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BIM Technology Empowers the Digital Transformation of Smart Construction

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Abstract. With the continuous advancement of digitalization and intelligentization in the construction industry, BIM (Building Information Modeling) technology has become an important tool for promoting intelligent construction and industrial digital transformation. Through its visualization, parametric, and information-based features, BIM provides data support and a collaborative platform for the design, construction, and operation and maintenance of buildings throughout their entire lifecycle. However, the deep integration of BIM technology into intelligent construction in China is still insufficient, especially in terms of collaboration with new technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain, where a complete system has not yet been formed. This paper analyzes the key paths for BIM technology to empower intelligent construction from the three stages of design, construction, and operation and maintenance, and explores its support system construction mechanism in digital transformation. Research shows that BIM is not only a core tool for building information management, but also an important foundation for promoting the transformation of the construction industry from experience-driven to data-driven, and from isolated operations to collaborative construction. Through technological integration and organizational change, BIM will further promote intelligent decision-making, intelligent construction, and intelligent operation and maintenance in the construction industry, providing new impetus for the high-quality development of China's construction industry.

Keywords: BIM technology; intelligent construction; digital transformation; building information modeling; artificial intelligence.

1. Introduction

The digital transformation of the construction industry is very profound and occurs due to the incorporation of Building Information Modeling (BIM), artificial intelligence (AI), and the Internet of Things (IoT). Although there has been a trend in using BIM as a visualization, coordination and project management tool, still not much has been done to explore its enabling role to provide intelligent construction [1]. Nowadays, BIM is usually not entirely tied to existing practices of predictive analytics, real-time monitoring, or decision-support systems, which restrict the impact of digital transformation on efficiency, safety, and sustainability. The existence of these gaps is crucial to overcoming the emphasized steps of the industry towards reactive project management as opposed to proactive and data-driven operations.

Extrapolatory studies of the potential of BIM-AI-IoT integration. To illustrate, AI-backed surveillance systems can enhance safety dramatically because they allow to recognize falls on the construction sites in a complicated situation [2]. Prefabricated construction project studies indicate that BIM reduces the amount of materials wasted and rework when used with IoT, thereby making the construction efficient [1]. Nonetheless, the systematic reviews have shown that high implementation costs and disjointed standards and organizational resistance remain as barriers to adopting the same [3]. These results demonstrate two fundamental gaps: the inadequate knowledge of how BIM facilitates intelligent construction both in the context of the workflow and organization, and shows a deficiency of empirical case studies that would measure the benefits and issues of such integration.

In this study, the researcher will explore the ways in which BIM enables smart construction with a focus on technological and organizational aspects. In particular, it discusses how to support joint working processes, maintain lifecycle, and make predictions in the context of AI and IoT and using BIM. Prefabricated construction will be examined as a case study through which empirical evidence will be obtained on the areas where rework and material waste are reduced [1]. The methodology comprises the synthesis of literature, counterpoint examination, and case justification concerning the theoretical and practical concerns of BIM-facilitated digital transformation.

2. BIM Technology in an Effort to Enhance Smart Building.

The strength of BIM in empowering the intelligent building construction is that it can run through the whole life cycle of a building. The operation, maintenance, design, and construction are the several steps through which the information flows efficiently and dynamically through the intervention of the BIM technology [1].

2.1. Design Phase

2.1.1. BIM -based optimization of performance and parametric design (building performance simulation).

The parametric elements of BIM make the building model no longer to be a two-dimensional drawing, but the system of a 3-dimensional information during the design stage; and it may include indicators of the building performance, the energy consumption, the lighting, the ventilation and so on. The model enables designers to make changes in real time to test the energy consumption simulation and performance optimization of the building, thus, enhancing its energy efficiency and comfort [1]. To illustrate, when designing arch bridges, BIM analysis in conjunction with Augmented Reality (AR) technology in visualization facilitates the design to enhance the accuracy of the design besides maximizing the structural safety [1].

Moreover, due to the combination of BIM and AI, design conflicts are also detected automatically, and layout configurations are optimized. Intelligent auxiliary decision-making can be achieved by running the algorithm of AI through various design schemes at the initial stage and evaluating their functionality [2]. Through this, the BIM design will not only enhance quality of design but will also have a more scientific foundation to the next stage of construction.

2.1.2. Prefabricated component library design and building: on a modular basis.

BIM technology assists in technical support of a modular design and components standardization in the field of prefabricated buildings. Scholar designers are able to develop a component library in BIM model, assign numbers and manipulate information of various modules and actualize the reuse of elements in various projects [1]. The design cycle can be greatly reduced with the help of this approach, and the design reuse rate can be increased.

At the same time, once the BIM component library is linked to the Internet of Things system, the entire mechanism of component originating in-design, production, delivery, and installation can be achieved [3]. With the Quick Response (QR) code or Radio-Frequency Identification (RFID) technology, managers are able to know the status of parts in real time, thus avoiding the wrong installation of parts or component omission. The latter is a simple indication of how BIM helps in the design of industrialized construction.

2.2. Construction Phase

2.2.1. 4D construction simulation and schedule optimization.

The main connection of intelligent construction is construction phase. Vernacular design and construction BIM application applications can be very rich like the scheme comparison, engineering quantity calculation, pipeline integration, construction scheme simulation etc. yet the application is

actually quite isolated and has no connection with data. BIM technology creates a 4D model by combining time dimension which, in turn, can establish the dynamics of simulation and optimization of construction sequence, progress and resources in a dynamic way [4]. The building units can test the process of construction and estimate and determine possible conflicts and risks in the construction process in advance and, thereby, to coordinate building organization and allocation of resources.

It has been revealed that the 4D simulation capability of BIM is capable of matching construction plan with actual site real time information hence the accuracy of construction period control is enhanced [4]. Moreover, the system can anticipate the risk of construction delays and offer optimization and adjustment plans to promptly respond to the intentions by adding artificial intelligence algorithms [5].

2.2.2. Construction safety management using BIM.

The construction phase is relevant to safety management. The BIM models can be coupled with the AI video surveillance to detect and alert the worker behavior in real time [2]. As an illustration, an AI system that is created on the basis of skeleton recognition by Kim et al. is able to identify several falls in complicated surroundings which can greatly enhance the precision of the safety surveillance [2].

Simultaneously, when using a BIM and Unmanned Aerial Vehicle (UAV) invention to detect construction deviations, it is possible to automatically identify and compare the deviations [6]. It is an intelligent quality and safety management model that enhances construction efficiency and reliability to a great extent.

2.3. Operation and Maintenance Stage.

2.3.1. Asset lifecycle management

Operation and maintenance stage is an extension and enhanced building management. The model of BIM can also act as the digital twin of the building information which stores equipment information, maintenance, and energy consumption information and this gives an authentic foundation to subsequent management [7]. The model allows the operation and maintenance personnel to know the building status in real time, achieve preventive maintenance and fault prediction, and therefore, extend the life of the building as well as cut down on the cost.

BIM with the application of the IoT technology can provide the opportunity to monitor and optimize the energy used in building in real time. As an illustration, sensors relay the operating condition of the equipments in the BIM system and the analysis of energy patterns and the automatic changing of operating parameters are performed by AI algorithms [8]. The model is mostly applicable in the big business premises and can lead to energy saving, consumption minimization and effective management.

Across all the life cycle of the building, BIM data is useful at the operation and maintenance, as well as in the future design and construction. The continuous improvement is based on the data that must be collected regarding the operation of a building, so that the designers can optimize new project plans and reach data-driven improvements [9]. This is also indicative of closed-loop nature of the BIM intelligent construction and is a significant process that can help the construction industry realize digital development.

2.3.2. Data analysis and optimization of the energy consumption.

The energy consumption monitoring sensors are implemented in different parts of the building, including office areas, commercial areas, and public areas, by combining a BIM model and an energy consumption monitoring system to capture data on the energy consumption, including electricity, water, and gas. This information is recirculated back to the BIM operation and maintenance system in real-time and connected to the equivalent areas in the model. A visual analysis of the building energy consumption is done with the help of the data analysis flex of the BIM operation and

maintenance platform. The energy consumption levels of the various areas in the model are indicated in different colors and this produces a heat map of energy consumption in a way that the energy consumption distribution is clearly displayed. To illustrate this, it was discovered that the exterior glass curtain wall facing a particular direction consumed too much energy in summer which was checked to be a result of the augmented air conditioning strain because of the heat of the sun. With the result of the energy consumption analysis, specific actions with energy saving renovations are undertaken. These are considered as installing an intelligent shading system on the glass curtain wall, that will automatically change the angle of the shading panels based on the angle of the sun and the people need of the light; and deal with the operation strategy of the Heating, Ventilation, and Air Conditioning (HVAC) system, which can reduce and increase the parameters such as temperature and wind speed in different times and locations, according to the presence of people. Once the renovation is made the result would be again through the aid of the energy consumption monitoring system which would then then be put to a comparative analysis to check the effect of energy saving and thus would be kept constantly at the optimum level of energy consumption in the building.

3. Building of a Support System of Digital Transformation.

The intelligent construction depends not only on the technological innovation but also on the systematic support to be realized. The digital transformation of the BIM is based on the synthesis with the new technological means and reorganization of the companies work.

3.1. New Technologies with BIM Technology.

BIM and Geographic Information System (GIS) can be combined to exchange both building information and geospatial data to provide city-level planning and management of infrastructure-level data [4]. By integrating BIM-GIS, planners are able to analyze the site, simulate traffic, as well as assess the environment within the same platform, hence streamlining the process of selecting the project site as well as laying out the site.

AI will enable the use of BIM to perform intensive data analysis and prediction. Considering the example, AI can automatically find conflict points in 3D BIM models, optimal construction paths, and cost risks prediction [7]. The systems of AI-based BIM decision making can enhance the transparency of a project as well as minimize human error [8]. Such integration changes the behavior of building management, turning the building management into paternal response instead of proactive prediction, an indicator of intelligent construction.

BIM and Blockchain can be considered the same term, as both aim to enhance customer experience and boost the quality of services provided.

Blockchain and its immutability and decentralized properties offer a client to share BIM data in a safe manner in a new approach [8]. To ensure the authenticity of information and traceability, design changes and the data of construction can be facilitated to the blockchain which can record these changes [9]. Moreover, BIM+blockchain model could provide the automatical verification in the execution of contracts, as well as in the purchase of materials and other provisions, minimizing transaction risks [8].

Data sharing and interoperability of the system are the main pillars of BIM and IoT integration. Being an integrated information provider of buildings, BIM creates a platform of data encompassing the whole lifecycle of a given building project that will support with accurate information all the steps planning, designing, construction, and operation of the building. IoT by use of sensors and smart devices that will be spread across the building, will capture and transmit all sorts of dynamic data in real time, which adds life to BIM model. Data sharing and interoperability of the system are the issues that should be considered first to ensure the successful integration of BIM and IoT. This necessitates that the industry come up with standard data exchange and interface protocols to allow smooth exchange and free integration of the static information in the BIM model and the dynamic information gathered by the IoT. Such foundation will offer BIM and IoT deep integration with strong technical

support, encourage data compatibility and sharing between systems and vendors, and spearhead the realization of smart construction.

3.2. Process Change and Organizational Change.

Collaboration of information is the key strength of BIM. With the traditional construction projects, the fragmentation is found in the information that is presented on the design, construction and operation, and maintenance, which leads to the communication barriers and lost efficiency. Nonetheless, BIM platform provides multiple parties to collaborate on a single model via information sharing, which inherently enhances the degree of project management [9].

To procede to the full extent of the synergistic effect of BIM, enterprises must built cross-departmental collaborative mechanisms including BIM manager system and information standardization system [10]. This is not all technical support that is needed, but also change in the organization culture. The potential of BIM technology to enable the digital transformation can be impacted only in case all participants establish the synergy at an institutional level of activity.During the construction stage, BIM technology, as well as the Internet of Things and construction simulation technology, can bring important outcomes. The project team embraced digital simulation prior to the construction to carry out elaborate simulation of the building site, thereby accomplishing the optimum allocation of resources and saving the construction preparation time to approximately 15% to that of the conventional model thereby significantly enhancing the efficiency of the initial-stage arrangement.

The use of the BIM implies the redefinition of the project workflows. Analogous linear processes cannot be used in digital construction anymore and dynamic management model, which is founded on the flow of information, is to be developed [9]. As an illustration, in the situation where design modifications are involved, the BIM system will be able to update the model instantly and relay the information to the departments concerned, which will prevent the occurrence of redundant modifications of every component and delays in information. This re engineering process makes projects flexible and responsive.

Both International and Local Companies must undertake the construction of their talent and management systems. Digital transformation does not exist solely in the technological upgrading, but also in re-organizing the talented system. The use of BIM is interdisciplinary and needs talents who have a background in architectural design, information technology, as well as project management [10]. Thus, it is recommended that the universities and enterprises should reinforce the establishment of BIM training system, develop innovative engineers to foster intelligent construction, and support the development of the industry via human resource provision.

4. Conclusion

BIM technology as a primary instrument of creating information integration and collaborative management becomes an even more significant part of the intelligent construction and digital transformation. In the examination of each of the three stages of design, construction, and operation and maintenance, it may be discovered that BIM does not only provide the centralized information management, but it also advocates intelligent and refinement of the entire building process. Its affinity to other new technologies including AI, IoT, GIS and blockchain has introduced new space of innovation to the building industry like never before. BIM is apparently all about data-driven, and the value of BIM is that it separates the information silos of the whole building life cycle with model-driven data expression to turn the process of decision-making into scientific prediction, and intelligent analysis, rather than the process depending on experience.

The issue of BIM promotion within the Chinese construction industry, however, still has certain issues like lack of standardization, expensive investment, and lack of organization and coordination. The use of BIM is still in the visualization phase, and has not yet fulfilled its data analysis and teamwork management promise, in small and, medium-size construction enterprises. The three prongs of the approach that should be used in the future are policy, technology, and education. To

begin with, BIM technical standard system must be brought together to create cross platform data exchange specifications. Second, the profound nature of the implementation of BIM and new technologies, like AI and IoT, is to be encouraged to establish a smart system of the building lifecycle management. Third, the innovation of BIM talent training and management mechanism should be enhanced to enhance the general digitization of the industry.

Moreover, it is important to summarize project practice experience in order to create repeatable and scalable directions of BIM implementation. As an example, the BIM collaborative platform can be built in the spheres of prefabricated buildings, urban infrastructure, and green buildings to gain a digital closed loop of the whole process of optimization of design and production of components through operation and maintenance management. Governments and industry associations ought to also create incentive policies to leverage enterprises to invest more in, and creative implementation of BIM. As a result of the harmonized policy-based, technological innovation, and organizational change, BIM will slowly develop to become not a supplementary but a necessity of the digital realm of the construction industry.

Altogether, BIM powering of intelligent construction is not only a technological breakthrough but also a reconstruction of concepts of management and models of the industry. It will propel the construction industry to grow out of information based management to intelligent decision-making that enhances quality and sustainable growth in the construction industry. As the artificial intelligence algorithms develop continuously, and the IoT sensing capabilities allow advancing further, in the future BIM will become the so-called central nervous system of the construction industry, introduced as a significant technological premise towards the realization of the objectives of creating the smart city and carbon neutrality, and bringing permanent impetus to the digitalization of the construction industry of my country.

BIM technology as one of the fundamental tools of building information integration and collaborative management plays a more significant role in the fields of intelligent creation and digitalization of the construction process. By examining the three phases of design, construction and operation and maintenance, it may be discovered that the BIM not only achieves centralized information management, but also enhances intelligent and refined process of the entire building process. It is allowing the construction industry to enter the space of innovations as never before due to its integration with emerging technologies including AI, IoT, GIS and blockchain.

Nevertheless, some of the issues that impede the encouragement of BIM in the construction industry in my country include unstable standards, high cost of investment and difficulties in organization and coordination. One should promote it in future in three facets which include policy, technology and education. The first solution is to develop a cohesive system of BIM technical standards; the second one is to ensure that BIM is closely combined with new technologies, including AI and IoT; and the third is reinforcing the innovation of BIM talent training and management mechanism.

On the whole the BIM empowering intelligent construction is not only the technological innovation, but also the process of reforming the idea of management and models of industry. Through the ongoing optimization of the BIM application system, the construction industry will progressively attain a complete shift on the conventional construction into a digital, intelligent and sustainable development that will pave a substantive path to the development of the construction industry in my country to be of high quality.

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