

The Application of Building Information Modeling Technology in the Whole Life Cycle of Buildings

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Abstract. With the rapid development of information technology, the construction industry is undergoing a profound transformation from traditional two-dimensional design to digitalization and informatization. Building Information Modeling (BIM) technology is the core driving force of this transformation. BIM enables efficient collaboration across all project stages by constructing a multi-dimensional data model covering the entire building lifecycle. However, most existing BIM research focuses on specific stages, lacking a systematic exploration of integrated applications throughout the entire lifecycle. This paper examines the application of BIM technology throughout the building lifecycle, analyzes its specific practices at different stages, and studies its integration mechanisms. Through a literature review and case studies, this paper explores the role of BIM in improving overall project efficiency. Research shows that BIM technology has significant value throughout the building lifecycle: in the design phase, it improves design quality through parametric modeling and simulation experiments; in the construction phase, it enables dynamic management and real-time control of construction through the integration of 4-Dimensional (4D) simulation technology and the Internet of Things (IoT); and in the operation and maintenance phase, it supports intelligent management as a digital asset. Practical data shows that BIM applications can reduce building energy consumption by approximately 20%, improve construction efficiency by more than 20%, and improve maintenance efficiency by 30%. In the future, should strengthen cross-stage data integration of BIM, continuously explore the integration of BIM with emerging technologies, and promote its transformation from "point-to-point application" to "full-process empowerment".

Keywords: Building information modeling; full life cycle; internet of things sensors; digital twins.

1. Introduction

As one of the harshest carbon emitting industries in the world, the construction industry is under pressure like never before with the establishment of the global carbon neutrality approach and the concept of the so-called dual carbon. Research indicates that the construction sector contributes about 36 percent of the overall final energy consumed in my country and its primary social carbon emission of more than 40 percent, including all the construction stages (building material manufacturing, and construction) through operation. As the construction sector has grown and the rate of urbanization has increased, low-carbon, efficient, and sustainable development via technological innovation has become an essential concern of the sector. Normal 2-Dimensional (2D) design drawings and incomplete and stage-by-stage management are no longer adequate to adequately address the complex demands of buildings nowadays, green building requirements and the need of optimal allocation of resources. Thus, during the technology-driven change endeavor, Building Information Modeling (BIM) technology has become one of the supporting tools in this upgrade. [1]

With the digitalization and intelligentization wave, Building Information Modeling (BIM) technology has slowly become a fundamental supporting apparatus through the revolution and modernization of the construction sector. BIM ensures features of visualization, parameterization and data provision of the complete project life cycle through synthesis and modeling of functional information, physical properties, and geometry of building elements. Its benefits are not limited to design cooperation and conflict checking, as compared with traditional approaches, the system benefits include optimization of construction organization, decision-making of operational and maintenance, and traceability of information. Specifically, BIM technology has proved to have immense resources integration



capability and utility in minimizing energy consumption, enhancing the quality of projects and encouraging green construction. As emerging technologies are developed, including the Internet of Things, digital twins, and artificial intelligence, BIM is slowly developing out of a single support tool into a complete process information management solution, which forms the technical basis and developmental perspective of the digital transformation of the construction industry [2].

Currently, researchers have also made comprehensive study on the utilization of the BIM technology at the life cycle of the buildings that include collaborative design, collision detection, engineering quantity calculation, construction simulation, facility management and many more. Nevertheless, majority of the studies remain concentrated on a particular phase, and there remains limited and disjointed comprehensive argumentation on the application of BIM in the whole life cycle. In particular, the possibilities of BIM technology in cross-stage integration and emergency response are yet to be researched when addressing the case of extremely complicated construction projects with little notice. Considering the Wuhan Leishenshan Hospital as an example, the use of BIM in integrated design and construction resulted in the realization of high construction speed in a very short construction time, as well as the demonstration of the usefulness of BIM in special conditions by innovative practices, such as digital twins, fluid simulation and prefabricated construction [3]. In the same light, Guo Wenbo also observed in the experience of residential projects that BIM has a significant role to play in fault simulation and hidden engineering management in the operation and maintenance process [4].

On the background provided above, the primary research line of the paper is considered to be the implementation of BIM technology in the full lifecycle of buildings. It will purposefully streamline its existing approach to collaborative modeling, simulation analysis, construction control, and facility operation and maintenance in the three main phases of the design, construction, and operation and maintenance, as well as investigate their role mechanisms in cross-stage integration, information flow, and efficiency enhancement. It integrates the common cases and available literature summarizing its practical findings in enhancing the quality of projects, reducing construction costs, minimizing construction time, and streamlining the management mode and shows the profound meaning of BIM in the field of the industry digital transformation. Besides assisting in filling in the systematic gaps of the current studies, the research also affirms the theories and gives more concrete inspiration on how BIM could be advanced beyond just a local use, to full-process empowerment, which has good consequences on the realisation of the green development, smart construction, as well as effective operation and maintenance in the building and construction field.

2. Research on the current status of BIM application in specific stages of construction

2.1. Design Stage

During the design phase, BIM technology has matured to become more than a mere auxiliary drawing tool to a platform upon which multi-disciplinary coordination and performance analysis can be done. Its usefulness is best appreciated on three features: First, the synergistic nature of the BIM technology and Geographic Information System (GIS) particularly in the three-dimensional site modelling offers an inclusive design and study of the site by construction projects. As opposed to modern design, traditional design techniques are challenging in establishing the links between buildings and environment. By using BIM with GIS, building information may be combined with a geographic data (topography, climate, transport, and so forth) to create a three-dimensional site model and hence, the optimization of building design. Using this combined model, designers can examine the relationship between the buildings and surrounding environment, model aspects of sunlight, ventilation and rain, and maximize energy use and envelope design of the building. Such combination of technologies not only enhances efficiency in designing, but also facilitates green designing and energy saving initiatives to buildings, which is a technical foundation of the sustainability and smart design development of construction projects [3]. Second, the simulation and optimization of performance. BIM is also incorporated with the analysis software (e.g., EnergyPlus and Green Building Studio) to

make postulations of energy consumption, sunlight, ventilation, and similar to the buildings, which can be used to support a green design. Third, generation of drawing and forward design. Directly derived BIM model may also create construction drawings such that the drawings and the model are always consistent and that design efficiency and accuracy is enhanced.

2.2. Construction Stage

BIM technology carries on construction management during the construction stage, thus being able to optimize the resources and management control dynamically. Construction simulation and progress management: Dynamic management and control is obtained. A 4D construction model can be achieved by connecting BIM model with construction schedule. More precisely, the BIM technology introduces all project assignments, resources, and deadlines in three-dimensional space. This will aid the construction team in well comprehending every stage of construction, maximizing the use of resources and properly preventing conflicts and omissions. [5] As an illustration, the Leishenshan Hospital project, BIM design of construction and 4D simulation allowed planning a construction sequence in every detail, which significantly reduced the construction time and made the construction process much more efficient during the hoisting of prefabricated modules. BIM and Internet of Things (IoT) go hand in hand to provide quality management. BIM and the Internet of Things (IoT) are technologies that offer quality control as the building occurs in real-time. The Radio-Frequency Identification (RFID) technology is also used by the BIM platform to monitor the transportation, storage, and installation of materials such that all the construction stages are of the quality and also all construction data is recorded up-to-date [6]. The offered data traceability will not only guarantee quality in construction, but also will provide needed data-support to future operations and maintenance management. The studies have also demonstrated that BIM and RFID management has minimized the waste material by 3% and also minimized the hard work that is incurred. Cost and resource management: delivering the correct foundation. With BIM technology, the engineering quantity can be calculated automatically, and the quota information may be associated with it; the construction cost dynamical management can be provided in real-time and the cost control based on real data can be taken as the accurate one.

2.3. Operation and Maintenance Stage

The stage of operation and maintenance is the most important connection of constant release of BIM value. The BIM model is delivered as an intelligent asset in a digital format to offer assistance in the intelligent management of facilities. To begin with, maintenance of equipment and early warning. BIM incorporates equipment information (models and maintenance records), as well as real-time monitoring of the state in real time through the use of IoT sensors to provide an opportunity to early detect faults in operation. The study by Dou Qiang et al. indicates that a BIM platform is used to monitor the Heating, Ventilation, and Air Conditioning (HVAC) system in an office building. An automatic alarm is set when the ratio of the energy efficiency (EER) is below the mark, and the maintenance efficiency is enhanced by 30 per cent. Secondly, space and energy management. BIM is integrated with the big data analysis in order to visualize the energy consumption distribution and optimize the operational strategy of air conditioning and lighting systems. Indicatively, as per past statistics, user patterns are trained, and environmental settings are dynamically optimized to save on 15 percent of energy consumption [7]. Also, a significant purpose of the BIM+digital twin platform is the energy consumption analysis. The system can automatically optimize the operation strategies of such equipment as air conditioning and lighting as well as reduce overall energy use by monitoring the buildings energy consumption in real time and thus reducing it. An example of this is that the platform forecasts the demand of energy consumption, depending on the real time weather and usage which dynamically controls equipment and assists buildings in meeting green energy-saving objectives. Lastly, decision support and emergency management. The BIM can add firefighting and evacuation routes and aid in the creation of emergency plans, and optimum evacuation routes during fire simulations to decrease any form of casualties. Moreover, a detailed analysis, using model data,

could give scientific decision-making assistance to managers to enhance their efficiency and safety of responding to an operation and maintenance phase.

3. Research on BIM Technology in the Entire Life Cycle of Buildings

3.1. Introduction of BIM Technology in the Entire Life Cycle of Construction

Information integration, process reengineering is basically what is applied in the building lifecycle with the use of BIM technology. Its essence is in that information is unified in one model between planning, design, construction, and operations and maintenance with the help of unified data standards, silos of information are broken down. BIM application also enhances efficiency during each phase of the lifecycle as well as optimizes decision-making due to continuity of the data. An example is that parametric models during the design phase give the prefabrication data to be used in the construction, and parametric models in the construction phase give the equipment information base to be used in the operations and maintenance [2]. In addition, the intrinsic blend of BIM and the new technologies is fueling the creation of intelligent and sophisticated building management. The BIM technology, when used throughout its life cycle, facilitates effective cooperation and information exchange at all stages of the project, has been found to support. The incremental implementation of the BIM at the different phases does not only enhance the design efficiency but also enhance the optimization of the construction management using applications like the 4D simulation and energy consumption analysis. At the operations and maintenance stage, BIM provides a smart management of the facility through the combination of asset management, monitoring energy consumption and equipment maintenance documents to allow constant optimization of the building lifecycle. Besides, a clear BIM project execution plan should be developed as it is essential to ensure that the value of BIM is maximized [8]. This involves the clarification of objectives in the application of BIM, process of standardizing the content of applying BIM applications at each phase and the collective work of all stakeholders in the project using a cohesive range of data standards. The precision standards of BIM model and the standardization of the data exchange control allow the BIM model to effectively support the decision-making process on every stage. BIM technology provides a smooth flow of information and project control in terms of design, operation, and maintenance [9].

3.2. Case Study

The application practice of the BIM full life-cycle to a 50,000 m² complex construction in which the project includes commercial, office, and residential functions, which is a typical manifestation of the role of BIM technology, was elaborated by Dong Dezhi in his research dedicated to the intelligent construction of complex projects [6].

In the design stage, high-precision 3D modeling was used in the project in the format of the Revit tool, which reached Level of Detail (LOD) 300. Some of the tools which were used by the research team in carrying out energy simulation and analysis were Green Building Studio and EnergyPlus. The building envelope was designed with the help of thermal calculations to minimize the cost of building energy (20 percent) and to speed up the building energy consumption to 3,600 kWh. The ventilation system was also optimized using the application of computational fluid dynamics (CFD) which made the heating system to consume less energy by 12%. The project was unique as it incorporated the use of BIM together with the RFID technology in the construction stage so that the construction process can be managed dynamically. The material waste rate was maintained at 3 which was much lower than the target 5 using the Earned Value Management (EVM) to track progress and expenditure. Topographical surveying and progress monitoring were performed using drones with an accuracy of less than 5 cm, which made the 3D printing four times more efficient in constructions and used 30% less material. One of the tasks that allowed robots to do was rebar tying, with a tolerance of 1 mm. The combination of the technologies led to the overall 20 percent improvement of the efficiency of construction, 15 percent of minimization of quality problems and 10 percent minimization of the number of safety incidents. An intelligent facility management system that

combines the EcoStruxure and building management system (BMS) was developed based on an IoT during the operations and maintenance stage of the project. The system incorporates LoRaWAN technology to relay sensor data live to the system and it relies on machine learning algorithms posted on the IBM Watson IoT platform to forecast equipment failures. In the example of HVAC system, below a defined quota of 3.5 the energy efficiency ratio (EER) the HVAC system will automatically send maintenance alert. Big data analytics framework is based on Apache Hadoop and Spark, which processes 1TB of data every day with less than 5 seconds latency and provides the data with a timely response. The convolutional neural network (CNN) anomaly detecting model has 95% accuracy, which is significantly lowering the cost of maintenance and unexpected downtime.

The importance of 4D BIM in all stages of the construction project has been proven based on recent studies. In one example, Rehman et al. showed how it can be applied in a modular construction to combine 4D BIM and construction scheduling and logistics, such that constructing off-shore followed by on-site assembly was seamlessly coordinated in terms of time saving and cost reduction in overall project lead times. Additionally, use of 4D BIM and virtual reality (VR) make construction planning more effective as project timelines are more detailed and immersive and assist in recognizing and eliminating any conflicts. They added that the superior visualization features of 4D BIM are essential in enabling the construction teams to have a better understanding of the sequence and spatial relationship of operations and, therefore, the coordination and decision-making of the stakeholders in construction sites are better managed. 4D BIM is also useful in the allocation of resources and optimizing the construction site logistics. Bortolani et al. took 4D BIM to model the layout of building construction sites to optimize the construction logistics and flow of the material to effectively utilize space and reduce disturbances on site. It is also adopted in the system whereby a laser-scanning technology is incorporated to allow real-time monitoring of progress of the project in which the construction teams can compare the actual progress with the planned progress to ensure that the project is delivered on schedule. The case study indicates that 4D BIM plays an important role in enhancing efficiency in construction scheduling, management of resources and project tracking, which reflects its high importance in the management of construction projects [10].

4. Conclusion

This paper concentrates on the use of the BIM technology in in the building lifecycle, with a structured analysis of the current status of its application and integration features in all the design, building,-use, and maintenance stages. This paper provides a summary of certain BIM application in the multidisciplinary teamwork, sample of performance simulation, construction management, and operation and maintenance of facilities by reviewing literature. Based on the specific case studies (Leishenshan Hospital project and a multifaceted smart project of construction), the analysis of qualitative and quantitative data in this study will show a detailed analysis of the practical impact of BIM technology on the quality of the project, project costs, and construction schedule optimization.

This paper concludes that BIM technology has a great value of application across the building life cycle. In the design phase, BIM is an effective approach in enhancing design quality and efficiency, minimizing design conflicts, and energy consumption with the help of the parametric modeling, multidisciplinary collaboration, and performance simulation. A BIM, which is offered together with technologies: 4D simulation, the Internet of Things, and RFID during a construction stage leads to dynamic control and maximization of resources necessary to reduce the number of waste materials and labor works. BIM as a digital resource facilitates intelligent facility management to enhance efficiency and safety by warning of faults, analyzing power consumption, and perfecting emergency simulation during the operation and maintenance phase. Case studies have indicated that the overall implementation of the BIM technology can save on building energy usage by levels of about 20, enhance building construction by more than 20 and building maintenance by 30 and this is a total testimony of its technological application and its economic worth.

The profound fusion of BIM with the new technologies (like AI and digital twins) remains in its preliminary phase, and the scope of this research does not embrace the possible challenges and application limitations thereof. Lastly, the conclusions of the study can be more accurate with respect to large-scale projects where the technical conditions are relatively mature, whereas their applicability to the projects of small and medium scales must undergo additional qualification.

It should be intensified with research on the cross-stage data integration and collaboration mechanism during the BIM lifecycle with a study on the smooth flows of information transfer with the third party of unified standards of data (e.g., IFC). Moreover, the application of the integration of BIM with new technologies, including smart decision-making using AI and real-time operation and maintenance management with digital twins, should be intensified. Also, BIM application models need to be extended to the realm of specialized application (emergency projects and renovations of existing buildings) to increase its flexibility and versatility. This will eventually ensure the process of digital and intelligent transformation of the construction industry, as it will enable the change of BIM technology usage as a point-by-point activity to a full-process empowerment.

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