

GREEN TOWERS AND ICONIC DESIGN: Cases from Three Continents

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Abstract

Recently, massive urbanization, increasingly denser cities and environmental consciousness are pushing architects to build “green” skyscraper. This paper examines the emergence of a notable type of skyscrapers that depart from purely image-driven structures, and emphasizes functionality and energy efficiency. It argues that breathtaking green design and practical clean technology are merged to give birth to green architectural aesthetics. Upon reviewing over 30 towers from various parts of the world, the paper identifies salient green design strategies that provide new iconicity including: structural efficiencies, renewable energy, façade technology, greeneries, and bioclimatic design. Findings suggest that a dynamic synergy among innovative green design strategies, new architectural languages and exciting aesthetics has constituted a trend that is more likely to prevail in the 21st Century.

Keywords: sustainable design; new technologies, indigenous forms; innovative approaches, green aesthetics.

INTRODUCTION

Sustainability, high-performance buildings and “green architecture” have become important architectural issues today as concerns about increased world population in conjunction with depletion of natural resources, renewal and recycling of natural and synthetic materials, as well as construction of non-renewable energy resources, take on global proportions. Architects have been in a race to build the greenest buildings, and most recently architects have an aggressive agenda to build the greenest skyscrapers (Al-Kodmany and Ali, 2013; Foster et al., 2008). “The green meets the blue” expression refers to how architects are incorporating sustainable design principles augmented with new materials and technology into the design of tall buildings (Yeang, 2006).

To be the greenest skyscraper in the city, designers are incorporating cutting-edge energy and water-saving technologies like helical wind turbine technology, thousands of solar panels, sunlight-sensing LED lights, rainwater catchment systems and even seawater-powered air conditioning. Recent green design demonstrates that energy-conserving measures can produce efficient tall buildings. New York City’s Hearst Tower is largely made from recycled steel and uses rainwater for 50% of its needs. The Pearl River Tower (also known as “Zero-Energy” Skyscraper) in Guangzhou, China, by SOM has semielliptical exterior and produces a considerable amount of energy (Beedle et al., 2007). The 71-story Pearl River Tower use wind, sun and geothermal energy to power itself, and even the Empire State Building, one of the world’s oldest skyscrapers, has been recently undergoing an energy retrofit facelift to stay in the race. As we see in this paper, architects have been implementing innovative skin design such as “rain coat,” “fur coat,” and “sun coat” in order to effectively respond to different climatic conditions. The articulation of these concepts evokes new “green” aesthetics rooted in sustainable design that gears to reduce energy consumption.

The “bioclimatically designed” (climate-responsive) buildings including T.R. Hamzah and Ken Yeang’s Menara Mesiniaga/IBM Building of 1992 in Selangor, Malaysia, employ passive ventilation and “gardens in the air” (Yeang, 1996). Fox and Fowle’s (later FX Fowle or FXFOWLE) 4 Times Square Building (also known as Conde Nast Building) of 1999 in New York incorporates an array of photovoltaic cells on its facades and roof to supply all its energy needs (Goncalves,

2012). The proposed Burj al-Taqa “Energy Tower”, a 68-story skyscraper with a 197-foot roof turbine and 161,459 square feet of solar panels, will create all its own power. This is a growing trend in skyscraper design during the present energy-conscious era (Al-Kodmany and Ali, 2013).

As a result, green design is transforming the architecture of skyscrapers; some scholars have already used the name “greenscraper” to indicate such transformation. Interestingly, the resulting outcome is architecture of new aesthetics that is based on eco-friendly design features and principles. In other words, the green design revolution has produced new aesthetical qualities, in some cases iconic and strikingly unconventional. These iconic green skyscrapers enjoy local even global status and are considered to be among the most attractive. These tall buildings possess powerful imageability and embrace green design technologies simultaneously. These eco-iconic skyscrapers put their cities on the map by making their cities receive national and international recognition (Parker and Wood, 2013). Although modern skyscrapers tend to focus on employing green technologies to attain sustainable design, the paper reminds with the ecological work of Frank Lloyd Wright, specifically the Price Tower, which relied completely on passive green design measures (Goncalves, 2012).

The overarching purpose of this paper is to examine green design ideas of recent towers. The paper focuses on a new trend, “eco-iconic”, and attempts devising a framework for understanding these new architectural expressions. In examining over 30 towers, analysis suggests that iconicity does not necessarily mean manipulating forms to compete for attention, per se. Instead, the findings suggest that there are genuine concepts and green design principles that dictated these shapes and forms; yet, the resulting forms are interesting and eye-catching.

The following examples illustrate a wide range of green design features, strategies and techniques. The examined tall building project examples include towers that are constructed, under-construction, on-hold, proposed, and on the drawing boards in an attempt to capture a wide range of innovative ideas and concepts of green skyscrapers. The review highlights the green features of each skyscraper project. The provided examples are placed based on their continents: Southeast Asia and the Far East, Middle East, Europe, and North America.

SOUTHEAST ASIA AND FAR EAST

Shanghai Tower

Shanghai Tower is located in Pudong Financial District in Shanghai, China. The 121-floor tower was topped out recently rising to 557m (1,826 ft.). The 121-storey tower is divided into nine vertical zones, with retail at the bottom and hotels, cultural facilities and observation decks at the top. The zones in between will contain offices. Designed by the architectural firm Gensler, the tower features numerous green design elements including: the façade’s taper, texture and asymmetry work in partnership to reduce wind loads on the building by 24 percent, offering significant savings in overall building materials. The building’s transparent inner and outer skins admit maximum natural daylight, thereby reducing the need for electric light. The tower’s outer skin also insulates the building, reducing energy use for heating and cooling. The tower’s spiraling parapet collects rainwater, which is used for the tower’s heating and air conditioning systems. The tower will be completed in 2014 (Figure 1).

Pearl River Tower

Located in Guangzhou, China, this tower was designed by Adrian Smith and SOM and is of 300m (984 ft.) tall with 71 floors. The building is renowned for being the first so-called “zero energy” building for it was designed to produce as much energy as it consumes. The Pearl River Tower’s innovative form embraces wind: the building’s sculptural, semielliptical form guides wind to a pair of openings at its mechanical floors. The rapid winds with greater speed push turbines that generate energy for the building’s HVAC systems. The openings also provide structural relief by allowing wind to pass through the building instead of pressing against it. It has several other sustainable features (Beedle et al., 2007). The project construction was completed in 2012 (Goncalves, 2012), (Figure 2).



Figure 1: Shanghai Tower, currently under construction. When completed, it will be the tallest in China and second tallest in the world after Burj Khalifa. Consistent with the present trend for skyscrapers, the tower has “out-of-the-box” form. Its sky-high stature and spiraling shape with a curved façade heralds the emergence of China as an economic powerhouse (Sketch by the author).



Figure 2: The design of the Pearl River Tower by SOM in Guangzhou, China aims at harnessing wind power and was touted as a “net zero energy building.” Wind turbines are located at vantage locations of the sculpted building to amplify the wind speed. The top-right sketch shows wind portals located strategically to harness wind power. They also reduce wind impact on the structure. Bottom-right sketch shows the shape of wind portals (Sketch by the author).

Wuhan Tower

The Wuhan Greenland Center, under construction, will make a new landmark in downtown area of Wuchang in Wuhan, capital of Central China's Hubei province, potentially transiting the city from a

regional center to an international one. Upon completion, expected in 2017, at a height of 606m (1,988 ft.) the 119-story tower will be the China's third-tallest building and 4th tallest structure in the world. The tower maximizes efficiency by adjusting form and structural system layout, taking into account the latest in wind engineering technologies. The design features a tripod like base forming the foundation of the tapered building. It enjoys an efficient, aerodynamic profile that combines three key shaping concepts—a tapered body, softly rounded corners and a domed top—to reduce wind resistance and vortex action that builds up around supertall towers and usually causes a building to sway (Al-Kodmany and Ali, 2013), (Figure 3).

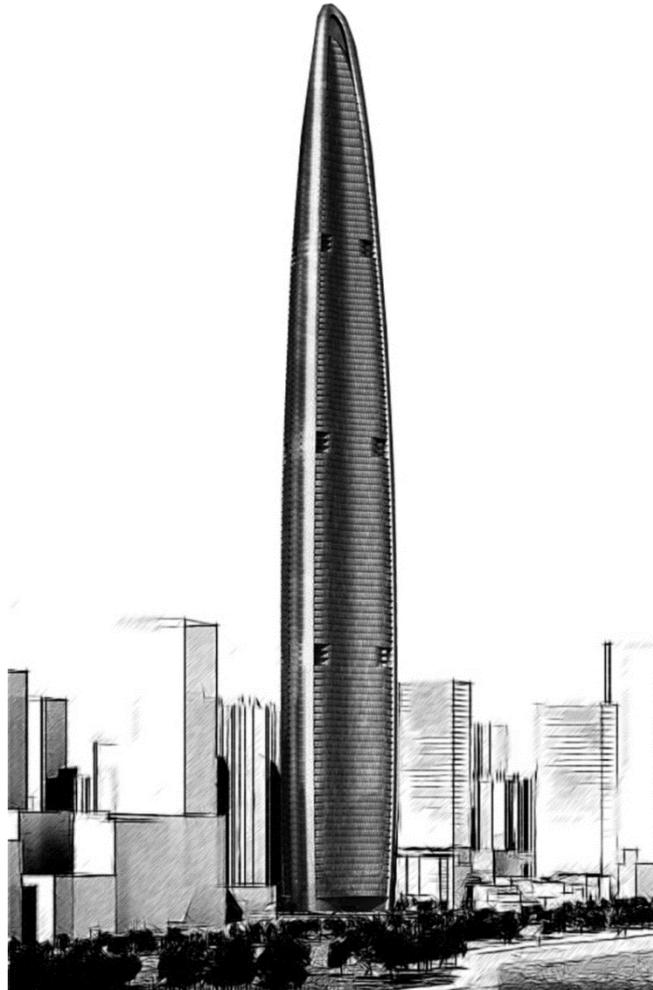


Figure 3: The proposed 119-story Wuhan Greenland Center in Wuhan, China by A. Smith. Its tripod-like base and tapered sides with rounded corners make an extremely efficient, aerodynamic profile that will reduce wind loading, thereby reducing the amount of structural material required for construction (Sketch by the author).

Menara Mesiniaga

A well-known eco-skyscraper by Ken Yeang is the Menara Mesiniaga located in Subang Jaya near Kuala Lumpur, Malaysia. The most striking design feature is the planting, which is introduced into the façade and the “skycourts”, starting from a three-story high planted mound and spiraling up the building’s height. Curtain wall glazing is used on north and south faces to moderate solar gain. All the windows facing the hot east and west faces have external aluminum fins and louvers to provide sun shading. Other features include natural ventilation systems and ample sunlight. The rooftop

sun terrace is covered with a sunroof of trussed steel and aluminum, which shades and filters light onto the swimming pool and gymnasium roof. The building also employs a range of automated systems to reduce energy consumption by equipment and the air-conditioning plant (Beedle et al., 2007, p.31).

Shenzhen 4 Tower in 1

High-tech green skins utilize cutting-edge technologies to optimize the utilization of natural resources and environment such as wind, sun and air. The Shenzhen project competition for the new “Headquarters of the China Insurance Group” may serve as an example. It is a 49-story solar- and wind-powered tower, conceived by the Austrian architecture firm COOP HIMMELB (L)AU, which won the First Prize in the competition. COOP’s tower rises to 200m (656 ft.) and has a footprint area of 40m × 40m (131 ft. × 131 ft.) and is divided into clearly separated functions, with business offices at the top, meeting rooms, a conference center, recreation areas and gardens in the center, and public housing in the lower levels. The façade’s design is driven by solar- and wind-powered energy generation. The outer skin of the building will be lined with photovoltaic cells and will feature mechanisms to provide natural ventilation, reduce wind pressure, shade the interior from sun and display multimedia banners.

MIDDLE EAST

Bahrain World Trade Center

Designed by the Atkins Design Studio, and of 240 m (787 ft.) height with 50 floors, the Bahrain World Trade Center (BWTC) in Manama, Bahrain is a twin tower complex and is the first commercial building in the world to incorporate large-scale wind turbines within its design to harness wind power. The mixed-use building (hotel, shopping and business) has three massive wind turbines that measure 29m (95 ft.) in diameter and are supported by bridges between the two towers. When turning, they will generate 15% of the power that the building requires. Each tower has a curve that helps to funnel the existing on-shore Gulf breeze right into prominent wind turbines to generate power. The tapering of each tower from bottom to top reduces wind resistance from higher velocity winds at higher elevations, thus keeping all three turbines spinning at more consistent speeds (Irwin, 2013). The building, the second tallest in Bahrain, was completed in 2009 and won the CTBUH Best Tall Building in the Middle East and Africa award that same year (Figure 4).

Doha Tower

Doha Tower is a 46-story (231 m/ 758 ft.) high rise located in West Bay (Doha), Doha, Qatar, and was completed in 2012. Designed by Jean Nouvel, the cylindrical form of the tower was decided upon for its efficiency in floor-to-window area and relative distances between offices and elevators. Additionally, the core of the building has been shifted off-center to allow more flexible floor area for the office spaces. The cladding system is a reference to the traditional Islamic “mashrabiya,” a popular form of wooden lattice screen found in vernacular Islamic architecture and used as a device for achieving privacy while reducing glare and solar gain. The design for the system involved using a single geometric motif at several scales, overlaid at different densities along the façade. The overlays occur in response to the local solar dynamics: 25% opacity was placed on the north elevation, 40% on the south, and 60% on the east and west. The overall façade system is estimated to reduce cooling loads by 20%. The building received the CTBUH Skyscraper Award for the Best Tall Building Worldwide from the CTBUH in 2012, (Figure 5).



Figure 4: Bahrain World Trade Center (BWTC) in Manama, Bahrain. The twin towers have been positioned and shaped to optimize harnessing wind energy via wind turbines. The mixed-use building has three massive wind turbines that are supported by bridges spanning the two towers. Each tower has a curved surface that helps funnel the blowing wind right into the turbines to generate power (Sketch by the author).



Figure 5: Burj Qatar in Doha, Qatar. This cylindrical tower, 45 m (148 ft.) in diameter, embraces modernist style of simplicity and creates a distinctive landmark in the city. To shade the building from the harsh desert sun, the façade employs screens with design that invokes ancient Arabic-Islamic geometry. The screens are made of multiple layers of aluminum with varying size, pattern, and density that respond to the solar path: the pattern is denser in areas that are more exposed to sun (Source: Photograph by W. Maibusch).

Al Bahar Towers

Al Bahar Towers house the new headquarters for the Abu Dhabi Investment Council and occupies a prominent site on the North Shore of Abu Dhabi Island, in UAE. The project comprises two 150m (490 ft.) tall towers that share a common podium and a two-level basement. Similar to the case of Doha Tower, Al Bahar Towers took inspiration from a traditional Islamic motif to design an innovative and visually interesting external automated shading system for the building. The dynamic façade has been conceived as a contemporary interpretation of the traditional Islamic “mashrabiya.” However, the “mashrabiya” at Al Bahar Towers comprises a series of transparent umbrella-like components that open and close in response to the sun’s path. Each of the two towers comprises over 1,000 individual shading devices that are controlled via the building management system, creating an intelligent façade. Each unit comprises a series of stretched PTFE (polytetrafluoroethylene) panels.

O-14 Green Dubai Tower

The O-14 office tower is a 22 story-tall high-rise in Dubai, UAE. The tower enjoys a unique façade made of 16”-thick concrete containing over 1000 circular openings. Designed by RUR Architecture, the building’s façade perforations serve as a solar screen, letting in light, air, and views through to the interior occupants. The one-meter space between the façade and the building’s glass surface also yields a chimney effect causing hot air to rise, creating an efficient passive cooling system. The façade also serves as a structural exoskeleton, absorbing all of the tower’s lateral forces and acting as a physical barrier for the building’s window wall (Mitcheson-Low and O’Brien, 2009), (see Figure 6).



Figure 6: O-14 Building in Dubai employs a folded eco-exoskeleton that, in addition to its structural functionality as a diagrid in concrete, acts as a ventilation chimney and provides shadow against the harsh desert sun (Source: Courtesy: Reiser + Umemoto)

Cactus Building

The project was conceived by Aesthetics architects GO Group for the Minister of Municipal Affairs and Agriculture (MMAA) building in Doha, Qatar. The office building and adjoining botanical dome are examples of biomimicry, where the skin of one of the hardiest plants of the desert is applied to

the design of the façade of a desert building. The building features hundreds of smart shades that automatically open and close depending on the strength of the sun, thus mimicking the activity of the cactus, which performs transpiration at night rather than during the day to retain water. The design, as it imitates the hardy cactus plant, has the ability to thrive in harsh desert climates, very apt for Qatar, a hot country covered in sand, which has very little rainfall. The dome at the base of the tower will house a botanical garden, which will include an edible garden and use plants to clean up wastewater.

EUROPE

The Swiss Re Tower

Designed by the renowned architecture firm Foster and Partners, the Swiss Re is an example of high-performance design of aerodynamic form. The building rises to 180m high and with a tapering profile that reduces the downward wash of turbulent wind gusts that often exists around tall buildings in urban settings. The form also disperses reflected light and deflects gusting winds thereby enhancing its environmental effects. The steel spiral “diagrid” structure creates an aerodynamic form that provides the lowest resistance to wind (Riley and Nordenson, 2003). The shape of the building also diminishes demands on the load-bearing structure, as well as the danger of strong katabatic (downward) winds in the area around the building. The office spaces are arranged around a central core with elevators, side rooms and fire escapes (Riley and Nordenson, 2003), (Figure 7).



Figure 7: The impact of 30 St Mary Axe on the visual character of the immediate context. The visual contrast is noticeable in its vicinity but diminishes somewhat from a distance as seen in the previous picture (Source: Photograph by K. Al-Kodmany)

Strata Tower

The Strata Tower is 148m/486 ft., 43-storey building at Elephant and Castle in the London Borough of Southwark in London, UK. Designed by BFLS (formerly Hamiltons), it is one of the tallest residential buildings in London; with 408 apartments more than 1,000 residents live in it. The tower is one of the first buildings in the world to incorporate wind turbines within its structure. The three

9m (30 ft.) wind turbines produce sufficient energy to provide power for the common areas of the building. The three turbines are rated at 19kW each and produce about 50Mega Watt hours of electricity per annum or 8% of Strata's total estimated total energy consumption. The tower uses post-tension slabs to reduce slab thickness, enabling greater floor-to-floor heights, and to eventually develop a high- performance, three-layer, aluminum-and-glass façade. The building's form enjoys a hierarchical structure of base, middle and top. The project was completed in 2010 (Figure 8).



Figure 8: The Strata Tower in London incorporates wind turbines in the roof top. It is one of the first buildings in the world to incorporate wind turbines within its structure. The three 9 m (30 ft.) wind turbines produce sufficient energy to provide power for the common areas of the building (Source: Photograph by K. Al-Kodmany).

Bosco Verticale, Vertical Forest

There is a wide insufficiency of urban green spaces and abundance of “concrete jungles” in cities worldwide. Placed in the center of Milan, the Bosco Verticale, or “Vertical Forest” tries to balance urban and nature. The plan consists of a pair of residential towers festooned with a series of concrete decks, staggered and offset from each other to give the structures their Jenga-like appearance. The project hosts about 900 trees (each measuring 3, 6 or 9m tall), alongside a wide range of shrubs and flowers on 8,900 m² (96,000 ft²) of terraces. These are placed mainly on large cantilevered staggered balconies of gracious height of two stories. The project also employs photovoltaic-based energy systems that produce energy, making the project nearly energy self-sufficient. The two towers---one 26 floors, 87 m/260 ft. tall, the other 18 floors, 119 m/360 ft.--- total 400 condominium units. The construction of the project is nearing completion.

La Tour Vivante

The concept of eco-tower's "Tour Vivante" aim for Rennes City in France is to combine agricultural hydroponic production, dwelling and activities in a skyscraper. A continuous agriculture, emancipated from seasons and climatic changes such as drought, or flood, will provide high-quality produce. The proposed vertical farm has a light-shading skin that wraps around the structure and admits sunlight to targeted locations for both functional and aesthetic purposes. Designed by French architecture firm Atelier SOA, the skyscraper's sustainable features include wind power, reclaimed rainwater, biogas production and on-site food production. The architects explain that the separation between city and countryside, urban planning and natural areas, places of living, consumption and production is increasingly problematic for sustainable land management. The concept of Tour Vivante aims to combine agricultural production, housing and activities in a single system.

The Mile High Eco-Skyscraper

Proposed for London by the British firm Popularchitecture in collaboration with Fluid Engineers and Pha Consul M&E specialists, his project envisioned a mammoth eco-skyscraper. This giant skyscraper will create 12 complete "neighborhoods" in the sky. It is a mile (1.6 km) high tower that will contain 500 floors and accommodate over 100,000 people, and will be a mixed-use development or vertical city in the sky intended for Tower Hamlets in East London. It will contain hospitals, schools, shops, pubs, ice-skating rings, swimming pools, farmer markets, tennis courts, town halls, alpine garden, fire stations and the like—all under one roof. The tower incorporates "vast internal voids" every 20 stories where botanical gardens, swimming pools, or even an ice-skating rink could be built.

NORTH AMERICA

COR Tower, Miami

Designed by the Chad Oppenheim Architecture + Design, the building is the first green, mixed-use condominium in Miami. The 25-story, 122 m/ 400 ft. -tall tower utilizes a wide range of sophisticated green design features and technologies including the latest advancements in wind turbines, photovoltaics and solar hot water generation. Similar to the Green Dubai Tower, the most conspicuous green design feature comes in the form of an innovative hyper-efficient exoskeleton shell that balances transparency and opacity of the recessed clear glass curtain wall. It also provides a thermal mass for insulation, shading for natural cooling, shade for residents, and enclosure for terraces. The 10 inch exoskeleton also integrates recent environmental technologies by incorporating wind turbines, near the top, and it has structural functionality. As such, it provokes an interesting interplay between structural engineering, environmentally friendly design, architecture and ecology. The tower was completed in 2009.

New York Times Tower

The 52-story, 319 m/ 1,047 ft.-tall New York Times Tower was designed by the Italian architect Renzo Piano in collaboration with FXFOWLE Architects, and interiors by Gensler. Completed in 2007, its chief tenant is The New York Times Company, publisher of The New York Times as well as the International Herald Tribune, and other newspapers. Among the green features of the building are a solar screen of ceramic rods, automated skylights, onsite cogeneration, and a courtyard garden. Other green features include curtain wall, fully glazed with low-e glass that maximizes natural light within the building. Mechanized shades controlled by sensors reduce glare, while more than 18,000 individually dimmable fluorescent fixtures supplement natural light, providing a real energy savings of 30 percent. The project was completed in 2007 (Goncalves, 2012), (Figure 9).



Figure 9: The New York Times Building in Manhattan by R. Piano. This skyscraper is both unique and contextual, while accomplishing a certain level of elegance in its refined décor. Piano's understanding of the streetscape-to-skyline relationship clearly demonstrates the conceptualization of the building. The focus on a lively ground plane that successfully integrates its base into the city and the way it touches the sky make it fit into the grand design of the City of New York (Source: Photograph by K. Al-Kodmany).

Sky Farming Tower

Rolf Mohr proposed a vertical farm, named it "Sky Farming", for the city of New York. The tower is proposed to be self-sustaining and even produce a net output of clean water and energy and feed over 50,000 people. It has the following features. First, there are solar panels that rotate to follow the sun and would drive the interior cooling system, which is used most when the sun's heat is the greatest. Second, there is a wind spire that uses small blades to turn air upward. Third, there is a clear coating on glass panels of titanium oxide that collects pollutants and prevents rain from beading. The rain slides down the glass, maximizing light and cleaning the pollutants and is then collected for filtration. Fourth, there is a control room that allows for year-round, 24-hour crop cultivation. Fifth, there is a circular design that uses space most efficiently and allows maximum light into the center. Sixth, a vertical farm could grow fruits, vegetables, grains, and even fish and poultry.

Torre Cube

Designed by the Catalan architect Carme Pinós, the 58m/190 ft. tall, 16-story Torre Cube is a landmark tower in the city of Guadalajara, capital of Jalisco, Mexico. The city is an area of high seismic intensity, and hence the tower's structure, shape and geometry had to count for that. The tower's design takes advantage of the mild and sunny climate to bring natural ventilation and light to the building. The building's double skin and central atrium enable 100% natural ventilation.

Also, wooden-latticework outer skin reduces solar gain; collectively obviating the need for air conditioning. Interior spaces also enjoy abundance of natural light. Construction was completed in 2005. This is a rare example of a tall building that relies entirely on natural ventilation and light year round which significantly reduce energy consumption and eliminates the spaces needed to house mechanical HVAC equipment.

Vertical Park, Stackable Solar Skyscraper

In the ever-expanding metropolis of Mexico City, green space is scarce. An estimated population of 22 million inhabitants bears an impressive weight on the Valley of Mexico and, in recent years, architects and urbanists have been examining solutions to combat air pollution. The proposed Vertical Park by Jorge Hernandez de la Garza intends to infuse the city with much-needed green space in the form of a modular skyscraper made up of a series of stacking units. The solar-powered structure contains sky-gardens in addition to spaces for living and working, and recycles all of its own water. Each module of the Vertical Park can be configured to provide space for public and private use, water and solar collection, and urban farming. The Vertical Park's steel frame will support solar panels used to power the building's diverse functions and allow wind to pass through structure on warm days.

DISCUSSIONS: KEY GREEN DESIGN FEATURES

The following is an attempt to classify the salient green design approaches that were adopted in the aforementioned case studies. The discussion illustrates how the new green-based design approaches are providing new architectural forms and expressions.

Structural Efficiencies

Because skyscrapers are reaching great heights, structural engineers are paying more attention to aerodynamic and wind (Baker, 2004; Holmes, 2001; Isyumov et al., 1992; Hayashida and Iwasa, 1990; Dutton and Isyumov, 1990; Sarkisian, 2012). For tall slender buildings, the across-the-wind motion induced by vortex shedding is the source of major wind-induced excitation. In this phenomenon, wind hits a building's façade swirling around adjacent faces revolving in vortices. They break away from the building on one side and then on the other, and continue this effect creating a "von Karman street". As each vortex breaks away, wind speed on its building side rises, lowering the air pressure and pulling in its direction. The building experiences a side-to-side repetitive push because of this alteration of the vortices (Terranova, 2003).

In reviewing our case studies, we find that the Swiss Re has adopted an efficient aerodynamic form. It also employed an efficient diagrid steel structural system comprised of triangular diagonal support beams, it also obviates the need for large corner columns and provides a better distribution of load. The employed diagrid system resulted in requiring 21 percent less structural steel than a conventional steel frame (Goncalves, 2012; Parker and Wood, 2013). In criticizing iconic skyscrapers, Jeanne Gang gave a credit to Swiss Re for being iconic and environmentally responsive. She explained: "To be fair, some of the iconic buildings, like the 30 St. Mary Axe (a.k.a. "The Gherkin"), have a strong climatic response and contribute more than a pure symbol to high-rise design" (Gang, 2008, p.3). Earlier, Norman Foster the architect of the Swiss Re, applied the diagrid structural system in the Hearst Tower in New York City. Recently, the 103-floor, 438 m/ 1,439 ft.) Guangzhou International Finance Center in Guangzhou, Guangdong, China, applied a similar diagrid system with an aerodynamic profile.

The Wuhan Tower also maximizes efficiency by adjusting form and structural system layout, taking into account the latest in wind engineering technologies. The design features a tripod like base forming the foundation of the tapered building. It enjoys an efficient, aerodynamic profile that combines multiple key elements including: a tripod like base, a tapered body, softly rounded corners, a domed top—to reduce wind resistance and vortex action that builds up around supertall towers and usually causes a building to sway. The tower also tapers to maximize stiffness at the base and to minimize wind sail higher up in the building, where wind loads are higher. Apertures



located at regular intervals in the curtain wall provide distinct aesthetics and fulfill important functions by assisting in venting wind pressure.

The tripod-like floor plan is also employed by the same architect, A. Smith, in prominent buildings including the 828m/2717 ft. Burj Khalifa, the world's tallest, in Dubai, UAE, and the one-kilometer Kingdom Tower, the next world's tallest, in Jeddah, Saudi Arabia, to be completed in 2018. Interestingly, the proposed Nakheel Tower's design segments the tower in the floor plan to four parts connected by bridges at assigned intervals in the elevations. The resulting vertical gaps in the facades help to mitigate wind pressure on the structure by letting air passing through. Shanghai Tower also employs an aerodynamic spiral form that was meant to "confuse" the wind. The twisting form of the tower is the result of wind-tunnel tests and is designed to reduce wind load by 24% during typhoons -- the region's greatest natural force (Irwin, 2013; Parker and Wood, 2013).

Renewable Energy

Wind is a renewable energy source, which can be advantageously tapped at higher altitudes of tall buildings where wind speed is considerably large. Tall buildings can be shaped to funnel wind into a zone-containing wind turbines without having negative effects on the structure, its surroundings and the occupants. Providing this structural profile, wind speed can be amplified so that it produces more energy.

In the cases of Bahrain Tower, Pearl River Tower, and Anara Tower and other towers, their shapes and forms considered harnessing wind energy. The Bahrain building was shaped to take advantage of prevailing local winds by funneling it and directing it to three large wind turbines, which in turn produced energy. Using laboratory wind tunnels, Atkins was able to define the tapering and angles of the building's "curves" to keep the wind source strong and consistent for all three propellers. The collective shape ensures that any wind coming within a 45° angle to either side will create a wind flow that intersects perpendicularly with the turbines.

The Strata Tower in London also incorporates three 9m (30 ft.) wind turbines in the roof top, which gives the tower a distinct "green" identity. In the case of Pearl River in China, the tower was shaped to invite wind to two major openings in the building that have wind turbines. The shape also helps to structurally reduce wind forces on the building. The tower is known as "zero-energy" skyscraper for it was originally design to produce energy as much as it consumes. Due to local regulations and codes, the original design was compromised (Parker and Wood, 2013).

Façade Technology

To enhance environmental performance and create dramatic visual effects, architects devise facades that adapt to changing conditions. The energy-led changes in façade design employ a range of technical provisions that accommodate aesthetics, efficient thermal performance, daylight penetration and interior environment control. Facades are no longer just enclosures; they constitute another vital system that can improve the holistic approach to buildings. The goal of sustainable design thus adds another critical dimension to the entire process of integration of various systems. Introduction of green features and systems to tall buildings makes integration more challenging for the designers. In reviewing façade design, we find that skyscrapers exoskeleton and innovative skins were reshaped to support ecological and green design principles.

We also find the cutting-edge high-tech skin employed in the 4 Tower in 1, Shenzhen, China. The façade's design is driven by solar- and wind-powered energy generation. The second skin of the building will be lined with photovoltaic cells and will feature mechanisms to provide natural ventilation, reduce wind pressure, shade the interior from sun and display multimedia banners. We also find that skyscrapers' exoskeleton and innovative skins were reshaped to support ecological and green design principles. In the cases of O-14 office tower and the COR Tower, Miami, the most striking features are the exoskeleton, which serves as a solar screen, letting in light, air, and views through to the interior occupants. The space between the exoskeleton and the building's glass surface also yields a chimney effect causing hot air to rise, creating an efficient passive cooling system. The exoskeleton also serves structural purposes and evokes a distinct look and architectural expression.

Al Bahar Towers' modernized mashrabiya evokes new "green" meanings on to the building's façade that effectively responds to the Abu Dhabi's sunny and hot climate. The agglomeration of small units of mashrabiya, forming the second outer skin of the building, is unique on multiple grounds. First, it revives an important traditional architectural element found in vernacular architecture of the Middle East. Second, the mashrabiya's opening and closing resembles the opening and closing of local flowers. Third, the continuous opening and closing of mashrabiya gives the tower an ever-changing dynamic form. Similarly, Doha Tower provides a new interpretation of the mashrabiya that varies in its density across the façade in response to solar orientation.

Also, the New York Times employed multiple green features. The glazed facade of the tower has a brise soleil consisting of 186,000 ceramic rods which link in with a dimmable lighting system. The screens of ceramic rods that float in front of the clear glass curtain wall are in many ways the building's signature. Renzo Piano, the architect of the building, called the screens a "suncoat" — as opposed to a raincoat — that would cut the transmission of light and heat into the interior, thereby permitting the use of clear, rather than tinted, glass.

Bio-Climatic Design

K. Yeang applied bioclimatic design principles to the high-rise tower typology emphasizing passive measures. He sought to find ecologically benign ways to make this built form green and humane to inhabit. Yeang, 1996, explains: "As the location's most endemic factor, climate provides the designers with a legitimate starting point for architectural expression in the endeavor to design in relation to place, because climate is one of the dominant determinants of the local inhabitants' lifestyle and the landscape's ecology." The Mesiniaga Tower (IBM Franchise) represents Yeang's culminating design of the bio-climatic model. The tower received multiple awards including the Aga Khan Award, the Malaysian Institute of Architects Award, the Singapore Institute of Architects Award, The Royal Australian Institute of Architects Award and a citation from the American Institute of Architects (AIA). Yeang's design ideals were most represented later in the un-built Tokyo-Nara Tower where the dynamic combination of excessive vertical landscaping and embedded technologies has created new aesthetics.

In the case of Torre Cube, the tower's design takes advantage of the mild and sunny climate to bring natural ventilation and light to the building. The building's double skin and central atrium enable 100% natural ventilation. Also, wooden-latticework outer skin reduces solar gain; collectively obviating the need for air conditioning. Interior spaces also enjoy abundance of natural light.

It is worth noting that arguably, the first eco-tower to break away from modernist's steel-and-glass box (see for example Mies van der Rohe's skyscrapers in Chicago and New York built in the 1950s) and that provided passive measures for sustainable design is the Frank Lloyd Wright's Price Tower, completed in 1956 in Bartlesville, Oklahoma, USA. The Price Tower employs largely opaque concrete walls punctuated with windows, resulting in a greater thermal mass to reduce solar gain and insulates against extremes of climates. Further, the tower employs louvers and fins as devices for controlling solar gain and light. Interior spaces enjoy natural light and ventilation, and terraces full with plants make seamless connection between indoor and outdoor spaces (Wood, 2008).

Greeneries

Throughout history, most celebrated architecture has had a green strain. For example, Frank Lloyd Wright, Rudolf Schindler, and Richard Neutra strived to ensure a fluid relationship between indoor and outdoor spaces, man and nature. Today, green roofs, sky gardens, sky courts, terraces and vertical landscaping are among the many greenery schemes of eco-design. In reviewing our case studies, we find that these concepts clearly prevail in the Sky Village in Copenhagen; Yeang's Menara Tower in Selangor and the EDITT Tower in Singapore; and the Vertical Park in Mexico City, etc.

Ken Yeang has promoted the “eco-design” or bio-climatic design which vividly express greeneries through the placement of escalating planters and vertical landscaping, and sky gardens, and plantings to filter and condition the interior air and microclimate (Gissen, 2002). Yeang believes that skyscrapers should mesh with the natural climate and biological world instead of being an isolated structure. This in effect results in a distinct character of the building in a very special way. There are many variations of eco-design resulting in diverse iconic forms. According to Yeang, greeneries should be an integral part of the exteriors and interiors and should become a vertical extension of nature and the local landscape (Yeang and Powell, 2007).

The hanging garden skyscraper organizes greeneries into gardens at various levels with vertical landscaping that connects them. For example, the Antilia Tower employs hanging gardens that are connected with a “living wall” or vertical garden that encompasses all walls of the building climbing to the final 40th floor. The various floor planes encompass a variety of garden tiers, terraces, waterfalls and ponds. Also, the New York Tower’s design features a series of ‘sky gardens’, at different heights of the building, cut out from its facade that provide enclosed green space and terraced balconies. Gardens provide pleasures to tenants and possibly can use them to grow their own produce.

The vertical park skyscraper is similar to that of the hanging garden but it invites the public to enjoy its gardens or some of them. The vertical park compensates for the lack of horizontal parks in urban areas, particularly in dense areas where land is scarce and expensive and hence it is not feasible to use land for traditional “horizontal” parks. In the case of the proposed Vertical Park in Mexico City, the design intends to infuse the city with much-needed green space by employing sky-gardens for living and working. It provides space for public and private use, water and solar collection, and urban farming.

Interestingly, Gwanggyo Power Center’s design is conceived as a vertical park that will have plantations around terraces that are planted with box hedges, which collectively create a strong, recognizable and cohesive park. The park will provide pleasure to the tenants and the public and will also improve the climate and ventilation and reduce energy. Similarly, The Mile High Eco-Skyscraper’s design provides public parks spread out on the vertical plane. These parks are opened to the outdoor (not glazed) and are large in scale so they are visible from far distances. The overall composition of these vertical pocket parks evokes an organic feel for the tower.

Vertical Farm

With a burgeoning global population that has ever-growing needs for both food and housing, many architects are looking up for sustainable solutions that will prevent further sprawl and provide fresh food to urban residents by flipping the horizontal plane of natural agricultural land on ground to a series of vertical or slanted planes stacked vertically. It is more likely that future population will face shortage of fertile soil to grow crops. Vertical farms incorporated in skyscrapers are envisioned as mixed-use projects that contain housing, recreation, work and tourism as well as farms that supply residents with food. They are miniature self-sufficient cities, complete with transit and on-site energy production, minimizing the building’s carbon footprint and that of its residents. Vertical urban farming in tall buildings involves sustainable energy use and new organic relationship among architects, engineers, farmers and local communities (Despommir and Ellington, 2008, CTBUH Dubai Congress).

Biosmic Eco-Design

Biomimicry is a discipline that studies nature’s best ideas and then imitates these designs and processes to solve practical human problems. This is increasingly a prominent approach and has yielded advances in fields as diverse as aerodynamics, robotic navigation, clothing design, Unmanned Aerial Vehicle (UAVs), and the detection of water pollution. The Biomimicry Inspired Cactus Building, Doha, Qatar, provides an innovative example of how eco-design mimics nature. The building skin is sensitive to the hot climate of Qatar as it comprises smart shades that open and close to control heat gain; thus, mimicking the activity of the cactus.

Hybrid

The hybrid design approach means that the design may incorporate selected green features without adhering to one theme as explained in the previous categories. This option is attractive and common for it facilitates creative thinking as well as affordability. Since some green design features could be costly, the hybrid may allow clients and architects to work together to optimize their budget on green design features. Hence, architects would not need to morph, twist and tweak their buildings to fit a particular green design scheme such as organic or bionic. Instead, they would be able to employ a wide spectrum of forms from a simple shape to a complex one and simultaneously incorporate a wide range of green design features.

CONCLUSIONS

The examples described in this paper embrace green design features and technologies in different ways and to a greater or lesser degree. Some are boldly iconic and others are subtly iconic. As such, they provide a mix of examples yet they share two prime qualities of being green and attractive. In most cases, there has been a rationale for adopting or declining an eco-design idea. We find examples of skyscrapers that are shaped to harness wind power. Other skyscrapers have aerodynamic forms so that the structure handles wind effectively. Some skyscrapers have employed and articulate exoskeleton to balance solar and heat gain and to provide natural ventilation.

Other examples illustrate employing high-tech skin of geothermal heat and photovoltaic panels to maximize energy and light gain. We find some examples that are located in hot desert climate such as that of Qatar and Dubai, where skyscraper's design did not have to take into account collecting rainwater, because it is scarce anyway. However, in areas where water is relatively in abundance, such as North America, we find skyscraper design was made to collect as much as possible, up to 100% of rainwater, as in the case of BoA, New York. Overall, the presented examples point to a new path for skyscrapers that clearly departs from the plain, monolithic vertical extrusions of an efficient floor plan, orthogonal, air-conditioned box.

Overall, in some design circles, iconic architecture has received harsh criticism for embracing inappropriate forms including awkward, insensitive, inappropriate, cost intensive and eccentric, for the mere purpose of competing for attention. "The problem is that the highly visible position of the tall building in global culture has led to one-liners and symbolism in a superficial battle for identity" (Gang, 2008, p.1). They have often been associated with irrelevant, ostentatious design meant to gain popularity and attention. Charles Jencks (2005), architect and author of *The Iconic Building*, has criticized the popularity of modern icon landmark buildings.

Signature architects or "starchitects" have been criticized for producing edifices that do not fit the ecological and cultural context and do not answer programmatic, practical and functional needs. As Andree Iffrig explained: "Iconic has become synonymous with wacky crowns on high-rise buildings that come down hard at grade, and unusual architectural forms" (Iffrig, 2008, p.1) According to Iffrig, these buildings outrageously defy basic needs and functionalities. They have added more harm than good to the built environment, and are considered inimical. Iconic used to be a way of identifying outstanding architecture; today, the term has fallen into disrepute. While it was a complement, for some critics, iconic is a dirty word (Binder, 2006; Iffrig, 2008).

Eco-iconic architecture may have the potential to regain the original meaning of iconicity as a way of identifying outstanding architecture that will stand the test of time. The forms in the eco-iconic skyscrapers mainly stem out of green design principles; yet, it is attractive. In his profile of Wright, *Frank Lloyd Wright: Architecture and Space*, Peter Blake (1961) observed that Wright was influenced by Louis Sullivan, who famously wrote that beautiful form could only be created after functional expression had been satisfied. Perhaps, it is time to re-appropriate the word iconic for the purpose for which it was originally intended, as a way of recognizing well-established architecture, which is beautiful, functional and fitting. For the 21st Century, the paper may suggest that beautiful forms could be created by embracing creative green design ideas, principles and technologies (Britannica, 2009).

It is not an easy task to produce eco-iconic skyscrapers. It is an interdisciplinary task that requires the collaboration of experienced green architects, structural engineers, visionary developers and planners. It also requires a combination of tax credits and government funding for energy-modelling and energy-saving equipment. Luckily, we see many governments and local officials are increasingly embracing green design. For example, New York Mayor Michael Bloomberg has proposed a renewable energy program for New York City that would include placing windmills on city bridges, solar panels on skyscrapers, and the use of tidal, geothermal and nuclear energy. International developers and property owners have recently seen that eco-iconic skyscrapers will attract creative, design-oriented businesses and trendy, eclectic professionals. Iconic skyscrapers may find luster in green design and could constitute an interesting trend for the 21st Century (Al-Kodmany and Ali, 2013; Martin, 2008).

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