Integration of Building Information Modeling and Artificial Intelligence of Things in the Post-War Reconstruction and Renovation of Buildings

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Abstract

The construction industry of Ukraine shall not only recover but also upgrade, enhance and reevaluate existing building projects. Further research raises two pertinent issues for Ukraine - retrofitting and reconstructing destroyed infrastructure. The study's priority objective is to restore damaged and ruined buildings rapidly. It may be achieved using the creation of recovery methods in Ukraine and countries in the post-conflict stage of development. The research involves creating technical specifications for the product of a new version of the automated construction management system, which provides working with the software complexes based on the BIM model. The system implies using Building Information Modeling (BIM) and Artificial Intelligence of Things (AIoT) to make organization of reconstruction faster, better and less costly. The research has been held to demonstrate the viability of the approach. In addition, we acquire a reduction of energy consumption and an increase in the lifespan of the building by choosing retrofitting methods. The efficacy of BIM and IoT technologies enables the integration of contemporary demands to diminish design time and costs. These technologies also optimise design solutions by assimilating knowledge from previous building and structure designs. Additionally, they offer essential information support for the entire investment project life cycle.

Keywords: BIM-technologies; AIoT; information modelling; retrofitting; historical buildings.

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Introduction

Main objective and expected outcomes of the study

Energy retrofits are frequently depicted in literature as a process that involves reconciling multiple criteria, with conservation and energy efficiency paramount (Webb 2017). Although no regulatory framework specifies minimum energy performance requirements for dwellings, the potential for energy savings and emissions reduction through retrofitting building stock has been widely recognised, as evidenced by numerous research programs and studies. Moreover, there is a growing implementation of pilot studies focused on integrating renewable energy systems in buildings, indicating promising future advancements in this sector (Durante et al., 2021). Retrofitting a building refers to modifying its systems or structure after its initial construction. This approach not only addresses the need for upgrades but also contributes to reducing adverse environmental impacts, ultimately enhancing the comfort and well-being of its residents. With the reinforcement of anthropogenic impact on the environment, it becomes necessary to develop and adopt the methods that allow estimating the ecological state of natural-anthropogenic complexes. The most pertinent aspect of environmental quality management is advancing diverse monitoring methodologies within the ecological and planning control system. These goals can be attained by setting objectives such as lowering operational expenses and enhancing the well-being and productivity of residents (Ezzat et al., 2023).

A crucial step is defining the main objective of rehabilitation works. There is a need for a more efficient decision-making process in construction planning without compromising reliability. Moreover, emerging goals such as adaptability and sustainability also present challenges that must be addressed. In particular, conservative repair involves preserving the original structural layout by employing compatible products and techniques (Stellaccia et al., 2018). On the other hand, slightly more intrusive interventions focus on addressing the structural characteristics with the primary goal of achieving higher target reliability levels.

The results of this study are a technical task for creating a new version of the BIM-based platform. This platform fully automates the processes at the stage of the construction organisation, namely the calculation of construction volumes, the creation of grid schedules, the definition of the nomenclature of work and the calculation of their duration. This platform will be an innovative application of artificial intelligence in the construction organisation, which will not have analogs. Now, the automation of the processes mentioned above is a vital factor for the Ukrainian construction industry because the reduction of labour and time costs has a highly positive effect on the efficiency of the redesign.

The application of the proposed technical assignment holds the potential to significantly enhance the Ukrainian version of an update for automated management technology within the program complex `Building Manager` construction enterprise by addressing critical operational challenges and integrating advanced features so the enterprise can achieve streamlined workflows, improved project outcomes and increased overall efficiency (Copyright registration certificate of automated technology of modeling and construction support `Building Manager`): https://docs.google.com/spreadsheets/d/13_p_mD_ZA3yHUG2F9CchyWWhymRLNG3e/edit?usp=sharing&ouid=102846270693069087543&rtpof=true&sd=true.

Automated technology of modeling and construction support `Building Manager` is a generalized name for a complex of information systems that allows, based on information models of a construction project, to generate: a statement of quantities, a calendar network schedule filled with resources, and to estimate the cost (in the form of interconnected models). To create the initial resource and technological model, the following systems were used: program complex `Solaris` for calculating the volume of work, Building Manager for calendar and network planning, and Calculation module for generating estimates. This solution was used to create mutually consistent construction information models and develop rules for their information interaction. After modeling the construction process, it is possible to load information models into any systems used by project participants, for example: CostOS (cost estimation), Primavera/Project (scheduling and network planning), EcoSys (cost control), and their further use when supporting the construction process.

Implementing proposed technical specifications stands to revolutionise the building manager construction enterprises automated management technology by incorporating features such as project planning resource allocation communication, financial management risk assessment, and real-time monitoring; the enterprise can achieve higher efficiency, transparency and project success. This holistic approach empowers the enterprise to meet challenges head-on, optimise operations, and deliver exceptional construction projects in the Ukrainian market.

Hence, by formulating appropriate strategies and utilizing diverse BIM programs, the buildings' energy consumption can be simulated. Consequently, opting for one of the retrofitting methods leads to reduced energy usage and prolonged building lifespan.

The efficacy of BIM technologies enables incorporating contemporary requirements, reducing design time and costs. It also facilitates optimising design solutions based on past experiences constructing new buildings and structures. Furthermore, BIM provides vital information support for the investment project throughout its lifespan (Ezzat et al., 2023).

Research problem

The problem of the sharp increase of the volume and range of work of the destroyed infrastructure can be resolved by the implementation of Artificial Intelligence in the evaluation subsystem of the volume of works. If reconstruction is unavoidable, the results of the reconstruction must comply with modern requirements for buildings, including requirements for energy efficiency and environmental friendliness. In turn, the desire to meet modern requirements for environmental friendliness and energy efficiency of reconstructed buildings significantly and further expands the range and volumes of works. Thus, the task of effectively determining the volumes and range of works becomes even more difficult to solve without the use of artificial intelligence tools integrated into automated construction management technologies.

With the advent of global climate change, sustainable development has emerged as a paramount focus in architectural design. Consequently, it is receiving heightened attention in the field. Simultaneously, the building industry is rapidly shifting towards intelligent and digitised practices. The architectural design process is becoming more centred around digital platforms, leading to more architectural 3D models. Throughout all stages of design, from the initial concept to the final result, digital 3D models have increasingly become the crucial link between conceptualisation and construction (Sandor et al., 2023). Consequently, 3D models have emerged as the primary means of communication and creation in architectural design.

Compared to traditional 2D representations, 3D models offer a more comprehensive depiction of spatial relationships inherent in a given design (Olawumi and Chan 2018) while providing an accurate and sufficient portrayal of architectural space and proportions. The shift from 2D to 3D has inevitably introduced greater complexity for architects in visualising and exploring new ideas, particularly during the early stages of the design process. Any promising design concept must be translated into 3D to convey its intent effectively. To tackle this newfound complexity, there is a growing interest in utilising artificial neural networks within digital design processes. However, training networks directly on 3D models remains a significant challenge (Sandor et al., 2023).

Building Information Modeling (BIM) technology offers various advantages for building environmental design and assessment. BIM offers several ways to support the creation of sustainable buildings, which include:

- Building Orientation: BIM can help optimise the building's orientation to maximise natural lighting, minimise heat gain or loss, and enhance energy efficiency.

- Building Massing: BIM enables exploring and optimising building massing strategies to improve energy performance, ventilation, and occupant comfort.
- Daylight Analysis: BIM tools can simulate and analyse the availability and distribution of natural daylight within the building, allowing designers to optimise window placements and shading devices for energy savings and occupant well-being.
- Water Harvesting: BIM can assist in designing and implementing water harvesting systems, such as rainwater collection and greywater recycling, to reduce reliance on external water sources and promote sustainable water management.
- Energy Modelling: BIM facilitates energy modelling and simulation, enabling designers to assess the energy performance of the building and identify opportunities for energy efficiency improvements through equipment selection, insulation, and HVAC system optimisation.
- Materials: BIM can incorporate databases of sustainable materials, allowing designers to evaluate and select environmentally friendly materials based on their life cycle analysis, embodied carbon, and other sustainability criteria (Deng et al., 2021).

By utilising BIM in these ways, architects and engineers can enhance the sustainability of building designs, promoting energy efficiency, resource conservation, and environmental responsibility. The necessary presence of these important factors creates a significant complication and expansion of the range and scope of works. This expansion of the range and scope of work makes it impossible, or very difficult and inefficient, to determine the main parameters of reconstruction management: resources, duration of works and costs of works. Additionally, when combined with Performance Analysis tools, the integration of BIM significantly streamlines the often intricate and challenging analysis processes. In green construction, considerable efforts have been devoted to developing and demonstrating integrated BIM frameworks and workflows (Olawumi and Chan 2018). Building Information Modeling (BIM) and the Artificial Intelligence of Things (AIoT) play pivotal roles in this transformative process and make significant contributions. AIoT is a transformative concept that leverages the synergy of AI and IoT to create data-driven ecosystems that enhance productivity, productivity and innovation across domains by exploiting the power of data connectivity and AI algorithms to generate adaptable solutions capable of making informed decisions in real time.

Although BIM was initially conceived as a project implementation and management tool, its utilisation has been limited due to a significant lack of interactivity in accessing data. The extensive growth of the AIoT and the widespread use of connected sensor applications have substantially increased data availability. However, the full potential of this data still needs to be explored, particularly in generating new insights, such as 3D visualisation of complex parameters like energy consumption (Mitchel, 2022).

Methods

Strategies to the integration of BIM and AIoT

BIM is a virtual representation of a building, enabling efficient collaboration between designers and builders to achieve a common goal. It combines software and methodology to enhance the efficiency and functionality of both new and renovated structures. When it comes to the adaptive reuse of demolished buildings, selecting the most suitable option is a complex task involving multiple parties and criteria.

In an adaptive reuse project, it is crucial to determine the most appropriate selection strategy shown in Fig. 1. BIM plays a significant role in this process by leveraging the BIM model to facilitate visualisation, allowing users to explore various design options. Through the 3D-BIM model, the evaluation and selection of an alternative design directly impacts constructability, coordination, 4D scheduling, and 5D cost planning. This approach helps generate a wide range of alternatives that effectively deliver the desired functions at an optimal cost.

Integrating BIM and AIoT holds immense potential for enhancing efficiency throughout various stages of the construction life cycle. Real-time input is being harnessed from an expanded network of AIoT sensors. Therefore, there may be optimisations in construction operations, monitoring projects, better health and safety management, and improvements in facilities management (Li, 2022).

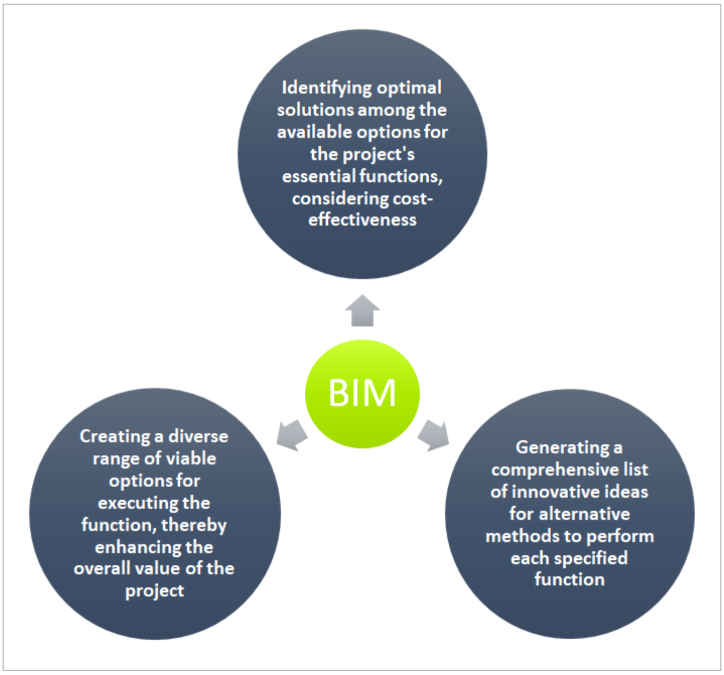

Fig. 1

The key objectives of utilising the BIM model in the adaptive reuse project

Expert system, developed by the authors, with elements of artificial intelligence when processing project data, in addition to the usual determination of the parameters of an element of a particular project, for example, the relationship of precedence between the types of project work, in the absence of a specific answer (knowledge) in the knowledge base, for example: when using new types of work in the project, using the appropriate "control module" embedded in the system, taking into account the spatial structure of a particular object, analyzes the response entered by the operator (export) to the system request and replenishes the "knowledge base" with new analytical knowledge that the operator did not enter and did not even have the opportunity to do this during work with a specific project due to the absence in a specific project of a number of basic elements with which the basic connection is determined.

The contemporary office environment is experiencing a surge in the deployment of sensors and smart devices, resulting in a vast influx of data. This data-driven approach fosters enhanced efficiency and sustainability in office operations. AI is taking centre stage in this data utilisation, which empowers organisations to extract valuable insights from these massive data pools for optimal benefits.

On the other hand, buildings often face the challenge of balancing modern sustainability requirements with architectural authenticity. This challenge is addressed by optimising energy consumption by AI-powered automated systems. By intelligently managing lighting, heating, and cooling systems based on ownership and environmental conditions, these systems enhance sustainability without compromising the building's identity.

Automated systems are seamlessly incorporated throughout the commercial structure, enabling responsive actions to real-time events. Temperature sensors play a pivotal role by identifying specific areas within the building that require additional heating or cooling, all without human intervention, thus contributing to reduced utility costs. AI`s capabilities extend to identifying areas needing of repair and detecting leaks. By monitoring changes in the building's conditions, AI can swiftly alert reconstruction teams to potential issues, facilitating proactive maintenance and offering essential data to determine the nature of the event and the most effective approach to handle it. This ensures the building's stability and minimises potential damage and associated costs. In addition to its water management capabilities, AI also plays a crucial role in optimising energy consumption within buildings. By tracking daylight levels and intelligently controlling lighting systems accordingly, AI ensures cost-effectiveness and minimises unnecessary energy usage. Integration sensors, cameras, actuators, and AIoT devices allows for prioritizing human-centric tasks while reducing the potential for human errors in managing building systems.

In the context of inteligent construction, the paper delves into an analysis of recent scientific articles, highlighting the trends, opportunities, and challenges in this field. It provides a comprehensive overview of emerging innovative construction applications, encompassing construction monitoring, site management, workplace safety, early disaster warning systems, and resource and asset management. Embracing these intelligent technologies promises a transformative shift in the construction industry, optimising efficiency, safety, and resource management (Shao, Sun 2013). As AIoT solutions for the construction sector are becoming increasingly widespread, partners can to efficiently supervise and manage each stage of the real-time development process, including planning, post-development and administration. AIoT solutions empower construction stakeholders to estimate construction volume and scalability accurately. Real-time data from sensors and devices enable the continuous monitoring of construction progress, allowing for better resource allocation and volume adjustments based on project requirements. This dynamic approach provides a project`s lifecycle without underutilisation or overexertion of resources. By monitoring resource consumption, tracking project expenses, and predicting cost fluctuations, informed financial decisions may be made. AI-driven analytics provide actionable insights into cost-saving opportunities, which help construction enterprises achieve better economic outcomes and optimised budgets. Moreover, AIoT applications can help create a feasible disposal plan by recycling and reusing production, educating the personnel on the sustainable construction concept, and leading to the adoption of zero waste technology. This plan will not only help to reduce waste but also promote understanding of its significance. AIoT technology can be effectively applied in various aspects of the reconstruction process. AI algorithms can identify structural weaknesses, assess the impact of proposed changes, and recommend preservation strategies that ensure the building's longevity. These applications generate a large volume of fast, accurate and various data. Among them are control of the production process, monitoring the production lifecycle and environment, manufacturing tracking supply chain, and energy saving and emission reduction (Stefanic and Stanovski, 2019).

Although BIM is considered to be beneficial, it has its limitations as well. For instance, it primarily focuses on constructing static models without incorporating dynamic detection and needs more interactivity. The digitisation of buildings necessitates optimising collecting, and managing information, thereby highlighting the importance of integrating BIM and AIoT (Elkwisni and El Maidawy, 2023). BIM and AIoT technologies are considered to contribute to intelligent development. While green buildings emphasise energy efficiency throughout the entire lifecycle of a building, they also rely on technological support and promotion. The integration of AIoT brings innovative digital solutions to various industries. At the same time, the BIM approach enables the sharing and traceability of data among stakeholders and facilitates integrated management of the lifecycle of buildings or infrastructure through 3D virtual models (Malagnino et al., 2021).

Digital Twin model

The expected outcomes may be achieved by developing an integrated information system that combines BIM technologies, artificial intelligence systems, AIoT and Big Data technologies. This system enables the creation of a digital replica of a construction site, known as a digital twin. To accomplish this research goal, the focus is characterising the BIM design aspects that facilitate real-time data collection through AIoT and Big Data. This data will be utilised for intelligent video surveillance using the multi-label classification of BIM attributes in the future digital twin model.

To begin with, BIM functions as a data repository that stores contextual information, which encompasses the geometry of the building, description of AIoT devices, static information and soft building data accumulated from occupancy patterns and schedule information, as well as from sources like social media, building feedback, interactions of residents, room allocation, financial pricing and weather forecast (Tang et al., 2019). The second element comprises time-series data, which involves continuously recording sensor readings. Conventional time-series data is typically accumulated in an organised relational database. The third aspect focuses on the integration method that connects contextual information and time-series data (Corry et al., 2014).

Based on the Digital Twin model, information is being gathered on the site using an AIoT structure, as shown in Fig. 2.

This data is further enriched with Big Data, forming a valuable source of information. Simultaneously, specialists from various fields asynchronously contribute to creating the project`s BIM «Reference Model». First, the actual data is collected on the construction site, then the algorithm classifies the data, and the model's attributes are entered explicitly or implicitly into the BIM Data Storage (Chernyshev et al., 2022). By multi-label classification, ready parts are connected using the FFNN (Feedforward neural network) model. This artificial intelligence approach enables determining the percentage correspondence between the actual construction processes and the state of the construction site compared to the reference object designed using BIM technologies across multiple parameters. Therefore, a digital twin is created using defined data and CAD systems (Honcharenko et al., 2021). In the future, the digital twin will be continuously supported by processing real-time data and facilitating operational adjustments as needed. The inclusion of elements in the list of works should be regulated by the accumulated and easily customizable Rule Base of the Solaris module - an integral part of the general Knowledge Base of the automated Building Manager technology. Adjustments to the BIM model itself, with the addition of new elements and adjustments to existing ones, are made in the CAD systems in which it was created. There is also an autonomous system for specifying the parameters of elements without using the original CAD systems, and there is also the possibility of manual configuration.

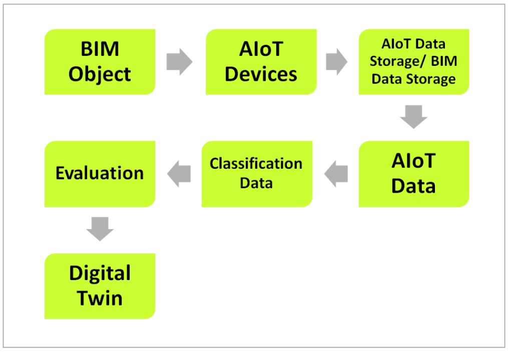

Fig. 2

Development of Digital Twin model (Chernyshev et al., 2022)

The Stages of Digital Twin Model Development

The initial step for the project team is to collect all necessary inputs, including on-site information, building documents, regulations, and relevant product information. This data-gathering process, a survey, involves utilising laser scanner instruments. Once the inputs are gathered, the next step is creating an external database and libraries. This process is guided by project templates, and the data is separated into AIoT and BIM Data Storages. Subsequently, the BIM model of the existing state is developed using a BIM authoring tool. This model is controlled by a specifically designed authoring tool template and is passed on to the AIoT devices. Once the model of the existing state, also referred to as the digital twin, is created, the intervention project can commence, focusing on effective data management.

The results indicate that the life cycle of a construction project can be divided into five distinct stages:

1. Preparation Stage: This initial phase involves design and decision-making processes. It encompasses planning, conceptualising, and formulating crucial decisions that will shape the project's direction.
2. Construction Stage: During this phase, the project's actual construction takes place. It involves the implementation of the plans and designs prepared in the previous stage.

3. Usage Stage: Once the construction is complete, the facility enters the usage stage, which is put into operation. This stage includes ongoing maintenance, regular operations, and any refurbishment or renovation necessary to ensure smooth functionality.
4. End Stage: As the facility nears the end of its useful life or when it becomes obsolete, the deconstruction process begins. This stage involves dismantling or demolishing the structure in a safe and environmentally responsible manner.
5. Complete Life Cycle: The complete life cycle encompasses all the abovementioned stages, from the initial preparation to the final deconstruction. It represents the entirety of the project's existence, from inception to closure.

BIM contains relevant semantic data about construction components yet cannot represent element states and indoor conditions. To transform static models into real-time information models, updating the forms of BIM entities using real-time readings from AIoT devices is necessary. A potential solution for achieving this is a developing a new design of SOA (Service-oriented architecture) patterns using RESTful (Representational State Transfer) Web Services, known as RESTful endpoints. These endpoints enable the update of BIM entities' statuses by receiving readings from AIoT nodes and performing create/read/update/delete CRUD operations in the BIM data layer (Stellaccia, Ratoa, Polettib, Vaconcelosb, Borsoic 2018). Different SOA design patterns can be utilised to enable the status update of BIM entities based on sensor readings. From other key perspectives, BIM also considers concepts such as engineering network design and reviewing BIM models at different stages throughout the lifespan of a construction project. The approach provided by BIM models contributes to the formation of a digital twin that visualises and predicts real-time decision-making and implements AFS (automatic feedback service) and control of the construction environment based on optimised results and management strategies (Banfi et al., 2022).

A systematic approach is described for implementing multi-label classification to address issues involving many input and output classes. It is established that each task in multi-label classification has its architecture, comprising multiple parameters and quality indicators. Furthermore, it involves managing a dataset with multiple parameters, conducting regression on numerous parameters, and training on various parameters. Additionally, it can represent a parameter space.

In addition, an important step for solving the problem is the possibility in the automated technology «Building Manager» of forming, calculating and manipulating summary models, which include many individual objects both as a whole and in the context of planned periods. This is especially important in calculations under conditions of limited resources, and material and financial limitations for the organisation as a whole or for the reconstruction of buildings and structures.

Importance of a digital platform in project evaluation

Information continuously evolves, replenishes, and transforms throughout the entire life cycle of a capital construction project - encompassing design, construction, operation, and eventual dismantling. Essentially, this process constitutes an information flow, forming a structural information model for an object's lifespan organisation. This model comprises interconnected information flows from various project subsystems (Banfi et al., 2022).

The digital transformation of construction management relies on the expanding capacities and tools provided by information and communication technologies alongside the unique characteristics of information flows within the construction sector.

The central idea behind digitalisation, both in general and within the construction industry, revolves around a digital platform. This platform is a unifying hub for all essential information and communication software tools needed to address industry-specific challenges. It grants specialists and other stakeholders access to tasks that may be accomplished with significantly reduced exertion. Among such tasks are organisation, planning and analytics of the project. With the platform's integration, the once time-consuming and labour-intensive process of manually calculating construction volumes is no longer necessary. The platform automates this aspect, streamlining the entire construction planning process and significantly reducing potential errors. This automation allows reconstruction projects, to progress more swiftly and accurately.

The platform's advanced capabilities extend beyond volume calculations, as it also facilitates the creation of detailed calendar plans and schedules. By harnessing the power of automation and intelligent algorithms, the platform generates comprehensive and accurate schedules, considering various factors such as resource availability, project dependencies, and potential risks. This orchestration considers multiple elements, such as resource availability, project dependencies, and potential risks. In the context of reconstruction, this precision ensures that the intricate restoration process is executed flawlessly and efficiently. A systematic thematic analysis has been held to validate the research data via initial codes to accomplish this. The codes relate to essential data segments and highlight the most significant components. The mind map diagram in **Fig. 3** helps develop initial regulations for code generation.

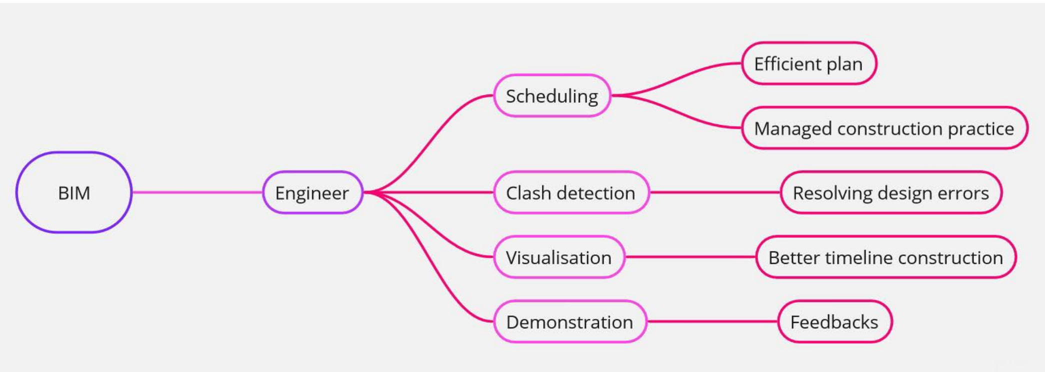

Fig. 3

Mind map diagram

Thus, the themes are classified into the main findings of this study. The platform's newfound efficiency and accuracy enhance the overall productivity of construction projects and provide project managers and teams with greater control and foresight. As a result, construction timelines can be optimised, and potential delays can be identified and mitigated proactively, leading to smoother project execution and improved outcomes. Thus, as reconstruction integrates into the digital transformation of construction management, it benefits from the potent capabilities of a unified digital platform. This platform propels the restoration process by automating volume calculations, enhancing scheduling accuracy, and harnessing the potential of information technology.

The functionality of the platform is its key attribute. It contains a set of algorithms that facilitate communication among production and participants of projects within a unified data area. The capabilities and efficiency of the digital platform are contingent upon the available interaction functions of project participants and the corresponding algorithms. These factors determine the platform's advantages, drawbacks, effectiveness, and level of development.

Effective construction project management requires implementing a flexible model with an organisational structure that caters to each stage's unique characteristics and accommodates the various participants involved in the project's life cycle. This model is often referred to as a «virtual design enterprise.»

An industrial digital platform must address various tasks within the construction industry and possess extensive performance. These tasks include:

1. Managing Information: The platform should enable easy access and efficient handling of project data and real estate market information.

2. Dealing with Infrastructure Challenges: It should provide access to various digital resources required for smooth infrastructure management.
3. Handling Technological Requirements: The platform should offer specialised tools and technologies for construction processes.
4. Streamlining Corporate Processes: It should optimise control procedures to enhance the overall efficiency of the construction project.

By adopting such a digital platform and utilising a flexible organisational structure, the virtual design enterprise can effectively navigate the complexities of the construction industry, ensuring the successful management of capital construction projects throughout their life cycle. Moreover, attracting resources can be streamlined, making continuous project monitoring feasible. The platform enables swift resource allocation, ensuring the right amount of resources is available at the required times, thus minimising losses due to downtime or search for help.

The virtual engineering enterprise offers organisational flexibility that allows it to optimise its use of resources to a sufficient minimum. This approach proves cost-effective since maintaining and sustaining owned assets can be more expensive, especially when not consistently use. In contrast, the virtual engineering enterprise employs its assets only for the extended duration required during the project's life cycle, increasing project efficiency and overall effectiveness.

The virtual project enterprise is operated both in real-world and digital format, managing the facility`s entire life cycle. The digital structure consists of data flows corresponding to each successive life cycle stage and is structured like a production chain after unification on a single industry digital platform. This platform is the central hub for integrating all organisational and resource-related modifications.

The project's digital twin is utilised to ensure real-time tracking and synchronization. This digital twin is a virtual representation of the actual facility, capturing all updates and changes throughout the life cycle. Cloud technologies, big data analysis, IoT, and advanced communication technologies facilitate the seamless transfer of vast information, keeping the digital twin up-to-date with real-world developments. This convergence of technologies enables efficient and accurate project management, improving productivity and performance throughout its life cycle.

Results

Functionality and efficiency of updated platform version

Ukrainian automated technology for construction management "Building Manager" integrates advanced features, including leveraging artificial intelligence (AI) for graph creation. This cutting-edge technology utilizes grid graphs as a foundational component to enhance various aspects of construction project management. The technology harnesses AI to automatically generate graphs that represent crucial project data and dependencies. These graphs provide a visual representation of construction workflows, tasks, resource allocation, timelines, and dependencies. AI algorithms analyze the grid graphs to optimise workflows and recognise potential bottlenecks, inefficiencies, or scheduling conflicts. This analysis assists project managers in making informed decisions to streamline processes and enhance overall project efficiency. By analyzing project data and grid graphs, these algorithms provide valuable insights that empower managers to proactively address potential risks and prevent setbacks throughout the project lifecycle.

Currently, the platform offers features that enhance project management and planning. By integrating 5D modeling into the workflow, the platform revolutionises the estimation process by deriving insights and forecasts directly from the 5D model.

In addition to the existing functionalities of scoping, automated task assignment, calendar planning, Gantt chart visualisation, and resource allocation, 5D modeling brings an elevated level of accuracy and foresight to the project management process. With the integration of 5D modeling, the platform harnesses the power of spatial representation (3D), time (4D), and cost (5D) dimensions. This dynamic combination allows for a more holistic understanding of the project, transcending traditional 2D planning and estimation methods.

By synchronising the project's physical components and associated costs within a unified model, the platform generates estimates that are inherently tied to the project's evolution over time. This real-time synchronisation ensures that changes to the project's scope, schedule, or resource allocation are immediately reflected in the cost projections, offering unparalleled accuracy in cost forecasting.

Regarding resource management, the platform enables the optimal allocation of resources by factoring in the physical progress of tasks and the corresponding financial outlays. This results in more efficient utilisation of resources and a reduced risk of cost overruns. Due to artificial intelligence, a new system for calculating the cost of construction may be introduced. The platform allows you to make a construction estimate, and artificial intelligence lists and compares the data with the normative price of the country. Moreover, the inclusion of 5D modeling fosters a data-driven decision-making culture, enabling project managers to make informed choices based on real-time insights. 5D modeling enhances the organization of construction projects by integrating cost-related data into the 3D model and project schedule. The models provide a digital audit trail by linking cost data to specific project activities and contracts. This supports compliance with contract terms, facilitates audits, and ensures transparency in financial transactions. The platform dynamically recalibrates estimates as project dynamics change, enabling proactive decision-making to mitigate potential risks and seize opportunities. In addition, the platform facilitates a comparison of present project expenditures and timelines with data derived from prior projects. This aids in establishing benchmarks, recognizing patterns, and making well-informed decisions grounded in past performance and cost trends.

Implementation and further development of Digital Twin Model

The ultimate level of advancement proposed in the ladder characterisation system not only involves real-time visualisation and prediction to aid decision-making but also includes automated feedback and control of the built environment, as presented in Fig. 4.

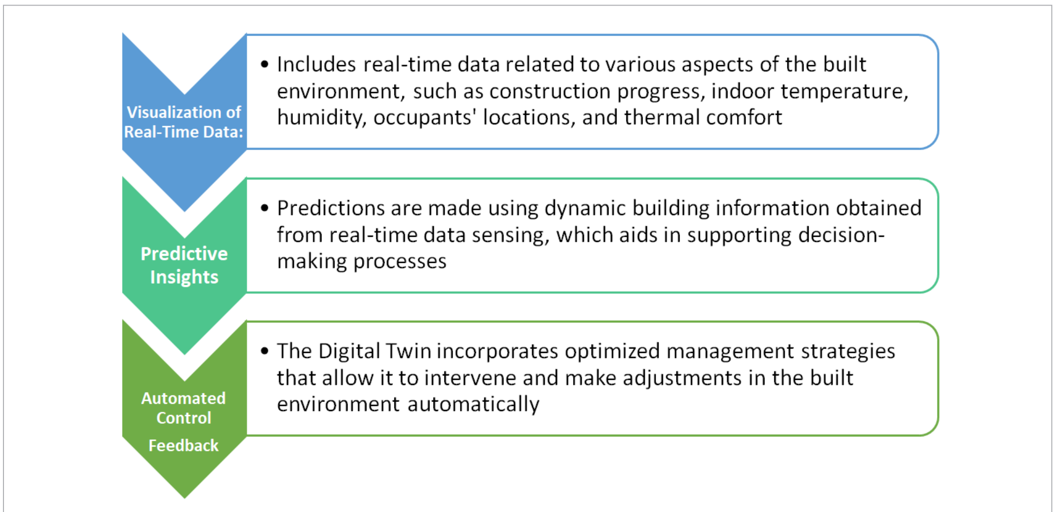

Fig. 4

Anticipated features and capabilities of the next-generation Digital Twins in the building environment

This level incorporates an intelligent feedback control system that enables the built environment to take actions based on optimised results and control strategies autonomously. Achieving this level of sophistication often relies on leveraging technologies like artificial intelligence (AI) and machine learning (ML) algorithms. Virtual and real-world built environments can seamlessly interact through these advanced Digital Twins.

An ideal next-generation Digital Twin must support buildings of varying scales, ranging from single structures to city-scale building stocks. The increasing complexity of elements must also be accommodated as the scale expands. The key results of this development process can be outlined as follows:

- Development of a cloud platform: This platform Is a hosting and sharing hub for scan-to-BIM projects. It effectively manages large volumes of data, including point clouds from laser scanning and digital photogrammetry (primary data sources), reports, digital drawings, and multimedia (secondary data sources).
- Enhanced workflow efficiency: The platform integration improves workflow, coordination, and stakeholders collaboration. It provides a user-friendly 3D visualisation interface, streamlining processes.
- Improved accessibility of Virtual Reality (VR) projects: The platform facilitates the sharing of VR projects by allowing the distribution of executable files that can be installed on dedicated applications.
- Augmented Reality (AR) object implementation and sharing: The platform supports integrating and sharing AR objects, enhancing the overall user experience.
- Enhanced interoperability of digital models: The platform promotes interoperability by utilising specific proprietary and open-source exchange formats, enabling seamless data exchange between different software and systems.

Diversification of digital uses: The platform enables various digital services, including smart glasses, VR headsets, PCs, mobile phones, and tablets, catering to different user preferences and device capabilities.The continuous advancement in Information Technology (IT) enhances the platform's interactivity, particularly by integrating monitoring data. The ultimate objective is to combine digital models and real-time data into a unified digital solution that supports awareness and building management over time. Table 2 illustrates the fundamental elements of integrating BIM and AIoT in intelligent construction. In our view, prioritising the analysis of potential consumers' preferences becomes imperative. Therefore, for new construction projects and the redevelopment of residential areas, builders and developers are encouraged to employ the provided scheme to identify promising directions for the company's growth and development.

Table 2

The fusion of Building Information Modeling (BIM) and Artificial Intelligence of Things (AIoT) in intelligent construction

Integration approach	Applications	Current Developments and Difficulties	Benefits of application in Organisation and Management of construction
Application programming of BIM tools Utilisation of a relational database Implementation of a new data schema Adoption of a new query language Incorporation of semantic web technology Utilisation of a hybrid approach	Construction operations and monitoring Construction logistics and facility management Health and safety management Facility management Document Management Quality Control and Inspection	Cloud-based working environment Service-oriented architecture and web services for BIM Requirement for integration and information standards Challenges in managing the interaction between BIM and AIoT	Early clash detection Enhanced Project Planning and Scheduling Resource Allocation Real-time Insights

Upon analysing the data, the BIM implementation guideline has undergone revision, leading to the removal of two modeling methods. However, the guideline retains the content related to data capturing, laser, and image survey data processing (as depicted in Table 3). The decision to eliminate the methods of mapping vectors onto point cloud and semi-automatically parametric modeling stems from the results, which indicate that these approaches are only widely accepted among some respondents.

Table 3

The integration of Building Information Modeling (BIM) and the Artificial Intelligence of Things (AIoT) in intelligent construction

Data Capturing	Data Processing	Modelling
Laser Scanning Photogrammetry Image-based and Range-based Combination	Data Cleaning and Resampling Data Registration Surface Meshing Texturing Creation of Orthographic Image	Manual Parametric Modelling

Discussion

This section delves deeper into defining and establishing a clear scope for sustainable building in BIM-AIoT integration. It also discusses the changes and future directions in this field and the impact of emerging IT and green reconstruction.

The integration of BIM and AIoT is currently experiencing rapid development, which involves applying device integration, VR, adoption of digital technology, innovative reconstruction and sensing information. Initially, “sensing information” garnered significant attention in terms of research focus. However, research activity in this area has slowed in recent years. It is important to note that sensing technology plays a crucial role as an enabler of AIoT. Sensor networks serve as end networks for data collection, enabling signal gathering and transmission within localised areas. AIoT is widely regarded as a pervasive global computing network that facilitates automatic organisation and information and resource sharing. Therefore, visualisation is provided using sensors and connected devices; data is monitored in real-time and processed through data analysis and mining (Ghosh, Edwards, Hosseini 2020). With the appearance of AIoT, smart cities have become closer to realisation and have attracted significant attention from researchers.

Conclusions

Based on this research, the following conclusions can be drawn:

1. The research to formulate technical specifications for the new iteration of the automated construction management system “Building Manager” marks a significant stride towards advancing the construction industry’s efficiency and innovation. The integration of this system, designed to collaborate seamlessly with software complexes rooted in BIM, opens access to accelerated progress and enhanced project outcomes. This approach allows not only to change the composition and values of basic components at will of the operator, when working with the object of external data (in our case with the BIM-model of a particular reconstruction object), but also to automatically analyse the operator’s managerial decisions and, on their basis, to develop new knowledge arising from the decisions taken and not contradicting the whole complex of knowledge accumulated by the system.
2. The research carried out has shown that by integration of capabilities of “Building Manager” with the prowess of BIM software, the construction industry gains a dynamic toolset that expedites project progression and elevates the quality of results. The synergy between the two technologies facilitates accurate project visualisation, seamless coordination of design and

construction processes, and the real-time monitoring of project developments. This leads to more rapid project timelines and improved project outcomes.

3. BIM technology offers various advantages for building environmental design and assessment. Integrating Building Information Models significantly streamlines the often intricate and challenging analysis processes when combined with Performance Analysis tools. Integrating all building information into a unified digital setting is essential for all professionals involved. It grants direct access to relevant information required for their respective consultations. This, in turn, enables energy engineers to offer revisions and recommendations for the design team throughout the entire project lifecycle, from initial concepts to detailed design phases. By doing so, time-consuming practices from the past can be minimised, and potential budgetary constraints can be avoided. Development of solutions for the use of artificial intelligence in automated technology of construction management "Building Manager" (technologies, tools and rules for information processing) makes it possible to obtain from the BIM model a complete statement of quantities of work in an automated way within one working day by one specialist for the entire facility with a level of detail up to extended work packages.
4. The emphasis of this research is put on enhancing building intelligence and BIM at the core of application development. Regarding sustainable building practices, current research on BIM-AIoT integration mainly concentrates on the initial stages of the building lifespan. The advancement in sustainable construction necessitates considering the human dimension. A BIM platform is offered for the entire life cycle of a building. It shares information and allows stakeholders to communicate during each stage of construction. Simultaneously, AIoT makes sustainable design and decision-making approachable for residents. Further improvements in endorsing sustainable buildings will require the incorporation of big data and cloud computing. A structure for the evolution of BIM may be proposed, which involves gradually transforming BIM's static 3D visualisation tool into the dynamic digital twin. This transformation integrates BIM, AIoT, and artificial intelligence methods into the unified system.
5. This research has shown that the "Digital Twin" model enables real-time object recognition and comparison through multi-label classification. The software integrates IT products, including AIoT and Big Data, to accumulate and deal with vast construction site-related data. The research summarises the improvement, demonstrating the reliability of the information system and its capability to provide accurate data for further coordination and design of digital twins. By developing automated technology "Building Manager" and using it to process "Digital Twin" model information in various contexts, it is possible to make the most informed organizational and technological decisions, thereby reducing the time and cost of construction and installation work, while simultaneously increasing the quality, increasing the reliability of organizational and technological solutions, and, accordingly, the likelihood of successful implementation works in target indicators.
6. In the broader context, this research extends beyond technical specifications. It speaks to the transformative potential of synergistic technologies, affirming that integrating BIM and AIoT is more than a theoretical concept – it is reality that can drive improvements in the construction landscape. The specific result of the authors' work is the development of an approach to the introduction of artificial intelligence in automated technologies for managing the reconstruction of buildings, which involves the presence of a knowledge base of the system, replenished in the process of operation, and the application of accumulated and developed, based on the operator's decisions, new knowledge in solving specific problems - for example, in the automated definition of the nomenclature and scope of work.
7. This research stands as a testament to the power of innovation, driven by the amalgamation of cutting-edge technologies. It underscores the feasibility of an automated construction man-

agement system that merges BIM and AIoT, resulting in faster, better, and more cost-effective reconstruction. As the construction industry embarks on a path towards greater efficiency and sustainability, the findings of this research provide a compass, guiding the way towards a future where heightened accuracy, reduced timelines, and optimised resource allocation mark construction projects.

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