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Application of an AI-Enhanced BIM Framework in Super-tall Buildings: A Focus on Wind Effects and Space Efficiency

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Abstract. Super-tall buildings are becoming increasingly prevalent, and in the future, super-tall buildings may become a major field of civil engineering. Due to its characteristics, BIM and AI need to be used to solve the problem. Now, BIM and AI are becoming more and more popular, and super-tall buildings have some questions that BIM can easily answer. This study identifies key challenges, such as wind effects and space efficiency. To address these challenges, a comprehensive analysis of existing literature and case studies was conducted. This study analyzes the problem and searched for much research to find others' findings on these questions. The proposed solutions leverage AI algorithms for predictive wind analysis and BIM for spatial configuration optimization, and support these suggestions with a comprehensive review of existing literature. This study found the questions super-tall buildings faced and reasonable ways to solve the problem. The study underscores the potential of AI-BIM integration to enhance the safety, efficiency, and sustainability of future super-tall buildings.

Keywords: Supertall Buildings; Building Information Modeling (BIM); Artificial Intelligence (AI); Wind Effect Analysis; Space Optimization.

1. Introduction

1.1. Research Background

With the gradual advancement of urbanization in China, the land available for urban construction is decreasing, which has brought super high-rise buildings into the focus of major construction enterprises. Meanwhile, the emergence and application of BIM technology enable construction managers to verify the integrity and rationality of project data through the use of multi-functional building information models, effectively improve construction production methods, and lay a foundation for the smooth construction of super high-rise buildings throughout the entire process [1]. BIM, short for Building Information Modeling, is a digital technology that plays an indispensable role in the digital transformation of the construction industry. The promotion of BIM technology is driven by its demonstrated potential in reducing costs and improving efficiency, thereby enhancing its effectiveness in the construction industry [2]. In the future, BIM technology will create substantial new potential for the design and construction of super high-rise buildings. Traditional BIM models, however, mainly function as information storage tools and do not have the cognitive abilities required for predictive analysis or independent optimization. This is exactly the scenario where Artificial Intelligence (AI) algorithms prove useful: they provide advanced functions in data excavation, pattern identification, and smart decision-making. The appearance and development of AI algorithms have enabled the combination of such algorithms with BIM technology, which in turn offers more robust support for the construction of super high-rise buildings. AI algorithms are highly capable in data excavation, deep learning, and smart decision-making. When AI algorithms are deeply integrated with BIM models, the models can be equipped with an intelligent "brain"—a change that turns them from basic information carriers into all-round platforms with functions of intelligent analysis and decision support [3]. With the help of AI algorithms, BIM models can rapidly analyze large volumes of construction-related data. This allows for accurate prediction of construction timelines, effective management of expenses, early alerts for safety dangers, and smart optimization of design plans [4]. As an example, machine learning algorithms can forecast construction delays through the analysis of historical data; at the same time, computer vision can improve safety monitoring by recognizing dangerous factors from on-site images. Generative design algorithms, on the other hand, can independently explore thousands of design alternatives to optimize for criteria such as structural performance and spatial efficiency. AI algorithms offer an extensive digital and contemporary platform for building and applying BIM models, which in turn support the construction, operation, and maintenance of super high-rise buildings. This paper summarizes and analyzes the achievements of combining AI algorithms with BIM technology. Taking the construction of Shanghai Tower and Burj Khalifa in Dubai as examples, the goals of reducing material usage and improving structural stability have been successfully achieved. This paper will deeply explore the application of BIM models integrated with AI algorithms in super high-rise buildings, and analyze aspects such as their application areas and implementation effects in combination with specific cases.

1.2. Literature Review and Research Gap

Nie et al. proposed that BIM should be used in the design and construction of super-tall buildings over 250 meters, and how to use BIM in the design and construction [3]. Li et al. analyzed the intelligent system in super-tall buildings and the function of BIM technology [4]. Li analyzed the Structural across-wind actions on super-tall buildings and how to measure the influence of wind effects on super-tall buildings [5]. Shi and Dou proposed that the space efficiency of buildings and constructions, as compared in the article, compares the super-tall buildings and common buildings, and they proposed that super-tall buildings offer unique views of it [6].

1.3. Research Framework

First, this study searched a lot of literature and selected the section that is relevant to the study. Next, this study finds some typical examples, such as the Shanghai Tower. This study analyzes the examples and uses them to prove views. Then, this study examined BIM and AI technology and tried to apply the technologies to the construction of super-tall buildings. During the article's writing, this study first analyzes AI and BIM technologies and the characteristics of super-tall buildings. Second, this study analyzes a typical example: the Shanghai Tower, to study the present situation. This study proposes some questions that need to be solved in super-tall buildings. Next, this study proposes some suggestions for these problems with the technologies. Lastly, this study summarizes the article.

2. Analysis of the Present Situation

2.1. The AI-BIM Framework: A Technological Foundation for Super-tall Buildings

2.1.1. Engineering characteristics and requirements of high-rise buildings.

In construction engineering, high-rise buildings are over 40 floors and 100 meters high. General Rules for Civil Building Design in China state that when the height of buildings exceeds 100 meters, the buildings are high-rise buildings. According to the new standard of the World Super-tall Building Society, buildings whose height exceeds 300 meters are high-rise buildings. Due to characteristics such as the long construction period, high construction difficulty, high construction risk, high-rise buildings need more unique technology and facilities. The selection of tower cranes for super high-rise building construction not only meets the requirement of planar coverage but also satisfies the needs of steel structure hoisting. These unique challenges necessitate a paradigm shift from traditional construction management methods, which often struggle with information silos, delayed response, and inadequate predictive capabilities. The combination of Artificial Intelligence (AI) and Building Information Modeling (BIM) has become a key technological solution for tackling these inherent complexities and risks.

2.1.2. The synergistic role of AI-BIM in addressing super-tall building challenges.

Super-tall buildings feature extraordinary complexity, so advancing relevant technologies is essential. The emergence of BIM technology offers a problem-solving approach for the difficulties faced in super high-rise building projects. BIM technology enhances the visualization of the building process: it overcomes the limitations of traditional 2D construction drawings and integrates disciplines from all professional fields into a single unified model [7]. Meanwhile, project-related tasks such as drawing review and collision detection can be carried out according to BIM. Simultaneously, the development of AI algorithms injects new possibilities for new-age BIM, and due to BIM's vigorous promotion, AI technology finds industry applications. Structured and unstructured data, high-precision BIM big data technology, based on internet storage resources, computing power, and computing frameworks, will directly trigger a revolution in the application of AI in BIM design. For example, machine learning algorithms can analyze IoT sensor data from the site to predict equipment maintenance needs and prevent delays. Computer vision can integrate with BIM models to compare as-built conditions with the design model for quality control. Natural language processing can automate the coding of building regulations into BIM objects to ensure compliance.

2.2. Case Study: Implementation of AI-BIM in Shanghai Tower

2.2.1. Design.

In the construction design of Shanghai Tower, due to construction difficulty, high construction cost and so on, architects use a large number of BIM and AI since design phase, plenty of innovative design concept applied to this construction, In order to pursuit the target of vertical city and green super high-rise building, the project adopts numerous advanced design concept, such as curtain wall system rotating, dividing and rising, wind power generation facility in roof canopy section, public atrium design for each area. Despite the maturity of the technologies employed, their implementation presented significant challenges during the construction phase [8]. At the same time, the introduction of AI technology makes BIM play a huge role in coordination and communication, improving efficiency, quality control, cost optimization, information integration, and so on. It sets a benchmark for the application of technology and pushes its popularization [9].

2.2.2. Construction.

In the construction phase, the construction of Shanghai Tower faced many difficulties, such as cost control being too difficult, information transmission being difficult, and difficulty in simulation. However, the appearance of AI-BIM provides a way to solve these problems. By the implementation of BIM in building site simulation, construction deepening draft design, 4D building emulation, space simulation of large machinery operation and so on, it achieves sound oversight and administration in building quality, safety, expense and advancements, it is on hoisting of steel structure, concrete construction, operation of steel platform system and large tower crane climbing highly effective [8]. AI's optimization capabilities were particularly evident in the intelligent allocation of resources (e.g., labor, materials, equipment) on site, leading to enhanced productivity and efficiency [9].

2.2.3. Operation and maintenance.

Compared to the design and construction phase, the operation and maintenance phase has longer cycles, more complex participants and machinery involved, and relatively less experience, so in this regard, there will be more emphasis on the use of BIM. In the O&M phase, the BIM model evolves beyond a mere 3D geometric repository into a comprehensive digital twin. It encapsulates not only the historical data of components and as-built spatial layouts but, most critically, the operational logic defined by the O&M team. This logic includes the functional relationships between systems, subsystems, and equipment, the spatial dependencies of assets, and the key performance indicators (KPIs) for monitoring system health [9]. Therefore, BIM, with the help of AI, can connect information and equipment systems during the operation and maintenance phase to form an organic whole.

3. Problem Analysis

3.1. Analysis of Wind Effects and Aerodynamic Challenges

In the construction of super-tall residential buildings, wind effects are not to be ignored. A relatively recent trend in super-tall and mega-tall building design has been the move from commercial use to residential use [10]. However, the full spectrum of environmental effects, particularly wind-induced motions, may not be fully appreciated in the initial design stages by all architects. Super-tall buildings are particularly sensitive to wind loads because of their high slenderness and low damping [11]. Consequently, architects and structural engineers must meticulously consider material selection, structural system design, and aerodynamic shaping. For example, across-wind loads may have a significant effect on super-tall buildings, so their effect is an important factor in structural design. At present, the function mechanism of across-wind load on super-tall buildings and structures is widely acknowledged to include inflow turbulence excitation, wake excitation, and aeroelastic effect [12]. The architects can use many ways, such as the wind pressure integration method and so on, to obtain more data so that wind effects will have less influence on super-tall buildings. BIM technology facilitates a more rigorous analysis of wind effects by enabling the creation of high-fidelity digital models for simulation. BIM can assist in making structural models for experimental methods such as the Wind pressure scanning approach and the high-frequency force balance method [12].

In today's world of super-tall buildings, there are some difficult situations to face in order to abate wind effects. The primary one refers to the operative mechanism of across-wind loads and their associated effects. Prior studies centered primarily on the operative mechanism of basic across-wind load [12]. At present, wind tunnel tests can acquire data on external across-wind aerodynamic forces, across-wind responses, and across-wind aerodynamic damping—all of which need to be calculated for the structural design of super-tall buildings and structures. The second aspect concerns across-wind aerodynamic forces. Such forces can generally be acquired via the following approaches:(i) identifying across-wind aerodynamic forces based on the across-wind responses of an aeroelastic building model in a wind tunnel;(ii) acquiring across-wind aerodynamic forces through spatial integration of wind pressures acting on rigid models;(iii) directly obtaining generalized aerodynamic forces by measuring the base bending moment with a high-frequency force-balancing technique [12]. Each way has its unique place to solve problems. Next is across-wind aerodynamic damping. In the past, people weren't aware of that and didn't have effective methods to measure it. But now researchers have developed many effective ways to solve it. The last is the application to the codes. Materials and design plans need to conform to Chinese codes.

3.2. Analysis of Space Efficiency and Vertical Transportation

Space efficiency is a significant factor in every construction and building. In super-tall buildings, space efficiency is a very important factor. Among these, modes of transportation such as vertical traffic and so on are the most significant. Nowadays, the competition for height persists at an increasing rate within the construction sector. Still, super-high-rise buildings incur higher costs for construction and operation on a per-square-meter basis, and they provide less usable floor space compared to traditional office buildings [13]. There are many angles to consider in terms of space efficiency and transportation. Several key research findings are as follows:(1) Space efficiency ought to be taken into account alongside other types of efficiency, including structural, operational, and energy efficiency;(2) Space efficiency is shaped by the functional distribution in mixed-use high-rises;(3) Space efficiency in single-function buildings tends to be higher than that in mixed-use counterparts;(4) Space efficiency can be enhanced if optimal structural systems and the corresponding building forms are co-developed;(5) Space efficiency may be greater if a building compromises its serviceability by cutting the number of elevators, thereby achieving a smaller core area [13]. Due to these complex angles and complex content, BIM technology may help people solve the problem. Nowadays, the world is calling for green and environmental protection, so people need to consider sustainability in super-tall buildings. Sustainably designed, high-efficiency buildings and "green building design" have emerged as key architectural standards in the present day [14]. So, people will use more environmentally friendly materials and adopt a greener design scheme. At the same time, iconic is increasingly used in super-tall buildings' space efficiency. But it is usually criticized. In some design circles, iconic architecture has received harsh criticism for embracing inappropriate forms, including awkward, insensitive, cost-intensive, and eccentric designs, for the mere purpose of competing for attention [14]. With the progress of the times, people's standards are changing over time. Today's vertical transportation proposes new standards. For example, some super-tall buildings need a new type of elevator, so some companies' next step aims to get back flexibility while reducing masses in the system, such as circulating rope-less multicar elevators, propulsion systems, lightweight cabins, and guiding elevator cars and exchangers [15]. In conclusion, space efficiency is a paramount concern that must be addressed from the earliest design phases of a super-tall building.

4. Suggestion

4.1. Integrated AI-BIM Strategies for Mitigating Wind Effects

Wind effects can have a significant influence on super-tall buildings, so architects need to take action to protect them. As a result, BIM and AI technologies are growing in popularity. With the widespread use of computing technologies and digital tools in architectural modeling, together with advanced structural analysis and innovative design and construction methods, extremely tall buildings can now be built with complex architectural and structural designs and intricate shapes [16]. In today's construction industry, architects prefer to use BIM technology to solve these issues. Using BIM improves collaboration and provides better control over projects of all sizes [17]. For example, architects can use it to simulate how super-tall buildings withstand wind effects. BIM can also simulate wind tunnel tests. It significantly reduces the workload of architects and allows for quicker access to data related to super-tall buildings. Additionally, AI technology makes BIM more user-friendly. AI algorithms automate labor-intensive data processing tasks, enabling rapid information synthesis and data-driven decision support. BIM Tech has great application potential in the intelligent system design of super high-rise buildings [18]. With the help of BIM and AI technology, architects can do more creative work. Through these technologies, people can determine the effects of wind, such as by using detailed data across the wind, so they have enough information to design a reasonable structure and use suitable materials.

4.2. AI-BIM Framework for Optimizing Space Efficiency and Vertical Transportation

While space efficiency is a critical consideration for all buildings, it presents a magnified challenge in super-tall structures. In order to plan the space of super-tall buildings. So as to develop, administer, and disseminate highly elaborate and information-dense three-dimensional models, design professionals are resorting to BIM [17]. Through the models, architects can use them to analyze the mode of transportation, such as vertical traffic.

The effectiveness of this approach is hinted at in projects like the Shanghai Tower, where its zoning and vertical transportation strategy contributed to its functionality. The proposed AI-BIM framework would systematize and enhance such decision-making processes. A typical building is the Shanghai Tower. As a representative mixed-function tower, it is split into nine vertical sections, with retail spaces on the lower levels, office areas in the middle tiers, and hotels, cultural facilities, and observation platforms on the upper levels. Crafted by the architectural practice Gensler, the tower incorporates a host of sustainable design features—including a tapering and twisting structure that cuts wind loads by 24%, resulting in substantial savings in total building materials. The building's transparent inner and outer facades allow maximum natural light penetration, thereby lessening the demand for artificial lighting. The tower's outer envelope also provides thermal insulation for the structure, cutting energy consumption for heating and air conditioning. Additionally, the tower's spiral-shaped parapet harvests rainwater, which is utilized for the tower's HVAC systems [18]. AI technology can also play an important role in this process. AI can handle lots of complex data, and architects can find valid information rapidly so that they can make quicker and more correct decisions. The rationality of space efficiency design can become better and better. BIM can additionally be employed to incorporate diverse design schemes, provide analysis, generate documentation, and help identify and solve issues in the design phase before construction. Due to this perfect preparation, super-tall buildings' vertical traffic can have a very reasonable arrangement, and the space efficiency can satisfy plenty of standards such as the China code, sustainable requirements, and environmental protection.

5. Conclusion

5.1. Key Findings

This research examined the key challenges of wind impacts and space efficiency in super-tall buildings, and put forward an integrated AI-BIM framework as a solution. The main findings can be summarized in three aspects:

First, in terms of the technological foundation, combining AI's predictive and optimization capabilities with BIM's comprehensive data modeling creates a paradigm shift for tackling the inherent complexities of super-tall buildings—surpassing the limitations of traditional BIM.

Second, from the perspective of problem analysis, addressing wind impacts requires sophisticated aerodynamic analysis, which is usually iterative and expensive; meanwhile, optimizing space efficiency involves complex multi-objective trade-offs, including balancing leasable area, vertical transportation systems, and structural stability.

Third, and most notably, regarding the proposed solution, the AI-BIM framework shows substantial potential. For wind impacts, it supports a workflow that integrates parametric BIM, generative design, and AI-accelerated CFD (Computational Fluid Dynamics), enabling rapid aerodynamic optimization. For space efficiency, it provides a data-driven method: by using BIM-integrated simulation and multi-objective optimization algorithms, it helps balance conflicting design objectives.

5.2. Research Significance

This research contributes to the field by providing a structured and technologically detailed framework for applying AI and BIM to super-tall buildings. Its significance lies in: (1) Systematizing the approach: It moves beyond general claims about AI-BIM benefits by outlining specific workflows for two critical challenges, offering a replicable model for practitioners. (2) Enhancing design decision-making: The proposed framework emphasizes early-stage, data-driven optimization, which can lead to safer, more efficient, and more sustainable outcomes. (3) Bridging the gap between technology and application: It demonstrates how cutting-edge AI algorithms can be practically integrated into the established BIM methodology, providing a clear path for the digital transformation of super-tall building design and construction.

5.3. Limitations and Future Study

This paper has certain limitations. First, it does not utilize primary data—most of the data and information adopted are secondary. Second, the paper lacks a sufficiently detailed analysis of BIM and AI technologies; this leads to a lower proportion of content about new technologies compared with the content introducing super-tall buildings. Additionally, the paper fails to conduct an in-depth analysis of relevant documentation, resulting in research findings that rely largely on superficial citations of existing literature. For future research, primary data could be obtained through surveys and interviews. Furthermore, the paper could carry out a more detailed analysis of documentation and conduct more in-depth studies in related fields. It could also incorporate more content about BIM and AI technologies, and conduct more thorough research on these new technical tools.

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