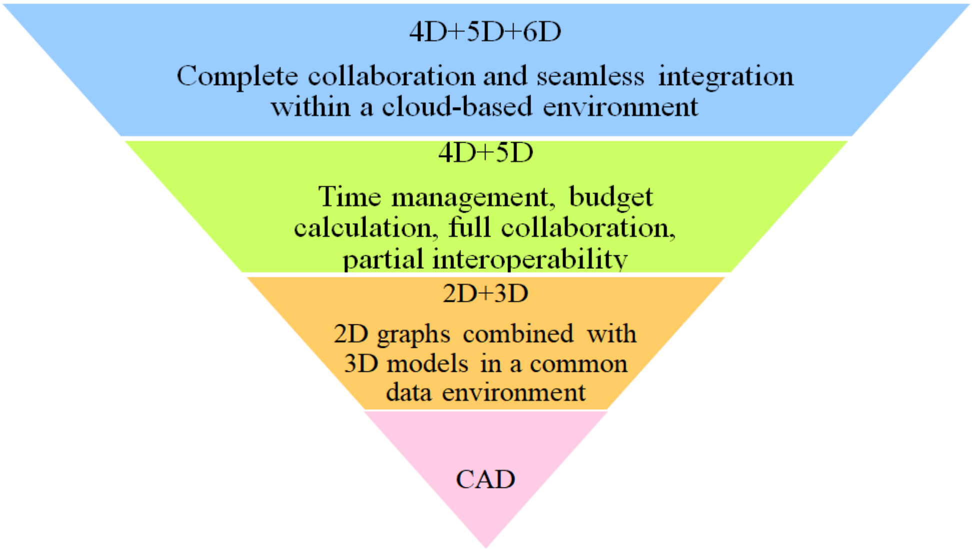

Fig. 1. BIM dimension, source: own study based on [3]

In the traditional approach to managing schedules in construction projects (CPs), work environments play a significant role in shaping the schedules, often leading to disruptions in the construction processes due to subjective factors. However, the introduction of 5D Building Information Modelling (BIM) has revolutionised the management of construction operations from start to finish, optimising processes and simplifying them.

With 5D BIM models, every construction phase can be meticulously planned and executed. These models capture crucial information, including the initiation and completion of tasks, planned schedules, and actual execution times. This data is invaluable for auditing planned schedules and providing real-time information to stakeholders. Moreover, any defects encountered during construction can be quickly identified and addressed.

A significant advantage of 5D BIM is its ability to seamlessly harmonise design and construction schedules. By integrating building models with the project schedule, the risk of potential delays is effectively reduced. Additionally, this integration provides the client with a complete and visual simulation of the entire construction process, allowing them to closely monitor the project's progress. The authors of this study see it as their task to develop specifications for the integration of BIM models into CIM technologies for software development teams.

Similarly, BIM provides clear, concise, and reliable cost estimation through automated scoping based on BIM models. This, in turn, speeds up the process of providing cost feedback on any design changes in building construction. Building Informatics (BI) BIM technology plays a key role in the creation and visualisation of building models, providing an accurate perspective of design changes for systematic construction project management (CPM) [3].

2.2. HBIM adaptations

The necessity to propose a new approach arose due to challenges faced in developing Historic Building Information Modelling (HBIM) within resource constraints. This approach offers a cost-effective, user-friendly, and efficient solution while considering all limitations and working within available resources. It presents a streamlined method utilising images. Previous methods that incorporated images for digitising historic buildings typically required on-site image capture, followed by intricate processes before commencing HBIM development. In contrast, the method outlined in this paper focuses on selecting a suitable image that requires minimal processing to develop the HBIM for the facade of historic buildings. The proposed method encompasses three phases: initiation, modelling, and validation phases, each essential for developing HBIM (Fig. 2).

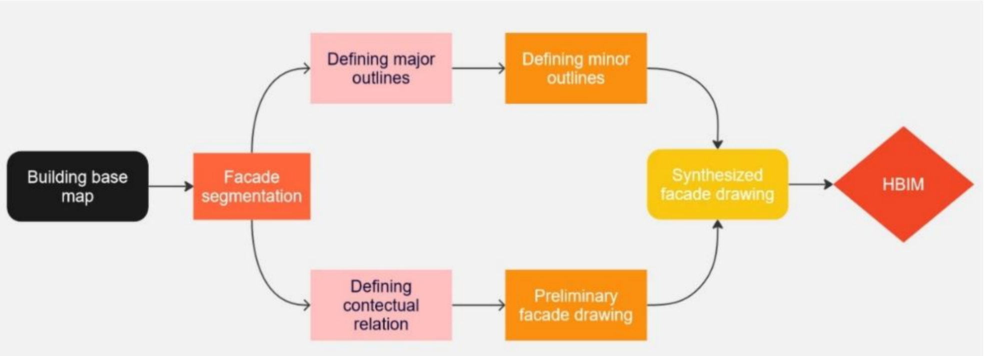

Fig. 2. Methodology of HBIM development, source: own study based on [17]

The following subsections will elucidate the approaches recommended within each key step [4]. After developing a synthesised façade drawing using either of the proposed approaches, parametric families can be created.

In scenarios involving the restoration of lost or damaged heritage structures, this study proposes a method for generating Historic Building Information Modelling (HBIM) within resource constraints. This approach requires making assumptions, utilising expertise, and informed decision-making to bridge the information gap. Beliefs play a crucial role in determining values like depth, and they are based on construction techniques, literature review, proportions, personal judgement, informed decisions, and other justifiable rationales. These assumptions are typically integrated into easily modifiable parametric models, minimising the impact of any initial errors in the assumptions.

Integrating Building Information Modelling (BIM) technologies within Construction Management (CM) has revolutionised how projects are planned, executed, and managed. Specifically, in the realm of infrastructure, this integration, often referred to as Infrastructural Building Information Modelling (InfraBIM), has emerged as a powerful decision support tool, leveraging a comprehensive repository of CM-related data for enhanced project development and utilisation.

InfraBIM serves as a central hub for information digital modelling, seamlessly intertwining scheduling and cost management dimensions. Employing this methodology makes it possible to simulate various phases of construction projects, especially those involving complex underground structures like excavations. These simulations provide invaluable insights, generating budgeted costs and time schedules intricately linked to the BIM models. One of the primary advantages of this approach lies in the ability to continually update the model with diverse information throughout the design and construction phases. This dynamic updating ensures that the 3D model, timeline, and cost estimations stay accurate and aligned with the project's progress. Moreover, it preserves relationships and interconnections between model components and associated information on activities and costs.

Additionally, integrating Virtual and Augmented Reality (VAR) techniques into this workflow facilitates effective communication of design and construction schedules. VAR technologies provide an immersive visualisation experience, enabling stakeholders to perceive and understand infrastructure projects tangibly and interactively. This not only aids in better comprehension but also enhances decision-making processes and collaboration among project teams.

In summary, integrating InfraBIM and VAR technologies offers a transformative approach to construction management, enhancing project efficiency, accuracy, and stakeholder engagement. This integrated methodology is poised to shape the future of infrastructure development by harnessing the power of digital modelling and immersive visualisation.

2.3. BIM and GIS integration

The integration of BIM and GIS data involves several methods and levels. Firstly, BIM data can be converted to GIS by transforming the IFC model into a CityGML model, resulting in the storage and management of BIM and GIS data within the CityGML model. This approach is typically used for projects requiring detailed, building-specific information and can be applied to historic buildings. The second method involves the conversion of GIS data into BIM by converting the CityGML model into an IFC model. This results in the storage and management of BIM and GIS data according to the IFC model, which is often used when architects or building managers using BIM software require building environment data.

Another approach to data-level integration focuses on a unified data model that combines BIM and GIS data for specific analyses and applications. In addition, a unified building model has been proposed to facilitate the two-way conversion of BIM-GIS data. Moving to the application layer, application server-level integration involves implementing new IT tools and extending existing applications to work together with BIM and GIS data, typically through a GIS application server [8]. The second method of application-level integration involves integration through client applications, where BIM and GIS data are loaded and managed by independent client applications such as a GIS or facilities management (FM) system.

For landscape information modelling (LIM), spatial information is of paramount importance, especially for small architectural or landscape elements. Incorporating data from GIS databases into a LIM model greatly benefits designers and facilitates cooperation in landscape architecture, for example, with geologists, soil scientists, or urban planners. The presented example emphasises the ongoing need for research in the field of GIS-BIM integration, especially in terms of database approaches and collaborative applications for historic buildings.

3. Results

In contrast to previous image-based digitisation methods primarily used for visualisation, the technique presented in this paper focuses on constructing sophisticated parametric models. These versatile composite models, created through the integration of varied data sources using HBIM, GIS, and IoT, offer numerous modelling benefits.

Parametric families can serve as a valuable reference library for subsequent applications, case studies, and projects involving the construction of buildings with similar architectural styles. The final HBIM of a historic building is created by using a synthesised façade drawing as a foundation, combining it with parametric models representing walls, floors, and fundamental building structures, and then enhancing the model with detailed features and semantic data [3].

Each BIM process theme illustrated in Fig. 3 incorporates a multitude of codes, signifying essential design collaboration processes and future requirements within the BIM cloud-based ecosystem. The representation theme includes three common BIM processes: 3D/virtual modelling, documentation and presentation, and design analysis and creative, intuitive visualisation.

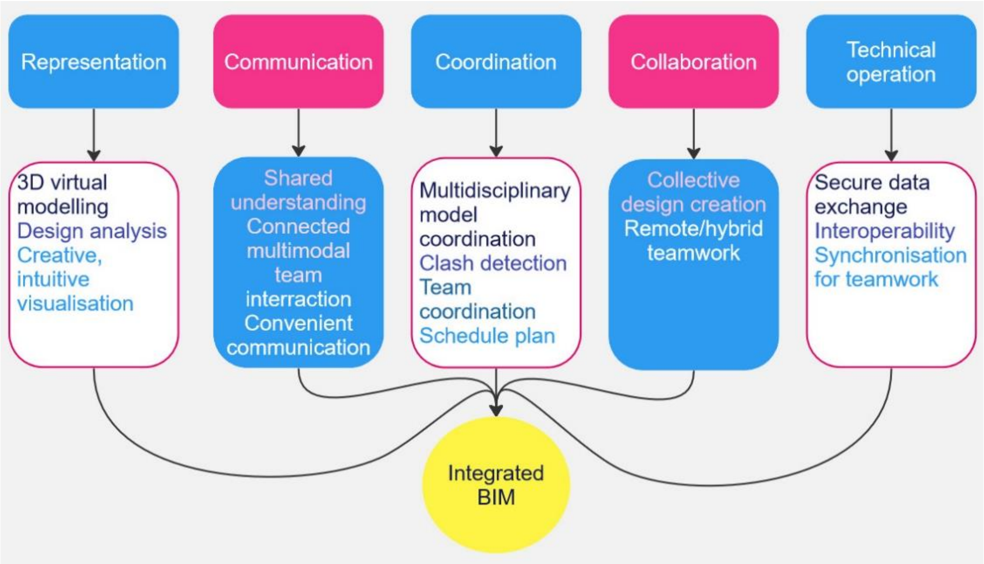

Fig. 3. An integrated model of BIM-enabled design collaboration processes, source: own study based on [16]

This model can be employed as an assessment framework for evaluating BIM practices, allowing for a sequential examination of each theme and process. Conversely, architectural firms or teams can iteratively apply specific themes to enhance BIM processes, thus meeting the requirements of interconnected themes.

While this integrated BIM process model can serve general purposes in terms of BIM adoption and implementation for architectural practice or education, it is crucial to recognise that all processes identified in this research are essential for the effective functioning of the BIM cloud ecosystem, particularly in supporting remote work. Consequently, this BIM process model also functions as a conceptual framework that provides the foundational principles for BIM collaboration, communication, and the management of diverse building information types, particularly within the context of remote teamwork.

In contrast to previous BIM frameworks, this model places significant emphasis on a sociotechnical perspective of BIM-enabled design collaboration in architecture. It can be effectively evaluated through a sequential process application, recognising the close interrelation of each theme with the others. While BIM practice has matured and achieved standardisation in numerous countries, it continues to introduce innovative design collaboration processes, such as "BIM and GIS".

The integration of HBIM applications within post-war reconstruction projects involving historical buildings offers a transformative approach. By swiftly converting disparate data into a real-time information platform and a robust decision-support system, HBIM significantly enhances the efficiency and accuracy of the reconstruction process. One of the key advantages is its ability to synchronise detailed data regarding building materials and their associated environmental impacts.

This synchronisation of data within HBIM empowers stakeholders to conduct thorough environmental analyses. It allows for a holistic understanding of the ecological footprint associated with various building materials and products. Consequently, informed decisions can be made during the selection of building materials, considering both historical authenticity and environmental sustainability.

By promoting a data-driven and environmentally conscious approach, HBIM applications contribute to a more responsible and forward-thinking methodology in post-war reconstruction. The careful selection of materials, mindful of both historical and environmental implications, not only preserves the historical fabric but also promotes sustainable practices, aligning with modern environmental standards and considerations. BIM tools allow designers to explore different design options at the initial stages of a project and quickly transfer design data to energy and simulation modelling tools for verification and analysis. This efficiency and speed are invaluable for ensuring a project meets performance and sustainability criteria. Conversely, owners can use HBIM tools to gain a comprehensive visual representation of their construction projects at various stages of renovation. These tools provide real-time insight into the development process. Historic building renovators also benefit significantly from HBIM models. These models are used to coordinate complex renovations of historic buildings, determine material quantities, and identify possible inconsistencies between equipment [15]. The result of a successful historic building renovation project includes improvements in many aspects, including design efficiency, resource management, and project coordination.

The authors of this study used the results obtained as the basis for developing technical specifications for a new version of the Ukrainian automated technology for managing a construction enterprise, “Building Manager”. The basis for developing these technical specifications is the integration of HBIM technologies and City Intelligent Modelling technology, based on the automated construction management technology “Building Manager”.

BIM integration facilitates optimal interaction between designers and builders, allowing them to work together cohesively to achieve a common goal. BIM is based on the fundamental principle of sharing and exchanging information between all project stakeholders throughout the life of a building. This approach is enabled by a platform-neutral file format that can be accessed and edited by any BIM or HBIM software, facilitating improved coordination and interoperability. In essence, it is linked to a centralised approach where all building-related data is stored. BIM also plays a key role in the decision-making process using versatile data processing and problem-solving techniques involving modelling, simulation, visualisation, and optimisation of alternatives. These capabilities also contribute to improving the accuracy and reliability of environmental analyses, which is essential for assessing uncertainty and sensitivity. The research encompasses the formulation of technical specifications for the development of an upgraded iteration of an automated construction management system. This system facilitates seamless interaction with software complexes rooted in the BIM model. A successful historic building renovation project yields a comprehensive set of improvements, as shown in Table 2. This emphasises the multifaceted benefits and improvements achieved by effectively integrating BIM directly into the renovation process.

Table 2. Expected results of the historic building reconstruction project

Area	Improvements
Operational Efficiency	Lower operating costs.
Conservation	Preservation of cultural heritage.
Energy Efficiency	Reduction of the building’s energy expenses.
Building Longevity	Extension of lifespan after reconstruction.
Investment Value	Maintenance of the project's investment value without traditional overruns.
Documentation and Maintenance	Updating of building drawings to facilitate future maintenance.
Indoor Environment Quality	Enhancement of the internal environment quality through reconstruction.
Environmental Sustainability	Reduction of carbon dioxide emissions from demolition and manufacturing processes, leading to resource savings.
Comfort and Well-being	Assurance of thermal and visual comfort for the building's residents.
Resident Health	Promoting the well-being and health of the residents.
Community Engagement and Utilization of Space	Enhancement of opportunities for social interaction and activity by utilizing previously unused areas of the building.

4. Conclusions

This paper identifies and addresses existing limitations within current digital simulations tailored for historical buildings. The proposed solution advocates the creation of a simulation analysis platform based on City Intelligent Modelling (CIM), presenting a clear technical task to achieve this objective. The primary goal is to establish a systematic and comprehensive approach for the digital preservation and effective management of historical dwellings. The technique emphasised in this study involves the development of intricate parametric models, offering numerous modelling advantages and providing an avenue for seamless updates to Historic Building Information Modelling (HBIM), ensuring accuracy and relevance in historical preservation efforts.

1. The study further formulates the terms of reference for the new version of the automated construction management system “Building Manager”. This marks a significant step towards increasing efficiency and innovation in the field of post-war reconstruction of historical buildings. Integration of this system, designed to interact seamlessly with software systems based on HBIM technologies, provides access to accelerating progress and improving project results.
2. By combining the capabilities of the automated Building Manager technology with HBIM software, the post-war renovation industry of historic buildings gains a dynamic set of tools that speeds up project delivery and improves the quality of results. The synergy of these two technologies ensures the necessary and sufficient filling of HBIM models, accurate visualisation of the project, smooth coordination of design and reconstruction processes, and real-time project development

monitoring. This leads to a reduction in project implementation time and improved project cost results.

3. Integrating all information about historical buildings damaged as a result of military operations into a single digital environment – the City Intelligent Model - is important for all involved specialists. This digital environment provides direct access to relevant information needed for appropriate joint consultations. This, in turn, allows engineers to propose changes and recommendations to the design team throughout the lifecycle of renovation projects, from initial concepts through detailed design stages. In this way, labor-intensive practices of the past can be minimised and potential budget overruns can be avoided.
4. The study pays particular attention to improving the use of artificial intelligence in City Intelligent Modelling, which underlies the development of applications as components of automated technologies, including the “Building Manager” technology. Regarding sustainable renovation, current research on integrating HBIM-AIoT mainly focuses on the initial stages of the building lifecycle. The HBIM platform is offered for the entire lifecycle of a building. It shares information and allows stakeholders to communicate at every stage of the renovation. At the same time, AIoT makes sustainable design and decision-making accessible to all participants in the renovation process. Thus, as a result of this and similar studies, it is possible to propose a structure for developing HBIM, which involves the gradual transformation of the static 3D visualisation tool HBIM into a full-fledged system. This transformation combines the methods of HBIM, AIoT, and artificial intelligence into a single system – City Intelligent Modelling as one of the types of Complex Intelligent Models.

This study is a testament to the potential power of innovation based on combining the advanced technologies listed above into a single City Intelligent Model, a type of Complex Intelligent Model. This highlights the opportunity to create automated reconstruction management technology that combines HBIM and AIoT, leading to faster, better, and more cost-effective reconstruction of historic war-damaged buildings. As the remodelling and renovation industry embarks on a path to greater efficiency and sustainability, the findings of this study serve as a compass pointing the way to a future where remodelling projects will be marked by increased accuracy, reduced schedules, and optimised resource allocation.

5. Discussion

The research presented in this paper focuses on the critical aspect of post-war reconstruction, particularly in the context of historic buildings and their energy efficiency. The integration of Building Information Modelling (BIM), Geographic Information Systems (GIS), and Internet of Things (IoT) technologies, as discussed in the City Intelligent Modelling (CIM) framework, is proposed as a comprehensive solution to address the challenges associated with the reconstruction of historical residential buildings.

Analysis and interpretation of results:

The integration of BIM, GIS, and IoT technologies emerges as a powerful strategy for managing and upgrading reconstruction areas, especially historical residential buildings. The results indicate that this approach facilitates efficient maintenance with minimal intrusion, precision, and productivity. The concept of "Community Intelligent Modelling" introduces a technical task for creating a platform that not only reconstructs residential structures but also serves as a crucial link between buildings and digital environmental analysis software. The benefits outlined in Table 1 highlight the efficiency gains and improved communication brought about by BIM integration in City Intelligent Modelling. This approach not only streamlines project progress monitoring and construction planning but also enhances communication effectiveness among stakeholders. The interdisciplinary collaboration facilitated by BIM proves instrumental in achieving a more sustainable and resilient reconstruction process.

Answering questions raised in the introduction:

The research successfully addresses the question of how to rebuild better after war damage. By focusing on energy-efficient retrofitting of historical buildings using advanced technologies, the study provides a roadmap for post-war reconstruction that goes beyond mere restoration. The proposed City Intelligent Modelling (CIM) system aims to bridge the gap in existing research by establishing reliable connections between various data sources, thereby contributing to the holistic maintenance and management of rural housing estates.

Limitations of the investigation:

While the research introduces innovative solutions, it is essential to acknowledge its limitations. The primary limitation lies in the focus on historical residential buildings, with a potential gap in addressing broader urban infrastructure issues. Additionally, the study predominantly emphasises the integration of BIM, GIS, and IoT technologies, potentially neglecting other relevant factors that contribute to the resilience and well-being of affected communities.

Future research directions:

To address the identified limitations, future research should explore the application of the proposed CIM system in diverse urban contexts beyond historical residential buildings. Investigating the integration of additional technologies or factors that contribute to the overall well-being of communities could further enhance the effectiveness of post-war reconstruction efforts. Moreover, the research community should work towards developing standardised frameworks for comprehensive data integration, ensuring the reliability and applicability of results across various scenarios.

In conclusion, the research presented in this paper provides valuable insights into post-war reconstruction, emphasising the significance of energy-efficient retrofitting for historical buildings. The proposed CIM system, with its integration of BIM, GIS, and IoT technologies, presents a promising avenue for enhancing the resilience and well-being of affected communities during the reconstruction phase. However, continuous exploration and refinement are necessary to address the identified limitations and ensure the comprehensive applicability of the proposed solutions.

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