Title:	**Case Study: Pearl River Tower, Guangzhou**
Authors:	Richard Tomlinson, Managing Partner, Skidmore, Owings & Merrill William Baker, Structural Partner, Skidmore, Owings & Merrill Luke Leung, Director of Sustainable Engineering, Skidmore, Owings & Merrill Shean Chien, Project Manager, Skidmore, Owings & Merrill Yue Zhu, Associate Director, Skidmore, Owings & Merrill
Subjects:	Architectural/Design Building Case Study Façade Design
Keywords:	Energy Efficiency Passive Design Renewable Energy Sustainability
Publication Date:	2014
Original Publication:	CTBUH Journal, 2014 Issue II
Paper Type:	1. Book chapter/Part chapter 2. **Journal paper** 3. Conference proceeding 4. Unpublished conference paper 5. Magazine article 6. Unpublished

CTBUH Journal

International Journal on Tall Buildings and Urban Habitat

Tall buildings: design, construction, and operation | 2014 Issue II

Pearl River Tower, Guangzhou

Is Net-Zero Tall Possible?

Braced Megaframe for Torre BBVA Bancomer

Mortality Rates in Swiss High-Rises

Debating Tall: Ice on High-Rise

Talking Tall: Korea's "Invisible" Tower

In Numbers: Highest Helipads

Council
on
Tall Buildings
and
Urban Habitat

Case Study: Pearl River Tower, Guangzhou

High Performance Design Shapes Sustainable Supertall Building

Authors

Richard Tomlinson II, Managing Partner
William Baker, Structural Partner
Luke Leung, Director of Sustainable Engineering
Shean Chien, Project Manager
Yue Zhu, Associate Director

Skidmore, Owings & Merrill LLP (SOM)
224 S. Michigan Avenue, Suite 1000
Chicago, IL 60604, United States
t: +1 312 554 9090
f: +1 312 360 4545
e: somchicago@som.com
www.som.com

Richard F. Tomlinson II has played a central role in guiding the firm's design practice. He specializes in providing clients strategic solutions to large and complex problems, orchestrating the resources and multidisciplinary teams needed to bring bold and innovative vision to reality. Richard has led some of the firm's most significant global projects for clients in a wide array of private and public organizations.

William F. Baker is a Structural Engineering Partner for SOM. Throughout his distinguished career, Bill has dedicated himself to structural innovation. His most well-known contribution has been to develop the "buttressed core" structural system for the Burj Khalifa, the world's tallest man-made structure. While widely regarded for his work on supertall buildings, his expertise also extends to a wide variety of other structures. Bill is also a member of the CTBUH Board of Trustees.

Luke C. Leung is the Director of the Sustainable Engineering Studio for SOM. As a LEED AP with BD+C focus, his work includes over 40 LEED buildings either certified, or, in different stages of the LEED process. Luke's work also includes 2 of the current top 10 tallest buildings in the world, Nanjing Greenland Tower and Burj Khalifa. His work ranges from the low-rise LG Art Hall, one of the first displacement performing arts centers in the world, to the Burj Khalifa, the world's tallest man-made structure with a first-of-its-kind stack-effect control system.

Shean Chien worked as a senior project engineer with SOM's structural engineering team, assisting with the structural design for individual projects or groups of projects prior to joining SOM's project management team. As a Project Manager, Shean is responsible for the day-to-day coordination of projects and serves as the key liaison with the client throughout the design and development process. Shean has extensive experience working on large-scale mixed-use developments in China and internationally.

Yue Zhu joins the team with experience in architectural design, technical expertise, urban design and sustainable design. He is currently a studio head leading the project team on many high profile, highly complex, large-scale urban projects throughout the design and development process, leading to numerous awards and worldwide recognition in the industry.

Skidmore Owings & Merrill LLP (SOM)'s design for the 71-story Pearl River Tower in Guangzhou, China, was selected in a 2005 competition. The 309-meter-tall high-performance building was designed with energy efficiency as its top priority. Its design philosophy combines active and passive sustainable measures to reduce its impact on the local electrical grid, reduce carbon emissions, and provide the most comfortable interior environment possible for its occupants.

Background

The design brief developed by the client, the Guangzhou Pearl River Tower Properties Co., Ltd., called for a 214,100-square-meter headquarters tower in the newly developing Pearl River New Town area of Guangzhou. Even in 2006 – when sustainability was not nearly as recognized a concept as today – a visionary client team led by Chairman Jin Cheng Xiang and Director Zhi Ming Ye sought to create an iconic new home whose "high performance" would significantly reduce the building's energy consumption. The initial form was set by the architect's competition entry – but the evolution of the design's sustainable solutions was the result of a highly collaborative effort between client, architects, and engineers. As completed, the building uses approximately 30% less energy than would be used by a similar structure built to China's stringent energy codes.

The Pearl River Tower's setting and its evocative, curving shape are performance-driven – an example of a 21st century tower that responds appropriately to local climatic conditions and global energy concerns. Its generally rectangular floor plate has been shifted slightly from Guangzhou's orthogonal grid in order to maximize its utilization of prevailing breezes, and to better capture the sun's energy through the strategic location of photovoltaic technologies.

East and west elevations are straight, while the south façade is concave and the north façade is convex (see Figure 2). The south side of the building is dramatically sculpted to direct wind through four openings, two at each mechanical level, to accelerate the air and drive a two-meter-wide-by-five-meter-tall energy-producing vertical axis wind turbine (VAWT) located within each building aperture (see Figure 1). The building's geometry significantly enhances turbine performance. At night, LED lights at the mouth of the wind tunnel change color and intensity to indicate the amount of energy created by the wind.

The owner's offices are located on Floors 59 through 68; lower floors will be leased to other tenants who require a prime location and want to enjoy significant energy savings against a conventional office building. The top two floors – which sit under a dramatic glass-vaulted roof – will be completed as a club-level amenity. A distinctive circular international conference center sits at the northwest corner of the tower's base.

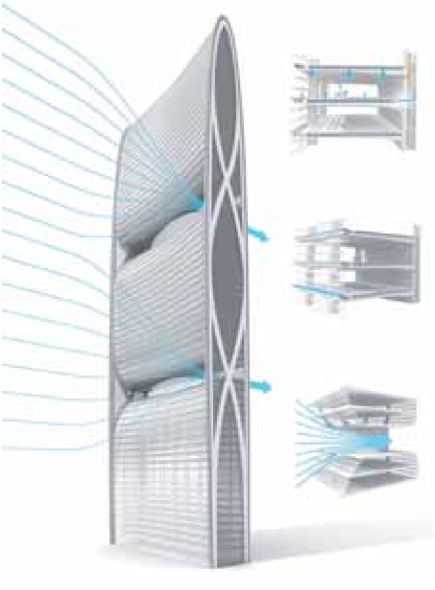


Figure 1. Sculpted façade directing wind through the vertical axis wind turbine (VAWT)

Structure

Pearl River Tower was shifted from Guangzhou's predominant grid to help capture the wind for energy generation. The broad face of the building is oriented perpendicular to the southerly prevailing winds, which occur approximately 80% of the year – a remarkably consistent directional bias for generating wind energy. But this orientation led to increased loads on the overall structure, especially because Guangzhou is a relatively high-wind region due to its proximity to the coast.

Wind tunnel testing by RWDI Laboratories predicted higher wind loads on the broad face than those calculated by the governing Chinese code. These higher loads were used for the design, with 100-year return period loads determining strength design and 50-year return period loads used for drift checks. Under these loads, accelerations and torsional velocities were well within accepted criteria.

The tower was classified as a Special Complex Supertall Building by Chinese codes since it was "over limit" based on both its height (over 190 meters) and aspect ratio (which, at 8.4, was above the code limit of 7.0). Guangzhou is in a moderate seismic zone in China, with a seismic intensity of VII and a design basic acceleration of 0.10 g. The baseline of the code in this area is the Frequent earthquake (80-year return period), but the tower's "over limit" status required that some elements of the lateral system be designed for Moderate (475-year return period) and Rare (2,475-year return period) levels. All elements of the lateral system were designed for response spectrum forces induced by a Moderate earthquake. Outrigger and belt trusses were designed to remain elastic under the Rare earthquake response spectrum. Additionally, seismic review experts required the performance of a nonlinear elasto-plastic time history analysis to validate that during a Rare earthquake, the maximum interstory drift would not exceed 1/100.

The tower's superstructure consists of a composite system, utilizing both structural steel and reinforced concrete elements to resist both gravity and lateral loads.

Figure 2. Pearl River Tower, Guangzhou.

> "The building envelope's cavity is mechanically ventilated from the occupied space via low-level inlets under the inner monolithic glass… The movement of room air through the ventilated cavity is critical to limiting solar gain, especially on the south elevation."

Figure 3. Lateral-load-resisting structural system.

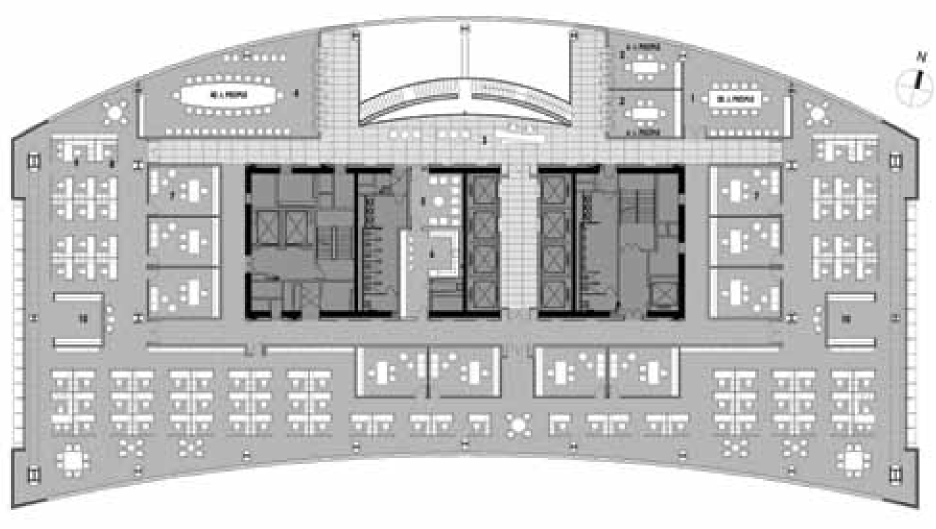


Figure 4. Typical floor plan.

The tower's lateral-load-resisting structural system provides resistance to both seismic and wind loading. The primary lateral system is comprised of an interior reinforced concrete "supercore" shear wall system, which is linked to the exterior columns by a series of outrigger and belt trusses and composite megacolumns linked by diagonal end bracing (see Figure 3). The supercore system exists in the tower's central core and surrounds the elevators, elevator lobbies, exit stairs, washrooms, mechanical rooms, mechanical shafts, and storage rooms (see Figure 4). Shear wall thicknesses of the core range from approximately 700 to 1,500 millimeters over the height of the building. Reinforced concrete link beams join adjacent sections of shear wall. The closed form of the supercore provides torsional stiffness to the building.

The supercore's cross walls have been aligned with the exterior columns to provide the best possible link and transfer of load between lateral system vertical elements. Exterior columns are linked to the reinforced concrete core wall and corner megacolumns by a system of outrigger and belt trusses at two mechanical areas in the building, Levels 23–27 and Levels 49–53. The belt trusses at the outrigger levels provide uniform distribution between exterior columns and link them to the corner megacolumns. Structural steel wide-flange spandrel beams are moment-connected to the exterior columns at each floor over the height of the building to create a secondary moment frame system. This system provides added torsional stiffness, structural integrity, and redundancy for the overall building.

The end-bay diagonal bracing consists of W-shapes spanning between steel columns, which are encased in reinforced concrete corner megacolumns. Exterior columns are composite from Level B5 up to Level 1, changing to built-up plate and W-shape from Level 1 to Level 70. The vaulted roof utilizes steel pipe arches, which are diagonalized with steel rods.

The tower gravity-load-resisting structural system consists of the central reinforced concrete supercore, the exterior composite or steel columns, steel spandrel beams, and steel floor framing that links exterior columns to the concrete core. The steel framing on each column line allows for erection of leaning exterior steel columns. Steel beams from the core to the exterior columns have shear studs that act compositely with reinforced concrete one-way slabs on metal decks in the final condition.

High-performance Features

Pearl River Tower is designed to be one of the world's highest-performing supertall buildings.

These high-performance sustainable features include:

- Exterior façade
- Wind turbines
- Integrated photovoltaics (PVs)
- Radiant cooling coupled with underfloor air ventilation
- Daylight-responsive controls
- Daylight reflectors
- High-efficiency lighting
- Vertical transportation
- High-efficiency chiller system

The tower is one of the first supertall buildings to be certified as a LEED® Platinum building by the US Green Building Council (USGBC) – the highest level of sustainable design recognized by the internationally recognized organization.

Exterior Façade

The tower's design incorporates a dynamic high-performance building envelope. The façade system is oriented to optimize the use of daylight while controlling solar loads. An integrated assembly provides superior thermal performance and high-visual transmittance that increases daylight to interior spaces.

The south and north walls are a 300-millimeter unitized system with a 240-millimeter cavity between two layers of glazing. A low-*e* coated, insulating glass unit forms the exterior, with a single monolithic glazed panel on the interior. Motorized blinds/sunshade devices within the cavity provide solar shading and glare control (see Figure 5). A building management system controls the tilt angle of the blinds automatically in response to solar intensity,

Figure 5. Motorized blinds/sunshade devices within the cavity.

Figure 6. Integrated photovoltaic (PV) system within the external shading system.

solar altitude angle and solar azimuth angle, as determined by photocells that track the sun position relative to the elevation.

The east and west elevations use a unitized frit glass with external shades and automated internal blinds. The external glass is low-*e* high-performance glass, which provides the best balance between low heat gain and high transparency. A PV system is integrated into the building's external shading system (see Figure 6).

The building envelope's cavity is mechanically ventilated from the occupied space via low-level inlets under the inner monolithic glass. A ducted return air connection at the top of the cavity pulls warmed air through the airspace and returns it to the air handling units located on the same floor. The movement of room air through the ventilated cavity is critical to limiting solar gain, especially on the south elevation. Volume control and smoke dampers in the return ductwork balance air volume and close this return air path when the office floor is in fire/smoke exhaust mode. Once the hot return air is delivered back to the air handling system, the building automation system (BAS) control sequences decide whether to exhaust this air or use some to mix with the ventilation air for heat exchange. The return air will typically be much drier than the outdoor ventilation air, thus lowering the moisture content of the air to be cooled by the system.

The internally ventilated double wall maintains a temperature on the inside surface of the exterior wall that is close to the ambient air temperature. This decreases the temperature difference between interior and exterior zones, creating a more comfortable mean radiant temperature for occupants. In addition, the double wall reduces outdoor noise, while indoor shades reduce direct glare.

Vertical Axis Wind Turbines (VAWT)

Energy is generated by the highly visible wind turbine system integrated into the building's design and structure (see Figure 7). The wind speeds in Guangzhou average 4.3 m/s at 50 meters height and 5.3 m/s at 300 meters height. The tower's curvilinear form enhances performance by funneling air through turbine inlets in the façade, optimizing the pressure difference between the windward and leeward side of the building. Wind studies predict the façade inlets will accelerate wind velocity by a factor of 2.5, resulting in more than 8 times the power generation when compared to a turbine located in an open field. The power is converted to electrical energy and used by the building.

Integrated Photovoltaics

Photovoltaics (PVs) are integrated with the building envelope, serving the dual function of building skin and power generator. Solar radiation was carefully studied and PVs deployed only on the portions of the façade where they yield maximum results. They are asymmetrically located on the building's vaulted roof glass (see Figure 8) and incorporated into the sunshade devices on the east and west façades (see Figure 6). Integrating PVs with the sunshades provides a dual benefit – they produce about 200,000 kWh/yr while protecting the building's façade from solar gain.

Radiant Cooling Coupled with Underfloor Air Ventilation

The radiant-cooling ceiling system delivers sensible cooling directly to the space, de-coupling the sensible cooling load from the latent cooling load. The radiant cooling panel system is combined with direct outdoor air systems (DOAS) and an under

Figure 7. Vertical axis wind turbine (VAWT).

Figure 8. PV panels located on the roof.

Figure 9. Ground floor lobby.

floor air delivery that provides improved indoor air quality and air change effectiveness. The underfloor fresh air supply flushes contaminants and return/exhaust at ceiling level. High-efficiency filters are provided to improve the quality of air entering the building.

This mechanical approach reduced the building's floor-to-floor height from 4.2 to 3.9 meters – essentially saving five stories of construction. This offered the owner additional floor area without compromising floor-to-ceiling height, while reducing exterior envelope costs. The energy savings associated with reduced airflow and radiant ceiling system is arguably the most sustainable aspect of the tower's design. Eliminating on-floor fan rooms and reducing air shaft sizes resulted in a smaller building core – thus increasing the building's efficiency.

Daylight Response Controls

Pearl River Tower uses daylight-responsive controls in conjunction with the ventilated cavity exterior wall system to provide ample natural light to the building's interiors. The application of these controls achieves significant energy savings while maintaining appropriate visual comfort. Daylight harvesting switches dim lighting automatically to reduce electric light levels in response to increased available daylight.

These switching controls have several advantages: a lower initial cost, less complicated design, and less involved commissioning than other options. Such switching systems can offer less flexibility to sudden changes in light level, but the benefits of continuous dimming include the highest realized energy savings and flexibility and the greatest occupant satisfaction. To achieve maximum energy savings, luminaries in the daylight zone placed less than six meters from windows use automatic dimming controls.

Daylight Reflectors

Within the ground floor lobby, the curved, white fritted-glass ceiling and hanging metal panels are designed as a series of reflectors so that daylight can be redirected deep into the lobby space, reducing electrical consumption by lighting fixtures (see Figure 9). The design was simulated in a lighting laboratory to maximize the efficiency of the reflectors.

High-efficiency Lighting

The high-efficiency fluorescent lighting fixtures in the tower use specially engineered, curved white radiant ceiling panels as reflectors to diffuse light evenly and efficiently into the office space. The shape of these curved ceiling panels was computer-analyzed to maximize the efficiency of the reflection. There are daylight-responsive controls and occupancy sensors on the headquarters floors that maximize daylighting and reduce electrical consumption.

Pearl River Tower's exterior night lighting is designed as a series of computer-controlled LED point lights installed within each curtain wall unit, simulating stars in the dark sky. The typical façade accent light ranges from 3–9 watts per fixture and has a life span of more than 10 years or 50,000 hours (at 70% light output), combining very low power consumption with a long life span.

Vertical Transportation

Double-deck elevators have been installed to reduce the size of the building's core and create a more efficient floor plate. The building is divided into four zones: low-rise and mid-rise zones that have seven elevators each; a high-rise zone for tenant-occupied floors, with four elevators; and the high-rise for the client's headquarters zone, which has four elevators.

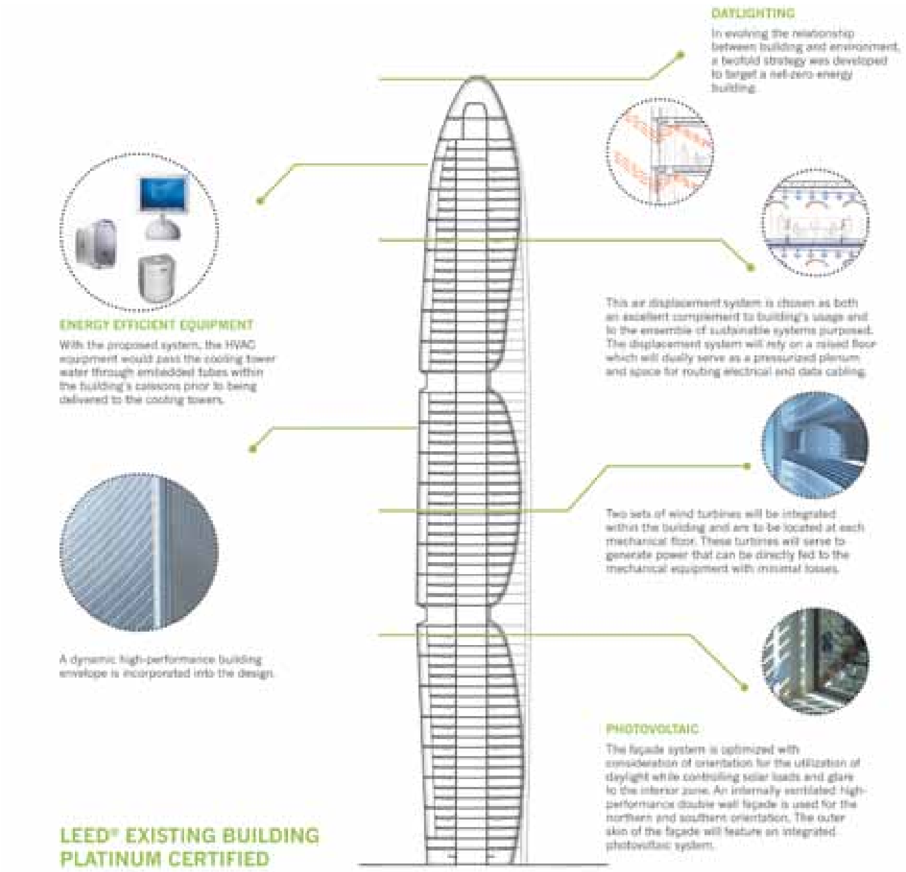
Two banks of seven 1,600-kilogram double-deck passenger elevators will serve the tower's low-rise Zone 1 and mid-rise Zone 2. Four 1,600-kilogram double-deck passenger elevators serve the tenants' offices in high-rise Zone 3, while an additional four 1,600-kilogram single-deck passenger elevators serve the headquarter offices Zone 4 at the top of the building. Using such double-deck elevators greatly reduces the core size and makes circulation more efficient.

High-efficiency Chiller System

Chiller heat recovery is used to recover the heat rejection from the chiller in order to produce domestic hot water.

Conclusion

Pearl River Tower's highly integrated architectural, structural, and mechanical solutions are more than the sum of their parts. The building's distinctive shape draws attention to its vertical axis wind turbines (VAWT), but the greatest energy savings come from the unique combination of sustainable initiatives uncommon in a supertall building (see Figure 10).



In evolving the relationship between building and environment, a twofold strategy was developed to target a net-zero energy building.

With the proposed system, the HVAC equipment would pass the cooling tower water through embedded tubes within the building's caissons prior to being delivered to the cooling towers.

This air displacement system is chosen as both an excellent complement to building's usage and to the ensemble of sustainable systems purposed. The displacement system will rely on a raised floor which will dually serve as a pressurized plenum and space for routing electrical and data cabling.

Two sets of wind turbines will be integrated within the building and are to be located at each mechanical floor. These turbines will serve to generate power that can be directly fed to the mechanical equipment with minimal losses.

A dynamic high-performance building envelope is incorporated into the design.

The façade system is optimized with consideration of orientation for the utilization of daylight while controlling solar loads and glare to the interior zone. An internally ventilated high-performance double wall façade is used for the northern and southern orientation. The outer skin of the façade will feature an integrated photovoltaic system.

Figure 10. Pearl River Tower's high-performance features.

The tower's design supports quantified energy savings of 30% versus the Chinese baseline energy code, and this savings manifests itself in many ways. The tower's enhanced thermal comfort, natural lighting, ventilation, and acoustics will result in improved human performance and increased human productivity within the corporate office spaces. The mechanical design approach allowed architects to reduce the building's floor-to-floor height and create an additional five constructed stories within the same square footage of exterior envelope. The double-wall façade allows greater flexibility to the layout of office space. And the absence of fan coils, VAV boxes, filters, ductwork, insulation, and other items that typically require tenant-specific alterations throughout most of the floor plate will result in reduced cost for tenant fit-outs and future retrofits.

Throughout the building's design, it has advanced the dialogue among design professionals about sustainable building. Leading up to its grand opening, it has already attracted visits from architects, academics, and other professionals interested in learning from the integrated approach to sustainability. Public education about energy generation will continue throughout the building's operation. ■

Unless otherwise noted, all diagram credits in this paper are to SOM, and photography are to SOM/Tim Griffith

Awards and Recognition

- 2013, Finalist – CTBUH Best Tall Building, Asia & Australasia
- 2012, CTBUH 54th tallest building in the world
- 2012, CTBUH Fourth tallest building in Guangzhou, China
- 2012, ASHRAE Illinois Chapter – *Excellence in Engineering*
- 2010, Chicago Athenaeum – *Green Good Design Award*
- 2008, Spark Awards – *Green, Carbon-Lowering & Environmental Category: Gold Award*

Project Data

Completion Date: April 2013
Height: 309 meters
Stories: 71
Area: 165,840 square meters
Use: Office
Owner/Developer: The Guangzhou Pearl River Tower Properties Co., Ltd.
Architect: Skidmore, Owings & Merrill LLP (design); Guangzhou Design Institute (architect of record)
Structural Engineer: Skidmore, Owings & Merrill LLP
MEP Engineer: Skidmore, Owings & Merrill LLP
Main Contractor: Shanghai Construction Group
Other Consultants: Fortune Consultants, Ltd. (vertical transportation); Rolf Jensen & Associates, Inc. (fire); RWDI (wind); SWA Group (landscape); Pivotal (lighting); Shen Milsom Wilke, Inc. (acoustics); Highrise Systems, Inc. (maintenance)

> “The building's distinctive shape draws attention to its vertical axis wind turbines, but the greatest energy savings come from the unique combination of sustainable initiatives uncommon in a supertall building.”