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*Article*

# Supertall Asia/Middle East: Technological Responses and Contextual Impacts

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**Abstract:** Supported by rapid economic growth, major cities in Asia and the Middle East have been rising as new centers for tall buildings. This article reviews the state of tall building developments in Asian and Middle Eastern countries with an emphasis on supertall buildings, with their greater urban and global impacts. Focusing primarily on physical construction, this article examines technological responses for building tall in Asian and Middle Eastern contexts. The architectural transformation and globalization of what was once called the "American Building Type" in Asian and Middle Eastern countries is studied. Sustainable design technology transfer and adjustment in Asian and Middle Eastern climates are presented. Further, future prospects on supertall design in Asian and Middle Eastern contexts are discussed.

**Keywords:** supertall buildings; tall building technology; sustainable design

## 1. Introduction

Tall buildings emerged in the United States in the late nineteenth century as a way of using dense urban land more efficiently. Breakthrough technology made this new architectural phenomenon possible. Traditional load-bearing masonry wall structures, due to their great thickness, were seriously limited in their functionality for tall buildings. It was not until the new technological concept of steel skeletal structures and curtain walls emerged that this limitation was overcome, opening up the history of so-called skyscrapers and leading to the present state of supertall buildings.

In the initial decades after their emergence, most tall buildings were developed in the United States, producing a term, "American Building Type." For this unprecedented new building type based on new technology, architects tried many different architectural design approaches, as evidenced by the variety of tall building styles from the late nineteenth to the mid-twentieth century. More than 200 international entries for the Chicago Tribune Tower competition held in 1922 demonstrated architects' great interest in tall building design through a broad range of contemporary design approaches [1]. Proposed tall building styles for the competition varied from Gothic to eclectic to modern. Starting in the mid-twentieth century, however, tall building design began to coalesce into the International Style, widely adopted for its foregrounding of technological innovation.

Today, tall buildings are no longer an American building type. In fact, the most active tall building development region has shifted in recent decades from the United States to Asian and Middle Eastern countries, such as China, Korea, Malaysia, and the United Arab Emirates (UAE), in conjunction with their rapid economic growth. Tall buildings have also shifted in function; originally developed as office towers, they now serve as hotels, condominiums, shopping centers, *etc.* Moreover, over the past couple of decades tall buildings have become much taller, resulting in many so-called supertall buildings. With the relocation of the most dynamic tall building development region to Asia and the Middle East, most of today's supertall buildings are also developed there [2].

This article reviews the current state of tall building developments in Asian and Middle Eastern countries with an emphasis on supertall buildings, and investigates their responses to technological evolution. There are many factors influencing tall building design, such as economics, technology, architectural style, social/cultural issues, municipal regulations, and politics. Though in general economy has been the primary factor governing tall building developments, without supporting technologies, tall buildings are physically unachievable. Focusing more on the physical construct of tall buildings, this article presents how tall building technologies, originated in the United States and evolving globally, are transformed in Asian and Middle Eastern contexts.

## 2. Supertall and Economy

Tall buildings have become much taller in recent years. The height of 300 m, which is generally considered the threshold height of the supertall building, was, in fact, already reached in the early 1930s with the Chrysler Building and the Empire State Building. However, the heights of the buildings at that time were not driven by economic equations, but rather by a strong desire to build the world's tallest building. As Carol Willis noted in her *Form Follows Finance*, "at some point in the construction of every skyscraper, the law of diminishing returns sets in, and rents for the additional stories do not cover costs [3]." This sets the most economical height at a certain level. According to the study by Clark and Kingston before the construction of the Empire State Building, among several schemes of different story heights, 63 stories was the most economical choice [4]. However, the result was the Empire State Building, with over 100 stories.

After the completion of the Empire State Building in 1931, no other supertall buildings were built until the late 1960s and early 1970s. The John Hancock Center of 1969, Aon Center of 1973, and Willis Tower (formerly known as Sears Tower) of 1974, all in Chicago, and the demolished World Trade Center Twin Towers of 1973 in New York City announced the reemergence of supertall buildings, in conjunction with structural innovations such as tubular structures, after the Great Depression and World War II [5].

However, except for these supertall buildings, most other tall buildings were within the range of economic building height—still about 60 stories—despite the technological evolution, until recent times.

Today, supertall buildings have been emerging again in unprecedented scales, especially in Asia and the Middle East. Rapid economic growth, oil wealth, and government-supported development are among the primary driving forces of this phenomenon. At present, among the 112 completed or topped out supertall buildings with heights over 300 m, only 17 buildings are in the United States; 60 are in Asia, 32 in the Middle East, 1 in Australia, 1 in Europe, and 1 in South America. Among the 17 U.S. supertall buildings, only six have been built within the past couple of decades, while all 95 supertall buildings outside the United States have been built since 1990 (http://ctbuh.org).

Though the supertall heights are still considered ego heights, it is also true that advances in materials science and tall building technology have been pushing up the economical building height continuously. Moreover, the extreme heights of supertalls, in association with signature designs by so-called "starchitects", draw great advertisement power, which makes the developments more profitable. While the global economic downturn has halted quite a few supertall projects throughout the world, some of them, especially in Asian and Middle Eastern countries, are still actively progressing.

## 3. Supertall Design in Asia and the Middle East: Regional *vs.* Global

Only a few tall buildings, such as the Bank of China in Shanghai and the Hong Kong and Shanghai Bank in Hong Kong, were built in Asia in the early 20th century [6]. Major tall buildings in Asia emerged in the late 1960s and early 1970s. Most Asian tall buildings in this period were built in the International Style then prevalent, as in the cases of the Kasumigaseki Building of 1968 and the Shinjuku Mitsui Building of 1974, both in Tokyo, and the Jardine House of 1973 in Hong Kong. Since then, tall building developments in Asian countries have increased steadily, primarily in densely populated major cities.

Although the world's current tallest building is in the Middle East, tall buildings were not developed in that region until very recent times. Previously lacking the dense urban areas prevalent in the United States and Asia, Middle Eastern countries today are rapidly cultivating new cities and city centers around tall buildings.

### *3.1. Vernacular Architecture*

One of the most significant trends for recent tall buildings constructed in Asian countries concerns the growth of vernacular architectural traditions in design motives. This trend is clearly visible in notable recent tall buildings such as the Jin Mao Building in Shanghai (Figure 1), Petronas Towers in Kuala Lumpur (Figure 2), Landmark Tower in Yokohama, and Taipei 101 in Taipei. These buildings have the more traditional looks of old pagodas or temples. Behind these traditional-looking images, however, are very contemporary technologies, from structural systems such as outrigger structures and tube systems to the glass curtain wall façades, widely used for tall buildings worldwide. Like the U.S. postmodern tall building design, these regional design approaches react to the technology-oriented building aesthetics epitomized by the International Style. However, unlike the postmodern buildings, which often irrelevantly adopt various exotic architectural languages, these buildings' regional expressions actively engage traditional vernacular architecture through building forms and detailing.

Thus, this marriage of the image of a particular region and modern technology is, at least, more contextual than postmodern architecture in general [7].

**Figure 1.** Shanghai Financial Center (left), Jin Mao Building (center), and Shanghai Tower (right) under construction (photo by Kyoung Sun Moon).

**Figure 2.** Petronas Towers (courtesy of Abbas Aminmansour).

Unlike the Asian countries that have a history of tall buildings from the International Style period, Middle Eastern countries are fairly new participants in tall building developments. With no previous tall building design to react to, the strong regional design trend remains relatively rare.

At the time of the International Style, many architects viewed regional architecture with great skepticism. In the conference "What is happening in modern architecture?" held at MoMA in 1948, noted architecture scholar Lewis Mumford made a presentation advocating regionalism. Mumford argued:

> "*Regionalism has to help people come to grips with the actual conditions of life that make them feel at home. Regional insight has to be used to defend us from the international style, the absurdities of present technology and the despotism of the mechanical order.*"

Certainly, his remark did not convince architects to abandon the International Style. We have witnessed many Asian cities losing their traditional identities amid forests of similar-looking Miesian skyscrapers. Although the regional design approach may already be on the wane, along with other recent -isms of short longevity [8], its emphasis on searching for traditional identity through design foregrounds important issues for tall building designs in countries with long and unique architectural histories.

It is interesting to notice how often the vernacular styles of Asian supertalls are the product of architects from the United States or other Western countries. The aforementioned Jin Mao Tower, Petronas Towers, and Landmark Tower, for example, were designed by Skidmore, Owings and Merrill (SOM), Cesar Pelli, and the Stubbins Associates, respectively. Among the 92 supertall buildings completed or topped-out in Asia or the Middle East, 48 buildings were designed by Western architects, predominantly U.S. architects, and 44 by local architects (http://ctbuh.org). Most of the buildings—including those designed by local architects—were engineered by American or European firms such as SOM, Thornton Tomasetti, and Arup. This phenomenon reflects the strong influence of Western technology, both in design and engineering, for the successful execution of tall building projects in Asia and the Middle East through close international collaboration.

### *3.2. Abstract Regional Motives*

Unlike the direct application of regional images, some supertall designs in Asia and the Middle East employ abstract regional motives. The design motive of the Lotte Super Tower project in Seoul by SOM (Figure 3) comes from the shape of Chumsungdae—a celestial observatory built in 647 in Kyung-Joo, Korea. The current design of the Lotte Tower by Kohn Pederson Fox (KPF) took design inspiration from traditional Korean art forms (http://www.kpf.com). The original design of the Shanghai World Financial Center by KPF reflects Chinese mythology. The square floor plans at lower levels represent the earth, while the circular aperture at the top symbolizes the sky, though this circular shape has been redesigned to a trapezoid (Figure 1, *The New York Times*, Arthur Lubow, 21 May 2006). The design of the Burj Khalifa (formerly known as Burj Dubai, Figure 4) in Dubai was inspired by the harmonious structure of a regional flower, *Hymenocallis* (http://www.burjkhalifa.ae).

Though the local identities reflected in the supertall buildings described above are not obvious, architectural and structural design solutions are integrated; behind abstract regional expression is solid technological reasoning. Tapering and morphing in the Lotte Super Tower, a large opening in the

Shanghai Financial Center, and irregular setbacks in the Burj Khalifa significantly mitigate the wind-induced structural motion of these supertall buildings. At the same time, through these manipulations of building forms, architects and engineers collaborate very closely to reflect local culture.

**Figure 3.** Lotte Super Tower (courtesy of SOM).

**Figure 4.** Burj Khalifa (photo by Kyoung Sun Moon).

### *3.3. Complex Form Design*

Another distinguished architectural design approach for today's tall buildings is sculptural complex form design. Early examples of this approach include Peter Eisenman's Max Reinhardt Haus and Frank Gehry's *New York Times* Building, both designed in the late twentieth century but not built [9]. Today, however, many complex-shaped tall buildings are designed and actually built worldwide. As the main ground for today's tall building developments, Asia and the Middle East are at the forefront of complex form design. Gensler's Shanghai Tower (Figure 5), with its twisted curvilinear form and a height of over 600 m, is one of the tallest buildings in China. With its two supertall neighbors, the Jin Mao Building and the Shanghai World Financial Center, the Shanghai Tower dominates the skyline of the Lujiazui financial district of Pudong, Shanghai. Contrary to the Jin Mao Building and the Shanghai Financial Center, which directly and indirectly represent regional identities, the sculptural form of the Shanghai Tower is, in a sense, a complete stranger to the traditional city of Shanghai. Perhaps, with its up-to-date green technology employing double-layered façades, this building is more tuned to the life of a global city. Supertall buildings of enormous scale and mixed uses may be better understood as self-contained cities in a global context instead of buildings in an urban context.

Other compelling complex-shaped tall buildings in Asian and Middle Eastern countries include the twisted Cayan Tower in Dubai designed by SOM, the continuously morphing Jiangxi Nanchang Greenland Central Plaza in Nanchang, also by SOM, and the flame-shaped tapering Flame Towers in Baku by Dia Holdings, to name but a few. Unlike more engineering-oriented form-finding approaches prevalent in the 1970s, many of today's sculpted complex-shaped tall buildings primarily follow a form-making approach. Engineering solutions, with the advance of structural analysis techniques using computers, are provided in conjunction with complex building forms. Though certain forms can still be quite challenging to engineer, complex forms, such as twisted, tapered, free forms, and their combinations, are generally more effective than prismatic regular forms to preserve a tall building from the dynamic wind-induced resonance conditions as they can mitigate wind-induced vibrations by disturbing the formation of organized alternating vortexes. Considering the fact that the vortex-shedding-induced resonance condition often produces the most critical structural design condition for tall buildings, structural contribution of complex forms can be significant. Constructive collaboration between architects and engineers can produce more creative sculpted forms having greater structural performance.

Design of some sculpted form tall buildings, especially in the Middle East and southern part of Asia, is driven by environmental performance. For example, the Al Hamra Tower in Kuwait City by SOM (Figure 6) is one of the most sculpted form tall buildings. The unique form and façade material selection and design were developed to shade the south façade of this building from the sun so desirable indoor environment can be achieved more economically [10]. At the same time, through this unique form, this building holds a strong iconic power. A similar design approach of performance-based sculpted self-shading form was employed for the National Commercial Bank Headquarters in Jeddah and the proposed Mashreq Bank Tower in Dubai, both also by SOM.

Today, in the era of pluralism, cities in Asia and the Middle East try to establish global identities with large-scale tall buildings having unique forms designed by starchitects. The international character of renowned tall building design firms, however, may create similar looking tall buildings in different countries with different traditions and contexts. For example, Adrian Smith explains that he drew design inspiration from regional elements for the design of the Burj Khalifa in Dubai [11]. Nonetheless, comparing the Burj Khalifa with one of his earlier projects in Seoul, the Samsung Tower Palace, one can find the similarity between these two tall buildings. Both buildings are composed of three petal-like wings stretched out from their triangular cores at the center of the buildings, as can be observed from Figure 7. It is not too difficult to notice the influence of the Samsung Tower Palace on the Burj Khalifa. As such, supertall buildings, which have significant global addresses, are sometimes designed based on the evolution of architects' design ideas to a large degree.

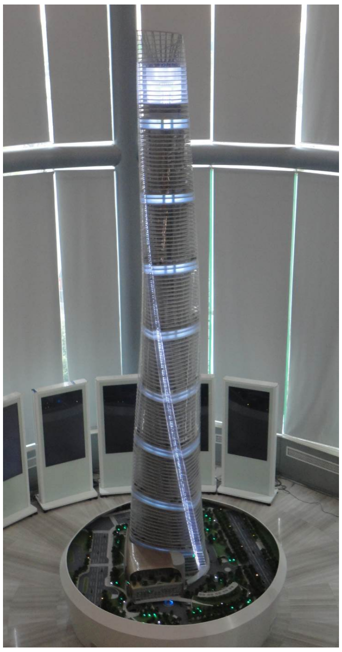

**Figure 5.** Shanghai Tower model (photo by Kyoung Sun Moon).

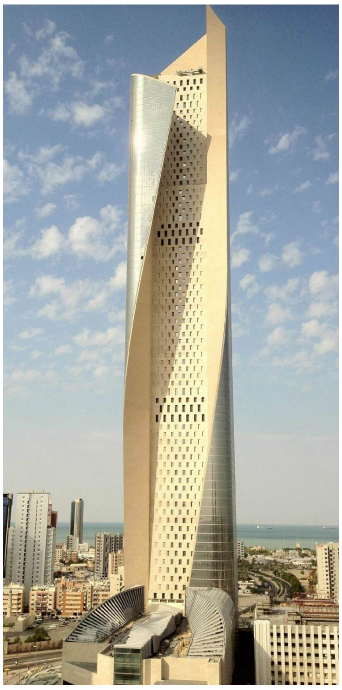

**Figure 6.** Al Hamra Tower (source: Wikipedia).

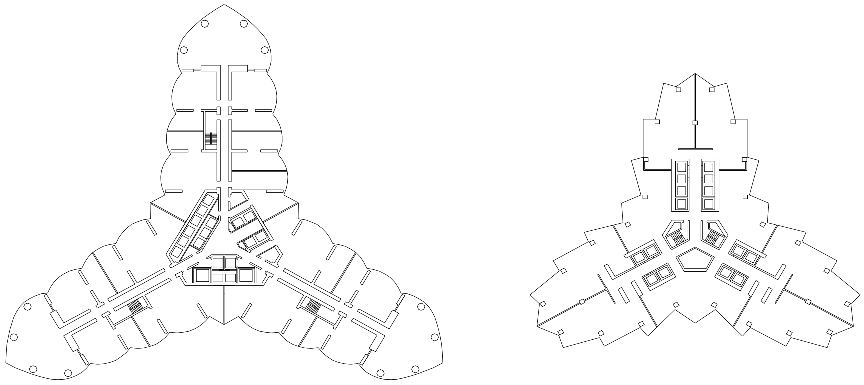

**Figure 7.** Typical Floor Plans of the Burj Khalifa (**left**) and Samsung Tower Palace (**right**).

*3.4. Diagrids*

In addition to the various architecture-oriented design approaches, a technology-oriented new strategy has also emerged as a new supertall design trend these days. So-called diagrid structures have been inspiring many architects and engineers designing tall buildings. Tired of orthogonal composition of building elements and recognizing the potential of diagonal arrangements of major structural members to resist lateral loads, architects and engineers alike seek design solutions from diagrid structures [12].

The 13-story IBM Building of 1964 in Pittsburgh demonstrates an early application of diagrids for multi-story buildings. Diagrids began to be used for recent major tall buildings such as the 30 St. Mary Axe of 2004 in London and the Hearst Tower of 2006 in New York, both by Norman Foster. Since then, this relatively new technology-driven design strategy has become prevalent for tall buildings worldwide, with Asia and the Middle East again leading this design approach for supertall buildings.

The Guangzhou International Finance Center in Guangzhou (Figure 8), with a height of 437.5 m, is one of the tallest diagrid structures in the world. Designed by Wilkinson Eyre, this mixed-use supertall expresses its bold diagrid structures behind its glass façades. Another supertall example of diagrids is the design project of the Lotte Super Tower in Seoul, Korea, by SOM (Figure 3). This tower even further maximizes the structural potential of diagrids. Unlike other diagrid tall structures in which diagrid members are usually placed at uniform angles, the diagonals at the Lotte Supper Tower are placed at different angles over the tower's height. The diagrid angles become steeper toward the ground in order to resist overturning moments more efficiently there and shallower toward the top, where the impact of lateral shear forces is larger [13]. The diagrid angles gradually change from about 79° at the bottom to 60° at the top [14]. This structural arrangement also makes visual expression of the diagrids much more dynamic.

While most diagrid tall buildings are designed with steel, some of them in the Middle East are designed with reinforced concrete, such as the Tameer Towers in Abu Dhabi by Gensler and the O-14 in Dubai by Reiser + Umemoto. Concrete diagrid design reflects the easier acquisition of material and relatively inexpensive local labor in Asia and the Middle East. In addition, due to the characteristics of the material, building forms can be designed much more fluidly with concrete, as is the case with the O-14 [15].

Diagrids have also been used effectively to structure freeform tall buildings. The Capital Gate in Abu Dhabi, designed by RMJM, has a leaning curvilinear free form. It would be very difficult to engineer this unique building form with a conventional orthogonal structural system. A perimeter steel diagrid structure in combination with a reinforced concrete core carry the load of this leaning tower efficiently [16]. In addition, the diagrid's triangular pattern allows the construction of this free form without distortion from the original design. A similar application of diagrid structures can be found in the Phare Tower in Paris, designed by Thom Mayne of Morphosis.

Due to increasing interest in the form, some tall buildings' structures employ diagrid structures in combination with conventional orthogonal systems, and express only diagrids on the façades. A good example is the China Central Television (CCTV) Headquarters Tower in Beijing (Figure 9), designed by Rem Koolhaas and Ole Scheeren of the Office for Metropolitan Architecture (OMA). In order to carry the load of this unique form tall building with a large cantilever, diagonal bracings are used extensively in combination with the conventional orthogonal frame structure. Therefore, the structural system for this building can be categorized as the braced tube system. On the building façades, however, only the diagonal bracings are strongly expressed, which makes the building look like a diagrid structure.

The steel skeletal structure, with its very functional orthogonal composition, created a new building type in the late nineteenth century and flourished globally in conjunction with the International Style. It took several decades for the new building design with its exemplary architectural style to be transplanted to Asia. Today, however, technology moves from one region to another within a fraction of that time. Many tall buildings in Asia and the Middle East have been built with tubular or outrigger structures that originated in North America, and have been formed and clad to have representational qualities ranging from highly regional to emphatically global. The diagrid structural system, which was initially employed for a multistory building in the United States and used by Norman Foster of the United Kingdom for major tall buildings, now stands as a strong accentuating element with unique compositional characteristics in any existing orthogonal urban contexts worldwide.

**Figure 8.** Guangzhou International Finance Center (source: Wikipedia).

**Figure 9.** CCTV Headquarters (courtesy of Jakob Montrasio, Wikipedia).

## 4. Supertall Design in Asia and Middle East: A Sustainable Approach

Sustainable design is one of the most important issues facing today's architecture. By their very nature, tall buildings have great potential to create sustainable built environments. Compared to cities with low-rise buildings, those with tall buildings use land more efficiently. Tall buildings provide denser occupiable spaces on smaller areas of ground. More land can be saved, therefore, for environmentally friendly green spaces. A tall building with many vertical layers of space has less of its exterior envelope in direct contact with harsh outdoor environments than multiple low-rise buildings containing the same total floor area. Thus, energy usage for environmental control can be less in tall buildings than in low-rise complexes. Power in tall buildings can be served with shorter-length distribution lines than in low-rise complexes, when identical total space served is considered. Hence, electricity can be delivered more efficiently in tall buildings. There are many other inherent sustainable features tall buildings can provide, due to their compactness and higher density [17].

### *4.1. Energy Generation*

In addition to the inherent, passive sustainable features of tall buildings, there is great potential to actively make tall buildings even more sustainable. Tall buildings can be designed to generate energy using free natural resources such as wind or sunlight. Quite a few recent tall buildings in Asia and the Middle East, such as the Pearl River Tower in Guangzhou (Figure 10), utilize wind turbines. Generally, a tall building's broader face is oriented not to face prevailing wind directly if possible. However, the Pearl River Tower's orientation was strategically determined so that the building's broader façade can face the site's prevailing wind to maximize wind energy collection using wind turbines. According to the designer, this building, with other energy generation mechanisms, is expected to use a substantially reduced amount of energy [18].

**Figure 10.** Pearl River Tower (courtesy of Terri Meyer Boake).

Other buildings equipped with wind turbines include the twin towers of the Bahrain World Trade Center in Manama. In this case, wind turbines are installed between the twin towers in order to increase the speed of the wind when it passes through the gap. Generating energy through wind turbines is not always highly efficient, but greater wind speeds at higher altitudes increase the benefits of this inexpensive form of energy for tall buildings.

Photovoltaic panels, which convert sunlight directly into electricity, are increasingly used for tall buildings such as the Pearl River Tower and the Federations of Korean Industries (FKI) Headquarters in Seoul. In the Pearl River Tower, photovoltaic cells are installed on the glass roofs so that they can be used to generate energy as well as to shade the floor area below. In the FKI Headquarters, PV cells are integrated with the spandrel panel of the curtain wall system. In order to maximize the efficiency of the system, the spandrel panels with PV cells are tilted by 30° to face the sun and the vision panels are tilted downwards by 15° to minimize the solar heat gain and glare (Figure 11, http://www.smithgill.com).

Geothermal power, effectively and sustainably generated by geothermal energy, can potentially be incorporated into the design of tall buildings that consume a lot of energy. However, only in limited volcanic regions, this energy is relatively easily accessible from the earth's crust [19]. Some Asian countries, such as the Philippines and Indonesia, have already installed large geothermal electric capacities, and these countries have great potential to incorporate geothermal electricity into tall building design. The Pertamina Tower in Jakarta, designed by SOM, is one of the most sustainable energy-driven supertall buildings. According to the designer, the building will have its own power facility and utilize geothermal energy to supplement the electricity generated by the wind and solar systems (http://www.som.com).

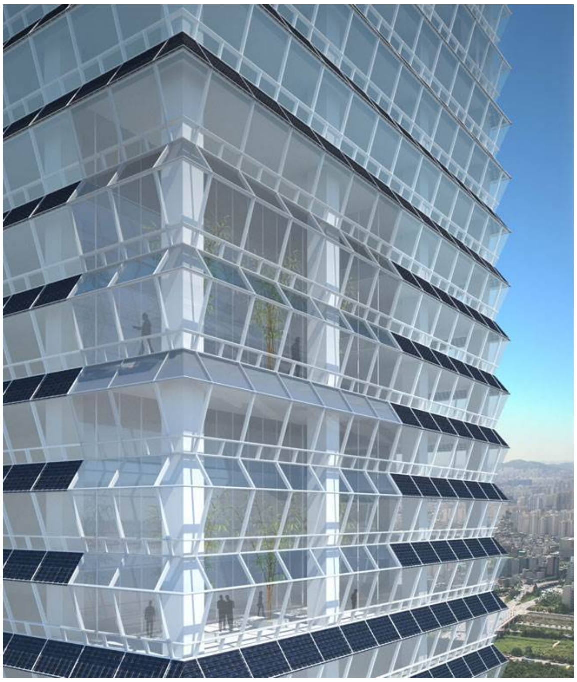

**Figure 11.** FKI Headquarters (courtesy of Adrian Smith + Gordon Gill Architecture).

Geothermal resources are limited in the Middle East [20]. In the regions with limited geothermal resources, the ground soil energy that is absorbed from the sun can alternatively be used for heating and cooling buildings. Though ground soil temperature is too low to generate power, heat pumps can be used to heat and cool buildings. Tall buildings constructed on dense urban land have very limited opportunities to use heat pumps for collecting and concentrating heat from the ground. However, new tall buildings constructed in less dense areas in Middle Eastern and Asian countries have greater potential to use the shallow ground heat pump loops.

### *4.2. Double Skin Façades*

Double skin façades have often been applied to tall buildings in Europe, such as the Commerzbank Building in Frankfurt, Deutsche Post Building in Bonn, and Rhine-Westphalia Electricity (RWE) Building in Essen. The Shanghai Tower in Shanghai is now the tallest building with double skin façades in the world. With two layers of glass and consequently enhanced environmental control, double skin façades help reduce buildings' energy consumption, though the initial construction cost is generally higher compared to the conventional single skin façades [21]. In the Shanghai Tower, the double skin façade system also helps reduce wind loads applied to the tower. Further, the atrium space between the inner and outer skins is designed to house indoor sky gardens [22].

### *4.3. Vertical Landscaping*

Incorporating sky gardens and vertical landscaping in tall buildings is becoming more common. Since Ken Yeang's pioneering work, Menara Mesiniaga of 1992 in Kuala Lumpur, he and other architects later designed a number of tall buildings landscaped vertically. Typical tall buildings disconnect occupants from greenery and trees on the ground due to their extreme height. By incorporating these missing elements, tall buildings can provide more nature-friendly environments.

Furthermore, vertical greenery helps cool tall building by reducing the heat island effect [23]. Ken Yeang has designed quite a few tall buildings of this kind in Asia and the Middle East such as the Ecological Design in The Tropics (EDITT) Tower in Singapore, Chongqing Tower in Chongqing, and Eco Bay Complex in Abu Dhabi. Adrian Smith + Gordon Gill (AS + GG) Architecture, led by Adrian Smith and Gordon Gill, is also one of the most green technology-oriented design firms today. Tall buildings designed by AS + GG Architecture with vertical sky gardens include the Elphinstone Mills (Figure 12) and Jupiter Mills in Mumbai.

**Figure 12.** Elphinstone Mills (courtesy of Adrian Smith + Gordon Gill Architecture).

### *4.4. Reversed Stack Effect*

In the climate conditions of the southern part of Asia and the Middle East, there are some unique challenges such as the reversed stack effect, not found traditionally in tall buildings in North America. In tropical climates, cooler and denser air from the top flows downward in summertime to exit from the tall building, as opposed to the normal stack effect, where warmer and lighter air moves upward. As the building height becomes taller in regions of hot climate, this reversed stack effect becomes a more serious design consideration. In the Elphinstone Mills in Mumbai by AS + GG Architecture, the multi-story garden atria over the building height are connected to a central atrium into which air flows from the exterior. The cooled air flows down through the central atrium. Series of wind turbines are designed to generate power using this reversed stack effect. Thoughtful design with scientific considerations can convert any factual challenges into better integrated sustainable design solutions.

### *4.5. Sun Shading*

Reducing solar heat gain through appropriate system design is also an important issue to save energy required for air conditioning in the southern part of Asia and the Middle East. Passive systems have fixed properties, and, in order to be performed as intended, they do not require energy, while active systems do need an energy source to modify the system properties against ever-changing solar conditions. Thus, active systems are typically more effective than passive systems. However, due to their economy and reliability, passive systems are more commonly used than active systems [24].

Passive shading can be accomplished by shaping the buildings to shade themselves or designing passive shading devices on the façades. As was discussed earlier, self-shading building forms were developed for the Al Hamra Tower in Kuwait City, National Commercial Bank Headquarters in Jeddah, and the proposed Mashreq Bank Tower in Dubai. Examples of passive shading façade design can be found from the O-14 Building in Dubai and the Doha Tower in Doha. In the O-14 Building, the reinforced concrete exoskeleton, which is set about 1 m outside the glass façade, substantially shades the indoor space. Furthermore, the gap between the exoskeleton and the glass façade is used to remove heat through natural ventilation [15]. In the Doha Tower, steel latticework sunscreens, inspired by the traditional *mashrabiya*, are placed over the glass façades. Different densities of sunscreens are used in this building for different areas of façades depending on the levels of exposures to the sun.

Active sun shading devices can more effectively mitigate the solar heat gain in response to the level of sun exposure. In the Al Bahr Towers (Figure 13) in Abu Dhabi, the origami-shaped sun shading devices, which are also inspired by the traditional *mashrabiya* and installed with about 2-m gaps from the glass façades, automatically respond to the movement of the sun to reduce the solar heat gain [25]. In the proposed Equator Tower at Kuala Lumpur, retractable sun shading sheathes are installed to shade the entire building from the sun. The tower is located on the equator and, consequently, the entire building façade is subjected to direct sun exposure. The retractable, Polytetrafluoroethylene (PTFE)–coated, glass fiber-reinforced sunshade protects the indoor space from the direct sun and still provides great views of the city. The sunshade can be partially or entirely removed depending on the outdoor sun conditions.

**Figure 13.** Al Bahr Towers (courtesy of Terri Meyer Boake).

## 5. Future Supertalls in Asia and the Middle East

Tall buildings, which began with 30-m office towers in the U.S. more than a century ago, have grown into mixed-use supertall megastructures such as the Burj Khalifa in Dubai, over 800 m tall. An even taller supertall building, the Kingdom Tower, which is expected to be over 1000 m tall, is already under construction in Jeddah [26]. Moreover, among the 111 supertall buildings under construction (but not topped out yet) at this time, almost all of them are also in Asian and Middle Eastern countries, with the exception of six in the United States. It is expected that Asia and the Middle East will remain the most dynamic supertall development regions for some time, and the heights of tall buildings will continuously increase.

The structural configuration of the Kingdom Tower is very similar to that of the Burj Khalifa, and has a great potential to produce an even taller tower, though its application may be somewhat limited for residential functions due to its unique form. There is a triangular central core, and three wings of shear walls are extended from the central core to maximize the structural depth of the tower against wind loads (Figure 15a). The tower is tapered towards the top to reduce the possibilities of vortex-shedding induced lock-in conditions.

Another recently emerging design strategy is conjoining two or more tall buildings functionally and structurally. Quite a few competition entries for rebuilding the World Trade Center in New York employed this approach, though the winning entry did not. In fact, the concept of conjoined towers dates back to the King's View of New York published by Moses King in the early 20th century. The King's Dream of New York in this publication shows New York's skyscrapers connected by sky bridges. Today, interconnected tall buildings are no longer a dream.

The Petronas Towers in Kuala Lumpur are twin commercial office towers connected by a two-story sky bridge on the 41st and 42nd floors. In the Pinnacle at Duxton in Singapore, seven residential towers are connected on the 26th and 50th floors by sky bridges. The same strategy is used in the proposed Sky Terrace at Dawson in Singapore, which connects four residential towers on two levels. While connecting structures in these examples are simple bridges between the buildings, some other connecting structures are designed to hold substantial programmed spaces. In the Marina Bay Sands in Singapore (Figure 14), three hotel towers are connected at the top by the sky park that brings together many hotel amenity facilities, such as swimming pools, restaurants, and gardens [27]. A very similar design approach is used in the Gate Towers at Shams Abu Dhabi on Reem Island.

A new conjoined towers typology has also been introduced in some projects. For example, the CCTV Tower in Beijing (Figure 9) can be better conceived as a closed loop type tall building designed to produce unique and enhanced functional performance, instead of two towers connected by bridging programmed spaces. The concept of closed loop type tall buildings can be found also in the proposed Infinity by Crown Mixed Use Tower in Sydney and City of Dreams Hotel Tower in Macau. By interconnecting towers with various new design concepts, tall buildings are no longer isolated individual towers. They are growing into organically interconnected, more dynamic megacities.

The concept of conjoined towers also has a great structural potential to produce very tall buildings. One of the tallest proposed conjoined towers was the Nakheel Tower for Dubai. The proposed height of the tower was over 1000 m, though the project was canceled due to financial problems of the developer [28]. The Nakheel Tower can be conceived as four supertall buildings structurally belted together every 25 stories. This configuration can provide excellent structural performance for supertall buildings. The large openings between the four towers significantly reduce wind loads, and the large footprint of the conjoined towers produces a great structural depth against lateral loads (Figure 15a).

Though it is very difficult to foresee what is coming next in the field of supertall design, the structurally conjoined towers concept employed for the Nakheel Tower project and the buttressed core concept used for the Burj Khalifa and the Kingdom Tower are expected to serve as two powerful prototypes for upcoming supertall towers over 1000 m. For very tall buildings, it is crucial to maximize their structural depths to efficiently provide lateral stiffness against wind loads. At the same time, it is very important to keep reasonable lease depths—about 8–15 m [29,30]—for the comfort of occupants. The structural concepts developed for the Nakheel Tower and Kingdom Tower in conjunction with building forms can satisfy these fundamental structural and architectural requirements successfully.

For extremely tall buildings, structural systems cannot be configured independently without considering building forms. If a structural depth of about 100 m is used for a 1000 m tall conventional rectangular box form building with a central core to maintain its slenderness of about 10:1, the lease depth between the façade and core wall will be very deep. This depth will be about 25 m when the square floor plan and square central core are considered, with a core to gross floor area ratio of about 25% (Figure 15a). Slenderness, which is usually defined as the height to width (smallest width on the ground) aspect ratio, is one of the most important factors for the structural design of very tall buildings. With the same slenderness and core area ratio, if the height of the rectangular box form building is increased to 1200 m, the lease depth should also be increased to about 30 m (Figure 15b). Extremely large lease depths for supertall buildings of unprecedented heights will produce many serious problems, such as occupant discomfort, interior columns within the lease depth to avoid floor beams of very long spans, and too large gross floor area, to list but a few.

**Figure 14.** Marina Bay Sands (courtesy of Philip Oldfield, Council on Tall Buildings and Urban Habitat).

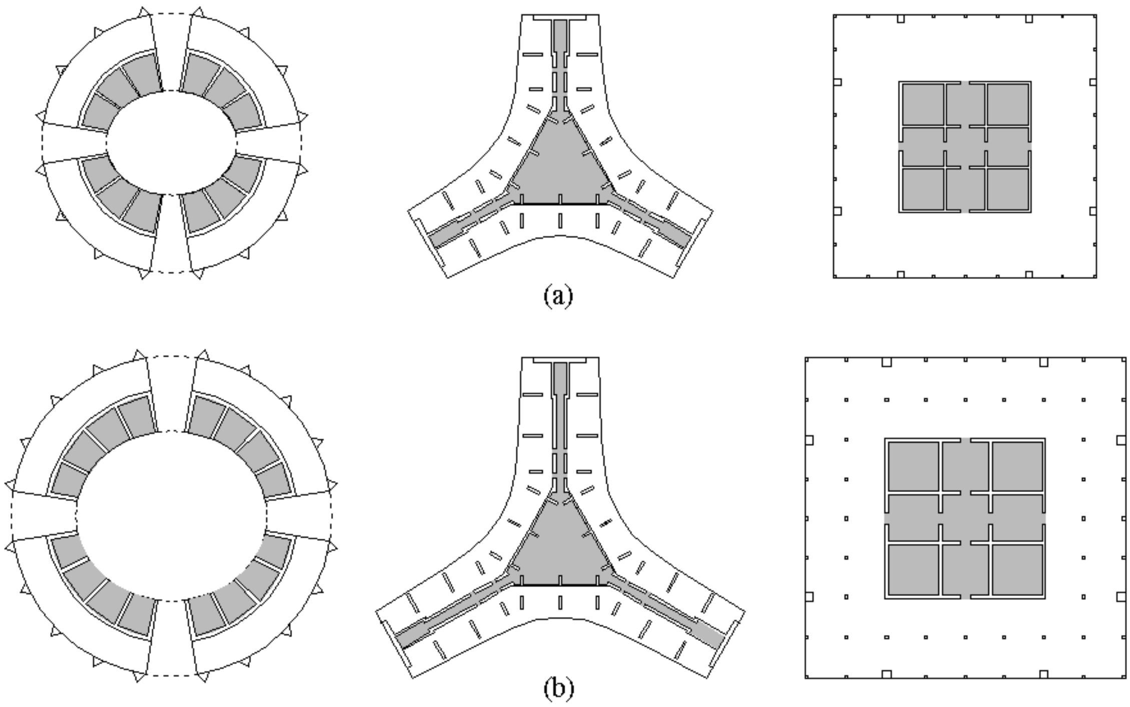


**Figure 15.** (**a**) Simplified structural plans for the Nakheel Tower (left), Kingdom Tower (middle), and a Rectangular Box Form Tower (right), about 1000 m tall and 100 m wide, with a slenderness of 10:1. (**b**) Simplified structural plans for the taller version of the Nakheel Tower (left), Kingdom Tower (middle), and Rectangular Box Form Tower (right), about 1200 m tall and 120 m wide, to keep the slenderness of 10:1.

In order to maintain the slenderness of about 10:1, the plan dimensions of the about 1000 m tall Nakheel Tower and Kingdom Tower on the ground are very large, about 100 m. However, the structurally conjoined tower and buttressed core concepts allow these buildings to keep reasonable lease depths. Furthermore, unlike the conventional rectangular box form tall building with a central core, towers of these two configurations can be designed even taller to a certain height without increasing lease depths, because increasing the overall plan dimensions to keep the slenderness and keeping the desired lease depth can be done independently to a large degree. Figure 15 comparatively shows the simplified structural plans of the structurally conjoined towers, buttressed core, and conventional rectangular box form concepts employed for 1000 and 1200 m tall buildings, respectively.

Despite their characteristics being very much appropriate for extremely tall buildings, these architecture-integrated structural concepts may not be easily employed for existing dense urban land because very large building sites are required for them. These design concepts, however, could be more easily employed for newly developing cities with large amounts of available land, such as those in the Middle Eastern and Asian countries.

## 6. Conclusions

Despite a global economic downturn and the consequent halting of many supertall projects, some of the buildings in Asia and the Middle East are still actively progressing. When the economic situation abates, more supertall buildings, including those already planned but on hold, will soar up to the Asian and Middle Eastern skies. Though there has always been skepticism regarding tall building development, they are an inevitable architectural phenomenon of the modern world.

Today's architecture can be best understood only through pluralism. Many different design approaches, from regional to global, are prevalent for tall buildings in Asia and the Middle East. Once the design direction is selected based on the collective decision of the project participants, design should be carried out in an integrative way among architects, engineers, and contractors. Integrative design is more important for tall buildings than any other building type due to their enormous heights and scales, which require the most advanced building technologies and have a greater impact on urban and even global contexts.

Today more than ever, achieving sustainability is one of the most important building design issues. Tall buildings can be one of the most effective sustainable architectural approaches. European tall buildings have traditionally led sustainable design. Even though green technology is very sensitive to the climate conditions of particular regions, through international collaboration, any of the most advanced building technologies can be transferred easily to any part of the world. In the climates of Asia and the Middle East, careful adjustments should be made for successful design solutions before incorporating sustainable technologies developed originally for different climates.

The history of tall buildings is relatively short in Asia and especially in the Middle East. However, no other cities draw more attention than Shanghai in China or Dubai in the UAE, for example, as cities of tall buildings. International design collaboration, which brings the best design practices from the reputable tall building design firms, often creates the most successful tall buildings. The zeitgeist welcomes the tall building as the quintessential building type of today and the future, creating a higher quality supertall environment through thoughtful design.

## Conflicts of Interest

The author declares no conflict of interest.

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