

SUSTAINABLE TALL BUILDINGS: CASES FROM THE GLOBAL SOUTH

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Abstract

This paper examines recent sustainable tall buildings in the Global South, mainly in the Middle East and China. These buildings are redefining how architects, engineers, and planners view skyscrapers, creating a new building typology in regards to function, ecology, technology, and user comfort, in the process. These “futuristic” buildings are setting new social, spatial, and environmental standards, setting a milestone in ecologically friendly architecture. Most of the reviewed projects in this paper have achieved national and international recognition from architectural and planning organizations. They represent the most recent work in the field and have exerted a profound impact on the architectural profession. This paper also summarizes the key lessons that sustainable tall buildings have brought to the field, highlighting the role of breakthrough technologies in enhancing the efficient performance and sustainability of future tall buildings.

Keywords: Sustainable design; new technologies; creative forms; innovative approaches; green aesthetics

INTRODUCTION

Sustainable tall buildings will become extraordinarily important in the 21st century, as many cities around the world embrace vertical density to house their growing urban populations. Twenty years ago, the world's urbanized population was only about 33%; today, more than half of the world's population lives in urban settings. By 2030, it is expected that about 60% of the world's population will reside in urban environments. Researchers project that in 2050, over 80% of the world population will live in urban areas, with the world's population reaching approximately 9 billion people, and most of this growth occurring in the Global South (Al-Kodmany, 2015).

Given the large-scale problems of conventional skyscrapers, the benefit of sustainable towers is that any improvement in their design and construction will be significant. Tall buildings serve many people and exert powerful demands on the environment and existing transportation, sewage, and electrical infrastructure. Thus, green design may better serve the tenants of these skyscrapers, while also mitigating their environmental impact and enhancing their integration with city infrastructure. Given a skyscraper's large size, there is plenty of justification to employ green features in the construction of new skyscrapers and to retrofit existing ones. These accumulated factors have engendered a substantial interest and demand in the research, design, and development of eco-towers. Historically, building competitions have centered on designing the largest and most iconic towers. Today, however, competitions are shifting toward building greener skyscrapers (Goncalves, 2012).

This paper examines the recent “green” solutions that have been integrated to make skyscrapers more sustainable. It strives to find ways to make future skyscrapers more sustainable at the architectural scale. Building on a growing body of work, in practice and from architectural literature, this research reviews key skyscrapers that have been labeled as “green,” “eco-friendly,” or “sustainable,” specifically in two regions: the Middle East and China (Hsu, et al, 2009; Martona, 2006). The towers examined by this research represent a new generation of tall buildings, offering high-performance systems, high-quality materials, and healthful interiors for both workers and residents.



These new designs are reshaping the future of tall buildings and employing green technologies at a prolific scale. For this reason, architects are designing cutting-edge energy systems, including helical wind turbine technology, water-saving technologies, solar panels, sunlight-sensing LED lights, rainwater catchment systems, graywater and blackwater recycling systems, and seawater-powered air conditioning to further reduce the environmental impact of these monumental structures (Kong, 2007).

THE MIDDLE EAST

In the Middle East, many cities are investing in skyscrapers. Example of these include Dubai and Abu Dhabi in the U.A.E., Doha in Qatar, Kuwait City in Kuwait, Manama in Bahrain, and Mecca, Jeddah, and Riyadh in Saudi Arabia. The height of these skyscrapers, along with the intensity with which they are being built, is rapidly changing the face of many of these cities (Al-Kodmany and Ali, 2013). In Mecca, Saudi Arabia, the 601 m (1,972 ft) megatall (exceeding 600m tall) Abraj Al-Bait Towers Complex, which overlooks the site of Islam's holiest shrine, the Kaaba, has recently been completed. It has a large elevated clock, a seven-star hotel, an enormous prayer area, and a shopping mall. It is the tallest building in Saudi Arabia and it has the largest floor area of any building in the world, at about 1.5 million square meters (16 million square feet) (Dupre, 2013). As of this writing, the construction of Jeddah's 1,000 m (3,281 ft) high Kingdom Tower is underway. When built, it will be the tallest building in the world surpassing the height of the Burj Khalifa in Dubai. Similarly, Qatar has also seen unprecedented growth in tall buildings, including the Burj Qatar, rising 231 m (760 ft), and the 300 m (984 ft) Aspire Tower, the tallest building in Doha at present (Al-Kodmany and Ali, 2013; Pacione, 2005). However, this new trend constitutes an architectural paradigm shift that focuses on sustainable design, exemplified in the following case studies.

O-14 Building, Dubai, U.A.E.

O-14 is located along the extension of Dubai Creek in the Business Bay area of Dubai, occupying a prominent location on the waterfront esplanade. Dubai is located in the United Arab Emirates (U.A.E.), a country situated on the southeast coast of the Persian Gulf. With over two million inhabitants, Dubai is the second most populous city in the U.A.E. and possesses the greatest land area in the country. In a matter of two decades (1990-2010), Dubai has emerged as a global city that functions as a hub for business, commerce, culture, and transportation.

O-14 is a 22-story commercial tower that rises from a two-story podium. The building contains 27,871 m² (300,000 ft²) of office space and offers ground level retail spaces that link the tower with the Business Bay's waterfront esplanade. Four levels of below grade parking provide capacity for over 400 cars. Reiser + Umemoto, RUR Architecture P.C., and the structural engineer, Ysrael A. Seinuk, (YAS) P.C. collaborated on this project, titling it "O-14" given the site's numbering system of the Business Bay district. The construction of the 37,036 m² (398,655 ft²) tower on a 3,159 m² (34,000 ft²) site was completed in 2010 (Al-Kodmany, 2015; Parker and Wood, 2013).

The dominant feature of the iconic O-14 tower is its curvaceous, white exoskeleton that stands 1 m (3 ft) away from the inner glass-walled enclosure, evoking a monumental and monolithic exterior. With swerving contours, the concrete shell is perforated by 1,326 openings of varying sizes that were positioned through a complex and "random" pattern, creating a lace-like effect on the building's façade. Architecturally, the varying openings seek to attenuate the monotony of the external façade. They also provide an ever changing sense of interior space through a fascinating interplay of natural light and shade. Furthermore, the random pattern provides flexibility in the possible re-arrangement of the floor plates in the event of potential structural change. Overall, the exoskeleton possesses a unique sculptural quality that expresses sublimity and monumentality (Al-Kodmany, 2012a and 2012b).

In addition to providing architectural and aesthetic quality, the tower's shell serves as the prime structural component. It provides an efficient exoskeleton that frees the core from the burden of lateral forces and creates a column-free, spacious interior of about 557 m² (6,000 ft²). The shell is organized in an efficient diagrid pattern that maintains a minimum structural member by adding material where necessary and taking away where possible.

The required structural effectiveness of the shell was achieved by balancing material strength and aperture size. That is, larger openings received greater support through changes in concrete mixture. The total height of the exterior shell is 106 m (347 ft) with a thickness of 60 cm (2 ft) at the ground level through the 3rd level, and 40 cm (1.25 ft) from the 3rd floor to the rooftop. The openings were classified into five different types based on their sizes with the smallest diameter spanning a distance of 1.4 m (4.5 ft) and the largest spanning a distance of 8.3 m (27 ft) or a full two stories. Altogether, the openings take up about 45% of the façade (Al-Kodmany, 2015).

Environmentally, the concrete shell responds well to harsh desert conditions more effectively than the typical glass-clad box. The shell functions as a sunscreen that is open to light, air, and views. In addition to structural requirements, the openings are modulated according to view, sun exposure, and luminosity. The one-meter gap between the main enclosure and the exterior shell creates a “chimney effect”, whereby hot air rises to cool the surface of the glass windows behind the perforated shell. This passive solar technique is a natural component of O-14’s cooling system, which has resulted in over 30% decreases in energy consumption and costs.

In order to create the perforated exoskeleton, O-14 used a slip-form construction technique that utilizes Computer Numerically Cut (CNC) polystyrene void forms. Super-liquid concrete was cast around these void forms, and once the concrete had cured, the forms were loosened and moved up the tower to resume construction on the subsequent level. This process reduced the costs typically incurred by a more geometrically complex structure.

Jesse Reiser and Nanako Umemoto have become best known for devising creative architectural solutions, bringing innovative designs and a distinct look to make the tower stand out from the generic office towers of the region. O-14 could function as a new and influential “desert prototype” that protects occupants from the high heat and the dust storms of the Middle East, while still providing attractive views. The building has garnered international interest and has been featured in major architectural magazines. It was also a finalist in the CTBUH’s 2010 Best Tall Buildings in the Middle East and Africa award. The jury’s statement emphasized the innovative and multi-functional façade, noting the building’s structural efficiency, natural ventilation, solar shading, and brilliant aesthetics. Specifically, they commended the spectacular light-and-shadow created by the perforated shell to evincing a unique internal mosaic. The building design offers a striking and successful departure from the modernist’s glass box, providing a skyscraper prototype that should be mimicked in desert climates (Figure 1).

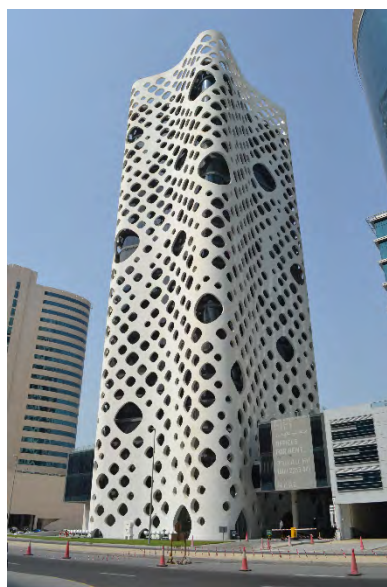


Figure 1. O-14 Building in Dubai, UAE. (Source: Author)

Al Bahar Towers, Abu Dhabi, U.A.E.

Al Bahar Towers, the new headquarters for the Abu Dhabi Investment Council, occupy a prominent site on the North Shore of Abu Dhabi Island, in the United Arab Emirates (U.A.E.). They overlook Eastern Mangroves, Sadiyaat Island and the Arabian Gulf. Abu Dhabi is the capital and the second largest city in the U.A.E., with about one million inhabitants. Completed in 2012, the project comprises two 25-story, 150 m (490 ft) tall towers totaling 70,000 m² (753,000 ft²) of office space. They can accommodate about 1000 employees and share a common podium and a two-level basement. The towers possess a distinct elliptical form, a slight bulging of the middle reminiscent of London's Swiss Re Building. However, the most striking feature of the Al Bahar is the modernized mashrabiya system it uses to protect itself from the harsh desert sun. In addition to the visual interest it evokes, the Al Bahar is a far-reaching feat of sustainable engineering. The towers are among the first buildings in the Gulf to receive the U.S. Green Building Council LEED Silver rating (Al-Kodmany, 2015; Wood, 2012).

In the last decades, Abu Dhabi has witnessed significant high-rise development that embraces Western models of all-glass curtain walls, ignoring local climatic conditions. Cooling all-glass buildings is costly, both financially and environmentally, particularly in hot climates like that of Abu Dhabi where intense sunlight causes temperatures to frequently rise above 38°C (100°F). Despite this fact, glass towers prevail in the Middle East. Genuine concerns have been raised against unsustainable practices resulting in the publication of the Abu Dhabi 2030 Plan, which consists of a comprehensive development framework based on the principles of cultural and environmental responsibility. This framework plan has been further refined by the Estidama environmental management standard and the Masdar initiative on renewable energy. Because of the Abu Dhabi 2030 plan, tall buildings have started to witness a design shift from "imported" to "custom-built", addressing environmental issues while simultaneously developing a unique desert aesthetic (Cilento, 2012; Parker and Wood, 2013).

The architectural design of Al Bahar Towers relies on local climate and culture, perhaps the most intuitive and longstanding sources of inspiration for any design. The towers have modernized the traditional mashrabiya, a shading device formed by perforated wooden-lattice screens in geometric patterns that is commonly found in vernacular Islamic architecture. The mashrabiya fulfills multiple functions by providing privacy, reducing solar gain and protecting inhabitants from glare. Furthermore, it adds visual complexity and interest to the building's exterior. Unlike the static and two-dimensional traditional mashrabiya, Al-Bahar's mashrabiya is dynamic and three-dimensional, consisting of a series of transparent umbrella-like units (made of PTFE-polytetrafluoroethylene) that open and close in response to external solar conditions. Sensors on the façades communicate solar conditions to the building's management system (BMS), which controls the opening and closing of the units, creating an intelligent façade.

The outer skin is set two meters from the inner skin which is comprised of a glass curtain wall. The mashrabiya system, forming the outer skin, features 2000 transparent umbrella-like units (1000 on each tower) which have been strategically placed along the exterior to block the direct light of the sun. In response to direct sunlight, the mashrabiya can unfold to cover the façade, and when the sun is obscured, they can close to allow for light penetration. Parametric and algorithmic modeling have been used to optimize the mashrabiya's location on the façade, precluding the use of dark tinted glass, which would permanently restrict incoming light. The system provides a 50% reduction in solar gain, resulting in decreased energy consumption and CO₂ emissions. Geometrically, the mashrabiya system follows a hexagonal pattern that simulates traditional Arabic-Islamic design. As a mashrabiya system opens and closes, the towers always change their appearance stimulating intriguing aesthetics. The south-facing roof of each tower incorporates photovoltaic cells to generate enough power to adequately operate the mashrabiya system. The system was designed by Aedas from London Studio in collaboration with the engineering firm Arup.

Al Bahar Towers have been well-recognized, earning the CTBUH Innovation Award and the Best Tall Building in the Middle East and Africa Finalist Award in the 2012 CTBUH Awards Program. The Awards Chair Richard Cook of Cook+Fox Architects has commented that "the façade has an interactive relationship to the environment which is reminiscent of the opening of a morning glory flower to the sun ...The winners display remarkable creativity, as well as a respect for the environment, connection with place, and the urban surroundings" (Al-Kodmany, 2015, 212).



Antony Wood, the council's executive director, has added that "the dynamic façade on Al Bahar, computer-controlled to respond to optimal solar and light conditions, has never been achieved on this scale before." The twin towers came second in the Emporis (a German-based skyscraper data company) skyscraper awards for projects completed in 2012. The Emporis praised the Aedis-designed office towers for providing "a dynamic, translucent façade that runs off power generated by photovoltaic panels and which reacts to sunlight" (Al-Kodmany, 2015, 212) (Figure 2).

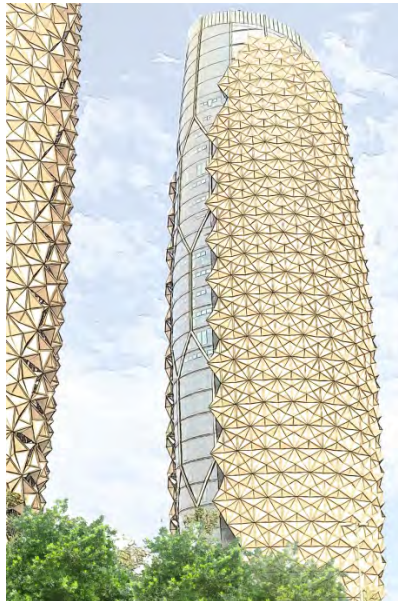


Figure 2. Al Bahar Towers in Abu Dhabi, UAE. (Sketch by author)

Doha Tower, Doha, Qatar

Doha Tower (2012) is a 46-story, 231 m (758 ft) tall high-rise located in the West Bay of Doha, Qatar. Situated on the east coast of the Persian Gulf, Doha, the country's capital, is home to approximately one million people, making it Qatar's largest city and the economic and political center of the country. Both day and night, Doha Tower is a remarkable building in the city's iconic skyline due to its innovative façade and integrated lighting system. Doha Tower (also known as Burj Doha and Burj Qatar) serves as a beacon and symbol of Arab-Islam's cultural melding with technology and modern architecture reviving local meaning in the face of rapid globalization.

Overlooking the Gulf, the 45 m (147 ft) diameter building contains 41 floors of offices, a restaurant with panoramic views located on the 42nd floor, and a private penthouse. The tower is topped by a full-span dome and spire, and clad in an intricately patterned stainless steel screen with Arabic-Islamic geometrical patterns. The light and shadow interplay facilitated by the intricate geometric patterns has created one of the most remarkable penthouse spaces in the history of tall buildings. Constructed without the central support column common to most skyscrapers, the tower is instead formed from a circumference wall of reinforced concrete diagrid columns. Giant X-shaped pieces are linked to create the building's tubular skeleton from which its floors are supported. This system creates a unique effect in the office spaces in conjunction with the façade screen. The cylindrical form of the tower possesses an aerodynamic profile that provides structural efficiencies. The circular floor plan maximizes the perimeter of the building with relatively short distances to the core, which house the elevators and services. The core of the building is shifted off-center to allow for more flexible configurations in the office spaces, with the subtly changing form of the building giving each floor a different capacity to meet various programmatic functions.

Designed by Jean Nouvel, the tower innovatively hints at a postmodern design through references to local culture and vernacular architecture. The outer skin of the tower draws on the "mashrabiya," a prevailing form of wooden lattice screen that integrates Arabic-Islamic geometrical patterns. Mashrabiya is often incorporated in the façades of vernacular Islamic architecture for multiple purposes including

privacy, reductions in solar gain, and protection from glare. In Doha Tower, Nouvel modernized the mashrabiya and applied it at a grand scale at various density patterns with multiple layers responding to solar orientations and weather conditions. In areas exposed to direct sun, extra, denser layers were used to cope with summer temperatures that often rise above 50°C (122°F). Approximately 25% opacity has been achieved on the north façade, 40% on the south, and 60% on the east and west (Parker and Wood, 2013).

The resulting visual impact is provocative. While the geometric patterns appear uniform from afar, the variation becomes clear up close, lending the building to multiple textural experiences. The inner skin of the building is a typical all-glass curtain wall that facilitates abundant natural light, with the mashrabiya and diagrid systems enhancing the spatial quality of the interior giving it ever-changing pattern of light and texture. The cavity between the tower's skins is spacious enough to prevent overheating from occurring while allowing for maintenance crews to walk in between. User-operable solar shades are also available behind the glazed curtain wall. The overall façade system is estimated to reduce cooling loads by 20%.

While the intricate façade gives the tower a graceful dignity during the daytime, Nouvel collaborated with lighting expert Yann Kersalé (designer of the Post Office Tower's lighting system, the second case study in this paper) to develop an appropriate lighting scheme that enhances the appearance of the tower at night. Kersalé employed a clever lighting scheme that accentuates the mashrabiya design with programmable capabilities that transition between 'gold' and 'silver', giving the tower a jewel-like quality and making it highly identifiable in the city's crowded skyline. Luminaires were placed in the cavity between the cladding system and the curtain wall, each lighting an area approximately 2 m (6 ft) wide by 3 m (9 ft) high. On average, 82 luminaires were placed in each of the 44 floors, while other luminaires were placed atop the tower to illuminate the long spire. Lighting units were carefully located so as not to clash with the window cleaning cradle that runs along a rail that circles each floor of the building. UNIVERS, an IP addressable control system, was used to operate the entire lighting scheme. It was also used to check the temperature of every luminaire on the project and to remotely update the programming.

The base of the tower is wrapped in a 25-meter-wide pergola that provides a shaded entry. A gentle grade slopes down to the lobby entrance, providing a smooth transition from the well-landscaped outdoor space to the interior of the building. A large interior atrium reaching a height of 112 m (400 ft) houses eight glass elevators which offer breathtaking views of the surrounding city. Three levels of parking that accommodate a total of 870 cars were built below grade. Located within the dome, the office tower houses a luxury residence that enjoys private access and elevator service. This penthouse offers an awe-inspiring 360 degree view of the city and a splendid interior aesthetic, the culmination of the mashrabiya cladding system.

Doha Tower reflects Jean Nouvel's deep interest in façade detailing and reveals his outstanding commitment to culturally-sensitive design, drawing on traditional practices combined with modern technology. In the eighties, Nouvel modernized the traditional mashrabiya concept by designing the southern façade of the Institut du Monde Arabe (IMA) [Arab World Institute] in Paris, France. He created a technology-based mashrabiya that incorporated several hundred light sensitive diaphragms which regulate the amount of light which may pass into the interior. The design simulates the opening and closing of camera lenses in response to various lighting conditions. Guided by the light sensors and based on the exterior solar conditions, the mashrabiya opens and closes to create changing geometrical patterns of squares, circles and octagonal shapes – a dynamic interplay of light and space. As in the case of Doha Tower, the IMA's mashrabiya system not only evokes an intriguing aesthetic, but also controls solar gain and glare. Whereas the IMA's mashrabiya is dynamic, the Doha Tower's mashrabiya is static. However, it is layered to respond to various solar conditions, creating similar visual textures and complexity. IMA won the Aga Khan Award for Architecture in 1989 and the Equirre d'Argent for French architecture in 1987.

The technological elements, holistic design, energy efficient strategies, and green features of this tower are commendable. However, it is the tower's cultural and geographic context that makes it a truly unique work of architecture as well as a national icon. Consequently, Doha Tower has received the 2012 CTBUH Skyscraper Award for the Best Tall Building Worldwide. Richard Cook of Cook+Fox Architects,



the Awards Chair, commented that the towers' skin is the most innovative feature of the building. By modernizing the mashrabiya, the building evokes a new aesthetic rooted in the Arabic-Islamic culture. The tower's design is particularly remarkable given that architects in today's globalized world typically give little consideration to local climate and culture (Figure 3).



Figure 3. Doha Tower in Doha, Qatar. (Photograph by W. Maibusch)

CHINA

China is the world's leader in skyscraper construction. In the world's entire history of construction, China's recent construction boom is unprecedented (Wood, 2011). With only 10 skyscrapers from 1929 until 1945, China was a non-factor in skyscraper discourse. Today, however, China has exceeded the United States in the number of skyscrapers within its boundaries. The country now accounts for 53% of the world's skyscrapers that are under construction. There are currently 259 skyscrapers (buildings over 150 m/492 ft) under construction in China, more than any other single country. Nine of the world's tallest 20 buildings under construction are located in China, three times more than any other country. China now plans to build the tallest skyscraper, Sky City, in Changsha that will be a 220-story structure standing at 2,749 ft (838 m). It will house 17,400 people and also boast hotels, hospitals, schools, office space, and 104 high-speed lifts (Wu and Mab, 2006; Zhang, 2007). Interestingly, similar to the case of the Middle East, the new trend constitutes an architectural paradigm shift that focuses on sustainable design, exemplified in the following case studies.

Pearl River Tower, Guangzhou, China

The 71-story, 309 m (1,016 ft) tall Pearl River Tower is home to the CNTC Guangdong Tobacco Corporation located in the Tianhe District of Guangzhou, China. Guangzhou, known in English as Canton, is a large port city and the capital of China's Guangdong province. It is located on the Pearl River about 120 km (75 mi) north-northwest of Hong Kong and north-northeast of Macau. Guangzhou contains a population of over 12 million people, making it China's third most populous city. The spacious Pearl River Tower brings an instant iconic identity to the city. Designed by Smith and Gill during their tenure at the Chicago-based SOM, the tower was topped out in 2010 and officially opened in 2013.

The Pearl River Tower serves as a pioneer in collaborative design. The form of the skyscraper not only minimizes wind pressure, reducing the need for structural steel and concrete and the carbon emissions embodied therein, but also utilizes wind power. Featuring a sculpted body that relieves wind pressure on its windward side, Pearl River Tower contains 4 large wind turbines (6 m by 6.8 m or 20 ft by 22 ft) which capture wind funneled by the building's unique form. The funneled wind (up to 1.5 to 2.5 times ambient wind speed) pushes the turbines to generate energy up to 15 times more powerful than freestanding turbines. In addition to powering the building, this wind is rerouted throughout the tower's

ventilation system, filtering the air through the building's floor and ceiling spaces. In order to maximize the wind effect, the tower has been positioned so that its broadest side faces the prevailing wind (Fairley, 2014).

The 212,165 m² (2,281,949 ft²) building is also fitted with advanced double-glazed façades that provide abundant natural light. The outer skin features a high permeability for solar heat while the inner skin prevents solar gain. The trapped heat rises up creating natural ventilation along the building's façade. Toward the top, exchangers absorb, reuse and store this rising heat. The inner skins on the eastern and western sides have been made of a triple glazed glass that helps insulate the building's interior. Given the tower's shallow floor plate, natural light is able to permeate most of the interior spaces. On the south façade, large-scale solar panels have been installed on the roof and on lower areas where wind openings are used to generate electricity. The skyscraper's metal window blinds automatically track the sun, opening and closing to regulate solar heat gain. These window blinds are also equipped with photovoltaic cells which capture the sun's energy when they are pulled shut. Because the building is located in a sub-tropical region (characterized by high heat and humidity), it faces challenges of cooling. In this regard, SOM utilized a passive dehumidification system that removes moisture, heat sinks, radiant slabs, and underfloor displacement ventilation to efficiently cool the building. Other sustainable features include the cooling beam structure and the graywater collection system. The design team's original goal was to construct a positive-energy building that would sell its excess power to the local electrical grid. However, due to local regulations and fire codes, the original design was compromised, and consequently, the completed building consumes about 40% of the energy a similarly sized traditional building might use (Figure 4).



Figure 4. The Pearl River Tower by SOM in Guangzhou, China.
(Sketch by author)

Shanghai Tower, Shanghai, China

The Shanghai Tower is the third tower in the trio of supertall buildings including Jin Mao tower and the Shanghai World Financial Center located in the heart of Shanghai's new Lujiazui Finance and Trade Zone adjacent to the Huangpu River. Spurred by the Chinese economic reforms of the 1980s, the Lujiazui district in Shanghai has been transformed from farmland to a skyscraper city (nicknamed Manhattan of the East) in just two decades. As is the case in many Chinese cities, rapid urbanization has engendered vertical density. With 23 million inhabitants, an increase of almost 50% in the past decade,

and 9 million migrant workers, the City of Shanghai has had no choice but to build upward. According to the city's officials, it is more efficient to build a giant skyscraper near mass-transit stations, referring to Shanghai Tower, than to build smaller skyscrapers in the suburbs.

The Shanghai Tower rises to a height of 632 m (2,073 ft) dwarfing its neighboring skyscrapers, the Jin Mao Tower 421 m (1,380 ft), and the Shanghai World Financial Center 492 m (1,614 ft) as well as every other skyscraper in the Lujiazui area. It is the tallest building in China and the second tallest building in the world, after Dubai's Burj Khalifa at 828 m (2,717 ft) tall. The twisted Shanghai Tower also surpasses the world's tallest twisting tower, the Cayan Tower, located in Dubai. That building was inaugurated in 2013 and stands at 307 m (1,010 ft) tall. This new iconic landmark in the ever evolving Shanghai's skyline enjoys an evocative curved façade that symbolizes the dynamic emergence of modern China. The 121-story tower anchors Lujiazui and offers a mix of functions including offices, hotels, shops, restaurants, as well as the world's highest open-air observation deck at 562 m (1,844 ft). Overall, Shanghai Tower's sustainable strategies will reduce the building's carbon footprint by 34,000 metric tons per year and the tower is targeting LEED Gold certification from the U.S. Green Building Council and a three-star rating from the China Green Building Council. The tower broke ground in 2008, and was topped out in 2013. It is anticipated to open to the public in 2015. The cost is estimated at \$2.5 billion (Xia, et al, 2012).

The Shanghai Tower represents a new paradigm of rethinking the sustainable vertical city. It is a city within a city, a collection of multiple neighborhoods. The 623 m (2,043 ft) tower is divided into nine neighborhoods, stacked vertically, making it a self-contained city. What also makes this arrangement unique is that one third of the tower is assigned as a "true" public space where all visitors are welcomed. This urban concept builds on practices of the Chinese culture and tradition, but represented vertically. Each neighborhood in the tower contains a sky garden intended to evoke the landscaped courtyards of Shanghai's historic homes. In traditional lane houses found in Beijing's hutongs and Shanghai's shikumen, families live in close-knit dwellings organized around a communal open space. In the case of Shanghai Tower, the neighborhoods are vertical, each comprising 12 to 15 floors and featuring a 24-hour accessible sky garden to foster social interaction and a sense of community. Each vertical neighborhood rises from the sky garden to create a sense of unity and community, as well as to support daily life with a mixed-use program that caters to both tenants and visitors. Furthermore, the sky gardens help to ease traffic jams near elevators and provide spectacular views of the city.

The sky gardens also provide energy savings and ventilation advantages. They act as buffer zones between the inside and the outside by warming up cool winter air and dissipating accumulated summer heat from the building's interior. Stale indoor air is blown across each garden before being exhausted from the building. Since only the lowest ranges of the 12-to-15-story-tall sky garden are occupied, these spaces will require minimal conditioning. Spatially, the sky gardens are formed by the interplay of the tower's two glass skins: the inner skin being circular, while the exterior skin takes on the shape of a triangle with rounded corners. The outer skin rotates around the inner skin almost one degree per floor, resulting in an impressive twisting form. The double-skin-façade (DSF), advanced lighting controls, and an efficient central plant, among other features, are expected to help the Shanghai Tower use 21% less energy than if it were compliant to 2004 ASHRAE 90.1 standards (Xia et al, 2012; Gensler, 2014).

In addition to being iconic, the tower's form is meant to resist the typhoon-level winds common to Shanghai. To that end, the form embraces multiple strategies including asymmetry, tapering, rounded corners, and a reduced floor plate as the tower rises. Testing scenarios and simulation were carried out to simulate typhoon-like conditions, suggesting a 120-degree twist as the optimal rotation for minimizing wind loads. The resulting form reduced the lateral loads of the tower by 24 percent, saving \$58 million in building materials (Gensler, 2014).

The structural system comprises a concrete core and several composite super-columns, which rest on a 20-foot-thick concrete mat of 1,079 bored piles. The building enjoys a strong 30 meters squared core that is designed to resist the threat of a windy climate, active earthquake zone, and clay-based soils typical of a river delta. The core acts in concert with an outrigger and super-column system. There are four paired super-columns, two at each end of each orthonormal axis. In addition, "four diagonal super-columns along each 45-degree axis are required... at the base between the main orthonormal super-columns" (Al-Kodmany, 2015, 260). The tower's inner skin is attached to circular floor slabs and the protruding outer skin is suspended from the building's mechanical floors, which are supported by a series of radial bars and encircling girds.



The tower's site incorporates a garden inspired by traditional Chinese landscaping, which satisfies the Shanghai government's requirement that 33% of the site is reserved as an open space. The garden engages people with nature, enhances the human scale, and provides a space for social interaction and relaxation.

Renewable energy technologies have been employed to provide on-site energy. Wind turbines, located directly beneath the parapet, generate power for the upper floors, while a 2,130 kW natural gas-fired cogeneration system provides electricity and heat energy to the lower floors. Rainwater is collected via the building's spiraling parapet and has been used for the tower's heating and air conditioning systems. Water treatment plants have been incorporated into the tower's shaft, podium, and basement to reduce the energy required for pumps. The building also recycles gray water and storm water for irrigation and toilet flushing. These strategies will result in a 38% overall reduction in water consumption.

The HVAC system, strategically placed in the mechanical floors, provides heating, ventilation, and cooling to the building's various vertical zones. It also preconditions, filters, and measures air quality before entering the building. Mechanical floors also house electrical transformers, water systems, and other equipment. Locally sourced materials with a high-recycled content have been used throughout. The sustainable measures employed by Shanghai Tower are expected to reduce the building's carbon footprint by 34,000 metric tons per year compared to a typical structure of the same size. The tower has a five-story, 37 m (121 ft) podium totaling 46,000 m² (495,000 ft²) that contains retail, banking, restaurants, conference meeting, and banquet facilities.

The level below-grade floors features retail, 1,800 parking spaces, services, and MEP (mechanical, electrical, and plumbing) functions. Designed by Mitsubishi, Shanghai Tower will have the world's fastest elevators, transporting visitors at speeds of up to 18m/s or 40 mph. It should be noted that Gensler Architecture, in collaboration with the Architectural Design and Research Institute of Tongji University, provided the sophisticated design work done on this building. The Shanghai Tower Construction & Development Co., Ltd served as the project's developer, while Thornton Tomasetti provided structural design inputs along with Cosentini Associates, which specialized in the building's mechanical and electrical design.

Parkview Green FangCaoDi, Beijing, China

Parkview Green FangCaoDi complex (literally in Chinese, "green, grassy area") is located in the heart of Beijing's Central Business District (CBD). It is an iconic landmark and a potent symbol of creative design thinking that promotes attractive forms, efficient utilities, functionality, and enjoyable experiences. The project was designed by Integrated Design Projects, engineered by ARUP, developed by Hong Kong Parkview Group, and is owned by Beijing Chyau Fwu Properties Ltd. Parkview Green FangCaoDi has earned multiple prestigious "green" awards, setting impressive sustainability standards in Beijing and in China at large. It has achieved LEED Platinum Certification. It was also named the "Best Green Building" in Asia by MIPIM Asia Award in 2010, the first mainland Chinese project to win the award. MIPIM Asia is an Asia-Pacific property market exhibition, first introduced to Hong Kong in 2006. In 2011, the project was presented with the International Green Award Copper Award for Best Green Intelligence Architecture, and in 2012, it was presented with the Green Building Award Asia Pacific Grand Award.

The project was first conceptualized in 2001, completed in 2010, and opened to the public in late 2012. The public opening was delayed due to fire code complications. The complex constituted a brand new type of indoor-outdoor hybrid for which fire authorities had to conduct special studies to ensure its safety. One of the benefits of receiving the LEED certification was that it helped the owner to secure commercial tenants with a global CSR (corporate social responsibility) policy that requires them to rent in LEED certified buildings.

The complex (dubbed the urban pyramid) simulates a city-within-a-city or a "vertical neighborhood". It occupies two city blocks covering an area of 200 m by 200 m (656 ft by 656 ft) and is sheltered by a mega pyramidal envelope. A spinal bridge connects the two opposite ends of the blocks diagonally allowing outside pedestrians to make a walkable short-cut through the complex. Parkview Green complex comprises four towers (two 9-story and two 18-story towers) that include 50,000 m² (538,195 ft²) of luxury retail spaces, 82,000 m² (882,640 ft²) of Grade-A commercial office space, a luxury boutique hotel, as well as restaurants, a state-of-the art cinema, and a 60,000 m² (645,834 ft²) underground parking garage. The complex's components include towers, atria, sky-gardens, terraces,

and bridges, which cluster around a central interior space (courtyard or public plaza) and are sheltered by way of a microclimatic envelope. Offices have a maximum depth of 15 m (49 ft) from façade to core and a floor-to-ceiling, glass curtain wall of 2.9 m (9.5 ft), which provide optimal daylight and reduce the energy required for artificial lighting.

The hotel, with 120 luxury rooms, including a 500m² (5,381 ft²) presidential suite, is located at the highest floors of the complex and is accessible exclusively via a private entrance and through glass elevators. The hotel rooms enjoy expansive outdoor terraces and private swimming pools. Among the hotel's most salient amenities is a suspended sky lounge located near the tip of the pyramidal envelope so as to provide spectacular views of the entire interior space of the development as well as awe-inspiring views of downtown Beijing. Also, most of the office spaces, hotel rooms and residential apartments enjoy direct views to the central courtyard.

The four-level retail mall surrounds the courtyard, which acts as the center stage for events form the heart of the complex. In the same way that streets facilitate access to a central city square, the courtyard has been designed as a "true" public place where everyone may gather. Retail spaces have been given flamboyant lighting systems, adding another layer of visual drama to the building's interior. The 236 m (774 ft) pedestrian bridge that diagonally cuts through the complex offers a bird's-eye view of shops and the public plaza.

Also, a series of glass encased lifts and 18 six-meter-long (20 ft) escalators dramatize the interior spaces. Mimicking the ceaseless activity of the city, the complex is open 24/7, and with easy access to various modes of transportation (metro, taxi and bus), the Parkview Green FangCaoDi has direct connections to other districts and facilities in Beijing, making the urban pyramid integral to the life of the city both spatially and temporally. In addition to providing functional services, the complex attracts people from all over the world, given that its accessible interior public space shelters visitors from Beijing's sweltering summers, freezing winters, and year round air pollution.

Technologically, the mega pyramid's microclimatic envelope comprises a Texlon ETFE membrane system of glass and structural steel façades. The envelope protects tenants and visitors from adverse weather conditions, while providing an outdoor environment with abundant natural light and thermal comfort. "Texlon consists of pneumatic cushions restrained in aluminum extrusions and supported by a lightweight structure. The cushions are inflated with low pressure air to provide insulation and resist wind loads," and they are composed of multiple layers of a modified copolymer known as Ethylene Tetra Fluoro Ethylene (ETFE).

ETFE provides numerous advantages. It does not degrade under ultra-violet light or atmospheric pollution. It also facilitates the transmission of light and is very low weight compared to that of glass (about 1%), creating light and elegant structures. The smooth and non-stick outer surface of Texlon ETFE is self-cleaned externally by rain, while the inner surface of cushions may be cleaned with water every few years. Texlon ETFE is 100% recyclable. This type of roof structure has also been used in the Olympic National Aquatics Center of Beijing, also known as the Beijing Olympic Water Cube.

The urban pyramid evokes a structural expressionism by jutting out of the diagonal structural steel frames from the building's exterior, leaving a space in between. The envelope's corners have been given vertical cuts to denote entrances, producing an effect of grandeur. While the pedestrian bridge, painted a bright red, protrudes from the connecting sidewalks to further accentuate the entrances. Finally, it should be noted that the tip of the pyramid reaches a height of 87 m (285 ft) (Al-Kodmany, 2015).

The microclimatic envelope creates a thermal buffer that enhances thermal conditions. In the summer, it reduces the need for air conditioning, and in the winter, it reduces heat loss. This is perfectly suited to Beijing's vacillating seasonal climate. Parkview Green FangCaoDi's microclimate is supplemented in the summer through the use of operable ventilation louvers installed at the top of the building's envelope. These louvers are strategically placed and computer-controlled so as to respond effectively to varying environmental conditions.

The pyramidal form stimulates the natural stack effect or "natural chimney" effect that allows hot air to rise up and exit through the roof. As the air escapes, cooler and fresher air is drawn up from the bottom of the building, creating air movement and natural ventilation. The ETFE roof is set at a constant 3 m (10 ft) distance away from the inner buildings so as to maintain air movement. Furthermore, the complex as a whole is "sunken" down 10 m (30 ft) below street level and recessed about 15 m (50 ft) to provide another buffer space that contains a sunken garden decorated with sculptures. In the summer,

this garden is the coolest space in the building and supplies the complex with intake air through operable openings in the envelope. Interestingly, a large water fall with fountains is located in the garden, which helps to cool air in the summer while simultaneously increasing oxygen levels. Consequently, the microclimatic envelope keeps the atrium warmer in the winter and cooler in the summer. Although air conditioning is still required, loading is reduced and, for much of the year, natural ventilation maintains comfortable conditions within all areas. At these times, supplementary heating and cooling is supplied via a radiant ceiling, enabled by a geothermal source that uses a 'closed circuit' water system.

Just as the geothermal system relies on the buffer of the earth to keep temperatures below ground around 13°C (55°F), the Parkview building relies on a buffer of external glass to keep temperatures within the building from rising too high or dipping too low. It is estimated that the hybrid passive and active mechanical systems will save 60% on cooling costs and 80% on heating costs (Al-Kodmany, 2015).

The complex also incorporates water-conservation systems, including "electronic taps, water-saving sanitary ware and low-flow shower facilities". Waste water from sinks, showers, and washing faucets is also treated for flushing and for irrigating the native, drought-resistant plants present in the surrounding landscape. The complex also gathers rainwater from the roof and paved areas, which is then filtered and recycled to irrigate the landscaped areas. Native plants and trees were chosen for their low water intake and low maintenance.

Collectively, the sustainable strategies employed at the Parkview Green FangCaoDi add up to a savings of 48% in water use. Its materials were selected based on their sustainability. The structure includes recycled content from building demolitions and 25% of the total building materials were made from recycled goods. Quickly growing softwoods were used instead of hardwoods. The design of the interior spaces embraces an adaptive reuse scheme to accommodate future changes and rising needs, enabling tenants to save 10-15% on renovation costs. The project also pursued a "green" construction standard where 81% of its own construction waste was recycled, minimizing the complex's carbon footprint.

In addition to emphasizing sustainable design, the complex takes a deep interest in art work by offering the largest private collection of artwork in China. The art focus reflects the interest of Leo Hwang's uncle (Leo is a third-generation successor in the Chyau Fwu Group and the Executive Director of the Parkview Green Project). The uncle's philosophy stresses that a building is not alive until it is landscaped and filled with art and people. Much of the older art pieces in the complex were donated by Leo's uncle. The complex's art pieces represent both the Western and contemporary Chinese arts. Within the collection are over a hundred original pieces by Salvador Dali, the largest collection of his sculptural work outside of Spain. The complex also exhibits the art work of contemporary Chinese artists such as Luyan Wang, Wenling Chen, Guangyi Wang, and Xiaowu Gao.

The lobby also contains an original Andy Warhol panda print. Parkview Green FangCaoDi hosts a space on its second floor for art galleries and institutions that hold commercial shows. Art exhibits form the core of the educational program for the complex, turning art appreciation into an informal and fun activity. Some of the art pieces are permanent while others are temporary, allowing new pieces to be introduced over time. Collectively, the project provides a unique opportunity to discover the work of some of the world's most famous artists in an intriguing setting.

The high quality and creative work of the complex is also attributed to Leo's father and grandfather. "From the very beginning, my grandfather has said that we need to place great care into everything we build. He has always looked at building as a privilege and a responsibility, and he believes that we are lucky to be in this position. My grandfather started from nothing, and he realizes that when you're building, you're creating places that will last way past your lifetime." (Figure 5)





Figure 5. Parkview Green FangCaoDi in Beijing, China.
(Source: Author)

CONCLUSIONS

The significance of embracing green or sustainable design principles for skyscrapers cannot be understated. A new generation of “green” towers aims to improve energy performance and enhance environmental quality. Shanghai Tower’s green design process, through its use of sustainable technologies, may provide a good model. The tower’s swiveling asymmetrical glass façade reduces wind loads on the building. The building’s spiraling parapet collects rainwater to be used for the tower’s heating and air conditioning systems, and wind turbines situated below the parapet generate on-site power. Furthermore, the gardens nestled within the building’s façade create a thermal buffer zone that improves indoor air quality. Power for the building will also be partially generated by wind turbines (Xia et al, 2012).

Skyscrapers are often cited as among the largest energy consumers in a city, but the new generation of skyscrapers is addressing these issues in innovative ways. Skyscrapers in Dubai could consider integrating photovoltaic technology to harness solar energy. Skyscrapers in Shanghai could collect rainwater to reduce flooding events. The treatment of waste has become a serious environmental issue in Dubai and green skyscrapers may provide self-treatment systems to address this issue. These tall buildings can also employ air filters to improve air quality, as can be observed in New York City’s Bank of America Tower (Al-Kodmany, 2012b; Aboulnaga, 2006).

Sustainable skyscraper development should take into consideration impact on city life, environment, transportation, public communal spaces and pedestrian life, sidewalks, and safety. In constructing futuristic skyscrapers and intensifying land use, public spaces have become fewer and smaller. Concern about the quality of public spaces is becoming increasingly important since new skyscrapers are often owned by private developers. Most importantly, cities need to reexamine the need for skyscrapers, since some have been constructing skyscrapers without sufficient underlying demand (Aucto, 2010).

Sustainable skyscrapers should be developed by multi-disciplinary teams that possess diverse qualifications and combine skills from several professions, encompassing both the modern technologies of the age and the richness of local heritage. In order to achieve a degree of consensus among existing residents, buildings can be constructed that respect the dominant styles of the locality. When considering globalization, architects and planners should perceive the opportunities that globalization provides in regards to place-identity considerations. In order to link global technologies (including green technology and modernization) with local values and cultures, these professionals must anticipate the threats that affect local heritage. This will require great sensitivity and substantial talent to successfully weave together appropriately chosen traditional characteristics with technologically modern elements. It will also demand a regionally derived form-making language with its own compositional grammar and vocabulary for materials and details that makes a skyscraper in the Middle East different from one in China. Essentially, a sustainable design should proceed “glocally”, a composite term that refers to an inclusive design approach that combines considerations of local needs and global forces. A sustainable design

should find a balance between these two factors, reinforcing a distinct urban identity while at the same time remaining open to positive foreign influences (Al-Kodmany et. Al, 2013; Bagaeen, 2007).

Design simplicity, elegance, and logic, coupled with exploration and experimentation of new forms, likely will form the basis of the next generation of sustainable tall buildings. Future designers will face several challenges when designing tall buildings. Some of these will include the debate of whether or not to build tall. The increasing demand for buildings to be energy efficient and sustainable will shape the future of skyscraper construction. In the endeavor to build tall buildings sustainably, new questions regarding environmental effects, property and space ownership, regulations, and real estate marketability, will arise. Insofar as it responds to emerging needs for energy efficiency and increased population pressures, the sustainable tower is likely to prevail as an architectural typology. Ultimately, as they embrace local culture, context, environment, and the technology of the era, these skyscrapers will set the path for future sustainable cities.

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