Council on Tall Buildings and Urban Habitat Korea

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
September 2025, Vol 14, No 3, 223-240
https://doi.org/10.21022/IJHRB.2025.14.3.223

Exploration and Practice of Technological Innovation in High-Rise Building Construction

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Abstract Over the past decades, high-rise buildings have rapidly evolved worldwide, achieving continuous breakthroughs in height, scale, and complexity. Along with the industry's transformation, construction methods for high-rise buildings have undergone significant innovation. This paper presents China's recent practices in construction technology, equipment, robotics, and digital construction, focusing on key techniques and systems such as synchronous top-down construction, integrated operation platforms, next-generation tower cranes, and site-wide digital mapping. It also discusses the challenges faced by high-rise construction development, including the shift towards more industrialized building products, the deployment of high-performance intelligent equipment, and the establishment of human–machine collaboration standards. These explorations provide insights into the future evolution of intelligent and industrialized high-rise construction.

Keywords: High-rise buildings, construction techniques, equipment, robotics, digitalization.

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1. Introduction

As a hallmark of engineering technology breaking spatial constraints, the development of high-rise buildings mirrors major transformations in construction technology. From the late 19th century to the mid-20th century, the application of steel in architecture and the invention of electric elevators led to the rapid emergence of high-rise buildings in cities such as Chicago and New York. Between the mid-20th century and the 1970s, the successful use of reinforced concrete in tall buildings sparked innovations in structural systems and construction technologies, further improving the form and performance of skyscrapers and resulting in iconic high-rise structures worldwide. Since the 1980s, the application of structural simulation and analysis technologies has advanced architectural design theories. Breakthroughs in construction equipment, such as tower cranes, high-speed elevators, and structure dampers, have made buildings over 300 meters feasible. In 2010, the 828-meter-tall, 162-story Burj Khalifa in Dubai became the tallest building in the world. Material advancements, structural innovations, and equipment breakthroughs have been the three main forces driving the evolution of high-rise construction.

Amid the ongoing wave of digital transformation, construction technology worldwide is rapidly evolving toward a deeper integration of intelligence and industrialization. Countries such as the United States, members of the European Union, Japan, and Singapore have all launched national strategies to promote intelligent construction. As a major member in the global construction industry, China has not only formulated strategic plans but also designated 24 pilot cities to explore key technological pathways, including the application of BIM and the development of construction robotics. Against this backdrop, high-rise construction technology has made notable advances, characterized by the integration of design and construction processes, coordination among multiple types of equipment, and the growing influence of digital technologies.

This paper presents representative case studies of recent innovations in high-rise construction, including construction processes, advanced equipment, and digital solutions, and provides practical insights for the implementation of intelligent construction practices.

2. High-rise Construction Organization and Technology

2.1. Synchronous Top-Down Construction Technology for Above- and Under-Ground Structures

2.1.1. Research Background

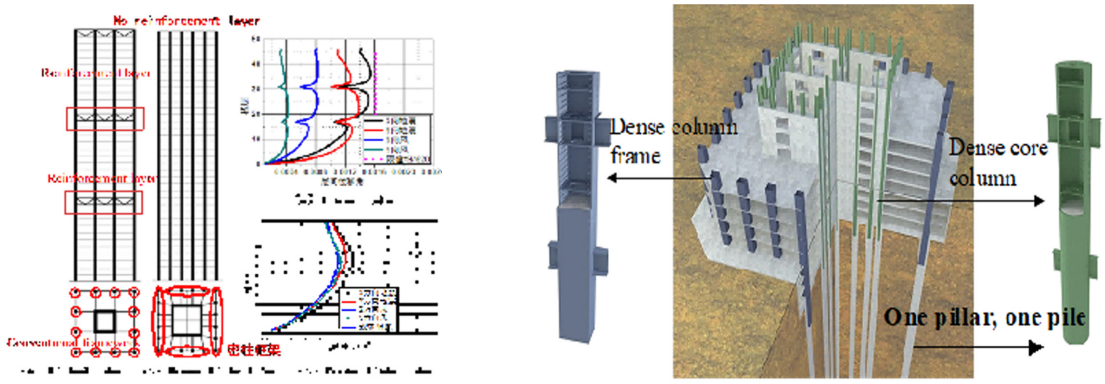
As urbanization accelerates, the efficient use of urban space has become an increasing challenge. In high-rise building construction, simultaneous construction of above-ground and under-ground structures has been explored,



Figure 1. Synchronous top-down construction technology for above- and under-ground structures.



Figure 2. Nanjing youth Olympic center twin towers.



(a) Comparison of Two Types of Frame-Core Wall Structural Systems (b) dense column frame-core wall structural system

Figure 3. Non-strengthen floor dense column frame-core wall structural system.

but its widespread adoption remains limited. This is primarily due to the complexity of structural joints in high-rise buildings, resulting in high construction difficulties, high costs, and challenges in quality control.

To address these issues, an innovative top-down construction approach enabling synchronous construction of above- and under-ground structures for high-rise buildings is proposed. This method involves optimizing the structural system, analyzing the optimal structure height, and refining key construction technologies to achieve greater efficiency and integration.

2.1.2 Key Technologies

2.1.2.1. Non-Strengthen Floor Dense Column Frame-Core Wall Structural System

By introducing a dense core column, combined with a dense column frame and a one- column-one-pile design, the structure achieves uniform load distribution and reliable force transfer for supertall towers of ten-thousand-tons level. This structural system effectively supports the synchronous top-down construction for above- and under-ground structures.

In addition, by research on the bond performance of large-section concrete-filled steel tube (CFST) columns,



Figure 4. Experimental study on CFST Column.

together with the development of rational structural layouts and reliable calculation methods, has significantly improved both the structural integrity and construction performance of CFST columns in top-down applications.

2.1.2.2. Multi-Factor adaptive algorithm for determining the optimal critical height in simultaneous construction of above- and under-ground structures

Based on a multi-factor coupled all-condition design approach, a multi-factor adaptive algorithm for determining the optimal critical height in simultaneous construction of

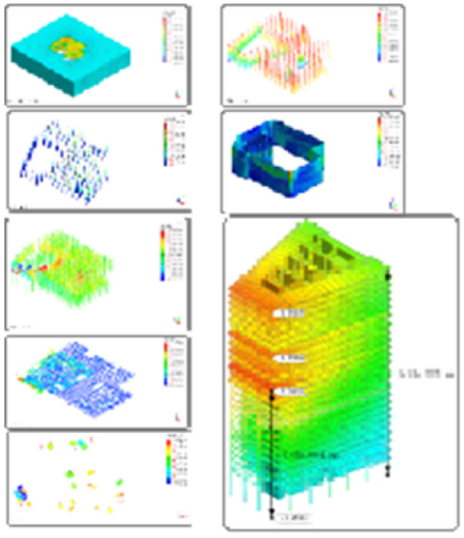


Figure 5. Multi-factor adaptive algorithm for determining the optimal critical height

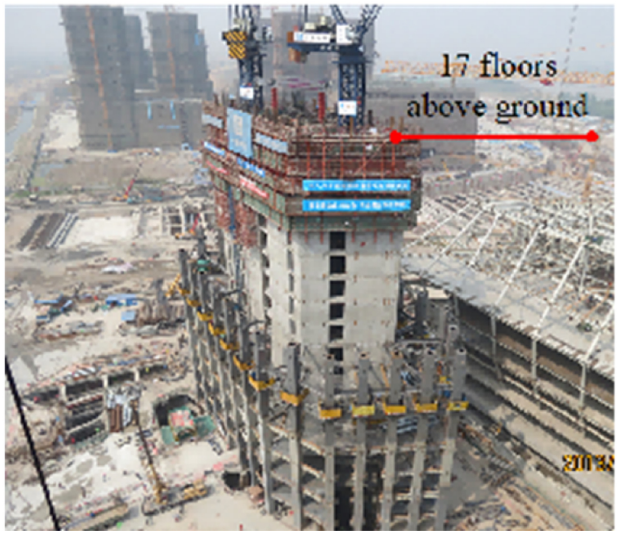
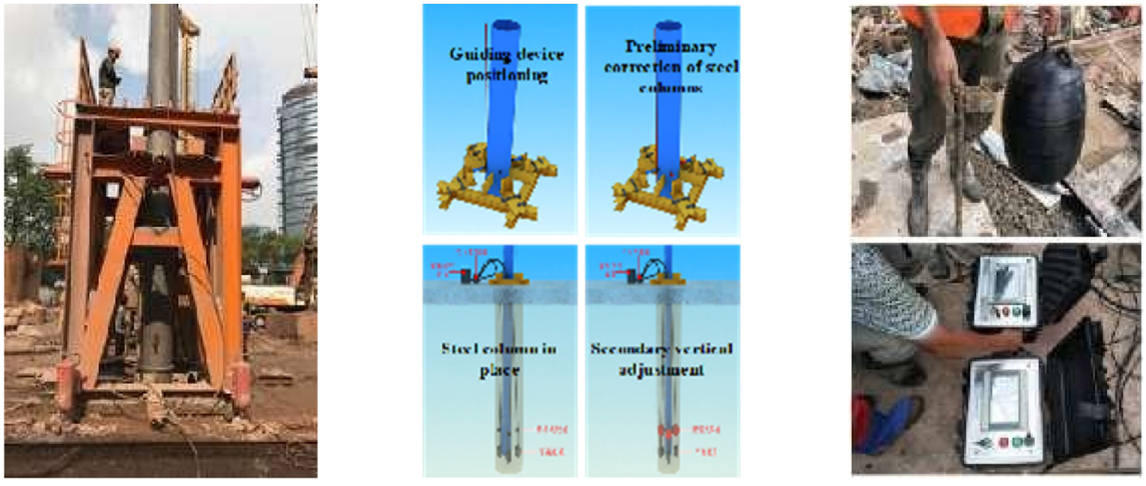


Figure 6. simultaneous construction of above- and under-ground construction of the Nanjing youth Olympic center twin towers



(a) the first verticality alignment **(b) the second verticality alignment** **(c) verticality monitoring**

Figure 7. Automated verticality alignment system.

above- and under-ground structures was proposed. This method addresses the challenge of optimally matching structural performance, construction cost, and construction height, and has set a world record for top-down simultaneous construction height (17 above-ground stories and 3 underground levels).

2.1.2.3. High-quality integrated top-down construction technology for heavy-load environments

A high-precision vertical alignment system for one-column-one-pile CFST columns in top-down construction was developed to address the challenge of controlling the verticality of core columns under the one-column-one-pile scheme. With this system, the verticality error of CFST columns is maintained below 1/1000, significantly outperforming the standard limit of 1/300. In addition, a novel foundation connection joint for the top-down method was designed, enabling continuous force transfer, reliable load conversion, and efficient construction in underground top-down structures, thereby ensuring both construction quality and structural safety.

This technology has been successfully applied in a series of major projects, including Nanjing Youth Olympic Center, Guangzhou Hengji Center, Phase II of Nanjing Jinmao Plaza, Jinling Central Complex Development, and the Nanrui Road Project, generating a cumulative economic benefit of over 126 million RMB across all applications.

3. Construction Equipment for High-rise Buildings

3.1. Construction integrated platform series

3.1.1. Heavy-duty construction integrated platform (CIP-H) of high-rise buildings

To address the challenges encountered during the core wall construction of super high-rise buildings exceeding 300 meters, including restricted working space, high safety risks, frequent conflict among equipment, and low construction efficiency, China has pioneered the development of a heavy-duty construction integrated platform (CIP-H) for high-rise buildings.

This platform incorporates an innovative fulcrum system based on the shear resistance of micro convex on the surface of concrete, achieving a maximum bearing capacity of 600 tons per fulcrum and several thousand tons for the entire platform. It can integrate tower cranes with a lifting moment of up to 3,000 ton-meters and withstand wind loads of up to level 17. With its high load-bearing



(a) Beijing China Zun, 528 meters **(b) Wuhan Greenland Center, 475 meters**

Figure 8. Heavy-duty for high-rise buildings.

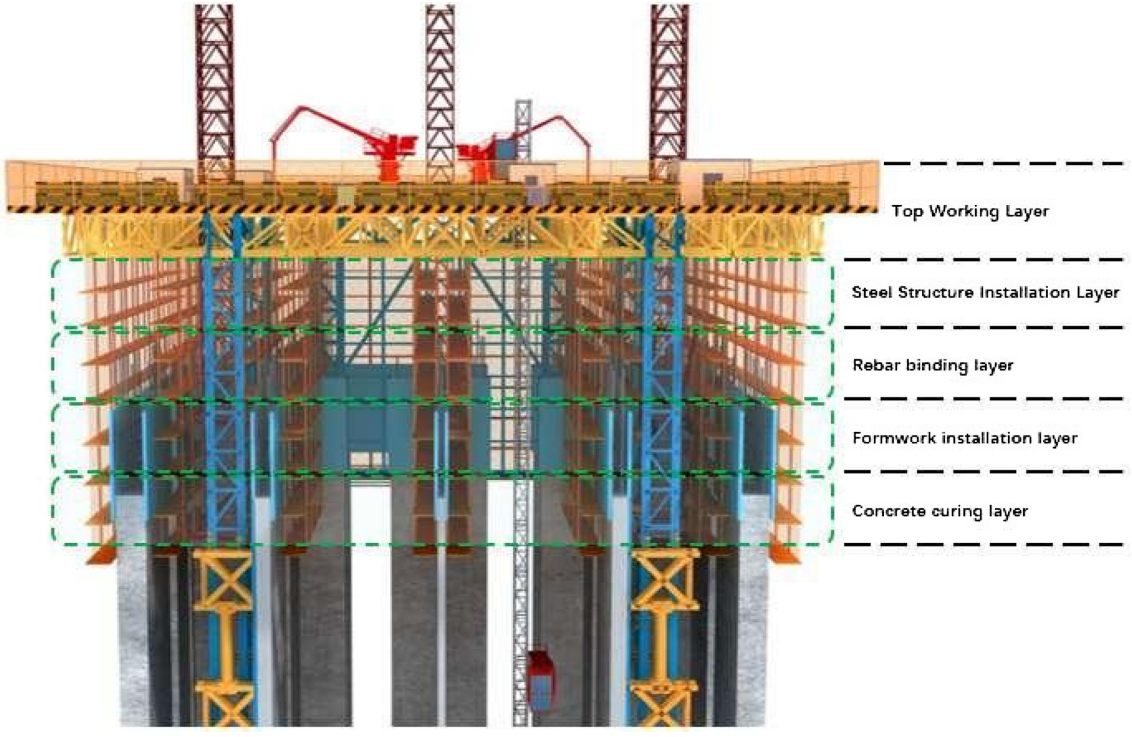


Figure 9. Simultaneous working platform.

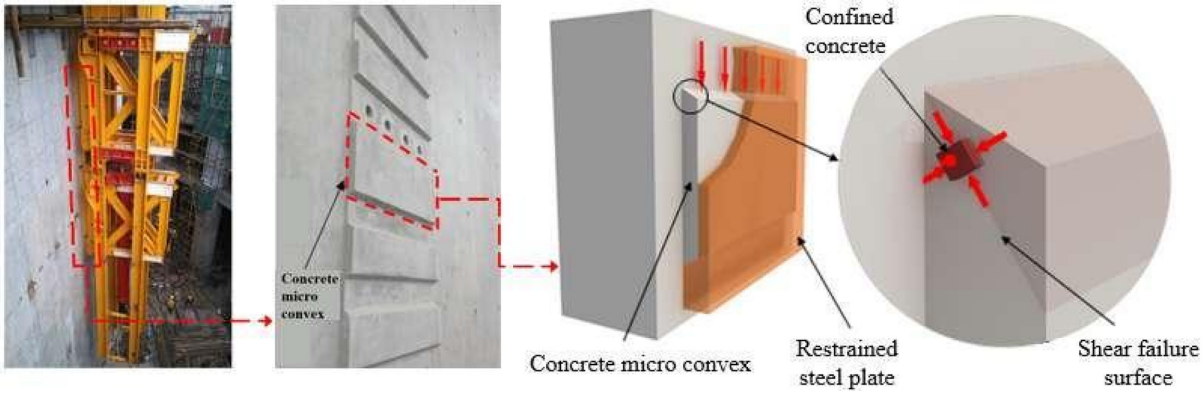


Figure 10. Micro convex on the surface of concrete.

capacity, the platform provides a factory-like construction space covering over 1,000 square-meter in horizontal and over 3.5 standard stories in vertical, enabling over 10 simultaneous working platform.

This configuration allows efficient, continuous workflows for wall and slab construction across both horizontal and vertical planes, improving productivity by more than 20% and reducing the construction cycle by 2-3 days per floor.

3.1.2. Light-duty construction integrated platform (CIP-L) of high-rise buildings

To address issues in the construction of 100-meter-class conventional high-rise buildings, such as inadequate safety protection, high sensitivity to environmental conditions, and low levels of mechanization, the CIP-H was redesigned with a lightweight, standardized configuration and expanded functionality, resulting in the development of a light-duty construction integrated platform (CIP-L) for high-rise buildings.

The platform adopts a lightweight Bailey truss steel working platform design, reducing steel usage to only 30-40% of that of the heavy-duty one. Its components are lighter, more standardized, and allow for more efficient assembly and disassembly, achieving a turnover rate of over 90%. An all-weather working support system with rainproof, sun-shading, cooling, and dust-suppression functions was also developed, minimizing the impact of adverse conditions such as rain and high temperatures, and creating a factory-like working space that extends effective working hours. The integration of concrete placing and other construction equipment further enhances on-site operational efficiency while reducing on-site labor.

3.1.3. On-site industrialized construction integrated platform (CIP-I)

To address the low efficiency of prefabricated component hoisting and the limited level of digital construction in conventional high-rise prefabricated residential projects, an on-site industrialized construction integrated platform (CIP-I) was developed.

The main load-bearing framework and support points were designed independently of the building's exterior façade profile, adopting a four-point ground-supported column system that enables rapid platform assembly and



(a)Guangzhou Dayuancun project, 99 meters **(b) Wuhan Yijiadun project, 130 meters**

Figure 11. CIP-L for high-rise buildings.



Figure 12. Lightweight Bailey truss steel working platform.



Figure 13. Hydraulic concrete placing.

one-click lifting. An intelligent hoisting system for prefabricated components was also developed. Based on BIM model data, the system identifies PC components using RFID and QR codes, allowing automatic path planning and precise installation during hoisting, thereby significantly improving lifting efficiency.

Furthermore, by optimizing construction circulation routes and integrating intelligent elevators with internal passage spaces, the platform establishes a three dimensional transportation network that achieves high-level human-machine collaboration and meets the attachment, movement, and operational requirements of various intelligent devices and construction robots. The construction integrated platform (CIP) technology for high-rise buildings has been extended to other fields such bridges, nuclear power, and silos. A series of specialized platforms have been developed, including the CIP for tall and slender structures, and the CIP for nuclear reactor buildings, and the CIP for concrete silos, forming a multi-scenario product system and enabling the technology to cover a wider range of applications.

3.2. Tower crane series

3.2.1. Top-added standard section piercing tower crane

To address the high safety risks associated with



(a) Wuhan Hanxin Mansion, 82 meters



(b) Wuhan Hanyun Mansion, 80 meters

Figure 14. CIP-I.

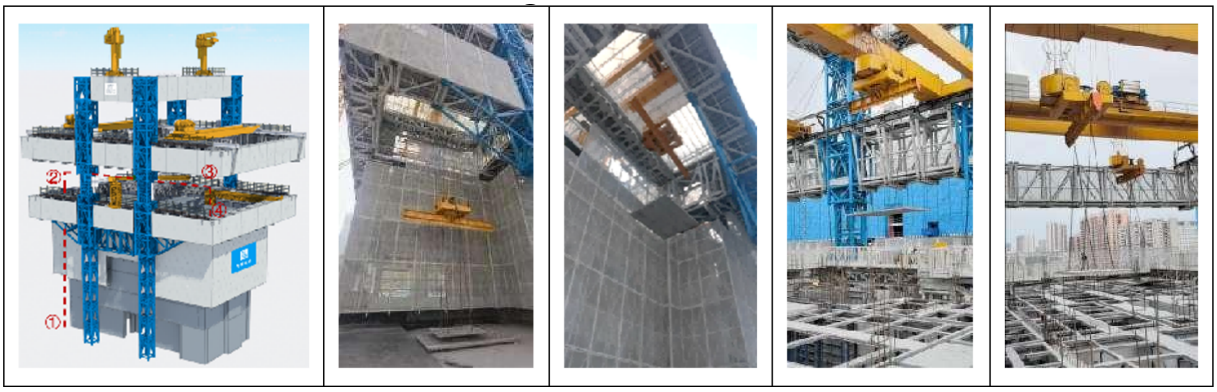


Figure 15. Data driven automatic lifting for PC components.



Figure 16. Three-dimensional human-machine collaborative transportation system.



Figure 17. CIP for tall and slender structures.



Figure 18. CIP for nuclear reactor buildings.



Figure 19. CIP for concrete silos.

traditional tower crane assembly, climbing, and operation under extreme weather conditions such as strong winds, a through-core tower crane with top-section insertion technology was developed.

This pioneering method of adding sections at the top fundamentally transforms the conventional climbing process, ensuring the structural integrity and continuous, reliable load transfer of the tower crane during section addition, thereby achieving intrinsic structural safety throughout the climbing operation. An integrated load-bearing and lifting tower crane sleeve system was also designed, enabling rapid lifting and precise positioning of the upper crane structure at any height. Before the arrival of severe weather such as strong winds, the entire crane can be lowered to a safe position without removing standard mast sections, significantly enhancing the tower crane's resilience to extreme conditions and improving safety throughout its service life.



(a) Haikou "super Operator" project **(b) Sanya Airport project**

Figure 20. Top-added standard section piercing tower crane.



Figure 21. Adding standard section on the top.

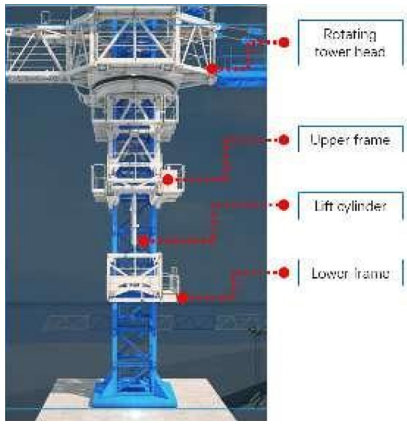


Figure 22. Integrated system.

3.2.2. Inclined tower crane

To address the challenges of traditional tower cranes when constructing tall and slender buildings with large-inclination structures, such as excessively long attachment lengths, high safety risks, and low operational efficiency—a world-first variable-angle inclined tower crane was developed, overcoming the difficulties of attaching to irregular structural forms.

Utilizing large-scale adjustable attachment technology and tower body inclination deformation techniques, the crane's mast can adapt to the external profile of inclined structures and operate in an inclined mode. This innovation breaks the conventional requirement for tower crane masts to remain strictly vertical, eliminating the adverse impact of inclined structural designs on crane selection and operational efficiency.

3.2.3. Self-climbing tower crane

To address the challenges of limited core tube space during the construction of super high-rise buildings, where tower crane climbing is difficult, inefficient, and carries high operational risks, a self-climbing tower crane was developed. A novel obstacle-crossing attachment support system was invented, featuring reversible or telescopic



Figure 23. Application of inclined tower crane at Great bridge of Putian Sanjiangkou.



Figure 24. Tower crane attachment length control technology



Figure 25. Transform section



Figure 26. Self-climbing tower crane.

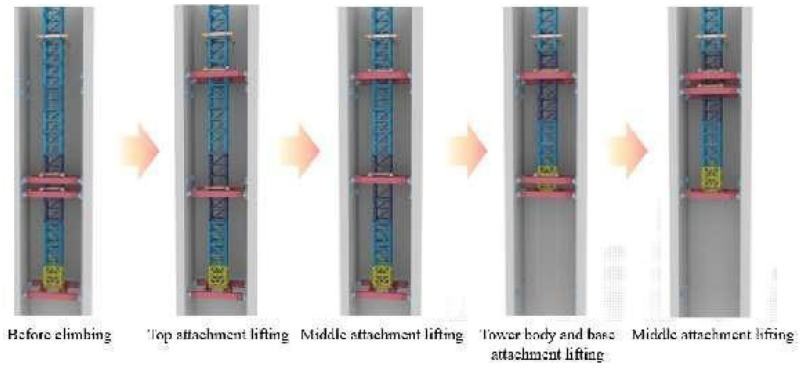


Figure 27. Self-climbing technology

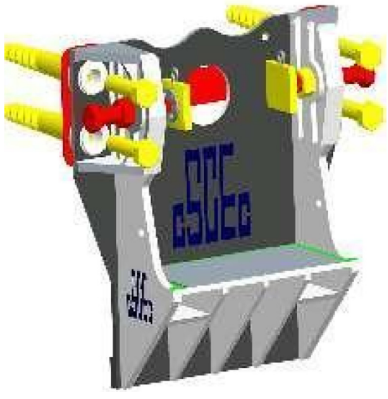


Figure 28. Reusable bracket

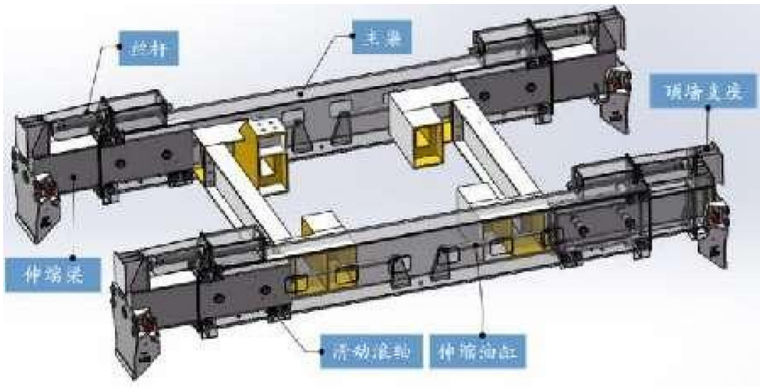


Figure 29. Telescopic support beam

support beam designs that enable integrated climbing without dismantling the beams, eliminating the need for high-altitude welding of support structures.

This approach provides safer, more convenient operation and is environmentally friendly. Utilizing a "leapfrog" climbing method, the system reduces the traditional climbing operation time from 1.5 days to just 4 hours, requires no auxiliary tower crane, improves climbing efficiency by over four times, and reduces labor demand by more than 50%.

3.2.4. Revolving platform tower crane

To address the issues in super high-rise construction such as excessive redundancy in large tower crane configurations, low operational efficiency, complex climbing procedures, high safety risks, and extended construction schedules, a



Figure 30. Revolving platform tower crane.

revolving platform tower crane system was developed.

The system features a spatial truss platform structure providing a large clear-span working plane, with multi-level tower crane connection nodes arranged at the corners. A high-capacity, low-speed, large-torque rotary mechanism enables the entire tower crane base to rotate while carrying load. The platform can integrate a series of tower cranes with overturning moments of up to 2700 tonf·m, significantly expanding the lifting coverage through base rotation. Using a single large tower crane as the core and configuring auxiliary cranes of different capacities in a coordinated manner reduces the need for 2–3 additional large tower cranes, cutting costs by over 30%.

3.2.5. Platform-integrated tower crane

To address the frequent interference and conflicts between large tower cranes and construction operation platforms during super high-rise building projects, as well as the complexity of tower crane climbing procedures, a platform-integrated tower crane system was developed.

An optimized layout design method for construction platforms and tower cranes was proposed, and a self-adaptive lateral restraint mechanism for the mast's horizontal attachment was designed. During the platform jacking process, the steel frame system of the platform and the structural walls serve as supports, enabling the large tower crane and the construction platform to climb as an integrated unit. The self-adaptive lateral restraint mechanism effectively limits mast sway during climbing and compensates for construction errors and defects in structural walls.

This approach significantly reduces the use of embedded parts, cantilever brackets, and other materials typically required for tower crane climbing, simplifies the jacking process, mitigates self-climbing risks, and improves operational efficiency by over 20%.

3.3. Construction elevator series

3.3.1. Single-guide rail multi-cage circuit working construction elevator

Addressing the limitations of traditional construction elevators, including low transport capacity of the single-guide rail with single-cage operation mode, prolonged waiting times due to manual dispatching, and spatial occupation from multi-rail arrangements, the Single-Guide Rail multi-Cage Circuit Working Construction Elevator (i.e. Rotary Elevator) was developed.

The cages laterally shift from the upward rail to the downward rail at the guide rail's apex via the Rotating Guide Rail mechanism, with reverse rail changing forming a cyclic path at the base. This enables multi-cages continuous operation within a single guide rail, achieving transport capacity exceeding 200% of conventional equipment. The group control scheduling and autonomous

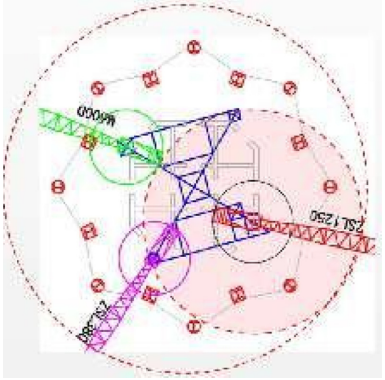


Figure 31. Lifting coverage.



Figure 32. Spatial truss system.

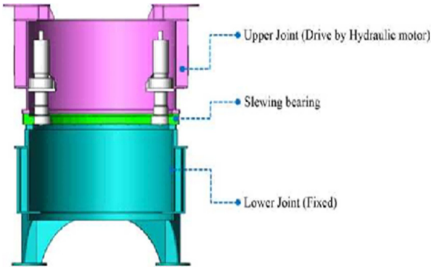


Figure 33. Revolving system.



Figure 34. Platform-integrated tower crane.

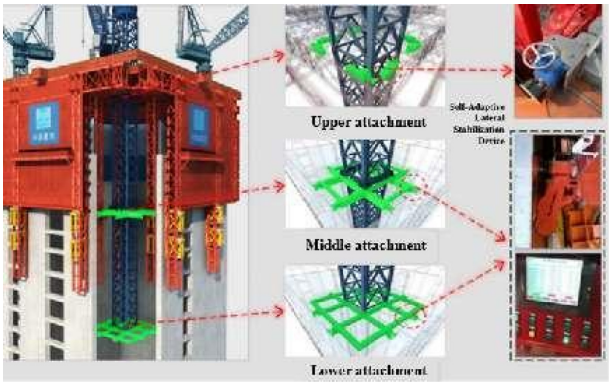


Figure 35. Integrated support and jacking system.

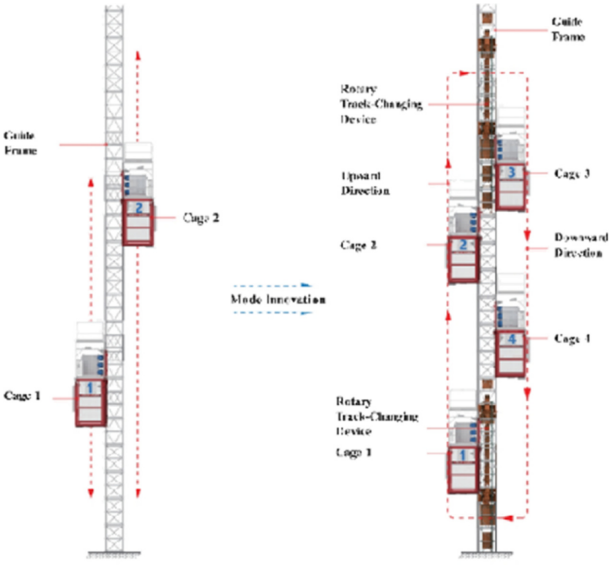


Figure 36. Conventional elevator (left) and cyclic construction elevator (right).

operation technology was developed, and the real-time monitoring of cage and guide rail status was implemented, propose an optimal task assignment strategy, and achieve intelligent, safe, and efficient dispatching of multi-cages. A cage safety distance dynamic control algorithm was proposed. Technologies including cage automatic recognition, emergency braking, and an anti-collision buffer system were developed, establishing triple-tiered progressive safety mechanisms to ensure operational safety of the construction elevator.

3.3.2. Traction-driven multi-car cyclic elevator

Addressing the limitations of conventional passenger elevators in high-rise buildings -including low transport capacity of the "direct vertical shuttle" operation mode, spatial occupation from multiple hoistway arrangements, and potential safety risks during high-speed operation—the Traction-Driven Multi-Car Cyclic Elevator was developed based on research foundations of single-guide rail multi-cage circuit working construction elevator. This

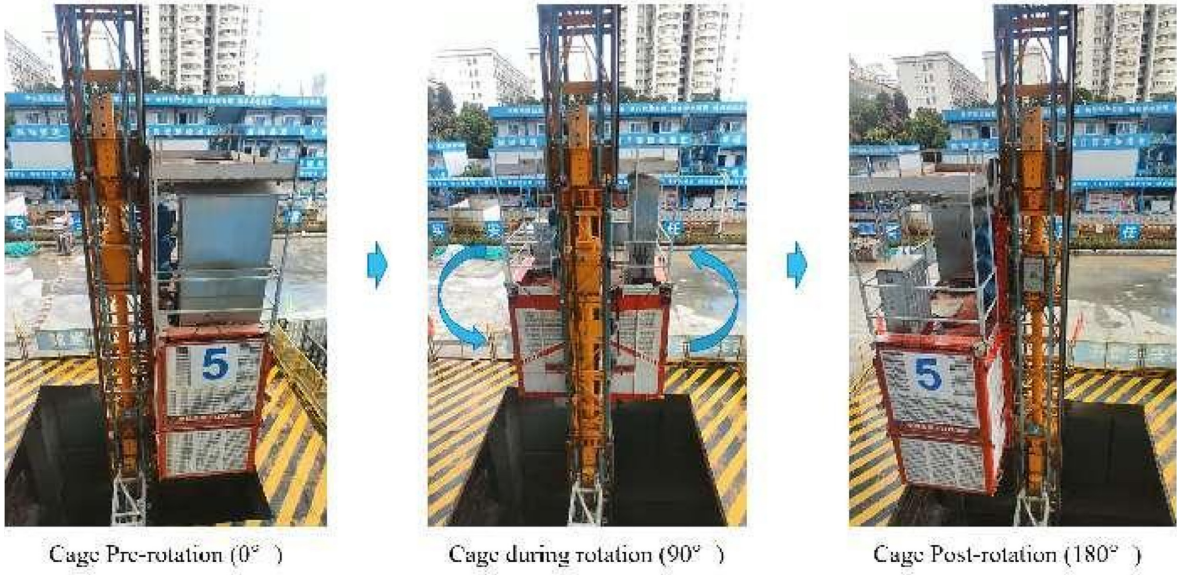


Figure 37. Rotary rail-change mechanism for cyclic construction elevators.



Figure 38. Application of mono-rail multi-cage cyclic construction elevator.

innovation significantly improves hoistway utilization efficiency in high-rise buildings.

The technology connects the tops and bottoms of two adjacent hoistways, enabling rapid and reliable disconnection/reconnection between elevator cars and traction ropes through a novel traction system. Rail-transition devices installed at hoistway tops and bottoms drive cars to complete vertical rail switching. An intelligent group control dispatching system coordinates safe operation and optimizes transport efficiency of multiple cars. Simultaneously, a high-redundancy safety protection system establishes multi-layer protective mechanisms to ensure full-process safety. This system enables elevator cars to operate in a "left-up right-down" cycling pattern within two adjacent hoistways, achieving the "multiple cars in one hoistway" configuration.

4. Construction Robots for High-rise Buildings

4.1. Autonomous material handling system

Addressing issues such as poor safety, low efficiency, high loss rates, and elevated costs associated with traditional material transportation, the unmanned material transportation system integrates various transport robots, intelligent construction elevators, and a dispatching system. Capable of transporting multiple types of building materials, it offers advantages including strong environmental adaptability, high transportation efficiency, advanced intelligence, and excellent safety. This system achieves fully unmanned transportation throughout the entire process—from outdoor stockyards to indoor floor work surfaces—covering loading, transportation, and unloading. Through autonomous material identification and handling, robot positioning and navigation, multi-robot path planning, robot-elevator coordination, and remote robot dispatching and real-time supervision, the unmanned material transportation system effectively reduces material loss, substantially improves transport efficiency, and significantly lowers labor costs. It provides an innovative solution for construction material logistics.

4.2. Concrete placing robot

To address issues in concrete pouring operations such as high labor intensity, low construction efficiency, and

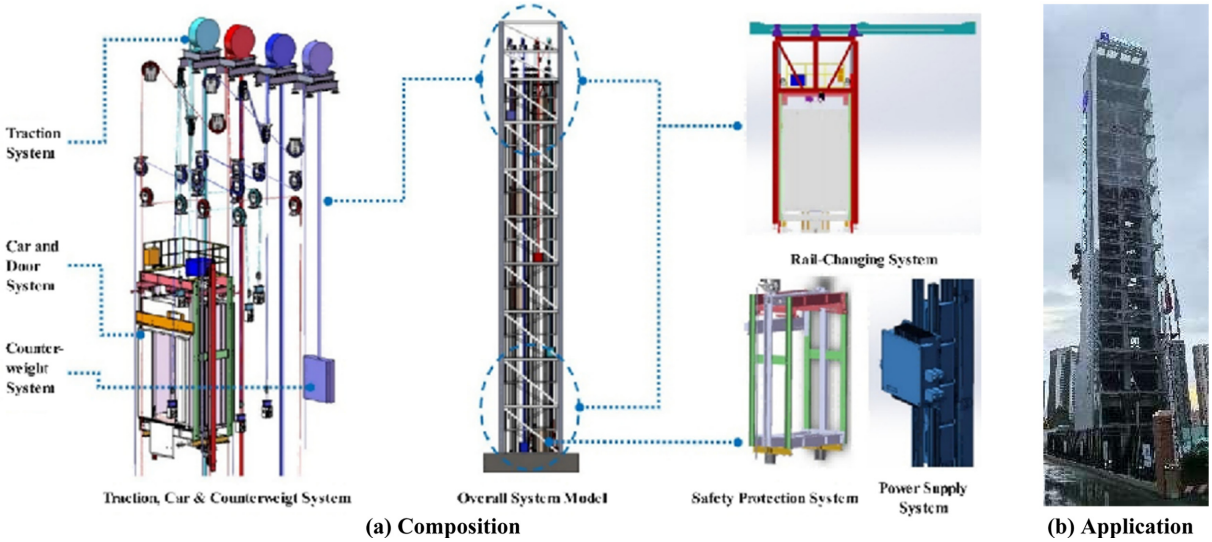


Figure 39. Traction-driven multi-car cyclic elevator.

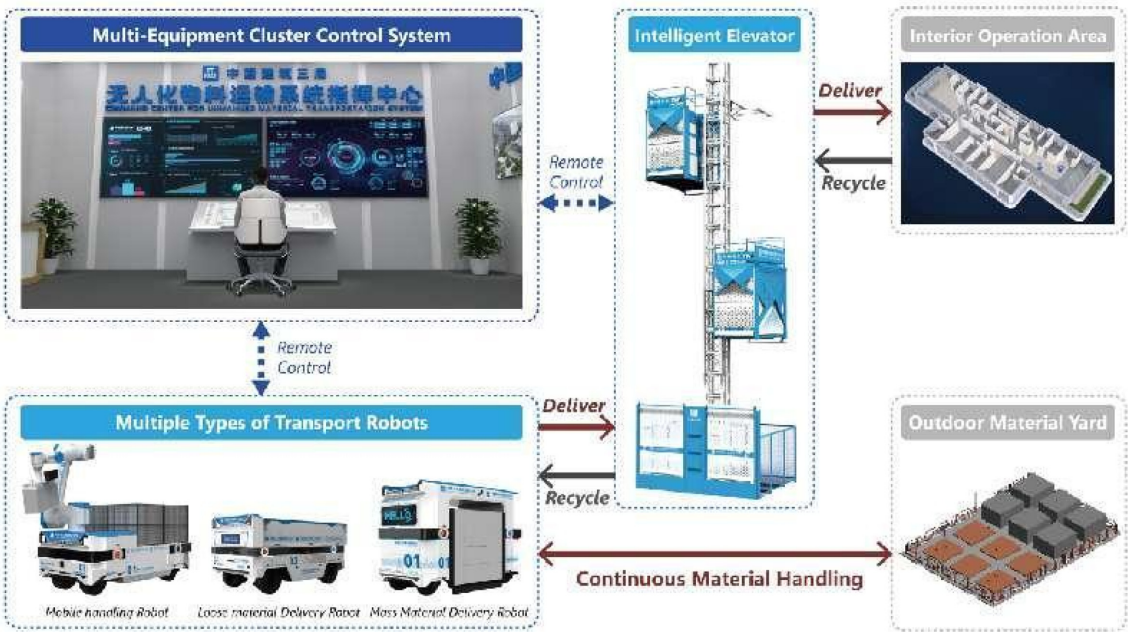


Figure 40. Autonomous material handling system.



Figure 41. On-site demonstration of autonomous material handling system.

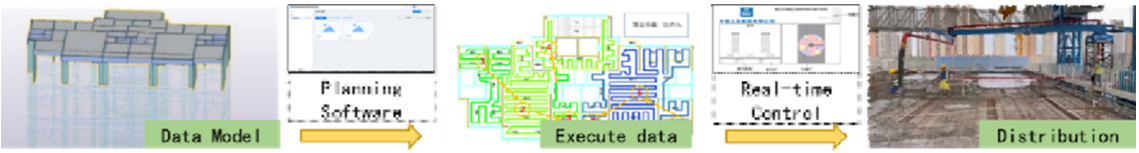


Figure 42. Planning and placing procedures of robot.

uneven distribution caused by manual operation, an intelligent autonomous concrete placing robot was developed, integrating a digital model with an on-site control system. A self-developed placing planning software generates pouring schemes directly from BIM-based digital models, enabling seamless data flow from design to construction execution. By combining obstacle detection, boom motion control, and flow monitoring technologies, the robot can autonomously avoid obstacles, change direction, and plan material distribution, achieving efficient and safe on-site pouring. This significantly reduces manual labor intensity and operational difficulty while improving construction efficiency and safety.



Figure 43. On-site demonstration of concrete placing robot.

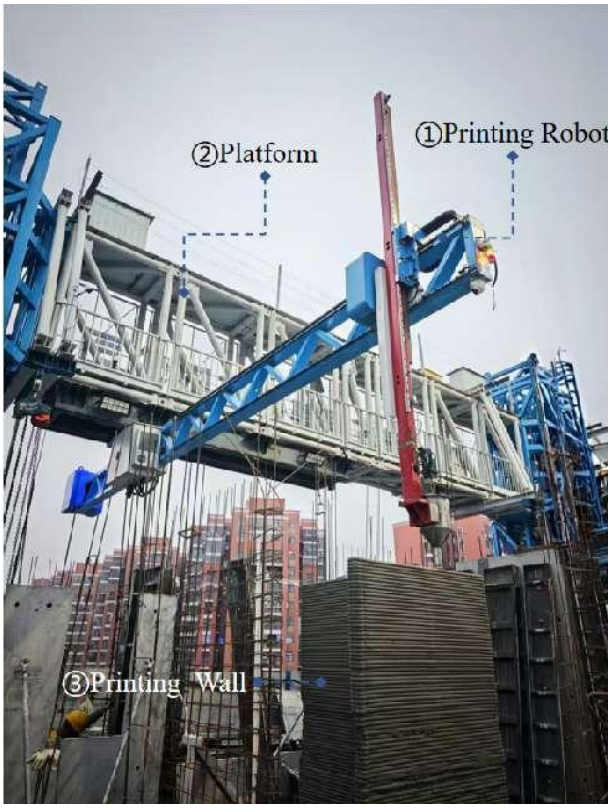


Figure 44. On-site demonstration of 3D printing robot.

4.3. Application of 3D printing robots in construction

In response to the complex construction techniques, low efficiency and high labor intensity of traditional high-rise buildings, an innovative solution is proposed to integrate 3D printing robots for buildings into the construction operation integrated platform, achieving template-free and automated construction of high-rise building walls.

Building 3D printing is an additive manufacturing technology. Firstly, the building model is decomposed into several two-dimensional layers, and then the printable robot stacks the adhesive materials layer by layer to finally form a three-dimensional solid building. In terms of materials, self-developed lightweight and high-performance printing materials are used to significantly improve the performance of the walls. In terms of equipment, a cantilever in-situ 3D printing robot for buildings that can be integrated into the construction operation integrated platform is developed.

By developing the overhang compensation algorithm and optimizing the core parameter matching, the key problems such as the end swing and movement accuracy of the large cantilever structure are overcome, ensuring the high precision and stability of the printing operation. In terms of construction technology, the wall printing technology and on-site construction organization are systematically optimized to achieve the synchronous construction of the main structure and secondary structure, creating a new construction mode for high-rise buildings.

5. Digitalized Construction for High-rise Buildings

5.1 Intelligent excavation and transportation system for foundation pits

To address the challenges in foundation pit earthwork operations, such as the high skill threshold for excavator operation, heavy reliance on manual experience, high labor intensity, and low levels of automation and intelligence, an innovative intelligent excavation and transportation system was developed.

By constructing a digital excavation model of the foundation pit and integrating multi-machine collaborative control technologies, the system coordinates all earthwork equipment in an orderly manner. It achieves breakthroughs in key technologies such as autonomous excavation and loading by excavators, autonomous transportation by dump trucks, and automated lifting by hoisting equipment. This enables a fully unmanned closed-loop operation scenario for the entire “excavation–loading–transportation–lifting” process within the foundation pit, paving the way for unmanned and minimally manned intelligent earthwork construction systems.

5.2. Digital map of construction site

To address issues such as low integrated operational efficiency of various intelligent systems and difficulties in general site layout management at construction sites, we have developed a digital construction site map. By using the integration of multi-model heterogeneous data, such as Beidou high-precision positioning and spatial coordinates, BIM models, and overall plans, to construct a high-precision spatiotemporal intelligent framework, forming as an "integrated air-space-ground" platform.

This foundation interlinked Geospatial IoT, 3D-modeling, Sensing perception and large-data AI analytics, enabling digitally reconstructs construction sites, restore the real-time status monitoring and all-round perception-control of key elements such as constructing equipment (tower cranes, building cranes, concrete placers, etc.), and vehicles.

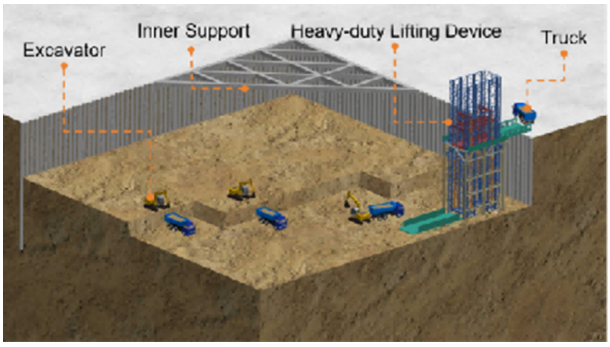


Figure 45. Illustration of the system.



Figure 46. On-site demonstration of the system.

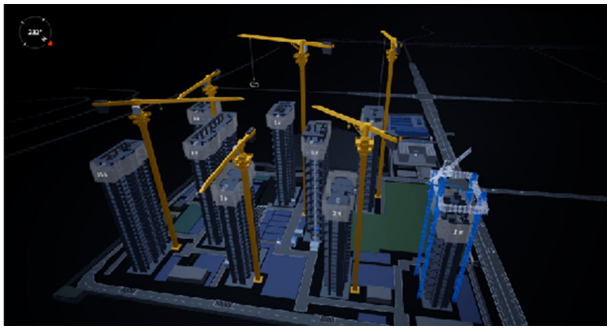


Figure 47. A unified digital map created, shared, and updated by multiple equipment.

Multi-task perception algorithms are employed to intelligently identify progress in complex structural processes, for achieving the spatiotemporally intelligent management of large-scale intricate construction planes.

5.3. Rebar cloud factory

To address the challenges in high-rise construction such as labor-intensive rebar processing, low production efficiency, inconsistent processing quality, and high material wastage, a cloud-based rebar fabrication plant was developed.

The system integrates functional modules including a magnetic feeding mechanism, combined cutting and sawing machine, intelligent threading machine, intelligent sorting robot, automated conveying line, handling robot, laser marking unit, and bending robot. On the software side, it incorporates a nesting and scheduling system as well as a production line control system, enabling automated optimization of rebar orders based on length and specifications. With one-click data import, the system automatically generates processing instructions to drive the production line.

It achieves fully automated feeding, cutting, rib-stripping, threading, bending, and sorting of rebar bars with diameters ranging from Φ12 mm to Φ32 mm, significantly reducing manual intervention while ensuring high efficiency, high quality, and minimal material loss in rebar processing.



Figure 49. On-site demonstration of intelligent production line for rebar.

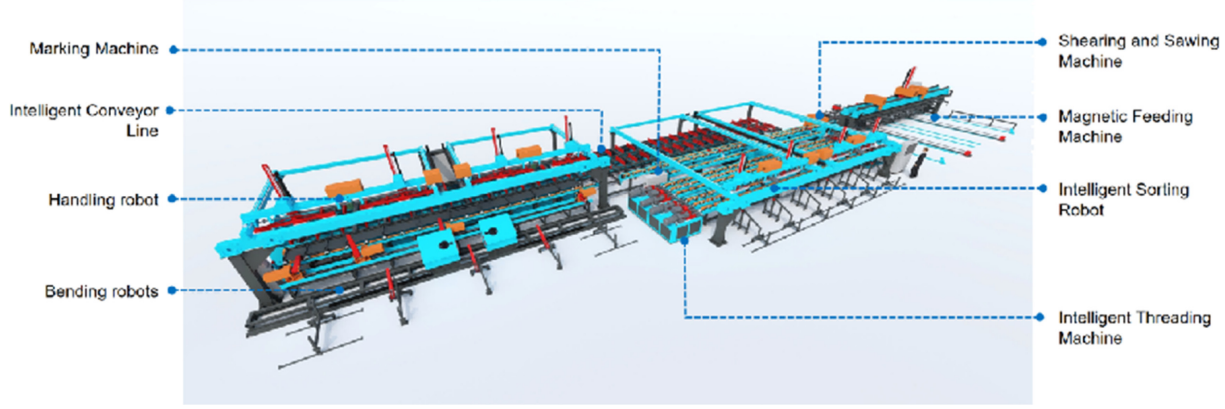


Figure 48. Illustration of intelligent production line for rebar.

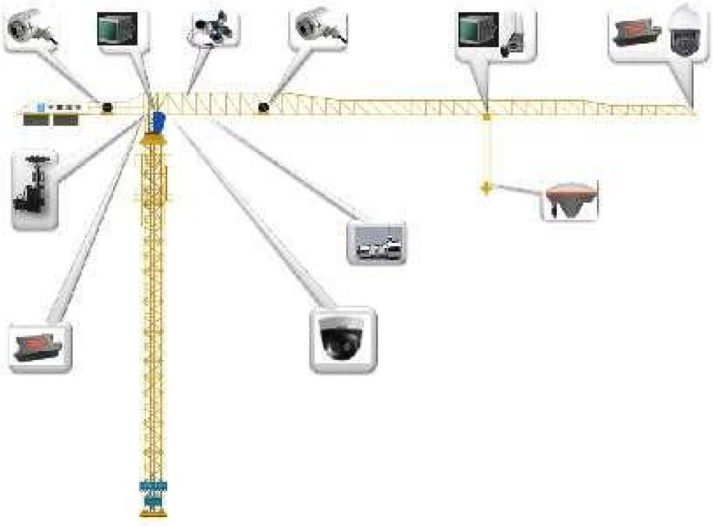


Figure 50. Comprehensive Real-time Sensing System.



Figure 51. Communication Network

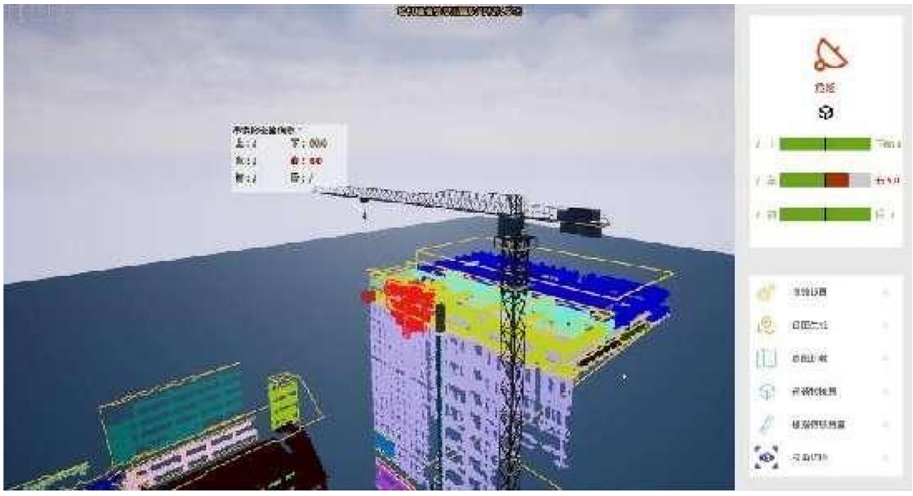


Figure 52. Intelligent Anti-collision based 3D Reconstruction.

5.4. Intelligent remote centralized control system for tower cranes

To address the challenges of high risks, harsh working conditions, and low efficiency associated in the high-altitude operation of tower cranes, we have developed an intelligent remote centralized control system for tower cranes. By overcoming key technologies including comprehensive information perception and reliable transmission for tower cranes, intelligent anti-collision based on 3D reconstruction, and multi-crane centralized management, the system has transformed the traditional high-altitude individual operation mode into centralized group control and management of multiple cranes in ground-based indoor environments.

This innovation fundamentally improves the working conditions for crane operators while enhancing safety and efficiency. Additionally, the system employs vision-based deep learning models to achieve semantic recognition of lifted objects. By combining statistics on lifting cycles,



Figure 53. Centralized Hoisting Operation of Multiple Tower Cranes..

lifted object types, and load weights, it enables data analysis of the lifting process. Through statistics on the quantities of various building materials lifted, the system provides data support for material management at construction sites.

6. Conclusion

China's exploration of innovative technologies in high-rise construction reflects the global trend of a construction paradigm driven by the synergy between intelligence and industrialization. This paper highlights several technological breakthroughs in the construction process of high-rise buildings:

1. Construction process: The integrated top-down synchronous construction method, combining process innovation with design-stage optimization, has redefined the construction sequence of super high-rise buildings and significantly accelerated project timelines.
2. Construction equipment: The development of a series of integrated operation platforms, along with technological advances in tower cranes and construction elevators, has greatly improved the working environment, safety assurance, and operational efficiency. These technologies have also been gradually extended to building operation and maintenance, and even to other engineering domains such as bridges and nuclear power plants.
3. Construction robotics: Intelligent, autonomous, and collaborative innovations are overcoming the labor dependency and process limitations of traditional construction. The integration of unmanned systems, data-driven operations, and additive manufacturing is propelling the industry towards the next-generation construction paradigm.
4. Digital construction: The integration of digital technologies such as remote control, digital twins, and information fusion provides clearer, more accessible, and more analyzable data for decision-making during construction, while enabling more efficient and automated process control.

These technological innovations demonstrate the core value of intelligent construction in terms of efficiency improvement, quality enhancement, and safety reinforcement, while also highlighting the inevitable shift of the construction industry towards a "human–machine collaboration and data-driven" model. However, the further promotion of high-rise construction technologies still faces challenges: (1) the non-standardization of building forms and construction processes hinders industrialized production; (2) the high cost and complex maintenance of high-precision equipment such as construction robots limit large-scale adoption; (3) existing construction standards lag behind the pace of technological iteration, especially in operation specifications for construction robots and interoperability protocols for intelligent equipment.

Future development must focus on addressing these issues through systematic innovation to enable the transformation of high-rise construction from "mechanization replacing labor" to "data-driven intelligence," thereby contributing to the sustainable development of global urban construction.

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