International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 729-736 www.ijaem.net ISSN: 2395-5252

Application of Smart Construction Based on BIM in the Construction Phase of Building Engineering

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Date of Submission: 25-08-2024 Date of Acceptance: 05-09-2024

ABSTRACT: With the emergence of advanced technologies such as Building Information Modeling (BIM), cloud computing, Internet of Things (IoT), GIS, and 5G, the application of smart construction in the architectural industry has come into focus. Aiming to foster the digitization of construction and urban management, and to enhance the efficiency and precision of project management, this study delves into the integration and application of these avant-garde technologies—particularly BIM—within a library construction project. By utilizing the "Pin Ming" series software based on Revit and CAD, we accomplished the application of three-dimensional modeling design by BIMand construction management techniques, ensuring real-time monitoring of project progress, engineering quality, and cost, thereby facilitating on-site construction management. Additionally, this research explores the methodology of employing emerging technologies to establish a 5G smart construction site, actualizing the synergy between architectural engineering, BIM, and smart technologies in smart construction.

KEYWORDS: Smart Construction;Construction Phase; BIM Technology; Construction Management; Smart Construction Site.

I. INTRODUCTION

Accompanied by the advancements in BIM, cloud computing, IoT, GIS, 5G, and other emerging technologies, society is gradually entering the era of intelligence. The digital transformation of the construction industry has become an essential path for exploring the future development of China's construction.

In recent years, the application of digital technology in construction and urban management has increasingly become a research hotspot. Specifically, BIM technology (Building Information Modeling) has showcased its value and potential in various aspects. Wang, Y., Wei, T., Zhang, X., et. al. explored the application of BIM technology from the perspectives of bridge construction management and residential building design, respectively [0-[2]]. Moreover, numerous researchers have delved deep into the application of BIM technology in different construction scenarios [[3]-[9]]. Of particular note, Guo, W. et al. and Sha, F. focused on the role of BIM in intelligent and green construction, while Pan, Y. & Zhang, L. further explored the combination of BIM technology with artificial intelligence [[10]-[12]].

Smart construction, an emerging direction focusing on the digitalization, automation, and informatization of the construction process, has also garnered widespread attention from both the industry and academia. More researchers analyzed the significance of smart technology in construction management [[13]-[15]]. Specifically, Jiang, Y. et al. and Chen, M. et al. studied applications related to smart construction sites and traffic flow prediction [[16],[17]]. Additionally, smart construction in the realm of green building has also attracted the research interest of scholars respectively used bibliometric methods and technological reviews to discuss the development trends of smart buildings [[18]-[20]].

Meanwhile, smart cities have become the core concept of modern urban construction and management. In this domain, Dang, A. et al. delved into the progress of urban information models in smart cities [[21]]. In contrast, Berglund, E. Z. et al. reviewed the application of smart city technologies

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from the perspective of civil engineering, emphasizing the crucial role civil engineers play in this process [[22]]. These studies and practices signify that construction and urban management are rapidly evolving towards a more digital and intelligent direction.

Smart construction is a digital construction platform built upon emerging technologies like BIM, IoT, GIS, cloud platforms, and virtual reality. As a nascent construction philosophy, smart construction is the amalgamation of intelligent information technology with modern construction management technology. Under the impetus of informatization, it encompasses data acquisition, information processing, information transmission, and information reuse in projects, gradually achieving the wisdom of construction patterns from digital construction. The development of smart construction technology has been increasingly applied to the entire construction process, from design and construction to operation and maintenance. Through the use of emerging technologies, digitalization of the construction site management process, spatial + architectural entity digitalization, real-time control, efficient management, and rapid and precise decision-making are achieved for on-site construction.

II. DESIGN PHASE - 3D MODEL CREATION

2.1. Project Overview

The project consists of a library and a corridor. The above-ground structure of the library spans five floors with one underground level. The elevation difference between the indoor and outdoor sections of each unit is 0.15 meters. The main body of the structure stands at 23.60m and is constructed using cast-in-place concrete frame beams and columns, layered slabs, and partially prefabricated beams. The heights of the first and second floors are 4.500m, the third floor is 4.200m, the fourth and fifth floors are 3.800m, and the mezzanine is 2.800m. The corridor is three floors above ground, with each floor being 3.9m in height. The main body has a height of 12.65m and also uses cast-in-place concrete frame beams and columns. The underground section serves as a civil defense area. The main focus of this study is the above-ground main structure, which, along with the roof, is made of reinforced concrete.

2.2. Civil Construction Model Creation

In China, the mainstream approach with BIM is to first complete the construction drawings, followed by 3D modelling. In contrast, BIM-based forward design entails the design of engineering projects entirely within a 3D environment from the sketch design phase to the delivery phase [[23]]. This paper primarily develops the BIM reverse modelling of the above-ground civil construction section based on architectural and structural professional design drawings. Model creation mainly uses the Pinming HiBIM software, which then undergoes collision checks, clear height analysis, model reviews, and other comprehensive analyses on the created model. Based on the results of these checks and analyses, optimizations are made to the design, leading to the creation of a civil 3D model, facilitating the subsequent intelligent application of the BIM model.

The paper mainly focuses on creating the model for the above-ground main structure. During the structural model BIM reverse modeling phase, based on the structural construction drawings, the HiBIM software is utilized for a one-click rapid and efficient reverse modeling, optimizing the modeling process, and completing the primary framework structure's model creation and design review. Based on the structural model, elements like walls, doors, windows, rain shelters, ramps, stairs, and other components are arranged to complete the architectural 3D model. The structural and architectural models are shown in Figure 1, respectively.

2.3. Comprehensive Optimization of Civil Engineering Model

After the construction of the civil engineering model, it is further refined and optimized based on construction requirements and relevant design standards to enhance the architectural structural model. The HiBIM software from Pinming is used to conduct advanced design analysis, collision detection, and net height analysis on the constructed model. This allows for swift identification of discrepancies between blueprints and the model, enhancing the quality and efficiency of the refinement process. By creating the 3D civil model, common issues in the blueprints across various construction disciplines are identified and checks for missed or erroneous components are performed. From a construction perspective, the model identifies challenging constructions and complicated structural nodes.

Collision detection aids in locating and revising the 3D model. Based on the report's findings, the model is adjusted in coordination with the design team, pre-emptively resolving issues related to basements, corridors, and headroom, thereby optimizing the design. Updated blueprints after collision check optimization are used for technical handovers to onsite construction

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personnel, enabling effective communication with designers, clear scheduling across disciplines, and efficient construction completion [[24]]. Net height analysis ensures a thorough check of the overall clear height, and upon analysis, necessary adjustments are made. The model also undergoes a comprehensive check and overlapping components are identified, ensuring that the model is standardized, complete, and accurate. This inspection aids in eliminating any overlapping components, ensuring subsequent component information is accurate, avoiding data discrepancies.

2.4. Blueprinting and Quantifying from the Civil Engineering Model

Once the model is refined, renderings are produced from the architectural and structural models. The blueprinting feature allows for quick annotations on the model, generating construction drawings compliant with national drawing standards and blueprinting guidelines. This process also outputs construction quantities aligned with cost estimations, significantly enhancing the output efficiency.

(a) **(b)**

Figure 1. (a) Structural Model Illustration; (b) Architectural Model Illustration.

III. CONSTRUCTION PHASE - OPTIMAL SITE LAYOUT

Construction site layout is designed for efficient on-site work by the construction crew. Considering factors like surrounding roads, rivers, residential buildings, and existing structures, internal space is planned rationally. Layouts are planned for on-site roads, material storage, entrance and exits, work zones, living zones, and machinery like cranes. Layout planning simulates paths and timings for construction workers and transportation vehicles, ensuring efficient movement and segregation on site. The arrangement and capacity of machinery like cranes are assessed to ensure they meet construction demands, allowing for smooth operations during peak manpower and vehicular activities.

3.1. Creation of 3D Site Layout Model

Based on the master plan provided by the developer, the construction site is planned and a BIM layout model is created, which aids in optimizing the layout plan. Virtual construction simulations are conducted in accordance with construction sequences and procedures, enhancing decision-making abilities of managers and visualizing on-ground strategies during the construction phase.

During the overall construction layout process, BIM technology is employed to produce visual representations like layout diagrams and panoramas, visually simulating the post-layout scenario, promptly identifying issues, aiding revisions, and assisting in decision-making. The article utilizes Pinming's 3D construction planning software, breaking down the construction site into phases and creating a 3D model, then leveraging features like map integration, construction simulation, and compliance check to standardize and smarten up the site.

Before construction begins, the overall site layout is modelled and planned rationally. The project is divided into earthwork, structural, and decorative stages, with individual layouts for each. For repetitive living areas, phase copying is employed for quick layout. Layouts for each phase are shown in Figure **Error! Reference source not found.**. In the BIM-based planning, existing structures around the site, proposed buildings, machinery, and various work zones are modelled in 3D. Using software, 3D site layout models, plans, route maps, and visualizations are created, depicting the entire construction panorama and specific zone outcomes, assisting in finalizing the

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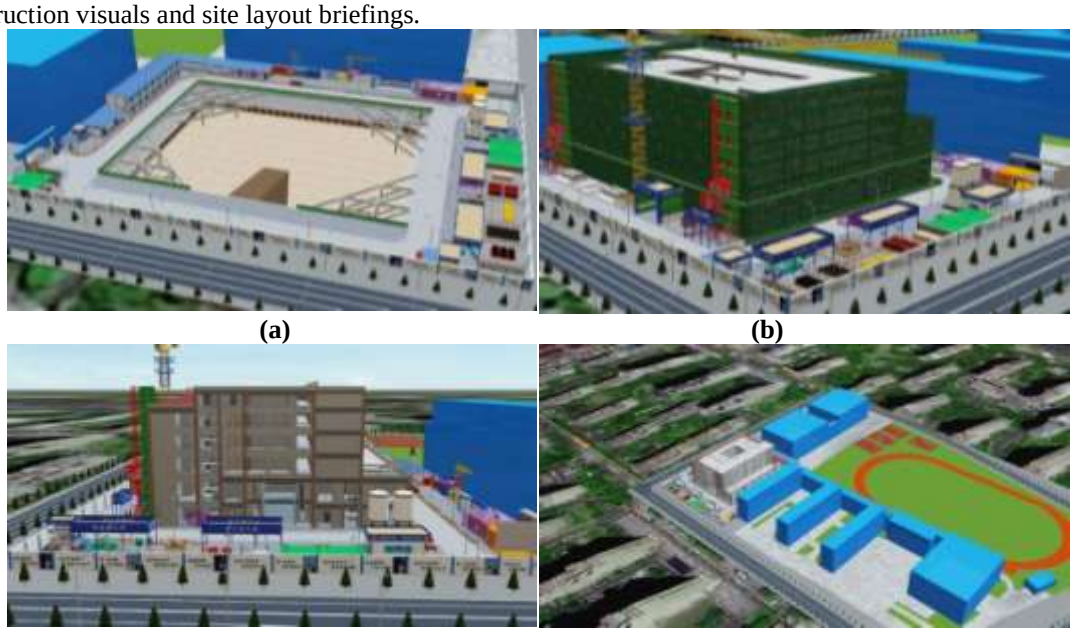
construction visuals and site layout briefings.



(a) **(b)**

(c) **(d)**

Figure 2. (a) Earthwork Stage Site Layout; (b) Structural Phase Site Layout; (c) Decoration Stage Site Layout; (d) 3D Linkage Effect Diagram.

Furthermore, using the map integration feature, 2D layout blueprints are linked to the map, creating a 3D integrated display. This melds the site model with the actual geographic scenario, allowing adjustments based on real conditions.

3.2. Site Layout Model Analysis and Optimization

During the construction site layout phase, a comprehensive application of various intelligent, digital, and model-based technological means is employed to ensure the safety of construction personnel on site. For instance, traffic analysis is conducted for construction vehicles and roads to ensure smooth access to and from the construction site. For tower cranes, an intelligent lifting capacity analysis is carried out to determine if collisions, overloading, or other incidents might occur during the lifting process, ensuring the safety throughout the construction procedure. Using planning software to layout prefabricated components, the layout and selection of tower cranes, as well as the arrangement of construction roads, are based on the fundamental principles of layout and selection, grounded on the model and fundamentally data-driven for intelligent analysis recommendations.

(1) Lifting Position Analysis

By selecting the site material stacking area, the location of the proposed building, etc., and in accordance with the internal safety specifications of the software, intelligent analysis of the tower crane's lifting capabilities, intelligent equipment model recommendations, and intelligent analysis of equipment positioning are carried out. This allows for the analysis and recommendation of selectable tower crane models, radii, and feasible positioning within the site, rational arrangement of tower cranes, and the positioning of material stacking areas for the earthwork, structural, and decoration phases, followed by the generation of related lifting analysis reports.

(2) Vehicle Traffic Analysis

Focusing on the construction site layout and construction road arrangement, an analysis of vehicle traffic on these roads is carried out. The simulation replicates the movement of vehicles on the construction site, checking if the road arrangement is logical and whether vehicles can pass smoothly. Reports on road bending, turning, and vehicle meeting scenarios are generated, with calculations for vehicle turning in bends and the corresponding analysis reports.

(3) Standard Inspection and Material Statistics

The site layout model is checked for compliance with the arrangement standards and the project materials are tallied. An intelligent analysis based on standards is used to identify content that doesn't comply with the norms. The site layout is optimized and modified according to rectification suggestions.

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3.3. Virtual Construction Simulation

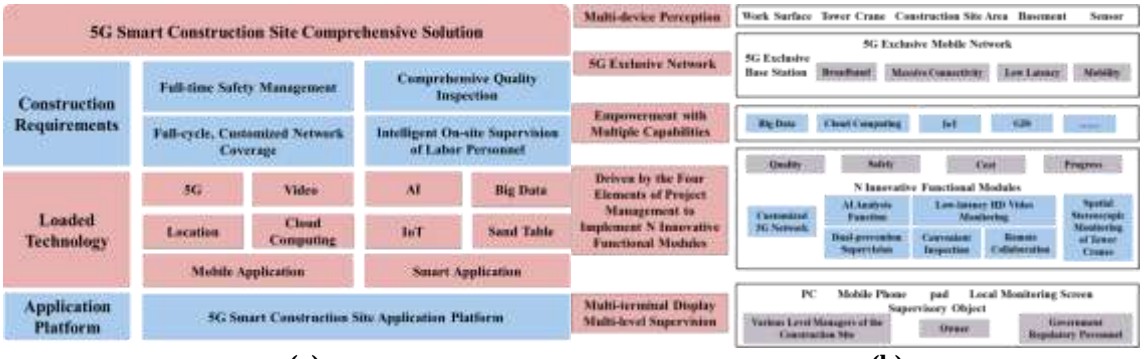
Using BIM technology, a virtual simulation of construction is conducted on the 3D site layout model. The feasibility and reasonableness of the construction schedule are assessed in line with progress. Via a cloud platform, real-time monitoring of actual construction progress is facilitated. Before construction, 3D animated videos are made for key construction nodes, complex processes, etc., to provide visual briefings to teams and management staff. Standardized and reliable briefing methods are employed to ensure effective communication, thereby ensuring the quality of construction.

For the main construction phase, planning software is used to simulate earthwork construction, external scaffolding, foundation pit support, tower crane operations, edge hole protection, project department temporary construction planning, temporary water and electricity layout, and overall virtual construction simulation. The site layout 3D model is time-linked to perform 4D construction simulation. The simulation supports collision checks and real-time video rendering, including collision check reports. After creating the site layout model, various construction sequences are arranged. Construction planning software links the construction schedule to simulate the construction process. The smart construction process involves comparing the actual and simulated plan progress, monitoring the construction progress in real-time, and ensuring the project is completed as planned.

During the construction process of architectural projects, it is imperative to have real-time control over the construction progress. The integration of BIM technology with 3D modeling for animation simulation makes the construction schedule more accurate and efficient, while also providing significant early warning and adjustability. Intelligent analysis and timely adjustments are made based on potential situations that might arise during actual on-site construction. In the project engineering deduction phase, using the BIM model in conjunction with the site plan layout of the construction site, simulations are made for site plan layouts during the earthwork, main body, and decoration phases, resulting in a construction process simulation animation. This refines the layout for each phase of the project, greatly enhancing the image of safe and civilized construction site management.

IV. INTELLIGENT CONSTRUCTION MANAGEMENT PLAN

The complexity and variability of the construction site environment, the instability of wireless networks, and the difficulty of wired network installation can hinder the success of smart construction site development. In recent years, with the continuous improvement and widespread application of 5G technology, integrating 5G into smart construction site development can achieve practical innovations in various intelligent features, realizing visualized operation in construction management. For the six elements of construction, namely, people, machinery, materials, methods, environment, and measurement, combined with 5G technology, digitalization, intelligent devices, and other innovative technologies, the 5G Smart Construction Site is created to implement smart construction and achieve comprehensive intelligent management (Figure 2).



(a) **(b)**

Figure 2. (a)Overall Scheme of the 5G Smart Construction Site; (b) Smart Construction Site Platform Architecture.

By merging traditional smart construction sites with technologies like 5G, an innovative smart construction site platform architecture is developed. Based on the actual operational requirements of the construction site, new technologies are integrated and optimized to gain a

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systematic understanding of the entire construction process, coordinate construction operations from all parties, perceive the construction process through intelligent analysis, VR real-scene experiences, simulation of construction, etc. This helps in realizing intelligent and precise operation and management of construction projects, continuously enhancing the ability to control the construction process.

By utilizing the "BIM+5G Smart Construction Site" management platform, it facilitates coordination and communication among all parties involved in the construction process, enabling real-time and efficient control and management of the construction workflow. This ensures the efficiency of real-time management of construction quality, cost, and schedule, achieving transparent and visualized construction management. The platform maximizes the application value of technologies such as BIM, 5G, and the smart construction site cloud platform.

Based on the GIS+BIM smart operation and maintenance platform, the richness, parameterization, and visualization characteristics of BIM model component data are fully utilized. This spans across various multi-dimensional business lines, connecting systems like leasing, security, warranty, cleaning, and curtain wall systems. Using the Internet of Things (IoT) and big data, perception capabilities are given to building components and equipment, extracting and analyzing the quantifiable value of energy consumption, assets, behavior, and management. By combining advanced technical methods and outstanding management philosophies with the construction process, an advanced construction management solution is explored, effectively addressing various issues in the construction process on-site.

V. INNOVATIVE APPLICATIONS

5.1. BIM Collaboration

All parties in the project communicate and exchange issues in real-time through the BIM 3D model, transforming communication to an online and centralized method. Compared with the traditional offline, fragmented way of describing in text or 2D drawings, this significantly enhances collaboration efficiency during the construction process. Using the big data project dashboard feature, various dynamic project information can be viewed online, enabling management to control the site without leaving their office. By adopting the engineering data cloud platform and based on the BIM model, progress is visually represented, contrasting with virtual construction simulation animations. It also integrates with on-site video surveillance, accurately analyzes actual progress, contrasts it with planned progress, quickly identifies lead or lag reasons, and assists project analysis decisions.

5.2. BIM+GIS+CIM Application

The Geographic Information System (GIS) represents 2D and 3D spatial shapes. By combining key factors like population, geography, socio-economics, and the environment, it provides environmental information about nature and buildings. BIM technology transforms 2D planar graphics into 3D physical models, integrating various building information to establish an informational model. GIS provides real-time data on the surrounding environment of the project to BIM, assisting designers and engineers in exploring and evaluating design and construction.

By integrating the construction site layout planning model with satellite imagery, the fusion of BIM+GIS is realized, authentically reproducing the actual surroundings of the project. This integration of the construction site layout and the surrounding GIS geographical environment creates a more realistic site effect. Viewing the complex environment around the project location assists in project planning decision-making more efficiently.

Based on BIM, GIS, IoT, etc., by merging urban perceptual data, a comprehensive urban data body is built – the City Information Model (CIM) platform. Currently, the application research of smart cities has achieved certain results. By linking big data and spatiotemporal engines, interconnection of everything is realized. By creating a CIM platform that merges various digital technologies, the implementation of CIM+ smart construction site application is realized, promoting the development and construction of smart cities. The fusion of BIM+CIM technology can assist cities in managing costs, progress, etc., at the component precision level, opening up a new situation for intelligent approval of construction projects.

At present, the application of CIM is not mature. Its development mainly focuses on the integration with BIM technology and the combination with Internet of Things (IoT) data. In the future, as the integration of BIM+GIS+CIM technology continues to mature, the creation of the BIM+GIS+CIM platform will achieve full spatiotemporal data fusion. This will promote innovative urban governance models, achieve spatial sharing, governance, and value-added, assist in the digital transformation of cities, and push for

the construction of a three-dimensional real-scene representation of China.

5.3. Lightweight Model Viewing

Through the document management module, online management of project materials is achieved. In the form of folders, each file and each project member is managed and controlled to prevent unauthorized file access. This enhances the scientific, orderly, and secure management of project documents. The related models and drawings of engineering projects can be viewed and managed across platforms, supporting formats like BIM models, drawings, documents, and PDFs for online viewing on both mobile and web platforms. Users can roam, measure, and slice models, collaborate across departments, and achieve lightweight BIM viewing. This meets the needs of on-site and remote lightweight viewing of engineering projects.

VI. CONCLUSION

This article primarily relies on BIM and information technology, integrating intelligent technology throughout the construction management process of engineering construction, aiming to create a smart construction site and achieve intelligent construction that particularly targets the construction process. By employing remote video monitoring, lightweight model viewing, multi-party interactive collaboration, and VR roaming simulation, and other smart technologies, the aim is to realize intelligent and visualized construction and management. This creates a smart construction site platform, thus elevating the technical application level of architectural engineering management.

By applying BIM technology, reverse modeling is carried out during the design and construction phase to create a civil BIM model to verify whether the engineering construction is correct and reasonable. During the construction phase, three-dimensional site layout planning and virtual construction simulations are used to simulate the construction site process. Using new technologies such as 5G and cloud platforms, a smart construction site is created for on-site operation and maintenance management during the construction process. Through cloud data, the design, construction, and management processes are linked to create lightweight, intelligent construction, improving management efficiency and construction quality in the intelligent construction process.

BIM technology is used to establish a three-dimensional model for on-site construction guidance, changing the interactive methods, operations, and construction management models of the construction industry in the past. By integrating new technologies like cloud platforms into the entire construction process, there is a commitment to comprehensive management at all stages of the construction site, real-time control of key construction processes, and efficient and high-quality coordination management with all parties. The goal is to create a visual, intelligent, digital, and simulated construction process, realizing intelligent construction of architectural engineering.

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