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Case Study: China Zun Tower, Beijing

A Finely-Crafted Vessel in the New CBD Core



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Robert Whitlock, with over 25 years of professional experience, has developed an expertise on high-rise towers, mixed-use developments, and large-scale master plans. Robert is also responsible for several supertall projects, including Chongqing International Trade and Commerce Center and Suzhou International Finance Square currently under construction.

Li Lei has over 17 years of design experience on a wide spectrum of project types. As Senior Designer he has led design teams on a number of significant projects including China Zun Tower, Beijing Huaneng Headquarters, Nanning Airport Terminal, and American Commerce Center.

Dr. Luo Nengjun is responsible for the overall planning and operation control of project management, design, construction of the China Zun Tower. He has been engaged in many Chinese supertall building projects, including the Shanghai World Finance Center and Tianjin 117 Tower.

Dr. Liu Peng is the leader of the Arup Beijing structural team. He has substantial experience in tall building design, seismic design, and China projects. He has been involved in or responsible for the structural design of many projects in China, including the China Zun Tower.

China Zun Tower will be the flagship building of Beijing's comprehensively planned 30-hectare central business district core. The 528-meter-tall tower will stand far above its surroundings and become one of the most prominent icons of the city.

The tower's gently rising and curving form embodies the historic capital's gracefulness, and resembles an ancient Chinese ceremonial vessel, called the Zun (see Figures 1 and 2). During the project's land bid phase, this conceptual reference was established as a part of the 2010 master plan by TFP, BIAD, Arup, and MVA. Since project design began, KPF has interpreted the cultural reference as a generative motif for designing tower form, envelope, and major interior spaces, by distilling and applying the articulation techniques of the Zun vessel.

Beijing has the highest seismic fortification requirement of the major cities in China, making the structural system particularly sensitive to adjustments of the complex form. During the schematic and design development phases, the design architect and lead engineer teams implemented parametric modeling, using a common software platform that greatly expedited the design and coordination process. The tower design was a result of a careful negotiation of multiple design parameters, to achieve an optimized balance between a sculptural, elegant and iconic form, optimized structural and elevator systems, and efficient and effective interior program spaces.

The project has undergone the precertification process with the US Green Building Council (USGBC) and is on the path to achieve eventual LEED Gold certification. Key design aspects supporting sustainability include a high-performance building envelope with an optimized window-to-wall ratio and triple glazing, energy-efficient mechanical equipment, use of local materials, and application of greywater toilet systems and rooftop solar panels.

Urban Context

The new Beijing CBD core is located at the northeast side of the Third Ring Road and Jianguo Avenue intersection, approximately 5.5 kilometers east of Tiananmen Square and outside the historic center of Beijing. The urban center's infrastructure will be completely modernized to support its densification and transformation into one of China's key international finance, service, and media centers.

Around China Zun Tower in the CBD core, there are more than 20 tall buildings, ranging from 150 meters to 350 meters in height. A linear public park with underground retail and



Figure 1. China Zun Tower, located in Beijing CBD. © KPF

parking facilities runs through the middle of the core area, with the tower anchoring the northern end (see Figure 2). The tower forms an iconic backdrop to the park, and a prominent new destination for visitors.

Apart from being adjacent to a major bus station above grade, the tower will also be rooted in a vast underground transportation infrastructure network, encompassing the CBD core currently under construction. These include a pedestrian passageway system, lined with retail space at Level B1, linking together four subway lines across three stations; and an entire Level B2 roadway network for passenger and service vehicles, providing direct access to the tower basement and public parking levels under the Central Green.

Overall Tower Design

The tower contains 350,000 square meters of gross floor area spread over 108 floors above grade (see Figure 3). While the tower profile is curved, its floor plates are square with rounded corners (see Figure 4). Combined with a square core, leasable interior office space is optimized.

Under a six-meter-tall parapet that screens window-washing machines, the main body of the tower is organized primarily into eight zones above the ground floor lobbies and a conference center at Levels 3 and 4. There are three office sky lobbies, with meeting and staff dining facilities, located at the tops of Zones 2, 4, and 6. They are accessible via a set of dedicated high-speed double-decker shuttle elevators. The tower will primarily house the headquarters of CITIC Group and CITIC Bank, occupying four zones, while the remaining three zones will be leased to tenants. At the top of the tower, an observation deck, with a multi-functional business center, provides 360-degree views of Beijing.

Below grade, there are seven floors totaling 87,000 square meters, primarily accommodating lower-floor office elevator lobbies, a bank, retail, building management, and parking spaces.



Figure 2. China Zun Tower is the centerpiece of the new Beijing CBD. © KPF

“Around China Zun Tower in the CBD core, there are more than 20 tall buildings planned, ranging from 150 meters to 350 meters in height. Apart from being adjacent to a major bus station above grade, the tower will also be rooted in a vast underground transportation infrastructure network, encompassing the CBD core currently under construction.”

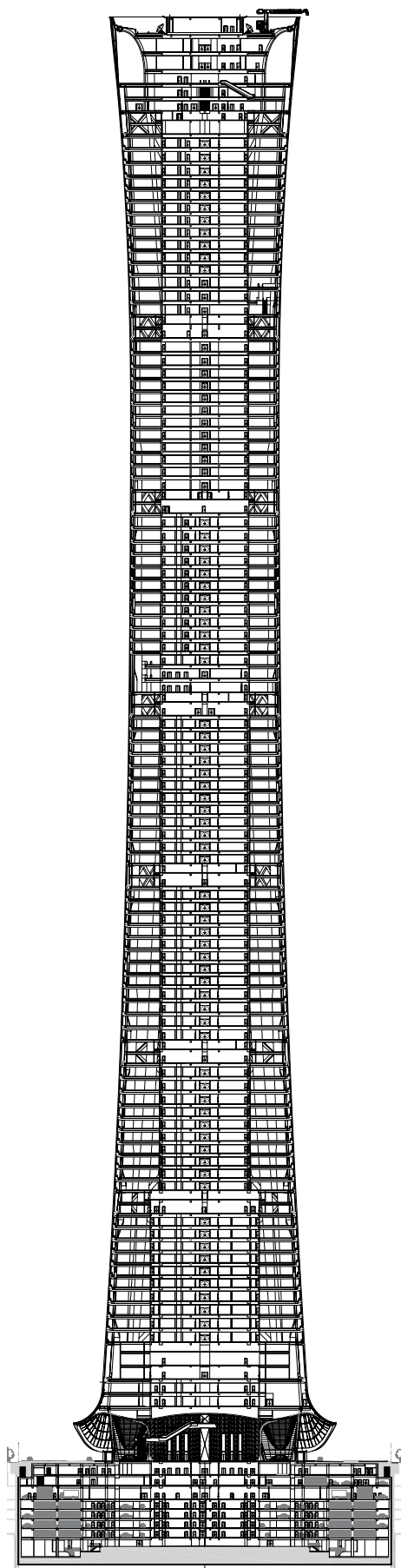


Figure 3. Section. © KPF/BIAD

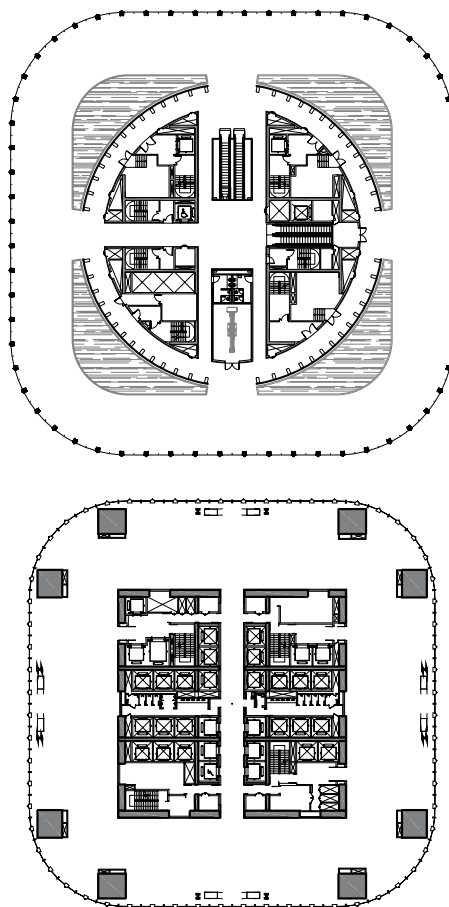


Figure 4. Floor plans – Level 106 Observation deck (top), Level 38 Typical floor plan (bottom). © KPF/BIAD

In essence, the concept design architect conceived of the tower massing as a transforming shell that gradually bends to create a dramatic and elegant form. The concept is also applied to other key elements of the tower, including the entrances, ground-floor lobby and observation deck.

At the bottom, the tower thrusts into the ground with massive corner supports, while the exterior shell is gently lifted up and stretched forward at the four sides. The design visually extends the lobby outward, forming dynamic drop-off spaces and creating a focal point at the CBD core area (see Figure 5). At the top, the exterior envelope becomes more transparent at the observation deck (see Figure 6) and allows more visibility to the inner trumpet-shaped business center, which lights up at night, forming a beacon that will be visible throughout the city (see Figure 7).

Compared to a typically straight or tapering supertall tower form, the concave tower profile offers more valuable prime-floor spaces and ample space for window washing, as well as other support systems, at the top of the tower. While the large top poses significant structural challenges, the larger base provides an opportunity for structural balance, formal contrast and preferred core-to-perimeter distances.

During the schematic design phase, in conjunction with variations in program stacking and resulting core configurations, the design architect and lead engineering teams tested various tower profiles for the effectiveness and efficiency of structural systems and office floor plates, while also balancing considerations for the elegance and iconic quality of the form. The complex design process was greatly enhanced by parametric modeling that clarified the geometric principles of both the building envelope and structural systems, as well as their corresponding relationships.

The final tower profile is composed of four tangential arcs with the base, center “waist,” and top, measuring 78, 54, and 69 meters across, respectively. The tower waist is set above all surrounding buildings, at a 385-meter height, to highlight its curved profile in the city’s skyline.

Exterior Envelope Design

The tower envelope is divided into 128 panels per floor, with continuous vertical panel divisions. The verticals are grouped into alternating major and minor ribs. Continuous window washing tracks are housed in the middle of the major ribs, while LED lighting strips are embedded into the sides of the minor ribs. The vertical ribs helps to mitigate the complexity of the curtain wall.

The subtly tightening and stretching envelope texture echoes the transformation of the tower massing. It is achieved by tapering and then widening the major ribs along the tower height. Not only does this rib design amplify the effect of the tower form; its



Figure 5. Tower base. © KPF



Figure 6. Tower top. © KPF

consistency helps to bridge the geometric transition between the straight faces and curved corners. Triangular in plan, the rib projections provide solar shading for the building and help to mitigate the visual impact of the ventilation slots required at mechanical floors.

At the top of the tower, the major ribs extend the full height of the business center dining floor and the observation deck at Levels 105 and 106 (see Figure 6). The minor ribs terminate at Level 104 and are replaced by a tensioned cable system with horizontal glass fin bracing, affording a wider exterior view.

At the bottom of the tower, where the exterior wall transforms to form the canopy, its geometry is the most challenging. Through a shingled articulation of a warped shell, the design achieves minimal complexity and reduction in cost by avoiding the need to use hot bent-glass panels. The lobby exterior wall

is a vertically tensioned system with low-iron glass panels. The lobby interior ribs extend through the tension wall to the exterior, and connect with the exterior ribs at the canopy edge. The strong reading of a transparent and welcoming lobby that integrates inside and outside is a reflection of the client's corporate identity.

Structural Design

Beijing has the highest seismic fortification requirement of China's major cities ($PGA=0.20g$ for a 475-year return period). The structural system of a tower with such a height must find a proper balance between stiffness and ductility.

The China Zun Tower has a narrow "neck" and an enlarged "head," which contrasts with most high-rise buildings that reduce width as height increases. The potential adverse effect

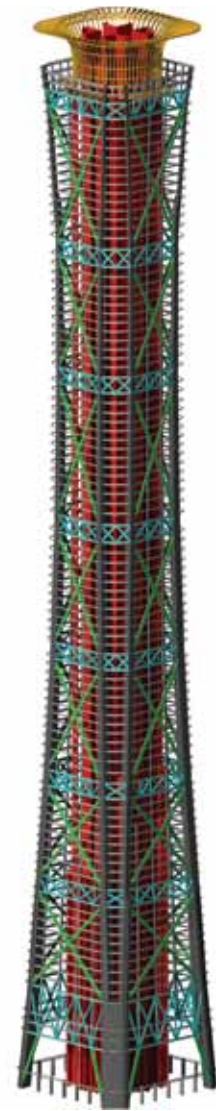


Figure 7. The tower's dual lateral resistance system. © Arup

of the additional mass located at the top was considered carefully in the structural design.

The dual lateral resistance system is composed of a perimeter megastructure and a central core (see Figure 7). The megastructure at the perimeter can be simply imagined as a "megatruss" rooted from the ground. Eight megacolumns at the corners act as the chord members, and merge into four columns at the base. The megabraces and transfer truss are the diagonals and posts of the "megatruss." This perimeter structure provides substantial lateral stiffness, which is essential to the safety of the building.

The megacolumns are concrete-filled steel boxes (CFBs), either with single compartments, or multiple compartments separated by steel plates. The core is mostly reinforced concrete, embedded with steel plates at lower and top floors for shear and axial resistance, and steel diagonal braces at

middle floors to increase ductility. The megaframe provides the majority of the lateral stiffness, and the core provides secondary reinforcement. Outriggers were studied, but proved too inefficient and thus were not used.

The gravity load is taken down through the composite floor to the secondary frame and core. The secondary frame at the perimeter passes the gravity load to the transfer truss at the bottom of each zone, which in turn transfers the gravity load to the mega columns, so as to balance the large tension force due to the overturning moment presented by lateral loads.

The perimeter megaframe

It is a challenge to design a megaframe system to fit a curving profile. For each approximately 15-story zone, the megaframe is maintained in one plane to facilitate connectivity and avoid additional forces. Furthermore, the various tower profiles have to be evaluated quantitatively. The latest parametric design technology was adopted to fulfill this task in a short time.

The geometry of the megaframe is built in Rhinoceros software with its parametric modeling plug-in Grasshopper. The key geometric parameters are input so that, when it is changed, the structural configuration is easily updated. An in-house-developed structural BIM plug-in is then used to input structural information such as materials, sections, and loading tolerances. The completed structural model is then exported to the commercial software for analysis.

Various options have been studied through this parametric modeling method. The main goals were to maximize the lever arm of the perimeter frame, maintain the column line in one single vertical plane, so as to minimize secondary forces, and minimize unrentable area between the perimeter structure and slab edge.

With this parametric modeling technology, engineers were able to evaluate geometrically varied options in a very short time and generate feedback with quantitative, actionable results. The final column line was determined as an optimal balance to satisfy the above criteria. With a single “kink point” at major zones and double “kink points” at Zones 7 and 8, the engineers achieved a structure-to-façade distance of one meter on most floors (see Figures 8 and 9).

The core

The concrete core is an atypical choice for super high-rise buildings in such a high seismic zone. In Chinese code, it is required that there be no shear failure during a maximum credible earthquake (MCE) event. To achieve this, steel plates with a thickness of 30 to 60 millimeters are embedded in the concrete walls from the ground to Level 41, increasing the shear capacity of the wall by three times, thus making the concrete core feasible.

The nearby China World Trade Center Phase 3A Tower, completed in 2010, is the first building to have adopted this composite wall approach. Since then, the composite steel plate wall has been used widely in supertall

buildings. Restrained from buckling by the surrounding reinforced concrete, the embedded steel plate provides very high shear capacity. The wall thickness can also be reduced, because the addition of the steel plates reduces the axial stress of the whole wall section under compression forces.

The enlarged top zone of the tower generates additional adverse shear in the perimeter at the “neck” floors. The smaller lever arm at the “neck” floors results in the higher-strength demands for the core wall elements. Non-linear analysis revealed that severe damage could occur on these floors if no special strengthening techniques were considered. Finally, steel bracing is embedded into the core walls to increase their shear capacity.

Extensive nonlinear analysis, using simulated and actual seismic records, has been carried out to evaluate the safety of the building under the MCE condition. A 1:40 shaking table test was conducted, to ensure that the structural design satisfies the criteria for different seismic levels.

The foundation and the basement

The tower is supported by a pile foundation that begins 79 meters below ground, in Layer 12 of Beijing pebble sand. As the site is quite small (84 meters in the north-south direction and 130 meters in the east-west direction), the basement contains seven floors, and the soffit of the base plate is 37 meters below ground. Thus, the effective pile length (the difference between the base of the pile foundation and the soffit of the base plate) is about 42 meters. The pile diameters are between 1.0 and 1.2 meters. The pile group supports the tower and the basement through a pile cap with a maximum thickness of 6.5 meters.

“Beijing has the highest seismic fortification requirement of China’s major cities (PGA=0.20g for a 475-year return period). The structural system of a tower with such a height must find a proper balance between stiffness and ductility.”

Project Management Approach

The developer has systematically devised an innovative design management model for effectively realizing the design scheme in the construction stage:

EPC-based design management system

Engineering, procurement, and construction

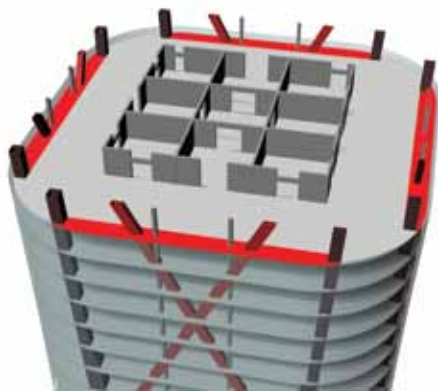


Figure 8. Office layout in relation to structure. © Arup

(EPC) is one of the most common models applied in international project management. It improves the efficiency of implementing in construction the required functions and programs specified in the building design. However, the policy of separately managing design and construction qualifications creates a gap in the information exchange and work handover between various design phases, as well as between design and construction. To bridge the possible gap in the information exchange and responsibility, the client contracted with a design consortium including major design firms responsible for different design stages, so as to achieve a seamless handover in design. Construction and building management experts, including contractors and building managers, were engaged to review design deliverables to ensure buildability and ease of building operation.

The design consortium

From August, 2012, a design management system that clarifies the work split, specifies responsibilities, and combines the advantages of all parties was gradually developed, referring to international project management experience and considering the design management needs of the China Zun Tower. After nine months of communication and coordination, a consortium was struck, composed of KPF, Arup, and PBA, primarily responsible for the schematic design and design development phases, with local design institute of record Beijing Institute of Architectural Design (BIAD) and CITIC General Institute of Architectural Design and Research carrying primary responsibility for the construction drawing phase. On April 10, 2013, the design contract forming the design joint venture was

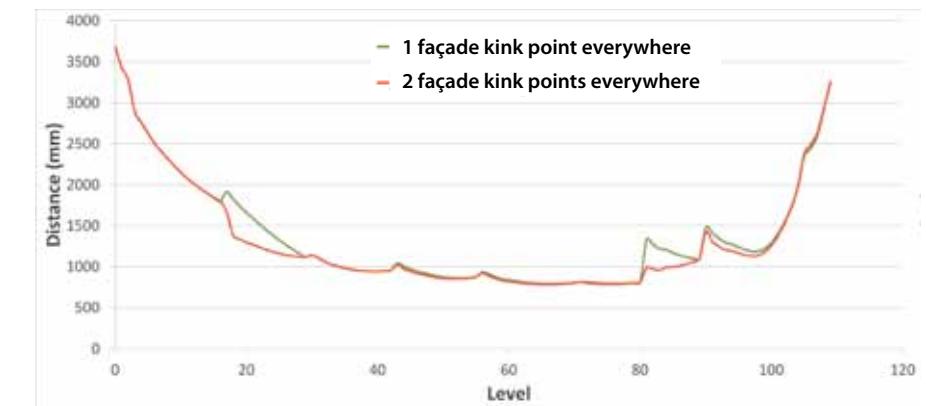


Figure 9. Optimal façade distance at each floor level. © Arup

finalized, establishing direct communication between various parties responsible for schematic design, design development, and construction drawing phases.

- *Effective coordination between specialist consultants and general design contractor.* Design services for the China Zun Tower are provided by the design consortium, as well as more than 30 specialist design companies and professional consultants. In order to increase the efficiency of cooperation, the specialist designers and consultants signed a three-party contract with BIAD, the general design contractor, and CITIC HEYE. The deliverables by the specialist designers and consultants are directly assessed and managed by the general design contractor.
- *Comprehensive assessment of design deliverables.* The key indicators for assessing the success of the design scheme include the satisfaction degree of the owner and final users, operation and maintenance costs, and fulfillment of social responsibilities.

Based on available statistics derived from the Jin Mao and Shanghai World Financial Center projects, the operation and maintenance cost of a supertall high-rise building over an estimated 65-year operation period is nearly triple its construction cost. Based on the design concept of "life cycle cost," the requirement for cost-effectiveness needed to be satisfied in every detail of the design procedure, including the window-to-wall ratio, the reasonable value for structure safety factors, and so on.

The social responsibility of the developer and the designers is reflected by the sustainable policies deployed during the design of the project. These include materials conservation, rationalized construction, and reduction of energy consumption. In the architecture field, green building standards, energy-efficient and environmental-friendly curtain wall systems were adopted. In the structural design field, the use of advanced modeling technology to select the appropriate displacement constraint and load parameters resulted in an optimized structural system and high structural efficiency.

- *The Application of BIM Technology* China Zun Tower is characterized by a large investment, a long development and construction cycle, complicated technologies, and the involvement of a large number of stakeholders. In November 2011, BIM technology was introduced to the project in order to: accelerate the program, reduce the cost, promote the efficiency of design coordination and constructability analysis, and provide a data foundation for the operation and maintenance of the building.

From the end of 2011, to the beginning of 2012, the owner organized nine BIM technology service providers to discuss how to apply the technology to the project, and establish rules and standards for the BIM application. The findings of this exercise were later published for future reference.

The Guide to BIM Execution in China Zun Tower was compiled according to the BIM

application experience of all the parties in the design consortium and in the 2D and 3D coordination work practice, covering BIM management regulations and technical standards. The guide was established to foster better communication and coordination of all parties. Moreover, to ensure that the BIM information standards would be applied consistently, a BIM execution framework system was developed, and continues to be improved as BIM application experience accumulates during the course of the project.

BIM management processes were developed according to the management system during the design and development

phases of the project. Such processes are developed according to a hierarchy that places the architect at the top (see Figures 10 and 11). The BIM responsibilities thus have a one-to-one correspondence to the project contractual liabilities. The deliverables of the design phase indicated that BIM technology has played a quite significant role in reducing coordination errors and promoting the implementation efficiency and constructability of the design plans. Taking the finished basement construction document (version 4.0) as an example, a total of 147 discrepancies were found, in which there were 8 discrepancies related to MEP facility locations, and 20 discrepancies in the MEP duct-routing integration.

The establishment of the design consortium for China Zun Tower changes the “zero-sum game” contractual relationship into a “multi-win” partnership, thus creating the basic setting for the formation of system integration and synergy. In the circumstance where the engineering procurement and construction (EPC) model was unavailable due to policy constraints, BIM played a key role in promoting the “seamless connection” of design and construction throughout the process. ■

Project Data

Expected Completion Date: 2018
Height: 528 meters
Stories: 108
Total Area: 437,000 square meters
Use: Office, observation deck
Owner/Developer: CITIC HEYE Investment CO. LTD.
Architect: TFP Farrells (*concept*); Kohn Pedersen Fox Associates (*concept & design*); Beijing Institute of Architecture and Design Co., Ltd. (BIAD) (*concept & architect of record*); CITIC General Institute of Architectural Design & Research Co., Ltd. (*architect of record*)
Structural Engineer: Arup; BIAD
MEP Engineer: Parsons Brinckerhoff; BIAD
Other Consultants: ALT Limited (*façade*); Altitude Façade Access Consulting (*façade maintenance*); Brandston Partnership (*lighting*); RWDI (*wind*)

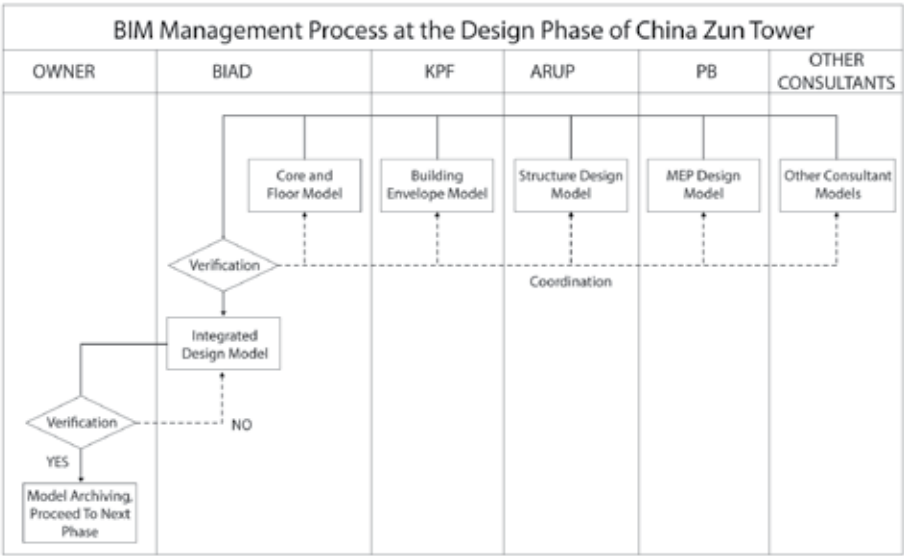


Figure 10. BIM management process at the design phase. © CITIC Heye Investment Co. Ltd.

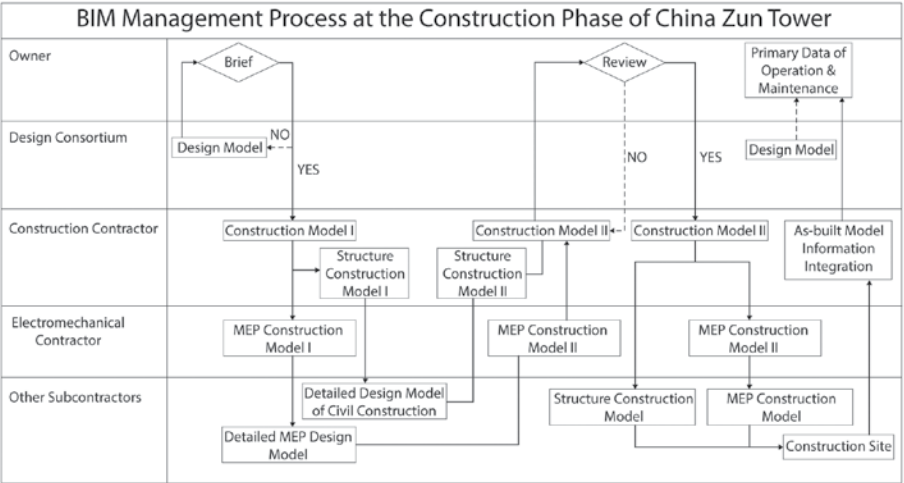


Figure 11. BIM management process at the construction phase. © CITIC Heye Investment Co. Ltd.

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The China Zun project will be featured at the Shanghai Conference, through the presentation by **Weiping Shao** of BIAD entitled “China Zun: Shaping the Future Skyline of Beijing,” Session 15: **Tools for Design Optimization**, Thursday, 18th September, 1:45 –3.15 p.m.

In addition, **Dr. Nengjun Luo** of China Zun developer CITIC HEYE Investment Co. Ltd. will be speaking in Panel Discussion 2, **The Differences in Developing Tall Buildings in Cities Across China**, Wednesday, 17th September, 1:45 –3.15 p.m.