Postprint on Integrated Smart Construction Site Application in the Zhuhai Hengqin International Financial Center Tower Project

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Abstract

Based on the smart construction site concept, the Hengqin International Financial Center Building has conducted a series of research and development initiatives in collaborative platforms, BIM, IoT, and related areas. In the collaborative platform aspect, it has established horizontal project-level and vertical corporate-level data transmission chains to eliminate data silos. Regarding BIM, it leverages advanced technologies including AR, VR, drones, and laser scanning to facilitate detailed design, and utilizes construction simulation to verify scheme feasibility. The IoT platform is committed to achieving automatic collection, monitoring, and analysis of on-site data, thereby providing a robust data foundation for project management.

Full Text

Preamble

Integrated Application of Smart Construction Site Technologies in the Zhuhai Hengqin International Financial Center Tower Project

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Abstract

The Hengqin International Financial Center Tower project conducted systematic research and development on collaborative platforms, BIM, and the Internet of Things based on the smart construction site concept. Regarding the collaborative platform, the project established horizontal data transmission chains across the project and vertical connections to the corporate level, eliminating data silos. For BIM applications, advanced technologies including AR, VR, drones, and laser scanning were employed to assist in detailed design and construction simulation for verifying scheme feasibility. The IoT platform focused on automatic collection, monitoring, and analysis of site data, providing a solid data foundation for project management.

Keywords: smart construction site, collaborative work, BIM, Internet of Things, cloud platform, integration, personnel management

1.1 Project Overview

The Hengqin International Financial Center Tower is located at Plot 8, Offshore Financial Island, Hengqin Central Business District, Hengqin New Area, Zhuhai. The project comprises a total construction area of 219,200 square meters, with a building height of 337 meters. The tower includes 69 above-ground floors, a 4-story podium, and 4 basement levels. As a urban complex integrating Grade-A office space, commercial exhibition facilities, dining, and business apartments, it represents the tallest building under construction in the Zhuhai-Macao region.

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1.2 Project Characteristics and Challenges

The project features high quality standards, tight schedules, extensive general contractor coordination requirements, complex architectural forms, and demanding technical specifications, posing significant challenges for smart construction site IoT technology in collaborative management:

1. The project aims for the Luban Award and National Green Construction Demonstration Project status, requiring exceptionally high management standards.

2. The office tower employs an intelligent self-climbing formwork system with innovative tower crane jacking technology that eliminates the need for beam removal, necessitating rigorous safety monitoring.

3. The total construction period is only 1,151 days, with massive project scale and numerous specialized subcontractors. Coordinating simultaneous workfaces across multiple trades presents enormous challenges. Traditional planning management methods suffer from low automation and

cumbersome processes, often leading to gaps in process management that cannot meet the project' s requirements.

2.1 Application Objectives

Through BIM technology applications and the introduction of new technologies such as drone aerial surveying, laser scanning, and AR/VR, combined with information systems including IoT and cloud platforms, the project aimed to achieve information interconnectivity. By integrating the "IoT+" concept with key management elements—schedule, safety, quality, and technology—the project sought to organically combine new technologies to create an intelligent construction site where the worksite functions as a "living organism." The initiative aimed to eliminate data silos, establish seamless data transmission chains, enhance construction site supervision and management levels, promote scientific and technological innovation in construction projects, and ultimately achieve lean construction goals. The specific functional division is illustrated in Figure 2 [Figure 2: see original paper].

2.2 Software and Hardware Configuration

Software selection is critical to project implementation, requiring clear understanding of platform capabilities and characteristics to support application objectives. Selecting complementary software that enables data sharing and efficient collaboration forms the core of building a smart construction site and achieving lean construction [1], as detailed in Table 1 .

Table 1 Software Selection

Management Platform Software	BIM Application Software
BIM-based Smart Construction Site IoT Management Platform (self-developed)	Revit, Tekla, Magicad, Rhino (modeling)
ProjectWise Information Management Platform (information storage and sharing)	ContextCapture, Descartes (reality modeling)
PMS/IMS/DSS Enterprise Information Platforms (self-developed)	SCENE, Pointscene, ReCap (laser scanning and layout)
	Construction O&M AR System (self-developed)
	Fuzor, Lumion (virtual reality)

3.1 Management Platform Overview

The project focused on eliminating data silos, establishing seamless data transmission chains, and achieving automatic data collection and monitoring. The three major enterprise management platforms and the schedule management system serve as the core "brain" for information management, conducting analysis and command across all aspects. The project attempted to integrate data from various platforms through unified data and interface standards, enabling data interoperability and sharing. Centered on the construction site management system, the initiative established horizontal information transmission chains to serve project management while simultaneously creating vertical transmission channels for planning and cost information to support corporate management and decision-making. The collaborative workflow of the smart construction site platforms is shown in Figure 53 [Figure 53: see original paper].

3.2.1 Corporate-Level Vertical Management

At the corporate level, three self-developed platforms were implemented (Figure 4 [Figure 4: see original paper]):

1. **Decision Support System (DSS):** Integrates key enterprise operational indicators and risk warning resolution status, providing big data support for corporate decision-making.

2. **Integrated Management Information System (IMS):** An internal control process management platform that controls enterprise operational risks.

3. **Project Site Management Information System (PMS):** An information application tool providing support and services for on-site project management.

These three systems address the different management requirements of three control levels, interconnecting through unified data and interface standards to achieve data interoperability and sharing. The smart construction site cloud platform serves as the "eyes and ears" that provide data support and project monitoring for these three management systems.

3.2.2 BIM-Based Schedule Management

The self-developed BIM-based general contractor schedule management system for construction projects provides functions including rapid parametric planning, linear analysis and optimization, and visual management of workface processes, significantly improving planning efficiency and executability while enhancing project schedule control capabilities [2]. The system is illustrated in Figure 64 [Figure 64: see original paper].

3.2.3 PW Collaborative Management Platform

As a super high-rise public building project with numerous participating units, the project utilized the PW platform and project management system to achieve cross-disciplinary data sharing and communication. Through efficient retrieval and data storage, the platform resolved information exchange issues among various participants (Figure 108 [Figure 108: see original paper]).

3.3 BIM-Related Applications

3.3.1 BIM Modeling

To improve design-construction collaboration efficiency, single-discipline models were created based on design drawings. This approach aimed to review spatial structures and complex nodes from a three-dimensional perspective, identifying omissions, errors, and optimization opportunities to avoid rework, thereby improving efficiency and reducing costs (Figure 9 [Figure 9: see original paper]).

3.3.2 Detailed Design

Based on the main building structure characteristics and prioritizing construction safety and main structure construction requirements, the project established a standard component library for the self-climbing formwork system, including Bailey panels, columns, hanging scaffolding poles, flaps, formwork, and other standardized components. The formwork system underwent modular design, with the jacking process simulated to verify safety protection and operational space. Various working conditions during formwork construction were considered to ensure design compliance with safety requirements and construction convenience [3] (Figure 10 [Figure 10: see original paper]).

3.3.3 Real-World Modeling, Laser Scanning, and Intelligent Layout

The project employed drone oblique photogrammetry for visual site planning and drone patrols to enhance inspection efficiency. To ensure precise positioning and layout of podium steel structures and curtain walls and to guarantee the executability of detailed design in complex pipeline areas, the project comprehensively utilized laser scanners and layout robots. Laser scanning rapidly and accurately collected point cloud data for as-built measurement, detailed design verification, and spatial positioning. Intelligent total stations precisely implemented layout data, achieving efficient and accurate positioning and layout on the construction site [4] (Figures 11 [Figure 11: see original paper] through 13 [Figure 131: see original paper]).

3.3.4 Other BIM Explorations

1) 3D Printing: The project converted the BIM three-dimensional site layout model into a physical BIM sand table model through 3D printing technology. This enabled more intuitive and profound reflection of project CI design and layout arrangements through deployment, planning, and simulation on the physical model (Figure 14 [Figure 164: see original paper]).

2) VR Applications: During design, VR provided immersive experiences that offered more intuitive perceptions than flat screens. In self-climbing formwork construction simulation and mechanical/electrical detailed design verification, VR facilitated easier problem identification and scheme adjustment (Figure 15 [Figure 175: see original paper]).

3) AR Applications: The project's AR application remains in the exploratory phase, with experimental development of AR construction and O&M systems. BIM models are loaded onto tablets, with QR codes precisely positioned on site. After scanning codes, personnel can view models superimposed on real-world images to assist management in understanding complex site conditions. During the O&M phase, the system helps managers view hidden pipeline models behind walls and access relevant information such as flow rates and power, with the capability to control switches for lines equipped with controllers (Figure 16 [Figure 186: see original paper]).

3.4.1 IoT Application Overview

The smart construction site IoT platform is an engineering information construction platform built upon BIM, IoT, cloud computing, mobile internet, big data, and other information technologies. It represents the integration of information technology with advanced engineering construction technology, with the most critical aspect being the collection and analysis of application data. Effective data analysis provides the foundation for data-driven project management. Based on current industry development status, a three-step smart construction site IoT development plan was formulated (Figure 179 [Figure 179: see original paper]).

The IoT application scope covers five major modules: personnel management, large equipment management, quality and safety management, environmental and energy consumption management, and material management. The IoT workflow (Figure 1820 [Figure 1820: see original paper]) involves data collection from various sensors at the construction site, data processing, transmission via universal wireless modules to the cloud platform, data processing and analysis on the cloud platform, and regulatory departments making decisions based on big data analytics.

3.4.2 Personnel Management Applications

1) Personnel Management Overview: The system primarily manages on-site construction personnel, enabling rapid understanding of workforce conditions while integrating management personnel attendance, security patrol inspections, and vehicle entry/exit registration into the project' s intelligent IoT for comprehensive management of non-construction personnel and vehicles.

2) On-site Personnel Management: The project installed RFID sensors at site gates and key area entrances, with RFID chips pre-loaded with personnel identity information embedded in safety helmets. This enables automatic attendance registration and qualification verification for entering/exiting workers, automatically uploading statistics of trades and personnel numbers in each zone to the platform. The system precisely manages worker quantities, specialties, and working hours on each floor and workface, providing data support for refined personnel management (Figure 19 [Figure 2119: see original paper]).

3) Patrol Inspection Management: QR codes are installed at inspection points, requiring designated personnel to scan codes along patrol routes at specified times and report inspection conditions through text, photos, or voice, with data uploaded to the platform for archiving.

4) Automatic Vehicle Entry/Exit Management: High-definition cameras installed at main site entrances photograph and register entering/exiting vehicles, capturing license plate numbers, vehicle types, and entry/exit times, with data uploaded to the platform for archiving (Figure 20 [Figure 220: see original paper]).

3.4.3 Quality and Safety Management Applications

The quality and safety management system integrates scattered applications such as mass concrete wireless temperature monitoring, high-formwork deformation monitoring, video surveillance, and restricted area alarm systems into a unified platform, with a mobile App developed for convenient data access by project management personnel.

The restricted area alarm system employs mobile sensors at edges of temporary openings or restricted access zones, triggering alarms when personnel enter the infrared sensor monitoring range, with warnings uploaded to the cloud platform. Video surveillance marks monitoring device locations on the three-dimensional model, enabling direct access to video feeds by clicking on monitoring points in the model (Figure 21 [Figure 231: see original paper]).

Mass concrete wireless temperature monitoring uses conventional equipment with data repeaters transmitting data to the cloud platform, allowing temperature variation curves to be viewed via computer to ensure concrete pouring quality. High-formwork monitoring employs deformation measurement components for real-time monitoring of support deformation, providing over-limit warnings through audible and visual alarms, with data uploaded to the platform for timely response (Figure 22 [Figure 242: see original paper]).

3.4.4 Large Equipment Management Applications

1) Tower Cranes, Elevators, and Self-Climbing Formwork Platforms: These represent the most critical construction machinery, and ensuring their safe operation is essential for construction safety and progress. The platform monitors and records the entire operation process through sensors, providing timely warnings.

2) Tower Crane Anti-Collision and Monitoring System: Real-time monitoring of tower crane operation includes rotation angle, boom elevation, wind speed, load, and radius data, providing real-time warnings for collision risks and overload conditions while implementing braking control.

3) Self-Climbing Formwork Monitoring System: The system comprises hydraulic and electrical control subsystems, enabling synchronized control of main cylinders and individual support cylinders. Sensors monitor component stress and strain variations and platform balance to ensure safe formwork jacking (Figure 23 [Figure 253: see original paper]).

3.4.5 Environmental Monitoring and Energy Consumption Management Applications

Automatic environmental monitoring instruments track PM2.5, noise, and wastewater conditions in real time. Data analysis and processing of environmental and energy consumption conditions meet green construction supervision requirements and enable automated green construction analysis (Figure 24 [Figure 264: see original paper]).

3.4.6 Material Management Applications

Material management primarily involves intelligent weighbridges and informatized warehouse management.

Intelligent Weighbridge: Sensors and cameras installed on the weighbridge system weigh material vehicles upon entry and exit, calculating net weight, photographing records, and automatically generating material entry reports in the platform.

Informatized Warehouse Management: QR codes are generated and attached to various materials upon entry, requiring scanning for material withdrawal. Inventory and allocation information is transmitted in real time to the intelligent cloud platform system (Figure 25 [Figure 27: see original paper]).

4 Application Effects

By treating the construction site as an organic entity through smart construction site practices and research, the project improved design and construction management efficiency, saved communication time and construction schedules, and achieved refined site management, generating significant economic and social benefits. Statistics show:

1. Identified 167 structural drawing issues and 36 architectural drawing issues.

2. Discovered and resolved over 30,000 collision problems, producing 5 categories and 36 sheets of detailed drawings.

3. Completed detailed design of over 50 nodes.

4. Assisted in 30 construction scheme briefings.

5. Hosted national, Zhuhai municipal, and Hengqin district smart construction site observation conferences.

6. Increased self-climbing formwork design and processing efficiency by 50%.

7. After the smart construction site cloud platform launch, project management capabilities improved significantly. During 104 days of operation, the system recorded 546 site personnel with 112,156 work hours; monitored 16 restricted area alarms and 9 self-climbing formwork and tower crane warnings; tracked dust, wastewater, noise, water, and electricity for 103 days, rectifying 7 issues and achieving water savings of 563 m^3 and electricity savings of 1,200 kWh.

8. The intelligent weighbridge performed 2,653 weighings, generating 33,265 data entries (including redundant data) and obtaining 2,653 stable values. Warehouse informatization management completed 32 entries and 27 exits during trial operation, achieving excellent research results.

5 Conclusion

The project conducted in-depth exploration and trials in multi-party collaboration, detailed design, real-world modeling, laser scanning and layout, AR, and integrated IoT applications, achieving certain results while identifying areas for further improvement:

1. **Excessive Integrated Platforms with Incomplete Workflow Processes:** Current collaborative workflows remain in the exploratory phase with low efficiency. Continuous improvement of collaborative workflows among all parties and transformation of traditional project management thinking are needed to better utilize smart construction site tools.
2. **Personnel Development:** Through improved incentive and assessment systems and multi-level systematic training, the project should focus on strengthening practical application capabilities for smart construction site technologies to enhance professional competence.
3. **Exploration and Innovation:** Continued in-depth exploration and research, along with ongoing innovation, will standardize more applications and integrate them into the smart construction site IoT cloud platform to advance toward lean construction goals.

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