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Case Study: Tianjin CTF Finance Centre

Determinism, Integration, and Articulation Lead Up to a Landmark



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Abstract

Completed in 2019, the Tianjin Chow Tai Fook (CTF) Finance Centre is currently the seventh-tallest building in the world, tied with the Guangzhou CTF Finance Centre at 530 meters (see Figure 1). Beginning with the circumstances of the commission, this case study describes the integrated design process, shares the creative strategies evaluated and pursued, and summarizes the innovations developed by the collaborative design team. This elegant mixed-use supertall tower is a unique form that was based on rational and thoughtful explorations of efficiency, functionality, and beauty. Reinforcing and emphatically marking Tianjin's new TEDA mixed-use, multimodal commercial business district, the aerodynamically-shaped form, curving sloped column system, and visually powerful envelope combine to define a new generation of landmark tall buildings.

Keywords: Mixed-Use, Transit-Oriented Development, Wind Engineering, Supertall

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Brian Lee received his Bachelor of Arts in Architecture with Highest Honors from the University of California, Berkeley in 1976 and his Master of Architecture with Commendation from Harvard University Graduate School of Design in 1978. After practicing in the SOM San Francisco office for 28 years, he joined the Chicago office in 2007.

Thomas Kinzl is responsible for the technical coordination and development of projects through the construction administration phase, organization of the construction documents and communication between client, contractors, and consultants. Kinzl is also responsible for the management of architectural project teams, deliverables and monitoring, and implementing current trends in building technology.

Inho Rhee collaborates and develops design concepts in conjunction with the design partner. He is responsible for the project design and for the leadership of the project team. Rhee implements and directs the design strategy of a project and is responsible for the project's adherence to the design intent.

Ronald Johnson works under the direction of the structural engineering partner and is responsible for the design and documentation of structural engineering projects. He collaborates with the architectural design team to incorporate a structural engineering system which is compatible with the project's planning, architecture and other required systems.

Location and Context

Tianjin is one of China's largest cities, connecting the national capital region to global trade networks. The Beijing-Tianjin high-speed rail line, inaugurated in 2008, links Beijing with several places in and around Tianjin, extending southeast through the city's core to the Binhai New Area, and reducing travel time to Beijing to approximately one hour. A metro line also connects Binhai with Tianjin's core, stitching the area more closely into the larger Beijing-Tianjin urban fabric (see Figure 2).

The Tianjin Economic Technological Development Area (TEDA) was established in 1984, and together with the adjacent Yujiapu CBD, have addressed growing needs for office, research, and residential space in Binhai. The Central Government has set sustainable design principles that guide developments with urbane street and open space networks, less resource-intensive development, and improved quality of design and construction for urban development in the country.

Tianjin CTF seamlessly integrates residential, office, hotel, and retail programs into a mixed-use, dense, walkable urban complex with excellent transit connections. The

design and engineering team's approach—to develop a solution that elegantly integrates a diverse program—demonstrates a method that not only makes multi-program supertalls possible, but meets and exceeds the guidelines shaped by the government to build a sustainable urban future.

Design Challenge

The architecture team was asked by the owner to work on the project after another international architectural and structural design team had proposed a scheme that the owner had been unhappy with—it was costly, viewed as slow to construct, and visually underwhelming to the chairman. Aware of the challenge to satisfy the last issue of creating something that inspired, the team presented a typology of tower forms in small models and diagrams, which addressed the relevant issues of building tall mixed-used structures.

The primary challenge for the design team was to create a tower that integrated three distinct program elements, in a form that was both rational and evocative. Each of the program elements—office, residential, and hotel—have very different dimensional



Figure 1. Tianjin CTF Finance Centre is the centerpiece of the Tianjin Economic Technological Development Area (TEDA). © SOM/Seth Powers

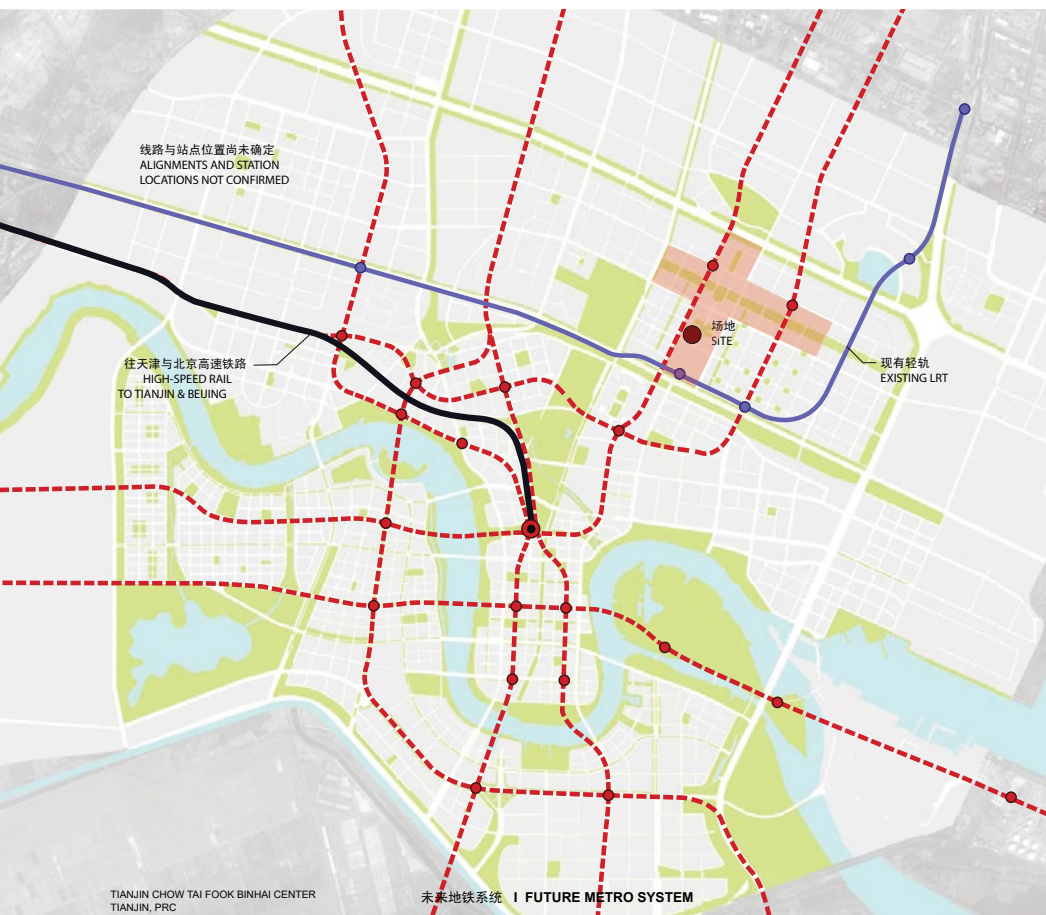


Figure 2. The tower site is located near an existing light rail transit line, several planned Metro lines, and the high-speed rail station connecting the TEDA with Tianjin and Beijing. © SOM

requirements for space planning and access to natural light. Key to the design work was recent research on, and experience with other tall buildings that demonstrated the effects of wind loads on structural performance. The effects of lateral forces due to wind and vortex shedding was well known to the design team.

The architects and engineers collectively studied tapering and softened forms that performed well in wind tunnel tests and optimization programs. In the end, the clear choice for development was the tapered, round-cornered, and scalloped form—a lyrical massing that seemed to easily distinguish itself from the other rectilinear, faceted, or angular articulated towers that were familiar to the experienced client (see Figure 3).

Working from the bottom up and from the core outward in a core-to-envelope approach, the sinuous topographic expression of the exterior envelope reflects the integration of disparate programs within a singular smooth object. This expression is optimized to accommodate the relationships between the different leasing spans, the varying structural core widths, and the



Figure 3. The tower's tapering and scalloped form presents a unique contrast with a backdrop of rectilinear neighbors. © SOM/Seth Powers

perimeter walls of the independent hotel, apartment, and office programs. Square in plan with rounded corners, the building geometry maximizes efficiencies of the three main uses, while maintaining a fluid, cohesive visual expression.

The design team proposed an approach to supertalls based on a set of innovative strategies that blend and integrate architectural and engineering concerns. Unlike approaches that start with willful shapes and then rely on a reactive engineering approach to execute them, the strategies that informed the final design of the Tianjin tower provide a model for future mixed-use, supertall buildings by encouraging an integrated, efficient approach to design and engineering.

Program and Design

The class "A" office program in the tower includes consistent lease spans of

approximately 13 to 15 meters from the core to the exterior wall. With an efficient square form, the central core contains local elevators that serve three zones across 36 office floors. The 3,500–3,800-square-meter plans were shaped with rounded corners to reduce structural spans and wind loads at the corners.

Above the office floors, the residential program of 300 luxury serviced apartments was planned with lease spans of 12 to 13 meters from the core. These residential units are accessed via private elevators, which are accessed from a sky lobby, located above the hotel sky lobby and amenities. As office elevators and portions of the structural core drop off below the residential levels, the floor plate reduces in size to approximately 2,000 square meters at the bottom of the residential program.

Crowning the tower is the 350-room Rosewood-branded hotel program, which is accessed from its own sky lobby, located

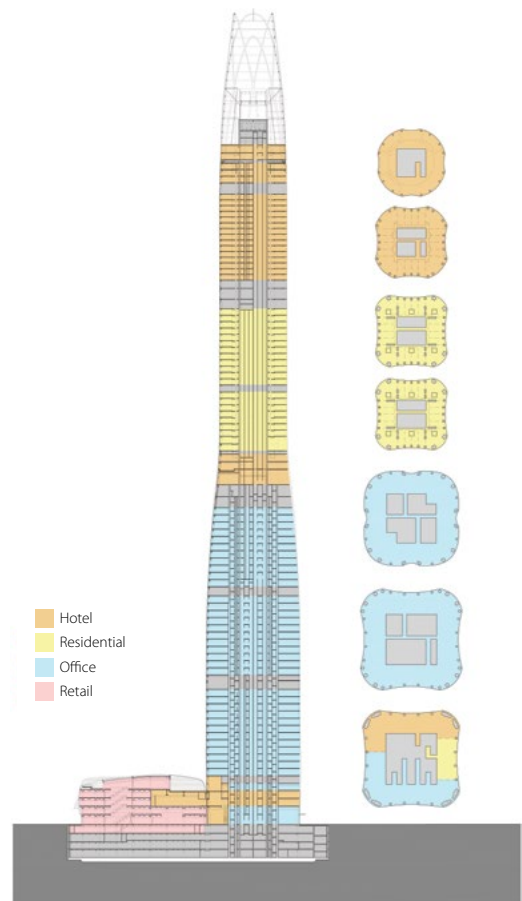


Figure 4. The stacking of multiple programs, and tapering the floor plates, afforded optimal efficiency across (from top to bottom) hotel, residential, office and retail functions. © SOM

above the office program. The hotel floor plates have an ideal size of approximately 1,800 square meters, and have eased corners for panoramic views and reduced wind loads.

By stacking floor plates, which diminish in size over the height of the tower, the tower tapers dramatically, optimizing the relationships between the lease spans, structural core and the perimeter wall of each of the major programs, to minimize the surface area exposed to wind, sun, and moisture (see Figure 4).

A luxury retail mall, branded K-11, is incorporated into the project in an attached five-level podium linking the tower and hotel lobbies. Containing a culture- and arts-themed collection of retail tenants organized around a central atrium, as well as the hotel's ballroom and function rooms, the podium structure helps to create a lower register of building mass and public space. A glass and metal diagrid curtain wall clads the K-11 retail podium and recalls the softer,

organic forms of the tower. At ground level, three landscaped vehicle drop-offs provide access to the tower's respective functions, with sleek glass-and-steel canopies, cantilevering up to 21 meters from the building face to shelter entrances and lobbies.

Stepped Core-in-Core: Architectural/Structural Integration

The stepped, core-in-core system is a major driver of the tower's architectural and structural efficiency. The core extending up through the residential and hotel zones was designed to be just large enough for the required architectural service elements. The residential core then extends down through the office zone, with an outer core placed around the inner core to accommodate the office service functions. This concept resulted in a very efficient architectural plan that reconciled the MEP, vertical transportation, and structural requirements.

In the residential zone, wing walls were added to the hotel core, creating an "egg-crate" structure that stiffened the box core and created a smooth transition from the small to the large core below. The stepped, core-in-core system allowed the residential floor plate to be as small as possible, which both reduced the wind "sail" area and the seismic mass at the higher levels of the building (see Figure 5).

Wind Engineering: Aerodynamic Shape-Finding

Intensive wind tunnel tests were conducted early in the Schematic Design phase to determine the optimal shaping of the tower and the effectiveness of various levels of cladding porosity and wind slots in the crown. The building's aerodynamic shape greatly reduces vortex shedding by "confusing the wind" and disrupting the opportunity for any resonating wind forces and loads on the structure. Reducing wind loads and optimizing the shape resulted in very low accelerations and wind loads that were less than the seismic loads. Numerous

crown configurations were studied, and it was determined that a zone of high cladding porosity at the base of the crown, along with variable porosity over the height of the crown, not only reduced wind loads on the crown, but also was effective in reducing wind loads on the upper portion of the tower (see Figure 6). Multi-story vents were studied along the height of the shaped tower to further minimize wind loads, but tests showed minimal benefits.

The wind performance requirements were coordinated with the floor-plate-size requirements to achieve an integrated design and the final shape of the building. The building shaping, with sloping corner columns at the upper part of the office and the amenity floors, resulted in a significant portion of the lateral shear forces being inherently resisted by the building shape, which minimized material use. The slight inward taper at the lower floors resulted in the same drift with less structural material, so this taper was included in the final shaping.

Sloped Column System: Elimination of Outriggers

The Tianjin CTF Finance Centre is in an area of high seismicity, so optimizing the

structure for both frequent and rare seismic events was of fundamental importance. In addition, for speed of construction and cost efficiency, outriggers and dampers were not desired. Outriggers greatly increase the stiffness of the structure, but since they have limited ductility, they also increase loads from earthquakes. Preliminary studies showed that an outrigger system required

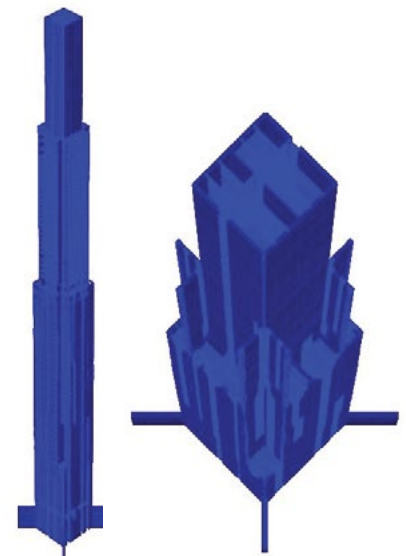


Figure 5. The stepped, core-in-core concept system is a major driver of the tower's architectural and structural efficiency. © SOM

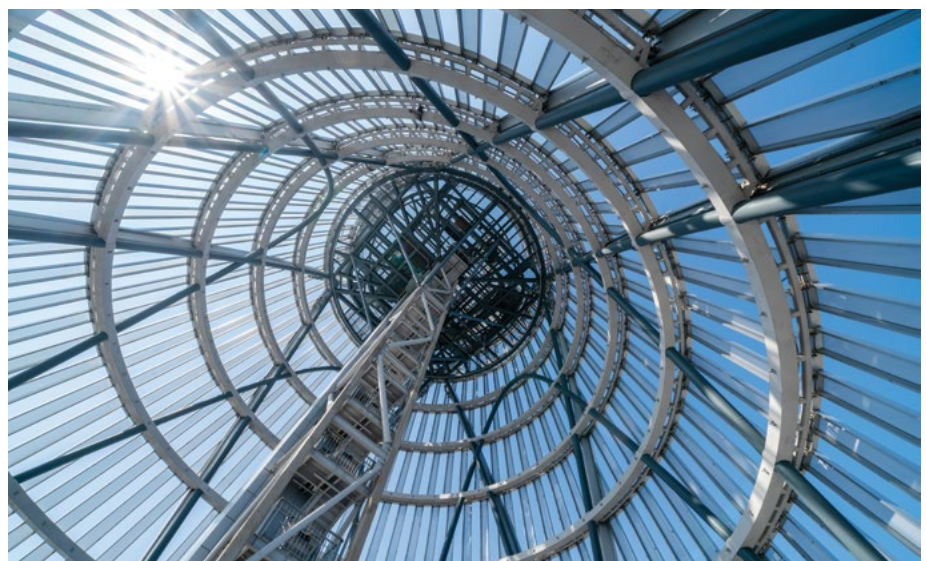


Figure 6. The variable porosity over the height of the crown, not only reduced wind loads on the crown, but also was effective in reducing wind loads on the upper portion of the tower. © SOM/Seth Powers

“The optimal building shaping, and the use of a sloping column system with simplified connection details, led to reduced material use, with lower fabrication and erection costs and a shorter construction time.”

up to 65 percent more material compared to a perimeter-frame system. Also, since the outrigger systems have limited ductility, performance under an extreme seismic event would be compromised. In addition, the detailing of outriggers is complex and costly, often delaying construction at the outrigger floors. For these reasons, elimination of the outriggers was a major design goal and was an important factor in reducing quantities, costs, and erection time.

Several options for the perimeter-frame system at the office zone were studied, leading to the optimal system of a frame with sloping columns, which provided both stiffness during frequent seismic events and ductility during rare seismic events. The curved geometry allowed the intersection of the sloping columns to be spread over multiple floors, which minimized axial forces in the perimeter beams. The sloping-column-to-vertical-column work points were also offset, which allowed the full area of both the column and the sloping column to be continuous through the joint, minimizing the stiffener requirements at the joint. The sloping columns at the office zone do not engage each other at the center of the building, which allows for ductile deformation of the beams in the center bay, while the bays with sloping columns provide stiffness for wind and frequent seismic forces. This allows the office floors to have relatively wide bay spacing, while providing necessary stiffness. A more closely-spaced moment frame provides enhanced ductile performance through the residential zone. Both the residential and hotel zones have minimal view interference from diagonal

members. At the hotel zone, sloping columns were also provided, enhancing the structural efficiency of the upper portion of the structure by functioning as a multi-story belt truss. A belt truss at mid-height transfers vertical loads from the residential zone grid to the office grid, and also transfers lateral loads to the megacolumns at the building corners. Two additional levels of belt trusses equalize column shortening at discontinuous columns, and function as virtual outriggers to stiffen the building (see Figure 7).

An additional innovation was realized by using different composite column configurations over the height of the building. Round concrete-filled tube columns were used through the office zone to both minimize size and reduce differential creep and shrinkage shortening between the core and the perimeter. Through the residential zone, concrete-encased steel sections were used to balance the residual creep and shrinkage related to differential shortening of the levels below. The mixed system resulted in minimal differential shortening between the core and the perimeter. The use of 3D software for both design and fabrication allowed the use of complex geometries, such as the sloping column system, with minimal impact on the fabrication process (see Figure 8).

Material and Space Efficiency

This innovative tower, a result of a close collaboration between the architects and engineers, has resulted in a significant

decrease in the use of necessary concrete and steel for construction in comparison to similarly tall structures. When compared to the previous design, the new tower had the same area, programs, and height, but was able to be about 3.8 percent more efficient in terms of net-to-gross area. More significantly, it was initially calculated that the new design would have a savings of 19,000 metric tons of steel, 10,500 cubic meters of concrete, and 3,900 metric tons of rebar. The integration of architecture and engineering creativity resulted in an extraordinarily efficient, high-performing structure and conservative use of resources. The optimal building shaping, and the use of a sloping column system with simplified connection details, led to reduced material use, with lower fabrication and erection costs and a shorter construction time (see Figure 9).

Envelope

The façade, a distinctive visual element of the integrated overall design, contributes to the high-performance project goals while

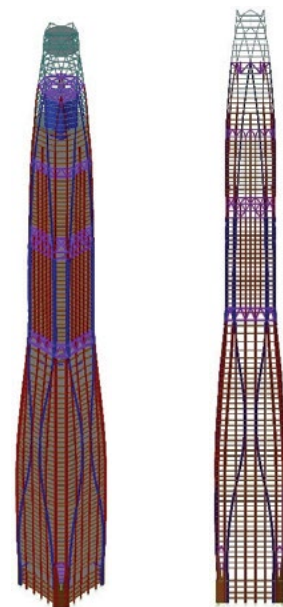


Figure 7. A belt truss at mid-height transfers vertical loads from the residential zone grid to the office grid, and also transfers lateral loads to the megacolumns at the building corners. Two additional levels of belt trusses equalize column shortening at discontinuous columns, and function as virtual outriggers to stiffen the building. © SOM

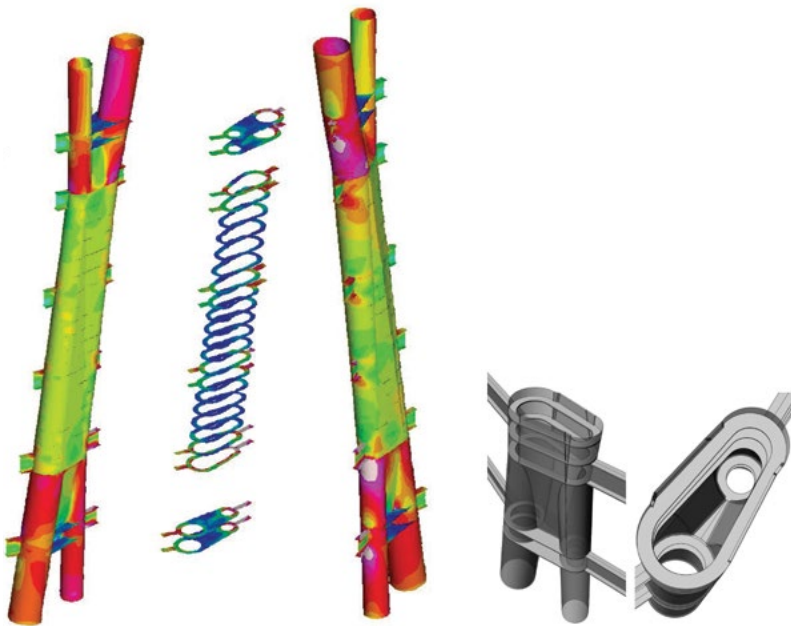


Figure 8. The use of 3D software for both design and fabrication allowed the use of complex geometries, such as the sloping column system, with minimal impact on the fabrication process. © SOM

minimizing costs through system optimization. The façade accommodates the tower superstructure's constraints, code requirements, and the owner's interior space planning and desired aesthetic concerns. The beautifully flowing curtain wall system presents an ever-changing surface. The wall cladding accentuates the robust proportions of the tower's taper, while subtly tracing the eight, curved sloping megacolumns that follow a lyrical line, connecting the centers and corners of all four elevations.

The high-performing envelope of the tower consists of insulated glass units (IGUs) with heat-strengthened, laminated outer lites and heat-strengthened inner lites with low-e coating, as well as bright silver, polyvinylidene fluoride (PVDF)-coated aluminum mullions, transoms, and insulated panels. Thirty percent of the façade is solid and contains insulation, achieving a lower U-value than that of the IGUs; these solid areas significantly reduce building energy heating and cooling loads, while maximizing daylighting and views. The vertical mullions are essentially "V"-shaped double mullions with a crescent insert, reducing the exterior glazing while maximizing interior sightlines. These reflective crescent inserts allow the

tower façade to dramatically catch the light during the day, while the inserts' integrated LED lighting efficiently defines the tower surface and silhouette in Tianjin's skyline at night.

In order to provide a cost-efficient façade, the envelope system was optimized in multiple iterations. Key to façade optimization is the reduction in the number of unique IGUs. While initial studies required 1,004 unique IGUs out of approximately 12,000 IGUs total, optimization resulted in a reduction, first to 720, and eventually 476 unique IGUs. Provision of a variable joint dimension between IGUs and framing with a maximum joint variation of ± 7 millimeters allows the use of unique IGUs for multiple unique curtain wall frames, and thus, reducing the number of unique IGUs to 476 (see Figure 10).

One design criterion was that mullions were to remain in the plane of interior partition and demising walls to allow for clean wall-to-façade-connections, defining the plane in which mullions can be located. In addition to cost reduction achieved through system optimization, the cost was further reduced by selecting flat glass over hot-bent



Figure 9. A view of the Tianjin CTF Finance Centre under construction, revealing the integration of envelope and structure. © New World Development



Figure 10. Among the design refinements was a successful effort to reduce the number of unique panels and glass units in the exterior wall. © SOM

glass. As the overall façade surface is mostly two-directionally curved, one in four corners of a typical façade module, which is shaped in the form of a quadrilateral—such as a rectangle, parallelogram, or trapezoid—is not in plane with the other three corners.

Two-directionally curved (bent) and flat IGUs were studied. Hot-bent IGUs were eliminated due to cost reasons. Cold-bent IGUs were not selected, as the maximum glass protrusion of 71 millimeters for a 4.7-meter-tall module exceeds the industry standard of 1 percent maximum glass protrusion over the diagonal IGU length. Later, a divided 3.7-meter-tall vision glass and 805-millimeter-tall spandrel glass with shadow box assembly was specified to reduce costs, and flat glass was chosen to reduce the risk of seal failure in cold-bent glass. Wedge-shaped metal infill pieces of varying sizes were provided along two glass edges to allow the flat glass to protrude from the frame, which follows the two-directionally curved tower geometry. The choice of complicated flat glass with infill metal pieces, in lieu of the cold-bent units, was an arguable decision, especially in consideration of successful precedents of cold-bent curtain walls, but the resultant

tower wall is a significant achievement of design, engineering, fabrication, and installation (see Figure 11).

As the façade perimeter length changes from floor to floor with varying façade curvature, the relationship between vertical mullions also varies. A stacked mullion would neither allow for the owner's requirement for a constant, 1.5-meter façade module, nor for a uniform façade appearance. Thus, a staggered vertical mullion was selected, achieving a consistent number of façade modules per floor, as well as a uniform appearance of the elevation. As flat glass was selected, both upper and lower transoms are straight, but not parallel, since they are staggered. An "adapter" was designed to be inserted between upper and lower transoms as a third component, which also serves as the gutter, accommodating the staggered units and non-parallel transoms (see Figure 12).

Summary

As Chinese cities continue to grow and evolve, the rational and efficient use of the environment and its resources become more

urgent. The success of the multi-program supertall tower—an effective building block of high density and an iconic marker for the vitality of the city center—demands a continued evolution of integrated architectural and engineering strategies. A scientific and creative inside-out approach to designing and engineering mixed-use supertalls is a crucial step in shaping sustainable urbanization, not only in China, but in growing cities around the globe.

Many tall buildings today are the result of willful exercises searching for iconic shapes. Too often these sculptural forms require reactive and expensive engineering to make them work. There are also many tall towers that settle for a "one size fits all" approach to multiple programs. These generic structures create a bland sameness in the city, and are ill-suited to the variety and complexity of vertical mixed-use density.

The design for the Tianjin CTF Finance Centre is based on three principles: a programmatic determinism that allows the tower form to accommodate the distinct needs and requirements of the uses and users within; a rigorous integration of structural engineering

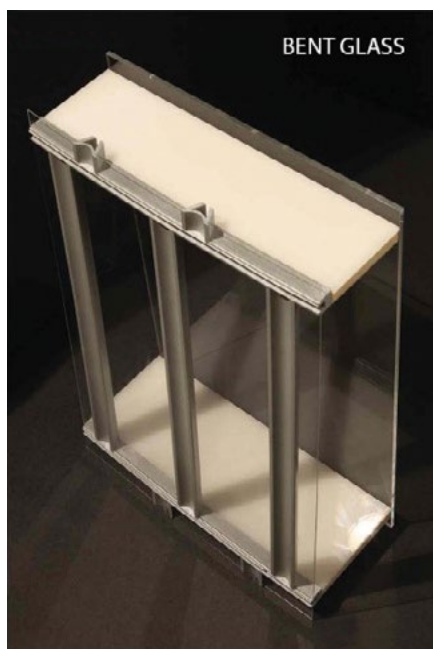


Figure 11. Extensive modeling was undertaken to ensure the optimal performance of flat glass, subjected to out-of-plane protrusions of more than 1 percent. © SOM

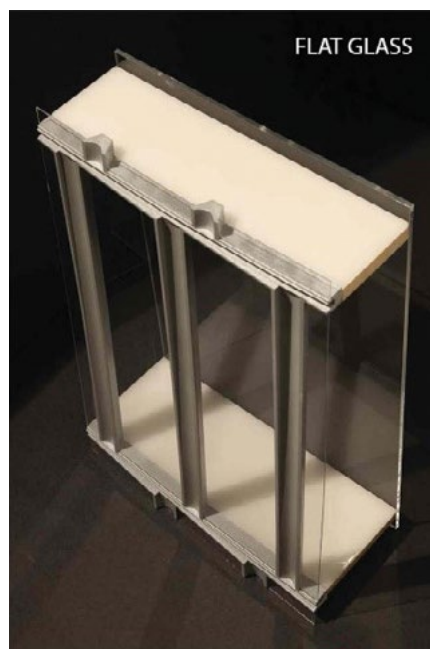


Figure 12. Close-up view of a unit adapter in a staggered-mullion configuration. © SOM

with the architectural development, to achieve the highest efficiencies in material conservation and performance, especially in relation to wind loads; and a sophisticated articulation of the exterior enclosure system, to efficiently clad the complex geometries of the tower surface, yielding a spectacular interaction of light and materiality worthy of a landmark structure (see Figure 13). ■

Project Data

Completion Date: 2019

Height: 530.4 meters

Stories: 97

Area: 252,144 square meters

Primary Functions: Hotel / Serviced Apartments / Office

Owner/Developer: Chow Tai Fook Enterprises

Architects: Skidmore, Owings & Merrill (design); Ronald Lu & Partners, East China Architectural Design & Research Institute (ECAD)(architects of record)

Structural Engineers: Skidmore, Owings & Merrill (design); East China Architectural Design & Research Institute (engineer of record)

MEP Engineers: WSP (design); East China Architectural Design & Research Institute (engineer of record)

Main Contractor: China Construction Eighth Engineering Division

Other CTBUH Member Consultants: Syntegrate (BIM); Rider Levett Bucknall (cost); Arup, Ronald Lu & Partners, Skidmore, Owings & Merrill (façade); AECOM (landscape); Brandston Partnership (lighting); WSP (security); BMT Fluid Mechanics (wind)

Other CTBUH Member Materials Suppliers: Armstrong World Industries (ceiling); Dow (cladding); CoxGomyl (façade maintenance equipment); Jotun (coatings)

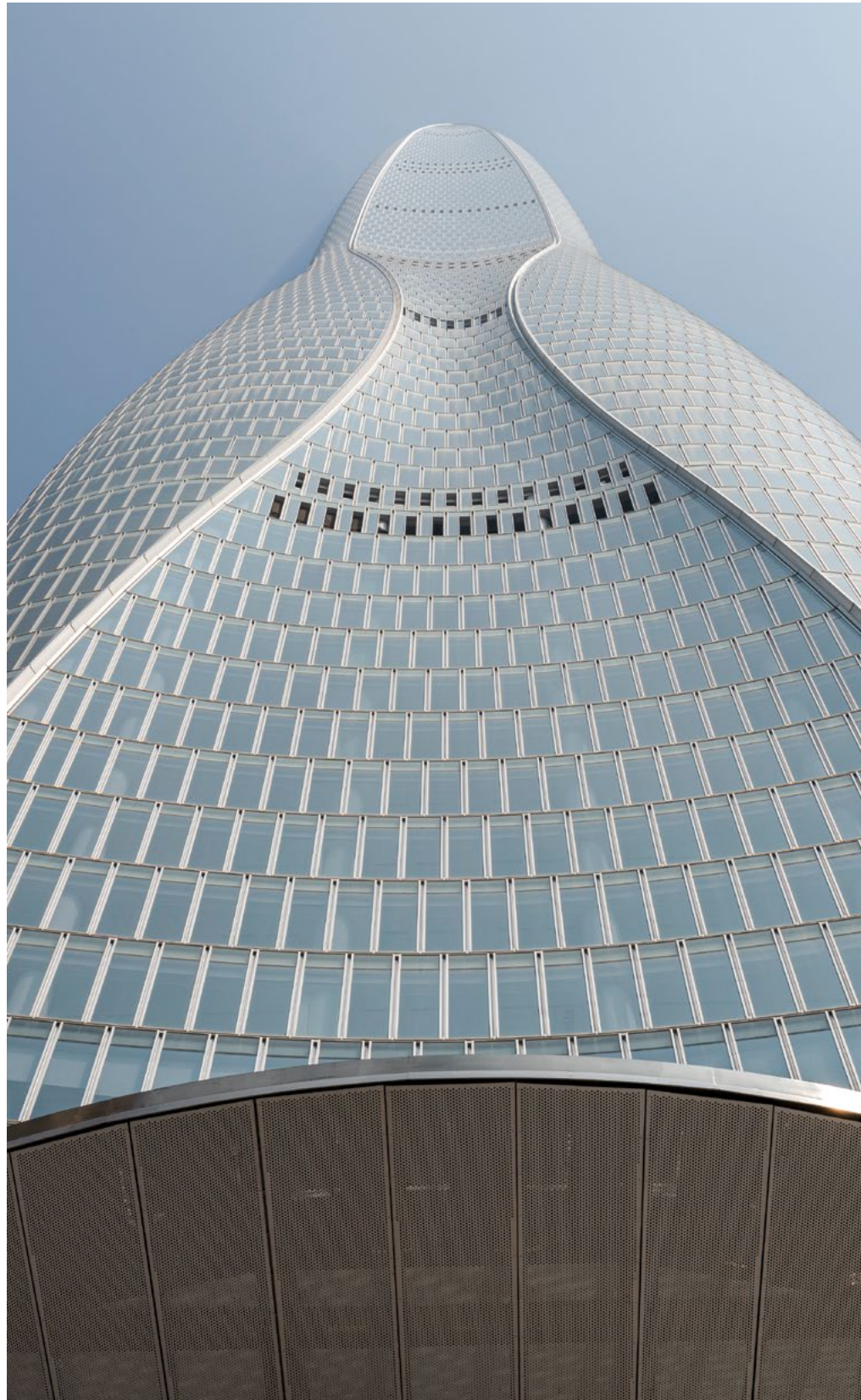


Figure 13. The tower's ultimate dramatic form was determined by program, engineering, and performance criteria.
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