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Citic Tower Construction Key Technology

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Abstract

Citic Tower is the first over-500 m-tall super highrise building in the world, located in the high seismic intensity area with paek ground acceleration over 0.2g in 475 years. This project is unique in its complexity, large volume, and challenging site conditions (zero site for construction). The traditional techniques can hardly meet safty, quality and schedule requirements of the construction. This article introduces the key construction technologies that are innovatively developed and applied in Citic Tower project construction, including intelligent super-high-rise building integrated construction platform system, independently developed by the CCTEB; Jump-Lift Elevator, which is the first of the kind with service height over 500 meters; combined temporary-and-permanent fire protection systems. The BIM technology is also applied in this project. Through technical innovation, and utilization of technologies, construction speed and safety had been greatly improved.

Keywords: Super high-rise building, Intelligent super high-rise building integrated construction platform, Jump lift elevator, Combined temporary-permanent fire protection system, BIM technology

1. Project Overview

Citic Tower is located in Z15 plot in the CBD of Chaoyang District, Beijing. When completed, it will be the headquarters of China CITIC Group and a new landmark of Beijing.

The plot area is 11,478 m^2 and with the superstructure height of 528 m. It's the first over-500-meter-tall super high-rise building in the world that is located in grade-8 seismic design zone. The shape of the tower is inspired by "Zun", which is the traditional Chinese wine container used in religious ceremonies. The plane is square shaped, the outline of the building is naturally reduced from bottom to the upper part, and then slightly enlarges at the top, forming (double-curved) concave profile. The square cross sectional view at the bottom size is 78m×78m, and 54m×54m in the upper middle part; top is gradually enlarged simultaneously with the size of 69m×69m, but smaller than the bottom size. The final form is a hyperbolic architectural shape building. The overall design is eco-friendly, which becomes the benchmark for Beijing's green living and sustainable development.

The "nested tube" structural system is applied in this building. The inner tube is a structural steel-reinforced concrete core, while the outer frame tube is consisted of giant bracing, mega frame and sub-frame. The inner and outer tubes form a redundant lateral force resisting structural system.

The inner tube is consisted of shear walls, which contains steel plates. The Steel plates are placed in the bottom of the structure to form a structural-steel-reinforced shear wall system. The steel frame's hidden bracing is evenly placed in the wall at the middle area of the tower. This system can improve the ductility of reinforced concrete shear walls, and meet the requirements of axial compression ratio with a limited wall thickness. At the same time, the concrete has high rigidity and good fire resistance, which leads to lower costs.

The outer frame tube is consisted of mega columns, mega diagonal bracing, transferring trusses and a sub-frame. The mega columns are concrete filled steel tubesat the corners of the tower, running from the base to the top of the structure. They are connected to the transferring truss and mega diagonal bracing in each section. The use of concrete-filled tubular-steel column can eliminate huge amount labor for rebar work and reduce complex formwork and bracing systems, thus simplifies the construction. The mega column is filled with high-strength concrete (grade C50 or higher) from bottom to top, which can effectively prevent buckling of the steel tubular and improve the material utilization ratio of the component. With the limit of axial compression ratio, the cross-section size and the weight of the structure can both be effectively reduced. In order to improve the ductility of the mega column structure and limit the effect of concrete shrinkage and creep in the mega column, the steel cage and the structural steel are arranged in the mega column.

The typical slab thickness of the tower core tube is 120 mm. The transferring truss, on the one hand, transferring gravity to the mega column; on the other, the presence of the trusses also produces an abrupt change in the interlayer

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Figure 1. Project Rendering.

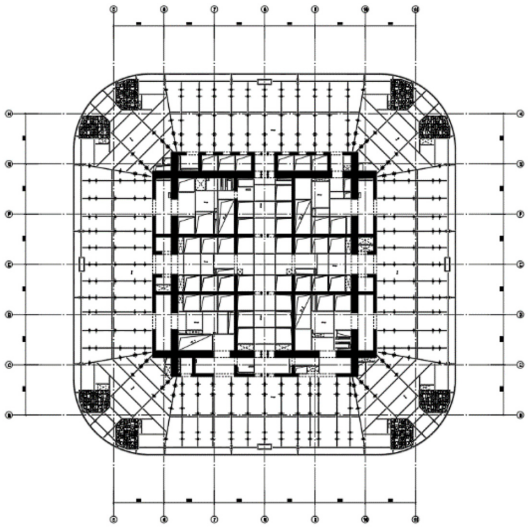


Figure 2. Typical floor plan.

stiffness and leads to a large shear transfer between the core tube and the outer frame tube. In order to ensure the transmission of the horizontal shear between the core tube and the outer frame tube, the thickness of the transferring truss floor slabs is increased to 200mm, while the thickness of the first-floor slabs and the embedded floor slabs are

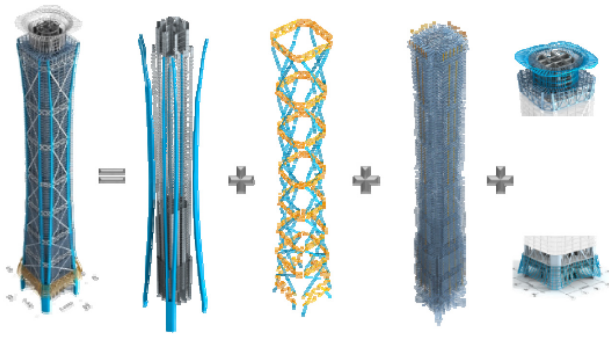


Figure 3. Structural system diagrammatic sketch.

250mm. Horizontal steel bracing is placed under the floor between the core tube and the outer frame tube to ensure structural safety.

2. Construction focal points & difficult points

2.1. Construction period

Citic Tower Building has 108 floors above ground and 7 floors underground. The inner tube is a structural-steel reinforced shear wall structure while the outer frame tube is mega column and mega diagonal bracing structure. The total construction period is 64 months. It is the shortest construction period for China's super high-rise buildings which is over 500 meters. The “two sessions” which are held in Beijing every March every year, limit the construction of the project. The confirmation of the construction of various formworks, the processing of various components, the purchase of various materials and large equipments and the technical difficulties in super high-rise building construction have a great impact on the total construction period.

2.2. Site construction area

The Citic Tower and the surrounding projects are constructed at the same time. The distance between each project is very close and the Citic Tower is close to the public underground pipeline, and the traffic organization is difficult. The construction site is very narrow, the red line (property line) is adjacent to the boundaries of the basement structure. There is almost no available space outside the basement of the building, which poses high requirements for the construction organization and manage-ment.

2.3. Vertical transportation

During the construction of this super high-rise building, the vertical transportation capacity is the lifeline of the construction, and it is also the bottleneck of construction organization. There are 101 elevators in the core tube of this project but the tight construction period lead to early elevator installation during the MEP installation stage and decoration stage. Thus the installation can meet the

construction milestone and it is impossible to arrange a large number of construction hoists in the elevator shafts in the core tube.

2.4. Safety management

Four mega tower cranes and 10 high-speed construction hoists work together during the construction. The safe operation of mega mechanical equipment is the key to super high-rise construction. There are more than 3,500 working staff in the building during the construction peak hours. The permanent fire-fighting facilities are not available during the construction process.

3. Key construction technology

3.1. Construction methodology for ultra-deep, ultra-thick -mass concrete foundation slab

The excavation depth of this building is 38 meters deep. The form of the foundation is a piled raft with the thickest part of the raft—under the podium—is 6.5 meters. It is the first time in China that the 40 mm-diameter grade HRB500 steel rebars are used in raft slab with the amount about 17,000ton. The following innovative technologies are used in the construction.

(1) Technology for the base anchor assembly of extra-large steel columns

In order to ensure the installation accuracy of the anchor bolts and to save labor, an adaptive anchor bolt sleeve is designed. It consists of three parts: detachable first layer beam, support frame body and independent columns. Constrained by the anchor support frame, the high-strength anchor is accurately defined within the support frame, after the bulk support frame is installed, all the support frames are integrated to form an integral support frame group. The support frame and the anchor bolt are assembled at on-site workshops. Before tying steel bar, the first beam of the support frame is removed to solve the difficulty of placing the super long top rebars and the insertion support frame. The first beam is replaced before the concrete is poured and the anchor position is corrected.



Figure 4. Anchor bolt frame on-site construction renderings.

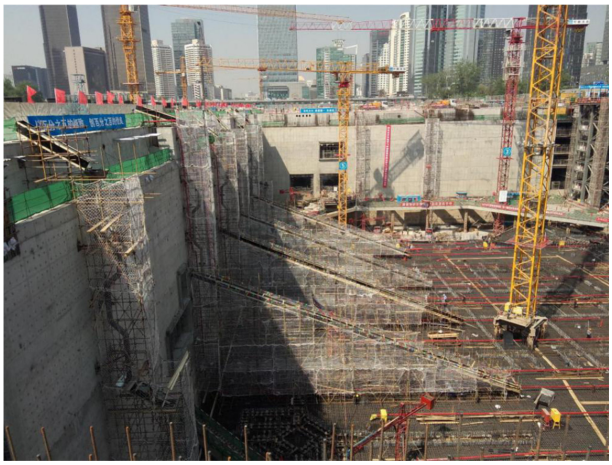


Figure 5. Tandem tube and chute combination system.

This technology reduces the construction hoist and improves the installation accuracy of the anchor.

(2) Technology for ultra-deep, ultra-thick and large-volume concrete raft

Citic Tower's concrete foundation slab contains about 56,000 cubic meter concrete. High-volume fly ash is added in the concrete that can impressively reduce the use of the cement and meet the design requirements. The use of fly-ash concrete can effectively solve temperature-induced cracking and reduce high hydration heat of the massive concrete raft. During the construction, an innovative system of chutes and pipes (connected in series) was adopted. The concrete can flow from high initial position through the system of pipes to the low position (elevation) of the chutes, and then through the chutes, finally the concrete flow to the designated casting location. This system effectively solves the problem of distributing concrete to the narrow surrounding areas of the deep foundation pit, and addressed the difficulties of continuously casting of large volume concrete.

(3) Key Technology of Grouting Construction for Super Large Structure Floor

The use of the multi-point pressure grouting technology in the construction is another innovation, it achieves monolithic grouting for a maximum area of 178 m^2 in the bottom zone of the mega column. The area of the mega column (including the wing wall) is divided into five sub-zones, in which the giant column body is treated as one sub-zone. The wing wall is divided into four sub-zones. Grouting material is pumped vertically into the subzones with a 450L mixer + grout pump. The middle cavity is used as the main grouting point, and the distal cavities on both sides of the giant column are used as the auxiliary grouting injection points. The pumping connection point is fitted with a four-way connection joint, which connects with the main and other three auxiliary grouting points respectively, and it is controlled by a valve. If the main

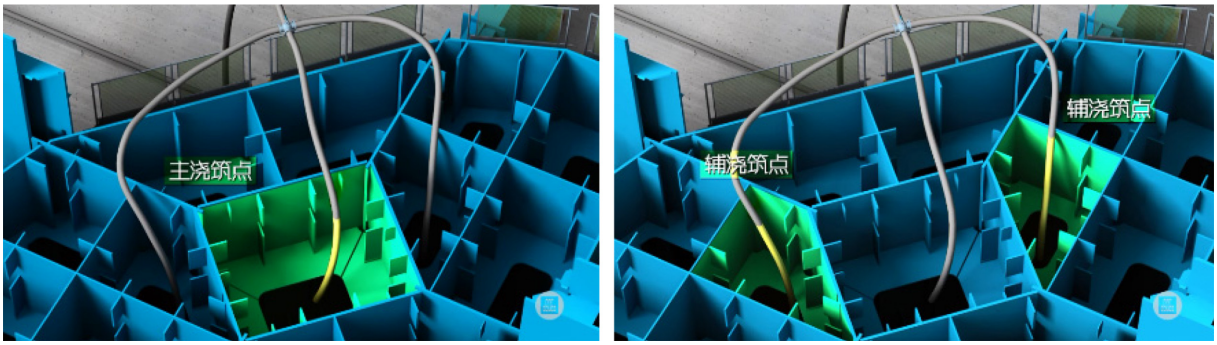


Figure 6. Schematic diagram of grouting and pouring of huge column bottom plate.

injection point's grouting material does not drop significantly, the three-way valve will open in, and the main and auxiliary pump pipes are simultaneously poured at three points at the same time.

3.2. Integrated super high-rise building construction platform

The construction limit time for Citic Tower is only 64 months, which is the shortest one among all the super high-rise buildings over 500 meters high in China. It is difficult to meet the safety, quality and construction requirements with traditional approaches. In order to improve the construction efficiency and meet the construction period, the intelligent construction equipment integrated platform system which is independently developed by the China Construction Third Bureau is used during the construction period.

The integrated super high-rise building construction platform consists of support system, steel frame system, power system, formwork system, pylon system and monitoring system. The steel frame system includes the beams, the frame columns and the opening / closing mechanism of the corner. The frame column is located at the outer walls of the inner tube, the structure is similar to the giant "steel cover" buckled on the upper part of the core tube. The top platform provides machine operation room and concrete placing booms, material yards, construction machinery, etc. It offers workspace for the workers who have to operate in the inner tube and also provide facilities that are needed to control the platform. The support system comprises a plurality of support points located at the lower part of the frame column. Each support point comprises a micro-convex fulcrum, an upper and lower support frame and a transfer column, and the steel frame system transmits the load of the platform to the structure below the concrete floor to be poured through the support system. The hydraulic jacking system includes a power source, a jacking cylinder and a hydraulic control electronic control components. It provides the ascending power of the platform, and the platform is lifted upwards together with the support system.

The formwork and scaffolding system used for inner tube construction is suspended from the bottom chords of the trusses of the main platform. During the construction period, the upper layer of the inner tube's rebars are tied first. After the steel rebar of the current layer are fixed and the underlying concrete reaches the sufficient strength for decluttering, the integrated platform is jacked up. The formwork and scaffolding system rise together with the steel platform to a structural height. After the platform is in position, adjust the formwork, seal the formwork, pour concrete, and carry out the next construction cycle. Workers can carry out l construction work (4 floors per cycle) in a fully enclosed platform at, achieving "building skyscrapers in the production-line like manner".

The entire platform is 43 meters long, 43 meters wide and 38 meters high. It has 7 floors and a maximum top thrust of 4,800 tons. The platform is the world's largest building construction area with the highest bearing capacity. The powerful space-truss structure system can withstand thousands of tons of load, and can resist strong winds above 14 high altitude.

Through the application of the integrated high-rise building construction platform, it can achieve a construction speed of one cycle in 6 days. The integration of tower cranes solves a series of problems such as safety, quality, construction period, pollution and impact by the tower crane self-



Figure 7. Citic Tower intelligent construction integration platform.

climbing. It also reduces the number of times for tower crane self-lifting by a factor of 28. Formworks and hangers are modular products that can be used for multiple projects. The application of this technology saves raw material consumption and improves labor productivity, thereby improving energy utilization efficiency and ensuring efficient and rapid construction.

3.3. The use of JumpLift

Under the traditional domestic construction mode, super-high-rise buildings basically adopt the wall-mounted hoist as the main tool for personnel transportation. But the speed of those hoists is slow and the transportation efficiency is low. The location of the hoists is limited, which cannot guarantee the requirements of the transportation capacity in super high-rise buildings. The long-time occupation of the hoists in the shafts affects the installation of the regular elevators, and then it will adversely affect the overall construction period of the project.

Jumplifts are used in the construction of Citic Tower as the construction elevators to transport workers and cargo. The machine room is a temporary one that can climb by itself. It is temporarily fixed to the inner shaft walls by the telescopic support beam on the self-climbing mechanism. With the construction of the upper hoistway, it gradually jumps upwards. Before the structure capping, the traction machine and the control cabinet used in the final elevator are transported to the regular machine room, and the electrical components and the worn parts are replaced. The elevator can be put into use after the tested and adjusted. This can impressively shorten the installation time of the regular elevator.

There are three protective layers above the jumplift with the functions of rainproof, waterproof and anti-smashing when the upper structure is unclosed. It is also used as a safe working platform when lifting. The protective layers can be installed step by step with the structure.

As a hopping elevator, the operating speed is about 4 times that of the ordinary temporary construction elevator, up to 4m/s with the maximum stroke of 514 meters. The passenger capacity of a single-deck elevator is theoretically about 12 times that of a construction elevator of the same specification, reaching 3,600 kg. For the large-scale transportation demand, the elevator needs to be put into operation in time, which has a significant effect. The installation method can be synchronized with the height of the building, effectively solving the vertical transportation bottleneck problem of the super high-rise building, and the transportation efficiency, safety and reliability are much higher than the traditional building construction elevator.

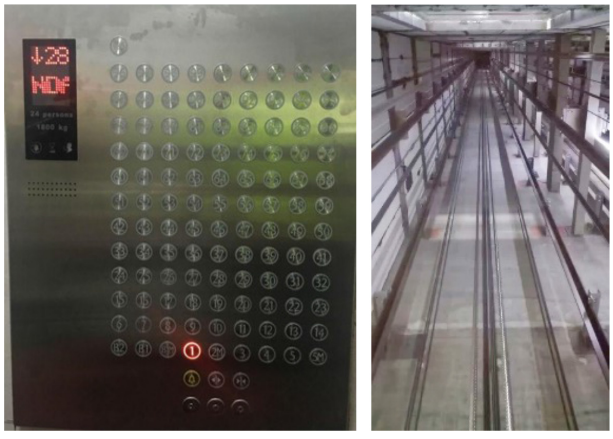


Figure 8. Jump Lift Elevator panel and elevator shaft.

3.4. Combination of temporary and permanent fire protection system

According to the current configuration of fire rescue facilities in China, super high-rise buildings can rely on external fire protection for fire rescue when the heights are less than 100 meters. When the height exceeds 100 meters, they can only rely on the fire protection system of the building. Therefore, during the construction of super high-rise buildings, temporary fire protection systems must be built to ensure fire safety during construction. However, this practice occupies a large amount of space of formal pipelines and equipments, affecting the installation of formal pipeline and the construction period. At the same time, fire safety cannot be guaranteed during the removal of the temporary fire protection system.

In order to solve the above problems, a new type of fire protection system is adopted in the construction of Citic Tower. This system consists of the formal transfusion tank with the effective volume of 60 m^3 in B001, F018, F044, F074 and the plumbing of the formal hydrant system, combine with a small amount of temporary pipeline and equipments. Above the water tank is a normal high pressure fire protection system. As the project progresses, the temporary facilities are gradually removed or replaced, and converted to the formal fire protection system.

According to the overall construction schedule, the entire program implementation is broadly divided into six stages:

In the first stage, before the F018 intermediate fire protection water tank is put into use, the municipal pressure water supply is adopted for levels below the B1M floor. The temporary high pressure system is used for water supply from F001 to F022. A temporary intermediate fire protection water tank and a temporary pump are set in B001 to ensure the temporary firefighting system in operation from F001 to F022, as well as the operation of the high-pressure system and water supply to the F018 permanent fire protection intermediate water tank.

In the second stage, after the F018 intermediate fire protection water tank is put into use, F001 to F006 use the normal high pressure system for water supply, and floors F007 to F052 use the temporary high pressure system for water supply.

In the third stage, after the F044 fire protection intermediate

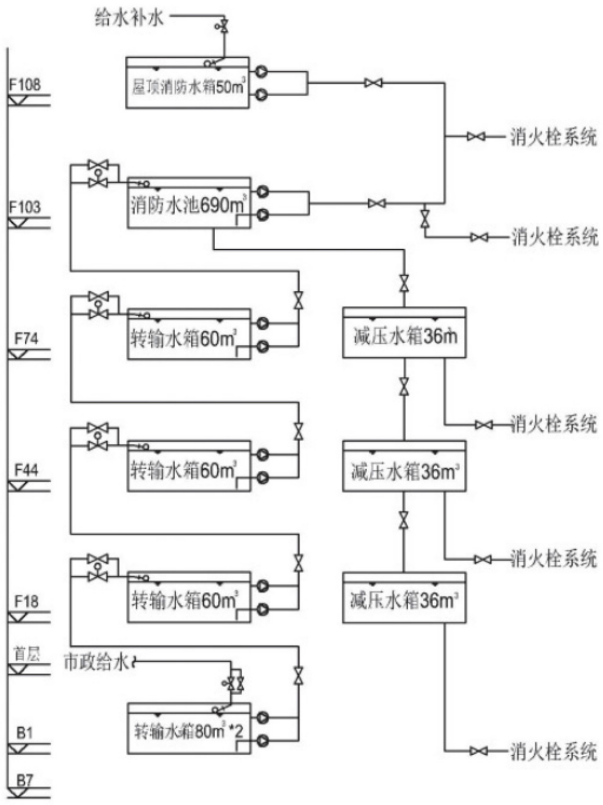


Figure 9. Schematic diagram of temporary permanent combined fire protection system.

water tank is put into use, floors F001 to F036 use the normal high pressure system for water supply, and floors F037 to F082 use the temporary high pressure system for water supply.

In the fourth stage, after the F074 fire transfer water tank is put into use, floors F001 to F066 use the normal high pressure system for water supply, and floors F067 to F108 layer uses the temporary high pressure system for water supply.

In the fifth stage, after the 103th- story fire protection water tank is put into use, this water tank supplies water to the F074, F044, and F018 break pressure tanks. Level F096 and below use the normal high-pressure system to supply water, and floors from F097 to the roof layer use the temporary high-pressure system to supply water.

In the sixth stage, after the water supply to the roof meets the service conditions for supplying water to the roof tank, floors F097 to roof level is will be supplied by a combination of fire water tank, a fire pump and a roof fire water tank; another temporary water pump is replaced with a permanent water pump. At this point, the temporary water pump can be completely removed and shipped out.

The technology described here achieves seamless relay or conversion of temporary / permanent fire protection, reduces the amount of closing work caused by temporary equipment and pipeline installation. It can reduce the investment and dismantling of temporary equipment materials, save a lot of construction time, cost, and improves the reliability of fire protection at the construction site of super high-rise buildings, ensures fire safety during construction.

4. The application of BIM

The general contraction team has a BIM Management Department to coordinate the planning and implementation of BIM application. Each department of the project designates a BIM specialist, responsible for BIM promotion in his specialized area. Each specialized sub-contractor sets up a BIM team to accomplish BIM-related mandates in the subcontract agreement. With the leadership of general contraction team, BIM technologies, such as design detailing, construction simulation, prefabrication and off-site processing, and 3D scanning, are efficiently integrated into construction process, so as to ensure cross-sectoral alignment, life-cycle simulation and life-cycle application.

4.1. BIM design detailing and coordination

In the process of deepening, the professional team fully integrated the 3D model with the 2D drawings to form a high standard deepening design results document. Among them, the main professional models such as steel structure, decoration and curtain wall have higher precision than LOD400.

Deepen the design to optimize building functions and improve building quality. The embodiment by optimizing riser wells arranged side pillars, increased building over 3000 m² of the floor area; by compressing sill fan coil width, increased building over 4200m² of the floor area.

Using software automatic calculation combined with professional engineer comprehensive review, record hard collisions and soft collision parts that affect construction or operation and maintenance, and implement design modifications. The project has completed more than 50 large-scale comprehensive coordination and solved over 6,000 problems. By several rounds of comprehensive coordination, solve 90% or more of the collision model, the scene based on the coordination of BIM material processing and installation model, compared with conventional engineering rework reduction of 65% or more.

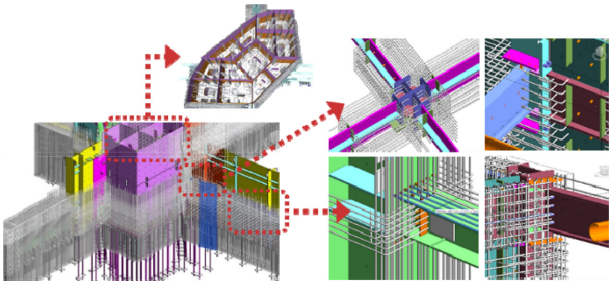


Figure 10. Complex node BIM deepening.

4.2. Construction simulation

The project BIM team participates in the major program preparation in the whole process, simulates the plan, and takes the contradiction between space, schedule and resources as the main analysis target, and optimizes the construction deployment and process flow.

Navisworks can be embedded in the characteristics of the construction period, the project will record the progress of the construction period and three-dimensional model of two-dimensional charts are associated using animation software to create dynamic growth, distinguished by different colors, it can automatically compare the actual progress with the planned duration, intuitive performance period Progress and key lines.

4.3. Digital processing

The engineering steel structure consumption is 140,000 tons, and all components are fully designed using BIM. Through the customized steel structure life cycle information management platform, the whole process tracking management of components is carried out. Optimize the typesetting and retrieving sequence, update the precise position of materials in real time, reduce material waste, and significantly improve processing speed.

The curtain wall unit plate is produced and processed by a high-precision model. In the production process, information such as material code, attribute code and process figure number are queried through the assembly schedule. After the components are shipped to the site, the coded information is read and transported to the designated floor, and the unit panel is installed efficiently and accurately.

The electromechanical professional research and development "modular design processing assembly system", using BIM software to assist in the establishment of electromechanical deepening design model, on the basis of deepening the design model to segment out the "components", after the arrival of the site, the overall rapid installation.

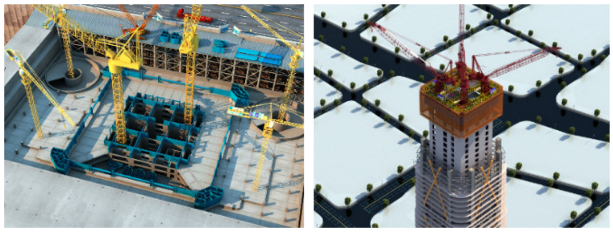


Figure 11. Construction simulation.

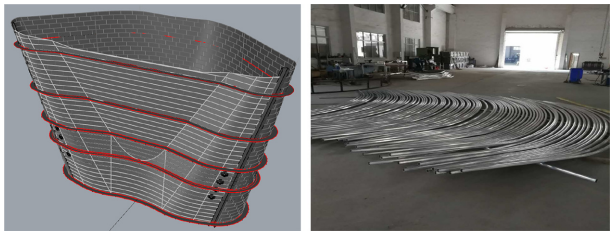


Figure 12. Prefabrication of decorative components.

In the fine decoration area such as the lobby and the high-grade office area, the production of the special-shaped members is completed by prefabricated processing. The parameterized design of complex components is realized by BIM , and it is imported into CNC machine tool processing, and the overall lifting of the site is realized after the assembly is completed in the factory.

4.4. 3D Laser Scanning

Citic Tower is the first super-high-rise building project that has comprehensively used full-scale 3D laser scanning technology: during the progress of the project; for each floor—upon completing the structural work, a high-precision 3D laser scanner (with accuracy of 2 mm) is used to scan and collect data. Then the mass amount of scanning data is feed to JetStream Data System and is stored on a cloud-based server, and the project personnel only need to install an end-user app, then can access the 3D scanning data remotely.

When conducting 3D Laser Scanning, the site survey coordinates are used as references, the resultant scanning data (points) are transferred into the BIM model's coordinate system. The development team combines the digital "virtual" model with the laser-scanned "real" points to verify and to complement the detailed design, which has prevented eliminated averse affects of accuracy-related problems on subsequent construction procedures.

In addition, by comparing the cloud data of hundreds of millions of laser scanned points of all floors with the BIM model, and analyze the discrepancies, engineers accurately determines defects and errors in the construction work, promptly making corrections. That has enhanced the construction quality.

5. Conclusions

Citic Tower Building project commenced on 29th of July, 2013; the main structure was completed on August 18, 2017; and the initial handover upon completion of works was on 18th of December, 2018; the entire project lasted 64 months. It is the fastest (over 500 m) super-tall high-rise building project in China, and its construction period is 30% shorter than comparable similar high-rise building projects (in China). The techniques that were used in Citic Tower project have now been applied to other projects with positive effects. In near future, the development of super-tall high-rise buildings in China as well as in Asia Pacific region will continue to make great progress. It is the author's wish that this composition can offer useful insight and reference for other practitioners or projects.

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