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Emerging Trends in Architectural Designing and Structural Engineering of High- Rise and High- Performance Buildings

Dr. A.N.Sarkar

Ex-Senior Professor (International Business) & Dean (Research), Asia-Pacific Institute of
Management, 3& 4 Institutional Areas, Jasola (Sarita Vihar), New Delhi
Email: ansarkar1@gmail.com

ABSTRACT

Until recently, tall buildings have been viewed as mega-scale energy consumers with little regard for sustainable architecture. However, this is changing with a new generation of high-rise buildings that have been designed with energy conservation and sustainability as their principal criteria. Sustainable design is an effort to meet the requirements of the present without compromising the needs of future generations by encouraging the wise and prudent use of renewable resources, alternative strategies for energy production and conservation, environment-friendly design, and intelligent building technology. As a major energy consumer, the tall building does not ordinarily conjure images of sustainable design. But a new generation of tall buildings is incorporating new developments in technology and design to produce smarter, energy-efficient buildings. Consequently, future sustainable high-rise buildings will need to be even more energy-efficient and functionally diverse with emphasis on multi-functional tall buildings that consolidate living, working, retail, and leisure spaces into a single building. Finally, concepts such as mega-structures and mega-buildings will need to be revised and allied with new building systems technology to meet the challenges of future sustainable tall buildings that are integrated with their urban habitats; and hence, it is considered well-timed and appropriate to discuss the emerging trends in architectural designing of High-Rise and High-Performance building looking into its long-term resilience and environmental as well as economic sustainability angles.

The article reviews the main trends of modern high-rise construction considered a number of architectural, engineering and technological, economic and image factors that have influenced the intensification of construction of high-rise buildings in the 21st century. The key factors of modern high-rise construction are identified, which are associated with an attractive image component with the ability to translate current views on architecture and innovations in construction technologies as well as exploring new opportunity to serve as an effective driver in the development of a complex of national economy sectors with the achievement of a multiplicative effect. The issue of economic expediency of construction of high-rise buildings, including those with only a residential function, has been adequately addressed in this paper.

K EYWORDS: **Architectural Designing, High-Rise Building, High-Performance building, global Business models of High-rise building,, Environmental resilience and Economic sustainability factors**

1.0. Introduction

A building is an enclosed structure that has walls, floors, a roof, and usually windows. “ A ‘ High-Rise (i.e. Tall) Building ’ is a multi-story structure in which most occupants depend on elevators to reach their destinations. The most prominent tall buildings are called ‘ high-rise buildings ’ in most countries and ‘ tower blocks ’ in Britain and some European countries. The terms do not have internationally agreed definitions (Challinger, 2008). ” However, a high-rise building can be defined as follows:

- “ Any structure where the height can have a serious impact on evacuation ” (The International Conference on Fire Safety in High-Rise Buildings) (Wikipedia Encyclopedia, 2009) .
- “ For most purposes, the cut-off point for high-rise buildings is around seven stories. Sometimes, seven stories or higher define a high-rise, and sometimes the definition is more than seven stories. Sometimes, the definition is stated in terms of linear height (feet or meters) rather than stories (Hall, 2005). ”
- Generally, a high-rise structure is considered to be one that extends higher than the maximum reach of available fire-fighting equipment. In absolute numbers, this has been set variously between 75 feet (23 meters) and 100 feet (30 meters), ” 5 or about seven to ten stories.

High-rise buildings play an increasingly important role in contemporary architecture. Their raising is a necessity for the process of population growth and its concentration in cities, as well as for the high demand for areas in city centers (Ali and Moon, 2018). It can be observed the dynamic development of their construction in terms of both quantity and quality (Rychter,2013). There are plans to build 219 high-rise buildings worldwide in 2019. According to the Global Tall Buildings Database of the CTBUH (Council on Tall Buildings and Urban Habitat) until now were erected 1647 buildings taller than 200 m. The high-rise building construction is characterized by high demand of construction technology and complex engineering works (Dai and Liao, 2014).

In contemporary architecture, designers go beyond the framework of standard codified construction assumptions in order to provide additional and unusual aesthetic experiences (Al-Kodmany, 2018). Geometric shapes, impressive in terms of body and scale, are used for this purpose, as well as the newest material technologies, thanks to which skyscrapers can be classified as eco-buildings.

The change in the approach in building design in the last two decades is reflected in the models for shaping a sustainable, energy-saving environment, which are specified in the context of comparable methods for assessing buildings with various criteria (quality assessment tools, including Leed). These changes are evidenced by many documents, including the Aalborg Charter (2018), the European Charter for Solar Energy in Architecture and Urban Planning (Herzog,, 1996), and the White Book of the Architects' Council of Europe (Survey on Architectural Policies in Europe, 2018). Energy-efficient architecture is promoted by such architects as Norman Foster (2003), Renzo Piano (2019) Eteghad et al (2015) and Moe (2013).

The main trend among new high rise buildings is the striving to achieve zero energy, which is associated with Leed certification (Amiri et al, 2019). Obtainment of Leed v4 certification at the Platinum level means the highest green building standard in the world. Bryant Park (New York, NY, USA) became the first high-rise building in the world to attain this certificate. Other buildings to achieve the Leed v4 certificate include, among others, Shanghai Tower (Shanghai, China), Taipei 101 (Taipei, Taiwan) and Hearst Tower (New York, NY, USA).One of the pro-ecological ideas is the design of bioclimatic skyscrapers, in which users' comfort is increased by greenery inside the buildings through the use of public terraces or multi-level atrias (Oasia Hotel, Singapore).

The problem of high building design particularly concerns problems related to the limitation of horizontal displacements of the building and ensuring its spatial rigidity, proper foundation and resistance to dynamic wind action and seismic effects. The key design challenge associated with acting loads is the appropriate selection of the structural system, while at the same time optimizing its geometrical dimensions. The existing construction solutions mainly differ in their way of transmitting horizontal forces from the wind and seismic impacts on the foundations. A sophisticated construction system allows building in seismic areas with strong wind (Tokyo Sky-tree, Tokyo) and artificially created land (United Tower, Manama; Marina Bay Sands complex, Singapore).

From the individual ' skyscraper ' to the urban 'clusters of concrete canyons', the names for high-rise buildings have always combined a kind of admiration and reverence for the magnitude of the feat with a kind of fear about the threat to human values implicit in operating on so large a scale. According to the Old Testament, after the Flood, people wanted to make a name for themselves by building a city called Babel with a tower that reached into heaven. In the 1890s, a building of ten stories more than qualified as a skyscraper, but today the word is rarely used to describe a building of fewer than fifty stories " (Sonder B. Skyscrapers . New York: MetroBooks, Michael Friedman Publishing Group; 1999:II). The word Babel is from the Hebrew balal (to mix up) (Levi M, Salvadori M. Why Buildings Fall Down: How Structures Fail . New York and London: W. W. Norton & Company; 1992:18). In an earlier book, Mario Salvadori refers to " mankind's aspiration to reach the sky, the ' Tower of Babel Complex ' " (Why Buildings Stand Up: The Strength of Architecture. New York and London: W. W. Norton & Company; 1992:21).

The tall building is the most dominating symbol of the cities and a human-made marvel that defies gravity by reaching to the clouds. It embodies unrelenting human aspirations to build even higher (Buildings 2012, 2, 384-423; doi:10.3390/buildings2040384). In effect then, a building is defined as high-rise when it is considerably higher than the surrounding buildings or its proportion is slender enough to give the appearance of a tall building. The construction of high-rise buildings started at the end of the 19th century in Chicago, with the evolution shown in Figure 1. This was made possible because of new inventions such as the safe elevator in 1853 and the telephone in 1876, that enabled transport of building materials and the ability to communicate to higher levels. In addition, the building materials changed as they went from wood and masonry to using steel frames with lighter masonry walls. Earlier buildings that were built with heavy masonry walls was limited to certain heights by its own self-weight. With steel frames the masonry could be thinner and act only as façade for weather protection and taller buildings could be constructed (Metrop, 1995). During the industrial revolution in Europe the need for warehouses, factories and multi-storey buildings were huge. Europe also played a major role in developing new materials such as glass, reinforced concrete and steel.

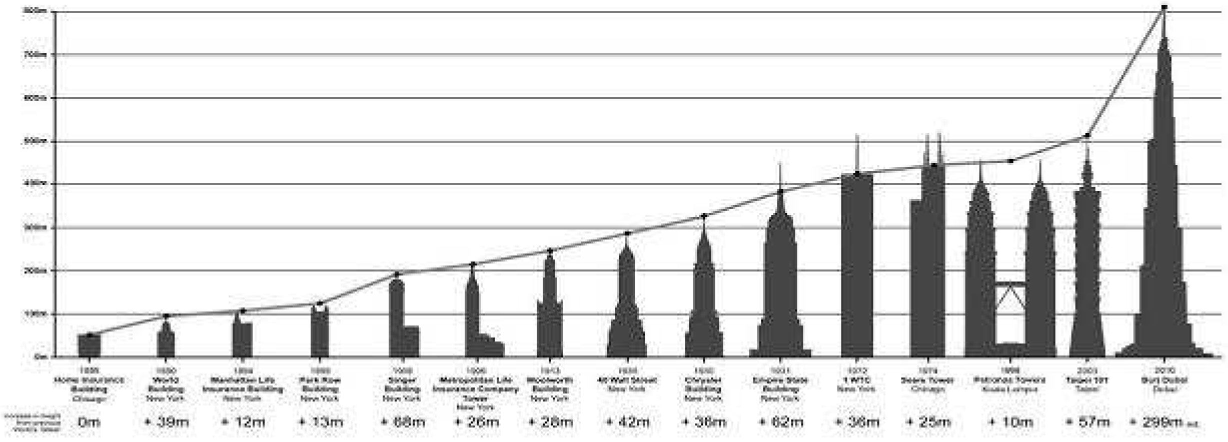

Figure 1: Diagram of Buildings that have once claimed the title 'World's Highest Building'

During the period 1963–69, the production of prefabricated buildings was increased six fold. 20% of all residences built during the time was prefabricated and four major principles for building with prefabricated concrete elements were used. In the 1970s, the million-program was aborted due to the recession and oil-crisis which led to a drastic decrease in the production of new residencies. The tallest building in Sweden today is Turning Torso in Malmö with its 190 meter and 54 stories above ground (Shepherd, 2003). Turning Torso is an in-situ cast concrete building with the facade rotating 90 degrees from top to bottom. When constructing usually much lower than buildings cast in-situ cast. The tallest building ever made with precast concrete is The Breaker Tower in Seef, Bahrain. The building reaches just above 150 meter and has 35 stories. Comparing this with the tallest in-situ cast concrete building which is Burj Khalifa in Dubai, United Arab Emirates, reaching 828 meters and has 163 stories. High-rise buildings does not only give more residencies on smaller area but is also a landmark for the city or country and represents power.

The use of a building has considerable influence on its security and fire life safety needs. There are different types of high-rise buildings classified according to their primary use such as the following ones:

1. Office buildings. An office building is a " structure designed for the conduct of business, generally divided into individual offices and offering space for rent or lease. "

2. Hotel buildings. " The term ' hotel ' is an all-inclusive designation for facilities that provide comfortable lodging and generally, but not always food, beverage, entertainment, a business environment, and other ' away from home ' services. " There are also hotels that contain residences. Known as hotel-residences, this type of occupancy is later addressed in mixed-use buildings.

3. Residential and apartment buildings. A residential building contains separate residences where a person may live or regularly stay. Each residence contains independent cooking and bathroom facilities and may be known as an apartment, a residence, a tenement, or a condominium. An apartment building is " a building containing more than one dwelling unit. " "Apartment buildings are those structures containing three or more living units with independent cooking and bathroom facilities, whether designated as apartment houses, condominiums, or garden apartments. "

4. Mixed-use buildings. A mixed-use building may contain offices, apartments, residences, and hotel rooms in separate sections of the same building. Hotel residences are another type of mixed-use occupancy. " The hotel residences trend is notably different from its predecessors such as fractional/time share hotel units, which are not wholly owned, or condo hotels, which are wholly owned hotel rooms without, for example, kitchens.

2.0. Third Generation High-Rise Buildings: Core Structural Features

The foundations of high-rise buildings must sometimes support very heavy gravity loads, and they usually consist of concrete piers, piles, or caissons that are sunk into the ground. Beds of solid rock are the most desirable base, but ways have been found to distribute loads evenly even on relatively soft ground. The most important factor in the design of high-rise buildings, however, is the building's need to withstand the lateral forces imposed by winds and potential earthquakes. Most high-rises have frames made of steel or steel and concrete. Their frames are constructed of columns (vertical-support members) and beams (horizontal-support members). Cross-bracing or shear walls may be used to provide a structural frame with greater lateral rigidity in order to withstand wind stresses.

Even more stable frames use closely spaced columns at the building's perimeter, or they use the bundled-tube system, in which a number of framing tubes are bundled together to form exceptionally rigid columns. Buildings constructed from after World War II until today make up the most recent generation of high-rise buildings. Within this generation there are those of steel-framed construction (core construction and tube construction), reinforced concrete construction, and steel-framed reinforced concrete construction.

2.1. Steel-Framed Core Construction

These structures are built of lightweight steel or reinforced concrete frames, with exterior all-glass curtain walls. As Salvadori stated, " The so-called curtain walls of our high-rise buildings consist of thin, vertical metal struts or mullions , which encase the large glass panels constituting most of the wall surface. The curtain wall, built for lighting and temperature-conditioning purposes, does not have the strength to stand by itself and is supported by a frame of steel or concrete, which constitutes the structure of the building (Salvadori, 1980). " In the center of these buildings, or infrequently to the side, there is an inner load-bearing core constructed of steel or reinforced concrete. Most building utilities and services — stairway shafts (stairwells); passenger and service/freight elevator shafts; air-conditioning supply and return shafts; communication systems (telephones, public address systems, and computer networks); water, electrical power, and gas; and restrooms (toilets) — are enclosed in this central core. The core braces the building against wind.

2.2. Steel-Framed Tube Construction

Tube structures represented a change in the design of steel-framed buildings to enable them to be built tall and yet remain strong enough to resist the lateral forces of winds and the possible effects of an earthquake. Tube construction used load-bearing exterior or perimeter walls to support the weight of the building. " The key to stability is a resistance to lateral wind or earthquake forces, which grow dramatically in magnitude with the building's height. " " If not counteracted by proper design, these forces would cause a tall building to slide on its base, twist on its axis, oscillate uncontrollably, bend excessively or break in two (Tucker, 1985). " Because the core and perimeter columns carry so much of the load, the designers could eliminate interior columns, with the result that there is more open floor space for tenants. " Floor areas tend to be larger, with little compartmentalization using floor to-ceiling walls and barriers.

2.3. Reinforced Concrete Construction

" Concrete that has been hardened onto imbedded metal (usually steel) is called reinforced concrete, or ferroconcrete. The reinforcing steel, which may take the form of rods, bars, or mesh, contributes tensile strength (Encyclopæ dia Britannica, 2008). " Reinforced concrete is " concrete containing reinforcement and is designed on the assumption that the two materials act together in resisting forces (Construction Dictionary , 9th ed). " Parallel to the development of tall steel structures, substantial advancements in high-rise structural systems of reinforced concrete have been made since 1945. The first of these was the introduction of the shear wall as a means of stiffening concrete frames against lateral deflection, such as results from wind or earthquake loads; the shear wall acts as a narrow deep cantilever beam to resist lateral forces. " Concrete requires no additional fireproofing treatments to meet stringent fire codes, and performs well during both natural and manmade disasters. Because of concrete's inherent heaviness, mass, and strength, buildings constructed with cast-in-place reinforced concrete can resist winds of more than 322 kilometers per hour and perform well even under the impact of flying debris (Madsen, 2005)".

Kajima Corporation, under the guidance of Dr. Kiyoshi Muto, investigated the method to improve the ductility of reinforced concrete members by lateral confining reinforcement, the method of nonlinear earthquake response analysis and the method for efficient construction and strict quality control. An 18-story apartment building (47.7 m in height) for the employees of Kajima Corporation was the first high-rise reinforced concrete construction, completed in 1974. The structure was moment-resisting frames with 3.0-m span in the longitudinal direction and 4.5-m span in the transverse direction. Other major construction companies followed the Kajima's efforts.

A technical review committee, chaired by Professor Hiroyuki Aoyama of University of Toyo, was formed at the Building Center of Japan in 1984 to examine and discuss the structural design procedure and construction technology for the rational development of high-rise reinforced concrete construction; working groups were formed to discuss technical development for each construction company, separately. Different structural design criteria were fostered in each company on the basis of its own experimental evidences of structural members under load reversals at their own research laboratory, and the response calculated by computer programs for nonlinear static as well as dynamic analysis. Construction technology for production of high-strength concrete, efficient and accurate fabrication of reinforcement cages, election of reinforcement cages in formwork and placement of concrete was also developed in each construction company, separately.

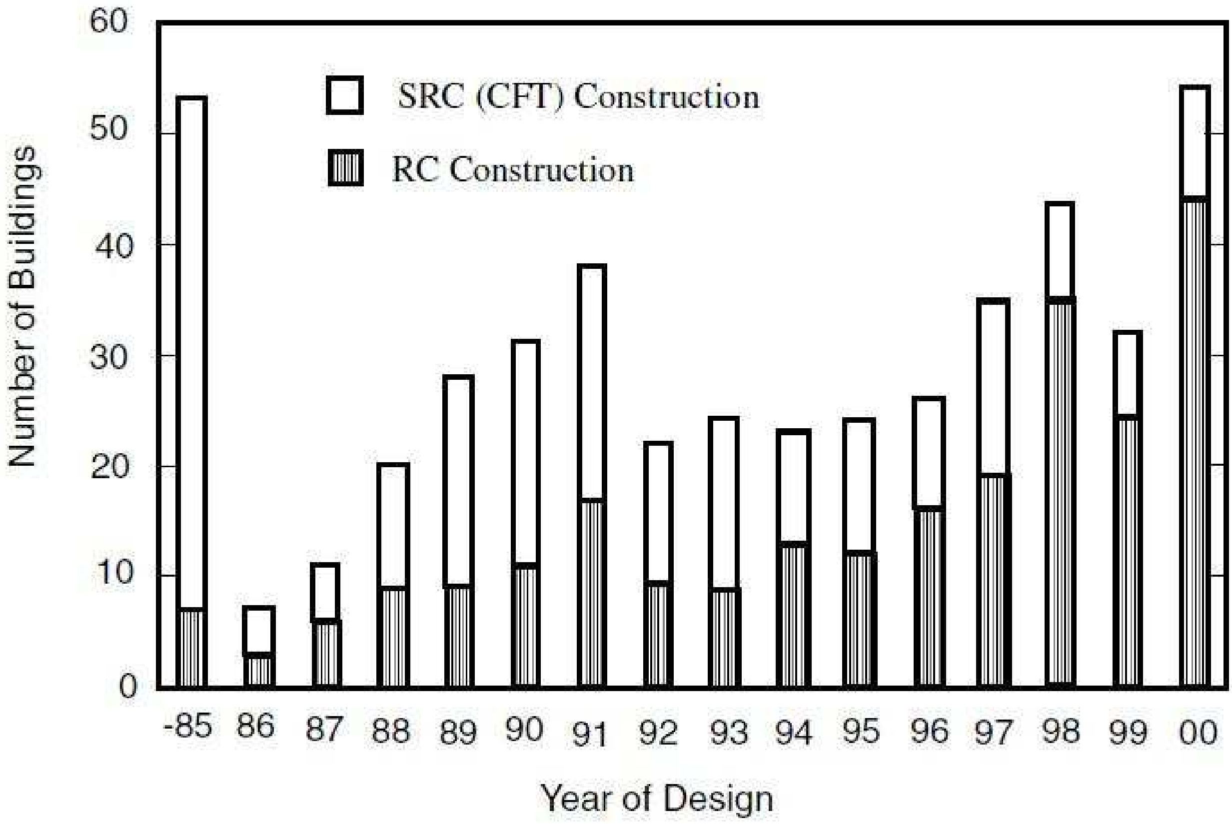

Figure 2: Construction of High-rise Reinforced Concrete Buildings in Japan

The construction of high-rise reinforced concrete buildings (more than 45 m high before 1981, and 60 m high after 1981) in Japan is summarized in Figure 2. Before and in 1985, the total number of reinforced concrete and steel-encased reinforced concrete (SRC) composite buildings was slightly more than 50, but most were constructed using the SRC composite construction. Concrete filled tube (CFT) column systems replaced the SRC construction in recent years due to the advantage in construction cost and efficiency. The construction of high-rise reinforced concrete buildings increased steadily to date.

2.4. Steel-Framed Reinforced Concrete Construction

These structures are a mixture of reinforced concrete construction and steel-framed construction, hence the name steel-framed reinforced construction. An example would be " a steel framed structure with a concrete shear core and composite floors built with steel decking (Celikag, 2004). " The term mixed construction is sometimes used to describe this type of high-rise construction. The worldwide use of reinforced concrete construction stems from the wide availability of reinforcing steel as well as the concrete ingredients. Unlike steel, concrete production does not require expensive manufacturing mills. Concrete construction, does, however, require a certain level of technology, expertise, and workmanship, particularly in the field during construction. In some cases, single-family houses or simple low-rise residential buildings are constructed without any engineering assistance. The extensive use of reinforced concrete construction, especially in developing countries, is due to its relatively low cost compared to other materials such as steel. The cost of construction changes with the region and strongly depends on the local practice. As an example, a unit area of a typical residential building made with reinforced concrete costs approximately US$100 /m2 in India, US$250/m2 in Turkey, and US$500/m2 in Italy. With the rapid growth of urban population in both the developing and the industrialized countries, reinforced concrete has become a material of choice for residential construction. Unfortunately, in many cases there is not the necessary level of expertise in design and construction. Design applications range from single-family buildings in countries like Algeria and Colombia to high-rises in Chile, Canada, Turkey, and China (Figure 3). Frequently, reinforced concrete construction is used in regions of high seismic risk, such as Latin America, southern Europe, North Africa, the Middle East, and Southeast Asia.

Figure 3: Typical Residential RC Frame Building in Turkey (WHE Report 64, Turkey)

2.5. Pre-stressed Concrete Structures

Pre-stressed concrete (herein after abbreviated as PC) structures have many combination of pre-stressed concrete (PC) members that are precast PC, site cast PC, precast partial PC, site cast partial PC, and site cast reinforced concrete. Adding on these combinations, pre-stressed level induced into structural members are various from non-crack control to crack width control. Their seismic performance curves are different, equivalent viscous damping ratio is also different depending on members combinations and pre-stressed level. It is difficult for their many types of PC structures to define the ultimate strength to secure the seismic safety rationally. And a design procedure for high rise building that is not so common structure because required strength for various PC structures against large earthquake is difficult to be clearly defined. The cooperative research project on PC building structures (Japan PC Project) to prepare the design and construction guidelines for high rise PC buildings (less than 60m) started in 1995 under the leadership of the Building Research Institute (BRI), Ministry of Construction, Japan.

3.0. Tallest High-Rise Buildings in the World

There are several claims and counter claims about the Tallest High-Rise Buildings in the world as the process of growth of such buildings are evolving world over time and space.

3.1. The “ World’s Tallest ” Race

Since 1885, 17 buildings have staked claim to the title “ The World’s Tallest Building. ” According to information obtained from Skyscraper, these buildings are as follows (Table 1):

Date	Building	Location
1885	Home Insurance Building	Chicago, Illinois
1890	World Building	New York City
1892	Masonic Temple Building	Chicago, Illinois
1894	Manhattan Life Insurance Building	New York City
1898	St. Paul Building	New York City
1899	Park Row Building	New York City
1908	Singer Building	New York City
1909	Metropolitan Life Tower	New York City
1913	Woolworth Building	New York City
1930	Manhattan Company	New York City
1930	Chrysler Building	New York City
1931	Empire State Building	New York City
1971–1973	World Trade Center	New York City
1974	Sears Tower	Chicago, Illinois
1998	Petronas Towers	Kuala Lumpur, Malaysia
2004	Taipei 101	Taipei, Taiwan
2009	Burj Dubai	Dubai, United Arab Emirates

Table 1: The World’s Tallest Building since 1885

3.2. Burj al Dubai - Now known as Burj Khalifa

Described as both a 'Vertical City' and 'A Living Wonder,' Burj Khalifa, at the heart of downtown Dubai, is also the world's tallest building. Developed by Dubai-based Emaar Properties PJSC, Burj Khalifa rises gracefully from the desert and honors the city with its extraordinary union of art, engineering and meticulous craftsmanship. At 828 meters (2,716.5 feet), the equivalent of a 200 story building, Burj Khalifa has 160 habitable levels, the most of any building in the world. The tower was inaugurated on January 4, 2010, to coincide with the fourth anniversary of the Accession Day of His Highness Sheikh Mohammed Bin Rashid Al Maktoum Vice President and Prime Minister of the UAE and Ruler of Dubai. Arguably the world's most interesting construction project, Burj Khalifa is responsible for a number of world-firsts. The tower became the world's tallest man-made structure just 1,325 days after excavation work started in January 2004. Burj Khalifa utilized a record-breaking 330,000 cubic meters (430,000 cubic yards) of concrete.

The tallest building in the world currently is the Burj Dubai, which has been completed recently. This mixed use tower contains retail, offices, residential apartments, and a hotel and seeks to exhibit Dubai's vision to set world benchmarks within the construction industry. In making this project a reality, one of the critical issues the design team had to resolve was regarding how to reduce and control the wind forces on the tower. The design team's solution to this issue was a tri-axial 'Y'-shaped plan, where each tier of the building sets back in a spiral stepping pattern up the building (Figure 4). This concept allows the facade to 'confuse the wind' because the wind vortices never consolidate with one another, due to the evolving building facade. This shaped floor plan has other advantages such as providing 'an ideal arrangement of residential units, having an optimal plan depth-to-perimeter ratio and allowing maximum views outward, without overlooking a neighboring apartment'.

The goal of the Burj Dubai Tower is not simply to be the world's highest building: it's to embody the world's highest aspirations. The superstructure has reached over 165 stories. The final height of the building is 2,717 feet (828 meters). The height of the multi-use skyscraper has "comfortably" exceed the previous record holder, the 509 meter (1671 ft) tall Taipei. The 280,000 m2 (3,000,000 ft2) reinforced concrete multi-use Burj Dubai tower is utilized for retail, a Giorgio Armani Hotel, residential and office. As with all super-tall projects, difficult structural engineering problems needed to be addressed and resolved.

Burj Khalifa has "refuge floors" at 25 to 30 story intervals that are more fire resistant and have separate air supplies in case of emergency. Its reinforced concrete structure makes it stronger than steel-frame skyscrapers. Designers purposely shaped the structural concrete Burj Dubai - "Y" shaped in plan - to reduce the wind forces on the tower, as well as to keep the structure simple and foster constructability. The structural system can be described as a "buttressed" core (Figures 4). Each wing, with its own high performance concrete corridor walls and perimeter columns, buttresses the others via a six-sided central core, or hexagonal hub. The result is a tower that is extremely stiff laterally and torsionally. SOM applied a rigorous geometry to the tower that aligned all the common central core, wall, and column elements. Each tier of the building sets back in a spiral stepping pattern up the building.

Figure 4. Burj Khalifa, Dubai

3.3. Nakheel Tower, Dubai

The adversary of the Burj Dubai, which will claim the world's tallest building when completed in the near future is the Nakheel Tower, which will stand over one kilometre tall. Unlike Burj Dubai, the design team for the Nakheel Tower is aspiring to achieve LEED Gold rating via numerous ESD initiatives, and in the process challenges the current model of what a sustainable tower should encompass, whilst providing the industry with the perception that the sky is the limit.

Achieving this world breaking height resulted in further research and analysis being undertaken, based on the lessons learnt from the Burj Dubai, along with the implementation of innovative sustainable principles. The design concept employed involved separating the tower into four stand alone towers, which were connected via sky-bridges at every 25 levels. Therefore, wind could pass through the building allowing the typical tampering of high rise tower floor plates was avoided (Figure 5). This sustainable solution provides larger than normal floor plates at the upper levels, resulting in greater return in investment being achieved.

Figure 5. The Nakheel Tower, Dubai

In further comparison to Burj Dubai, the Nakheel Tower also contains retail, offices, residential apartments and a hotel, however, further to this also contains an experience centre and observation facilities along with a special sky function space – creating a vertical community of over 15,000 people (Figure 6). This new concept of sky bridges serves multiple purposes such as providing community and public spaces where visitors and residents alike can interact, whilst joining the four separate towers together and allowing transfer points between lifts.

3.4. Home Insurance Building

The 10-story Home Insurance Building (Figure 7), built in Chicago in 1885, is generally considered to be the world's first skyscraper. As stated in the Architectural Record , before the Home Insurance Building was demolished to allow construction of the New Field Building, " a committee of architects and others was appointed by the Marshall Field Estate to decide if it was entitled to the distinction of being the world's first skyscraper. This committee, after a thorough investigation, handed down a verdict that it was unquestionably the first building of skeletal construction (Shepherd, 2003). " Engineer William Le Baron Jenney designed this 180-foot (55 meters) tall building using a steel frame to support the weight of the structure. Jenney stated in 1883, " we are building to a height to rival the Tower of Babel (Dupr é, 2001). " In the 1890s, " most European cities like London, Paris, and Rome rejected tall buildings in their historical city centers meanwhile opting for height control regulations to maintain their low skylines. Today, however, we witness Paris and London giving away their horizontality in favor of the vertical scale (Beedle et al, 2007). "

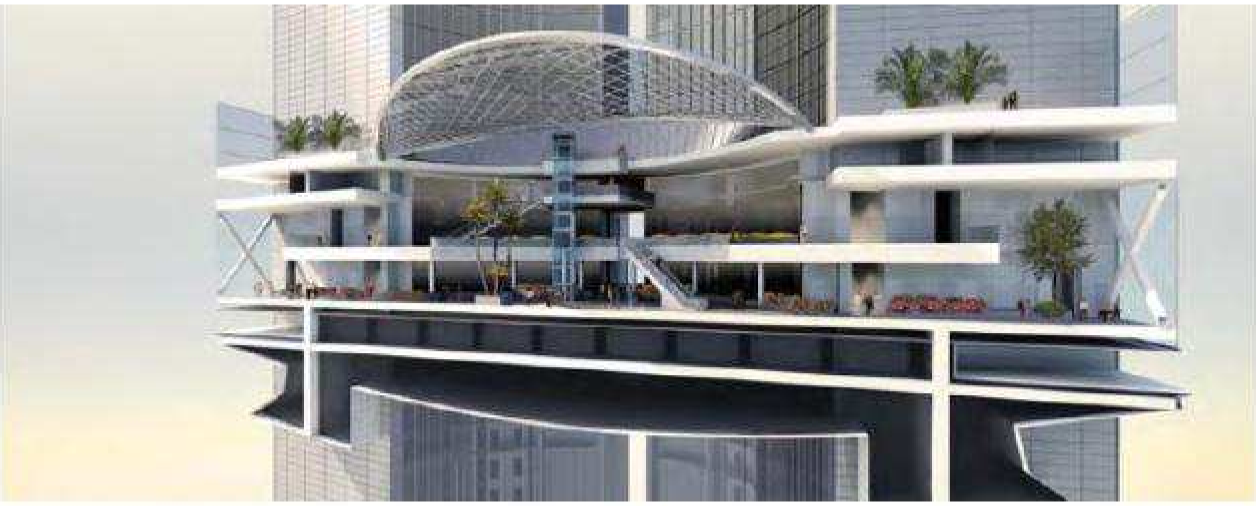

Figure 6: Nakheel Tower Sky Bridge Section

Figure 7: Home Insurance Building 1885. This 10-story building, Designed by Engineer William Le Baron Jenney

3.5. Waldorf-Astoria Hotel, New York City

An example of a hotel of this era was the Waldorf-Astoria (Figure 8) in New York City. At the turn of the century, tall buildings began to spring up in New York City —in 1903, the triangular-shaped 22-story Flatiron (Fuller) Building, 285 feet (87 meters) high; in 1909, the 50-story Metropolitan Life Insurance Building, 700 feet (213 meters) high; and in 1913, the 57-story Woolworth Building, 792 feet (241 meters) high. " Residential high-rises were also built near city centers so people could live close to their place of employment. "

3.6. Ritz Tower, 465 Park Avenue, N.Y

The city's most elegant apartment hotel, the Ritz at 465 Park Avenue on the northeast corner at 57th Street, is best known for its rooftop finials, and as the former site of Le Pavillon, the famous and expensive French restaurant that for many years occupied most of its 57th Street retail frontage. Its real significance, however, was in making an individualistic tower an acceptable residential building form and in creating setback terraces. When it was built, it nearly tripled the heights to which luxury apartment houses were then soaring. With its prime location and classic formality, this 540-foot-high tower. Figure 9 shows the First Modern Residential High-Rise 41-story skyscraper, Ritz Tower.

Figure 8: Waldorf-Astoria Hotel. This sprawling hotel was an 1898 combination of the Waldorf and Astoria Hotels in New York

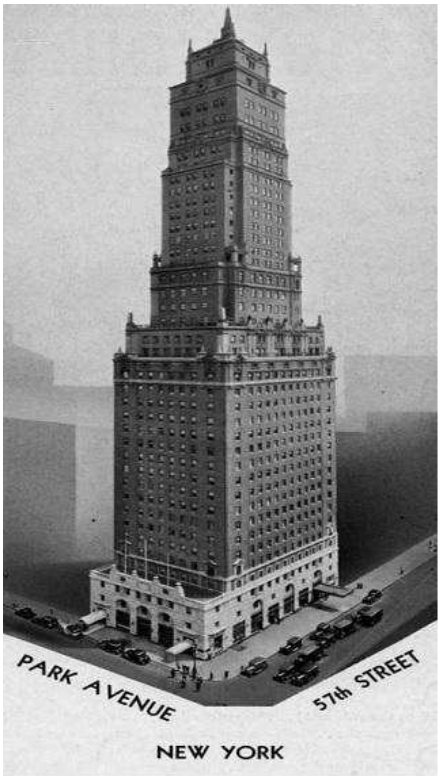

Figure 9: First Modern Residential High-Rise Building 41-story Skyscraper, Ritz Tower, Park Avenue, N.Y.

Figure 10: Dynamic Rotating Tower

3.7. Dynamic Rotating Tower

Pioneering architect Dr Fisher from the Florence based Dynamic Architectural Group, has created a world breaking concept involving a high rise tower's facade, which constantly rotates (Figure 10). The Dynamic Tower is 80 floors high and is a mixed-use development containing offices, residential apartments and a hotel. This construction procurement method is unique to the construction industry as it will be the first factory-built skyscraper (Pierce, 2009). It will be made possible by constructing only the building's central core on site, which contains the buildings vertical transport system and services, while the remainder of the structure is prefabricated in a factory in Italy (Chamberlain, 2008). Each apartment is integrated within a prefabricated module, which is completely fitted out and only requires owners to move their furniture in (Pierce, 2009) .

Chamberlain (2008) highlights some advantages of this procurement method stating designers estimate that the prefabrication approach should cut construction time from 30 months (for a traditional build) to 18 months. Furthermore, an estimated 90 employees will be required on site and an additional 700 employees in the factory, in comparison to over 1,000 employees for a typical project of this size on site. However, although these factors present potential cost savings for the project, it is believed the tower in Dubai will cost around $330m. This significant cost can somewhat be justified by the investment in advancing today's technology in high rise developments, whilst ensuring a sustainable concept is projected. Fisher further discusses this issue stating the Dynamic Tower will be so energy efficient it will have enough surplus to power five similar-sized buildings. This is achieved by large photovoltaic cells installed on the roof, along with 48 carbon fibre wind turbines which are positioned between each of the 80 levels. In summary, Fisher (2008) claims that the Dynamic Tower is the 'first real green building' because no building before has been designed to produce much more energy than it can use.

3.8. Capita Green High-Rise Building, Singapore

CapitaGreen is located within Singapore's central business district and in close proximity to the extended downtown Marina Bay. Greeting those entering the structure is an expansive lobby that has a triple-height ceiling and handcrafted Kakiotoshi (earth plaster) walls. Along with its ornate design, the building is unique in that it became the first in Singapore to use Supercrete, an ultra-high-strength concrete which significantly reduced the amount of concrete needed, resulting in a savings of energy and manpower. The building is designed like a plant growing towards the sky. Green living vegetation covers 55 percent of the perimeter of its façade, giving the landmark its iconic appearance. Its innovative double-skin façade features an outer layer of frameless glass and an inner envelope of double-glazed floor-to-ceiling glass that reduces solar heat gain by up to 26 percent.

At the top of the tower, a petal-like structure serves as a wind scoop to draw in the cooler, cleaner air from above and channel it though a cool void that penetrates the full height of the building delivering fresh air to tenants. The development will feature specially commissioned art installations by internationally acclaimed artists on level 1 and exceptional facilities such as an exclusive club on level 38, and a sky forest and restaurant on level 40. Located in the heart of Singapore's Central Business District, CapitaGreen have close access to the station Raffles Place and Telok Ayer MRT stations. CapitaGreen is an ecological building with its environmentally-friendly features and a green 'living' façade (Figure 11). With the inclusion of numerous state-of-the-art energy-saving features, the completed office tower is designed to achieve the Green Mark Platinum award, the highest accolade in recognizing environmentally friendly buildings from the Building & Construction Authority of Singapore. trade, especially exports of services, goods, high technology and rapid economic growth. In addition, improving efficiency and stimulating innovation translates simultaneously increasing the attractiveness of a location for foreign direct investment in the area of high technology. These changes additionally enhance national long-term competitiveness by increasing the attractiveness of the location for inflows of high-tech foreign direct investment.

4.0. Basics to High-Rise Building Design

The structural system of a high-rise building often has a more pronounced effect than a low-rise building on the total building cost and the architecture. As a result, those faced with an initial venture into tall building design need to be aware of concepts that are not emphasized for low-rise design. High-rise design comes into play when a structure's slender nature makes it dynamically sensitive to lateral loads, such that a premium is associated with its lateral system development (Figure 12). The simplified model for the behavior of a tall building is a vertical cantilever out of the ground. In this model, the moment of inertia of the cantilever is calculated considering each of the vertical elements, such as core walls and perimeter columns, active in the lateral system. Deflection is due primarily to axial shortening and elongation of these elements.

Due to shear deformation, this idealized stiffness is not fully achievable. A measure of how closely a system can approach the idealized model is reported as a ratio of deflection of the ideal cantilever system to the actual deflection, and is referred to as the building's cantilever efficiency. It is important when selecting a system to realize where shear deformation loss occurs and to ensure that analytical modeling techniques accurately account for it (Figure 13).

Figure 11. CapitaGreen (2012-2014), Singapore; Architect Toyo Ito & Associates

Each lateral system choice brings its own practical limits. For the two main structural materials, steel and reinforced concrete, suggested practical ranges are illustrated in Figure 3. While steel systems offer speed in construction and less self-weight, thereby decreasing demand on foundations, reinforced concrete systems are inherently more resistant to fire and offer more damping and mass, which is advantageous in combating motion perception by occupants. Composite systems can exploit the positive attributes of both.

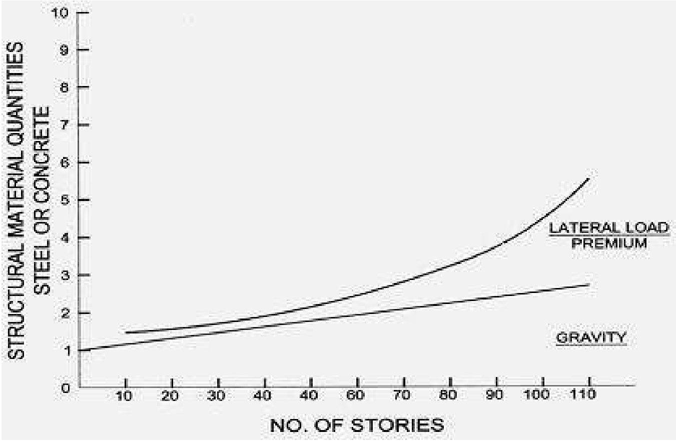

Figure 12: High Rise Premium

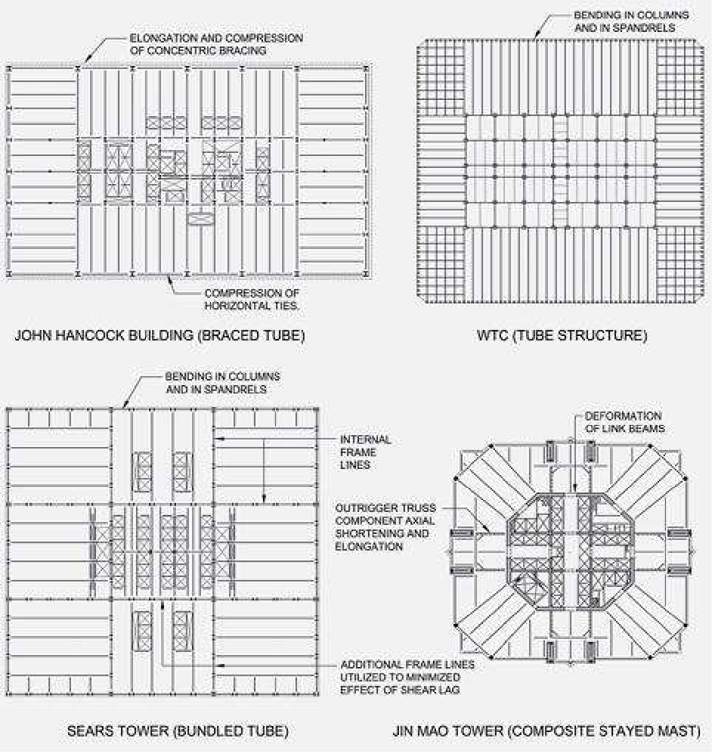

Figure 13: Shear Deformation Effects

Because code prescribed equivalent static wind loading cannot accurately predict the gust effect on tall buildings or turbulence created by adjoining buildings, wind tunnel tests are routinely conducted. Gusting effects become especially problematic and pronounced when pulsating transverse loading, called vortex shedding, is created in tune with fundamental periods of the building (Figure 14).

Wind tunnel testing considers appropriate loading for overall lateral system design and cladding design, and predicts motion perception and pedestrian level effects. In a wind tunnel test, block models, scaled 1:300 to 1:600, are incorporated into a proximity model on a turntable which includes buildings and other obstructions from 300m to 800m around the building site.

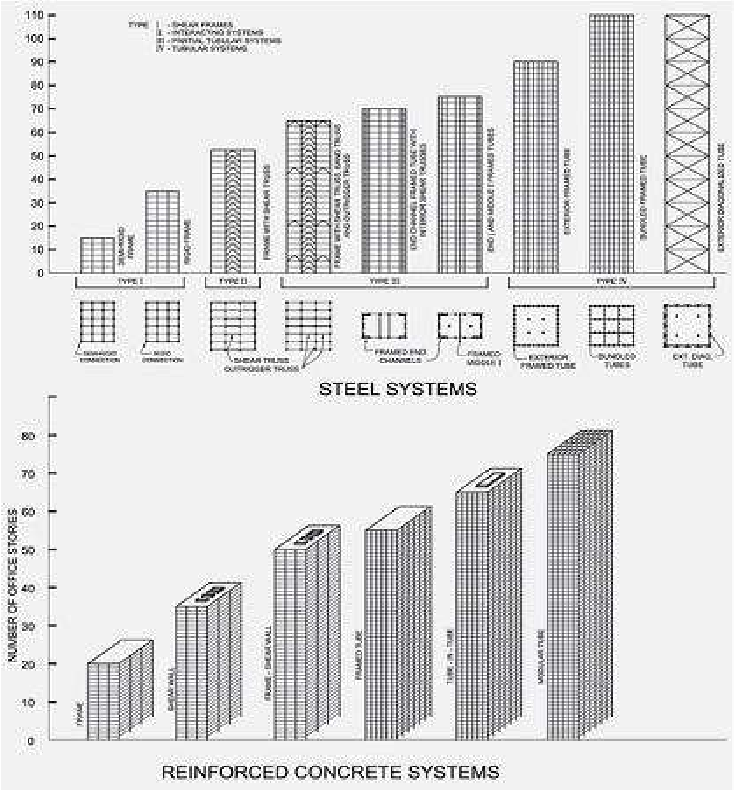

Figure 14: Practical Limits of Lateral Systems

5.0. High-Rise Building Structural Systems

Nowadays, High Rise buildings are built in abundance to maximize the land use and investment return. Success of these high investment projects are centered around choosing the appropriate structural system, optimizing the space requirement, earthquake resistant design and design for wind loads. Moreover the complexity of modern high rise buildings has meant that the successful completion of initial design has become more important and therefore choosing the most economic frame has become more difficult.

Extremely efficient designs are desirable for economic feasibility therefore highest performing high rise building structural systems are needed by performing optimization of structural parameters in an efficient and structurally rigorous manner. Structural optimization method explores a diverse range of structural topologies and geometries (Ballal T., Sher W., and Neale, 2006). Such an optimization method at initial stage of design would not only ensure financially beneficial designs but would also reduce the engineer's design burden. Conceptual design stage being iterative can be exploited to the fullest in maximizing the returns from such large investment projects. It gives a structural designer the freedom to choose the best structural system suited to the building and site requirements. Conceptual stage designing requires sound knowledge, past experience, imaginative power and creativity skill. Thus Architects can give shape to the building to enhance its aesthetic appeal.

Different geometry of floor plan can be used and experimented with, to achieve the desired space efficiency. Wind tunnel testing and aerodynamic shape to the building can be given at conceptual stage of design. Thus, conceptual design presents a number of feasible options to the designer, which incorporates both aspects i.e. limitations and advantages, thereby making it easy for the designer to take sensible decisions at the final stage of design. Based on the distribution of the components of the primary lateral load-resisting system over the building, the structural system of High Rise buildings can be broadly classified as: a) Interior Structures; b) Exterior Structures. In Interior structural system, the major part of the lateral load-resisting system is located within the interior of the building. Whereas in Exterior Structural system, the lateral loads resisting system, is located along the building perimeter. The various structural systems used by the architects for high-Rise buildings are described below.

5.1. Framed Tube Structures

The framed tube is one of the most significant modern developments in high-rise structural form. For framed tube structures the lateral resistance is given by very stiff moment resisting frames that form a tube around the perimeter of the building. The frames consists of closely spaced columns, 2–4 meters between centres, connected by girders. The tube carries all the lateral load and the self-weight is distributed between the outer tube and the interior columns or walls. For the lateral loading the perimeter frames aligned in the load direction acts as webs of the tube cantilever and those perpendicular to the load direction acts as flanges. The tube structure is suitable for both steel and reinforced concrete buildings and have been used in the range of 40–100 stories.

Framed tube systems have been the most significant modern development in high-rise structural forms and is easily constructed and usable for great heights. Largely, the framed tube structure consists of: Framed tube (b) Braced framed tube (c)Tube-in-Tube frame (Design of Steel Structures: http://nptel.ac.in/courses/105106113/3_multi_storey/6_structural_forms.pdf.)

5.2. Bundled Tube

The bundled tube structure consists of four parallel rigid frames in each orthogonal direction, interconnected to form nine bundled tubes (Figure 15). The principle is the same as for the single tube structure where the frames in the horizontal load direction acts as webs and the perpendicular frames acts as flanges. By introducing the internal webs the shear lag is drastically reduced and as a result the stresses in the columns are more evenly distributed and their contribution to the lateral stiffness is more significant. This allows for the columns to be spaced further apart and to be less striking.

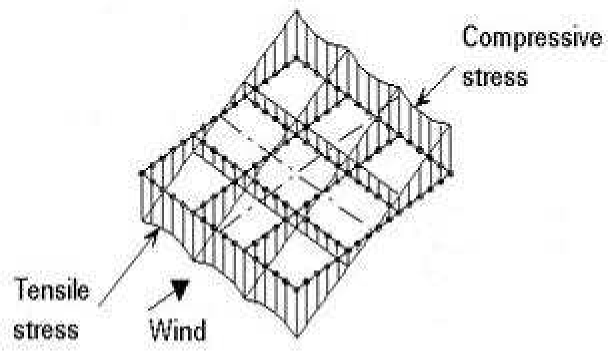

Figure 15: Bundled Tube Intersection

5.3. Tube in Tube

Tubular structures are common structural system for tall buildings over past few years. The tubular structures are of different types in which tube in tube structures are more suitable for high rise buildings. A tube in tube structure is formed by outer framed tube and inner core tube connected by floor slab. It is act like a huge tube (i.e. Peripheral tube) with a smaller tube(i.e., core tube) in middle of it. The load is transfer between these two tubes. In which a strong center tube of high strength concrete is the main load carrying structure. Avoiding this center tube a new structural system for tall building is developed known as Tubed Mega Frames. In which the load is carried by long vertical tubes at perimeter of building connected by periphery walls. This structural system improves the structural stability and increases the floor space to be utilized. What differentiates the tube in tube concept from other structural systems is that an outer framed tube (hull), is working together with an internal tube (core), usually elevator shafts and stairs, to resist both the lateral and vertical loading (Figure 16). This provides increased lateral stiffness and can be seen as the shear and flexural components of a wall-frame structure.

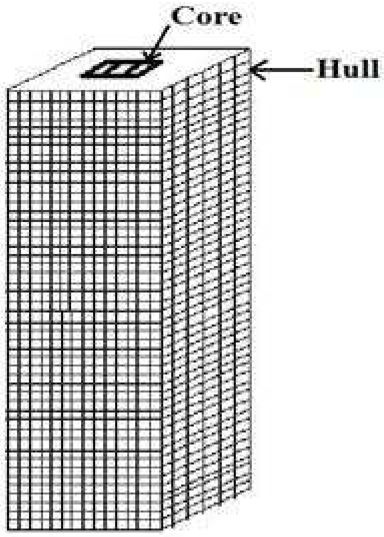

Figure 16: Tube-in-Tube Structure

5.4. Diagonalised Bracing and Rigid Frame

In braced frames the lateral resistance is given by diagonal members that, together with the girders, form a web of vertical trusses, where the columns acting as chords (Figure 17). Bracing systems are highly efficient of resisting lateral loads. This due to the horizontal shear in the building is resisted by the horizontal components resulting in tensile and compressive actions in the web members. The bracing system is an almost steel exclusive system since the diagonals are inevitably subjected to tension for one or the other direction of the lateral loading. Braced systems are able to produce a very stiff lateral structure for a minimum of additional material which makes it economically efficient for any height.

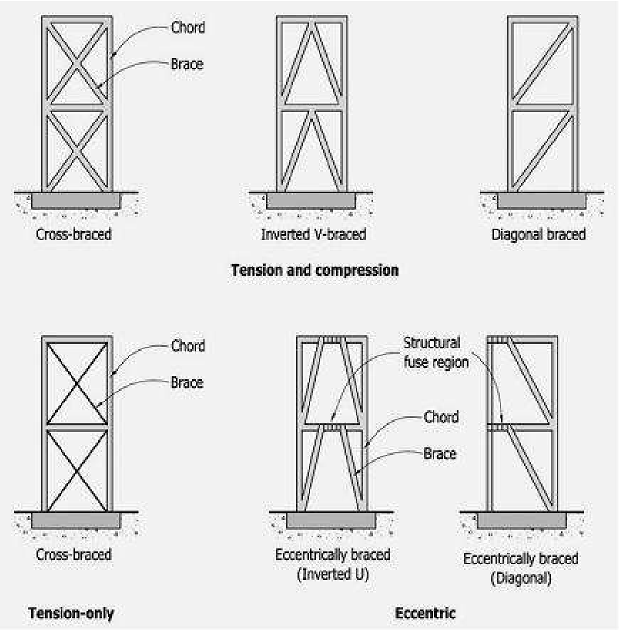

Figure 17: Different types of Diagonal Bracing Frames

In rigid frame structures the columns and girders are joined together by moment resistant connections. The lateral stiffness of a rigid frame depends on the bending stiffness of the columns, girders and connections in-plane. This type of structure is ideally suited for reinforced concrete buildings because of the stiffness from reinforced concrete joints. For steel, these connections can be made although they are expensive. An advantage with rigid frame structures is the possibility of planning and fitting of windows because of the open rectangular arrangement. A disadvantage is that the self-weight is resisted by the action from rigid frames. Negative moments are induced in girders adjacent to columns causing the mid-span positive moments to be significantly less than in a simply supported span. For buildings where self-weights dictate the design, usually below 10 stories, economics in member sizes that arise from this effect tend to be offset by the increased cost of the rigid joints.

6.0. Load Bearing Systems of High-Rise Buildings

There are a variety of different load bearing systems for high-rise buildings, which one to use depends on the height of the building, where the building is located and the architectural design. The higher a building is, the more material is needed to resist lateral loads. At approximately 50 floors the material costs for resisting lateral loads in a rigid frame becomes greater than those for the vertical load bearing system. This is why an appropriate load bearing system is required. Some of the most common structural systems used in high-rise buildings are explained below.

6.1. Rigid Frames

For buildings with a fairly low height, a rigid frame can be used. A rigid frame consists of columns and girders with moment resisting connections (Figure 18). It resists lateral loads with the bending resistance of the columns and beams. When designing buildings with moment resisting frames, the size of the columns and beams are often controlled by the bending stillness and not by the load capacity. The high bending stillness is needed to limit the drift due to lateral loads. Furthermore the behaviour of the building depends on the design of the connections, if a big rotation between the beam and column is allowed, the lateral sway of the building will increase rapidly and cause problem with the comfort in the building. Steel or concrete can be used for this type of system. For steel, the maximum appropriate height is about 30 stories and for concrete about 20 stories. For buildings over 30 stories there is a risk of large lateral swaying from wind and earthquakes, the connections between the beams and the columns also become too complicated and too expensive in order to withstand the large moments, especially for steel frames.

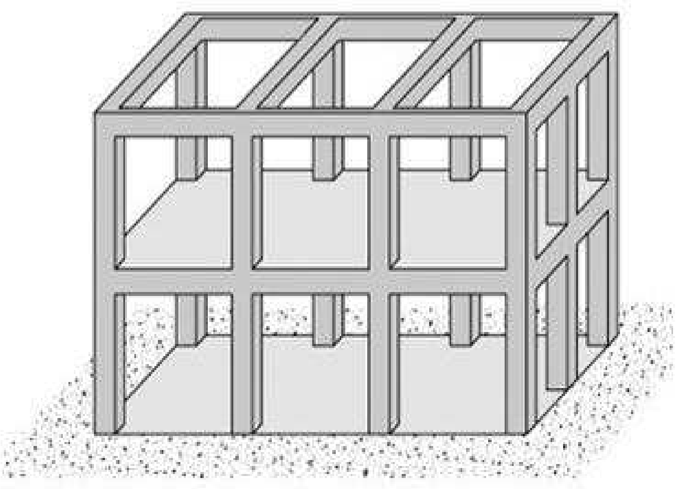

Figure 18 : Illustration of a Rigid Frame

6.2. Shear walls

Shear walls have a high resistance in their own plane and are used to resist lateral loads. Shear walls can resist overturning moments, shear forces and also torsion if they are properly placed in the building. Shear walls can be used in different ways. One way is to use a system of columns with a slab and shear walls, which will extend the effective height up to about 20 stories compared to 10 stories for a similar system with just columns and slabs. A shear wall system is shown in Figure 19. By connecting shear walls a coupled shear wall is obtained. The walls are coupled by placing beams between the shear walls as shown in Figure 20. This is an effective way to greatly increase the lateral stillness of a building. This is often done to accommodate holes for windows and doors, this type of system is effective up to 40 stories.

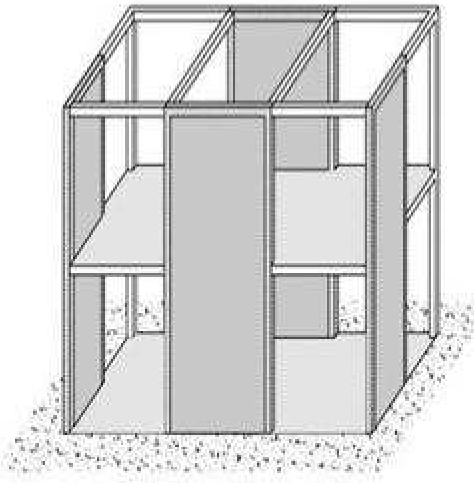

Figure 19: Illustration of Shear Walls

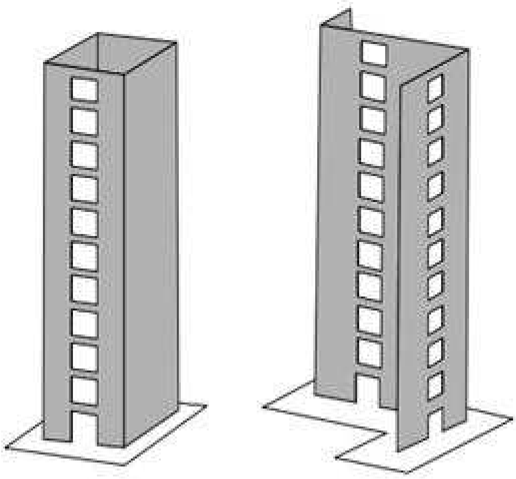

Figure 20: Illustration of Coupled Shear Walls

5.3. Core and Outrigger Systems

A very common way of using shear walls is to use them in a core supported structural system, which means that shear walls are cast around elevator and stair shafts to create a core. The core can resist lateral, vertical and torsion loads. The shear walls are often placed around elevator and staircases to create a core while the frames are on the exterior of the building which allows deep beams to be placed on the outside of the building. This type of structural system reduces the overturning moment and the risk for uplift at the core (Taranath, 2010). A core can be complemented with an outrigger structure to greatly increase its bending stiffness. The outriggers are connected to columns that stretch along the perimeter of the building down to the ground. When the structure is subjected to lateral loads they are resisted with axial forces in the exterior columns and the moment in the core is decreased. Belt walls are used to resist the rotation of the outriggers and to engage all columns in the exterior. Belt walls consist of walls or trusses placed on the perimeter of the outrigger. Outriggers will reduce the lateral displacements of the building due to bending, however they do not increase the shear or torsional resistance of the building which still must be resisted by the core (Figure 21).

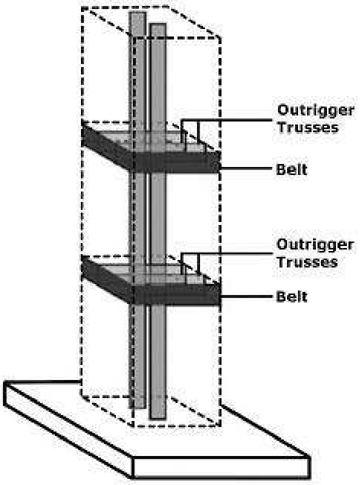

Figure 21: Illustration of an Outrigger System

5.4. Braced Frames and Shear Trusses

Diagonal braces can be a supplement to a rigid frame in order to create a more rigid building. Braced systems reduce the large shear racking deformations by decreasing bending of girders and columns. Diagonal members are placed inside the frames which carry lateral loads and therefore reduces bending of beams and columns. Braced frame systems are often more economical than moment resisting frames (Figure 22). The braced frames are often placed in the core of the building. Depending on the size of the core, the torsion resistance may be the controlling design parameter. The braced frame system is used in steel buildings and is effective up to 40 floors. There are a wide variety of different bracing systems which can be used (Taranath, 2010). There are two types of braced frame systems, concentric braced frames (CDF) or eccentric braced frames (EDF). In the concentric braced frames, many of the members intersect in a common point. This is not a requirement when using eccentric braced frames. Concentric braced frames are very strong and does not make them ideal in seismic zones due to their poor inelastic behaviour. In seismic zones it is better to use the eccentric braced frames, since this bracing type combines the strength and staidness of a braced frame with the inelastic energy dissipation characteristics of a moment resisting frame. This type of system is effective up to 25-30 stories.

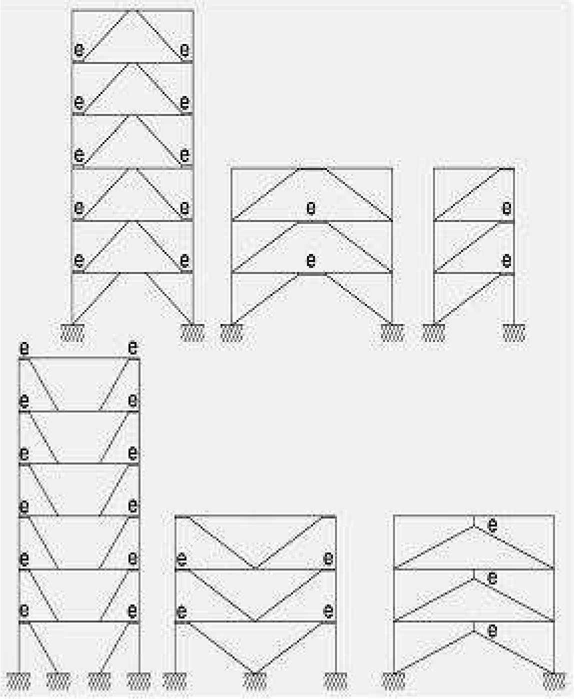

Figure 22: Eccentric Braced Frames

Another type of truss system is the staggered truss system (Figure 23). This bracing system was developed for residential buildings that are fairly long and narrow. Normally the system can be used for heights up to 25 stories.. Since the truss system should not block the passage through the building, some diagonal members of the truss must be removed. This is normally done in the centre of the building. Since the diagonals are removed the shear is instead carried by a stiff moment frame, which is added around the opening in the truss system. Openings in the truss system should be avoided since it is expensive to implement (Taranath, 2010).

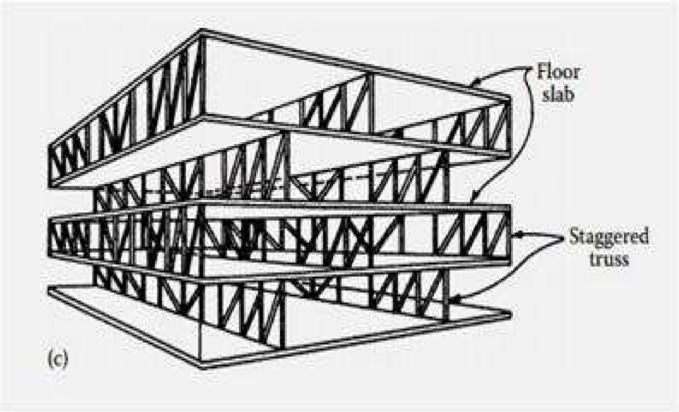

Figure 23: Staggered Truss System

5.5. Tubular Systems

There are many different types of tubular systems. Even if they are partly different, they use approximately the same technique to carry loads. Most of the tall buildings in the world are designed with some kind of tubular system. The framed tube system is used for buildings up to 60 stories. The load bearing capacity of the structural system is provided by the moment resisting frames that form a tube around the edge of the building. The tubes around the perimeter of the building engages the entire building to resist lateral loads. To create the frame for the tube systems, columns are placed closely together around the building's exterior. To obtain an even better structural system, additional bracing can be mounted on the exterior of the building. This type of system is called an exterior diagonal tube system and is one of the most used system. The exterior diagonal tube system can be used in buildings up to 100 stories. In Figure 24, the exterior diagonal tube system is illustrated.By connecting individual tubes, a bundled tube system is obtained. The tubes working together results in a very strong structural system, this means that the columns can be placed at an even greater distance which allows big openings for windows. An illustration of the bundled tube system is shown in Figure 25.

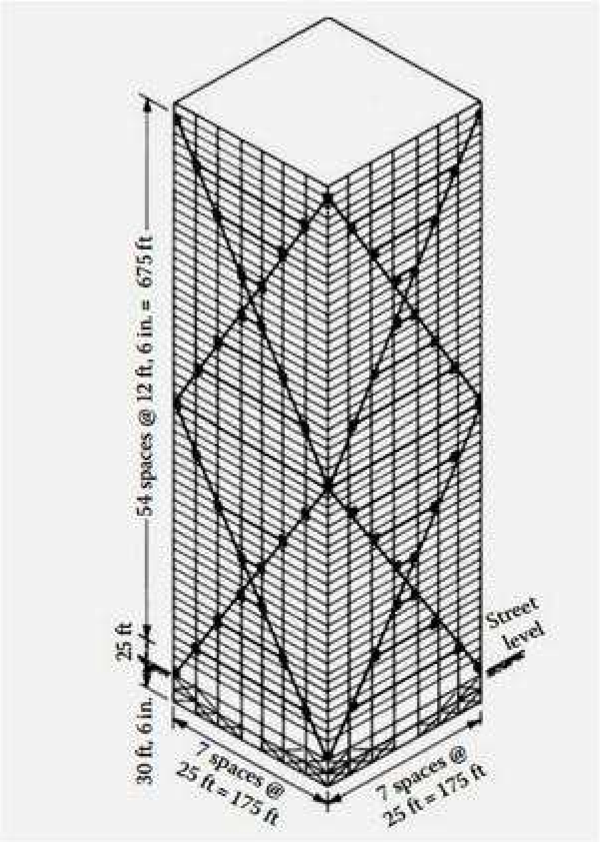

Figure 24: Exterior Diagonal Tube System

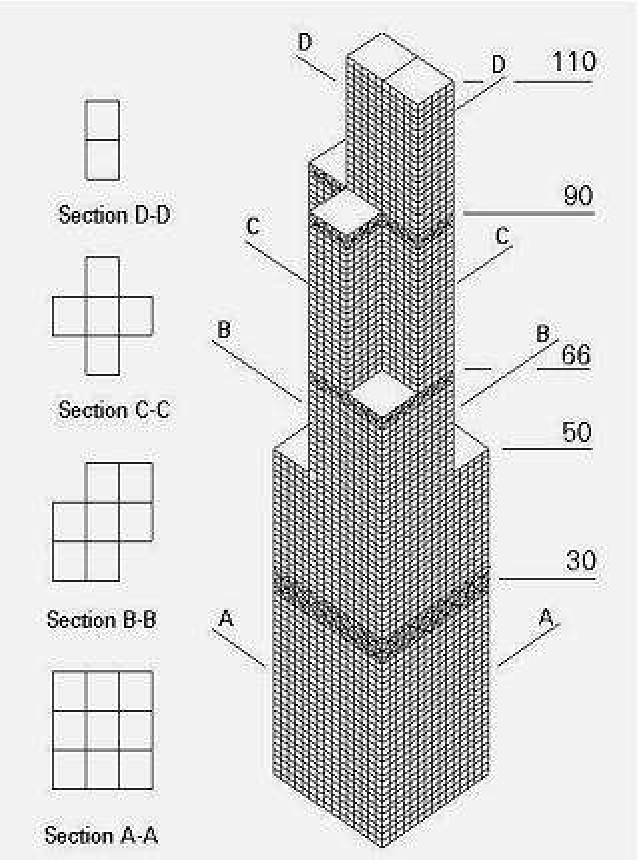

Figure 25: Bundled Tube System

By using a structural core inside the framed tube system, another type of tubular system is obtained; the tube-in-tube system. It uses the advantages achieved by a central core and combines it with very efficient framed tube system. The central core often contains the elevator shaft and service shaft (Taranath, 2010).

6.0. The High Performance Tall Buildings

Tall buildings are massive consumers of energy. They are the dominant elements in urban architecture due to their scale and purpose, and should be the focus of sustainable design. A high performance tall building is one that achieves the peak efficiency of building functions while meeting the requirements of optimum performance employing green technologies. These technologies and innovations offer radical changes to the built environments in terms of energy usage, structural performance, and environmental effects. In other words, a high performance tall building warrants an optimal approach to design for maximum sustainability. Designing a sustainable tall building, therefore, requires a 360-degree view of the entire building enterprise considering the local and global environment, the availability of renewable and non-renewable resources, community impact assessment, and the collaborative input of architects, planners, engineers, social scientists, behavioral scientists, and other community-based groups. Clearly, the design process is significantly complex since the designer has to understand the building performance in terms of different design factors and variables and under differing conditions. Some overall benefits of high performance design are: energy efficiency, design flexibility, resource conservation, indoor environmental quality, etc. (Donaldson and Lippe, 2000).

6.1. The Design Factors

The principal design factors that are crucial for achieving a high performance tall building are site context, environment, structure and use of materials, energy consumption, use of water, ecological balance, community development, etc. Because of these diverse aspects of design for tall buildings which have enormous scales as a building type, the amount of information that guides the design is often very complex, and shared by professionals of different disciplines. Further, the design factors assume different forms, such as conceptual, schematic, physical, economic, environmental, and socio-cultural. This demands smart design and integration, which hold the key to high performance buildings. The design team comprising different professionals must aim for the common goal set early on that "the building will offer optimum performance" and must have a respect and understanding for each other's mission. This goal must have clarity and be performance-oriented, attainable, and mostly measurable.

For high performance buildings, the full integration of architecture and engineering is crucial. A well integrated high performance building may incur a slightly higher cost than a regular one which is however offset by lower operational cost (Ali and Armstrong, 2006). An integrated process is necessary because of their scale and the fact that green design affects so many different elements of a building, such as day-lighting, which in turn concerns sitting, orientation, building form, facade design, floor-to-floor heights, interior finishes, electric lighting controls, and cooling loads, among other things. A green or vegetated roof, with its impact on storm water runoff, building structure and form, thermal insulation, and plantings, is another example where integration must be considered (Malin, 2006).

Integration among the hardware components of building systems is approached with three distinct goals: Components have to share space, their arrangement has to be aesthetically resolved, and at some level they have to work together or at least not conflict with each other (Bachman, 2003). Bachman (2003) lists three types of integration: physical integration, how components share space or fit together; visual integration, how they achieve visual harmony; and performance integration, how they share functions with other components and systems. The Hong Kong and Shanghai Bank Building, designed by Foster and Partners, in Hong Kong is an example where the visual expression of the physical systems and components of the building creates a powerful aesthetic impact.

6.2. Integration Web: The Tall Building System

Integration Web (Figure 26) is a tool to assist architects and engineers in the decision-making process at critical stages by clearly defining the relationships of all physical systems and subsystems of a tall building (Ali and Armstrong, 2006). While all buildings require integration, sustainable tall buildings require a greater level of integration at the early stages of the design process because they require coordination of complex, interdependent systems. However, over-emphasizing integration at the conceptual phase of a project can also be a drawback especially when considering LEED (Leadership in Energy and Environmental Design) credits. The checklist of LEED points can be helpful in identifying measures to pursue, many of which benefit from an integrated approach. But focusing on individual credits too early in the design process can also get in the way of design integration producing a “point-chasing mentality,” which drives up project expenses by causing people to forget how the points work together. During initial meetings, it is more useful for a team to focus on sustainable goals and opportunities on a broader level (Malin, 2006).

6.3. Case Studies: Focus on Sustainable High-Rise Buildings

A new generation of sustainable high-rise buildings is challenging conventional high-rise building practices and setting trends for future projects incorporating innovations in materials and intelligent building systems. The are some of the illustrative examples.

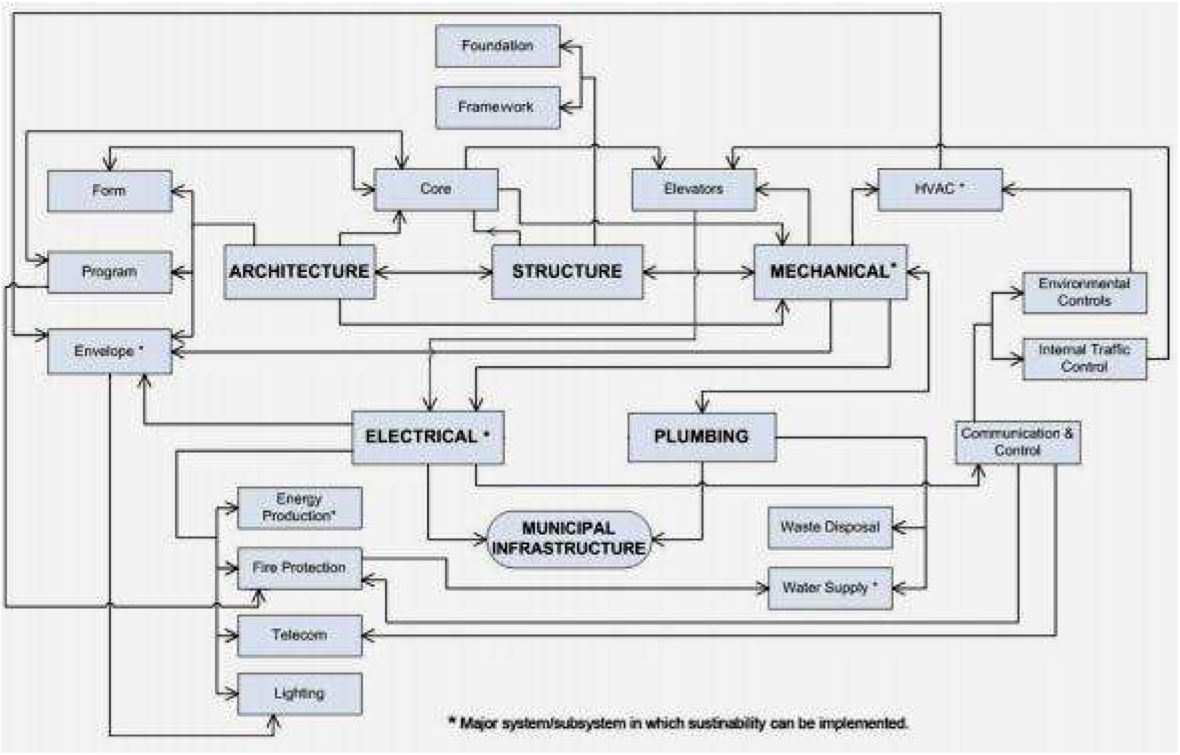

Figure 26: Integration Web - The Tall Building System

6.3.1. Menara Mesiniaga

Ken Yeang and T. R. Hamzah were among the first architects to apply ecological principles to their “bioclimatic skyscrapers.” The Menara Mesiniaga in Subang, Malaysia (Figure 27), designed in 1992, presents an early model building for the physical translation of ecological principles into high-rise architecture (Abel, 2003).

The fifteen-story tower expresses its technological innovations on its exterior and uses as little energy as possible in the production and running of the building. Instead of a continuous facade, the building open and closes in sections arranged in stages around the tower. It has an exterior load-bearing structure of steel with aluminum and glass, and a crowning superstructure for the roof, planned as a future support for solar cells. The interior and exterior structure of the tower is planned around climatic considerations and its orientation toward the daily path of the sun. The massive core of the building, with elevator shafts and staircases, faces east and screens off the penetrating heat up to midday. Deep incisions and suspended aluminum sunscreens on the south facade ward off the direct rays of the noon and afternoon sun into the interior. Most of the office space faces west and north. Around the base of the tower lies a semicircular, steeply sloping garden, which continues into the building itself in the form of spiral terraces planted with grass. This visibly brings the natural environment into the architecture.

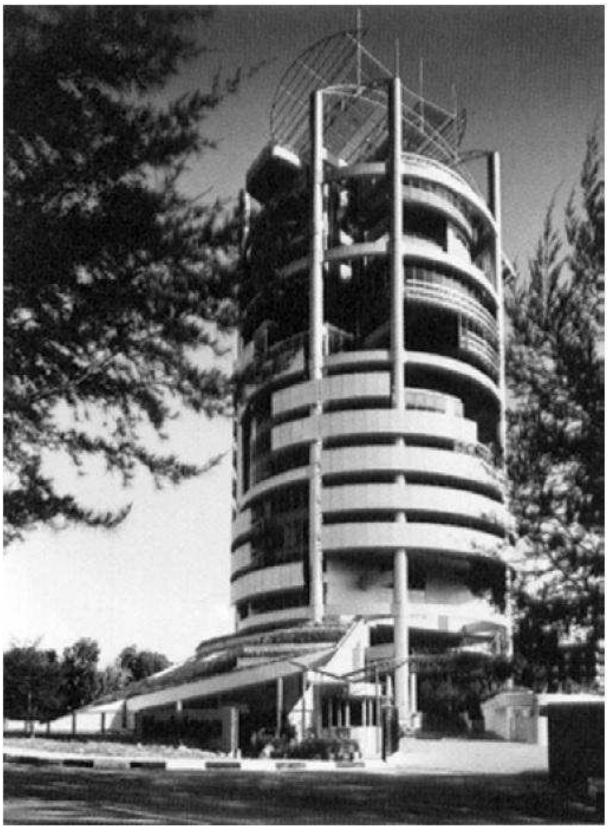

Figure 27 Menara Mesiniaga, Kuala Lumpur, Malayasia

8.3.2. Swiss Reinsurance Headquarters

Foster and Partners developed new technological, urban planning, and ecological design concepts in the Swiss Reinsurance Headquarters building (Figure 28) constructed in 2004 in London. The steel spiral “Diagrid” structure creates an aerodynamic form that provides the lowest resistance to wind and diminishes demands on the load-bearing structure, as well as the danger of strong downward winds in the area around the building. The office spaces are arranged around a central core with elevators, side rooms, and fire escapes. The net-like steel construction of the load-bearing structure lies directly behind the glass façade and allows support-free spaces right up to the core.

The Swiss Re Tower has a circular plan that widens as it rises from the ground and then tapers toward its apex. This form responds to the specific demands of the small site and reduces its apparent bulk as compared to a conventional rectangular mass of equivalent floor area. The slimming of the building’s profile at its base reduces reflections, improves transparency, and increase daylight penetration at ground level. The aerodynamic form of the tower encourages wind to flow around its face, minimizing wind loads on the structure and cladding, and enables the use of a more efficient structure. Natural air movement around the building generates substantial pressure differences across its face, which can be used to facilitate natural ventilation within the building (Foster, 2005).

Figure 28: Swiss Reinsurance Headquarters, London, U.K.

Figure 29: Conde Nast Building, Times Square, New York

8.3.3. Conde Nast Building

The Conde Nast Building (Figure 29) at 4 Times Square of 1999 in New York City is a 48-story office tower, is the centerpiece of the 42nd Street Master Plan prepared by the 42nd Street Development Corporation, a public/private consortium created to promote the redevelopment of this traditional heart of Manhattan (Wired New York, 2007). Designed by Fox & Fowle Partners, many of its innovations are considered standard for office buildings today.

The facades of the building address Times Square entertainment district to the west and the corporate Midtown area of Manhattan to the east. The building sets new standards in energy conservation, indoor environment quality, recycling systems, and use of sustainable materials. The large areas of glass curtain wall maximize daylight penetration into the office floors and incorporate low-E glass coating to filter out unwanted ultraviolet light while minimizing heat gain and loss. PV panels have been integrated in spandrel areas on upper floors of the east and south facades, generating a meager but symbolic amount of electricity by day. Sophisticated mechanical systems ensure high indoor air quality by introducing filtered fresh air into the office environment. Tenant guidelines produced by the architects established environmental standards for living, power usage, furniture systems, carpets, fabrics, finishes, and maintenance materials to ensure indoor air quality and also as a comprehensive strategy to maintain environmental sustainability for the life of the building.

8.3.4. The Solaire

Located at Battery Park in New York City, the Solaire (Figure 30) is the first residential high-rise building in the U.S. to integrate green features in a comprehensive way (Carey, 2006). It is a 27-story, 293-unit luxury apartment building located on the Hudson River developed by the Albanese Organization and designed by Cesar Pelli & Associates. Its sustainable features include PV panels incorporated into the building's facade, a planted roof garden, and fully operational blackwater treatment system. It is based on guidelines developed by the Battery Park City Authority, which address five areas of concern: 1) Enhanced indoor air quality; 2) Water conservation and purification; 3) Energy efficiency; 4) Recycling construction waste and the use of recycled building materials; and 5) Commissioning to ensure building performance (Carey, 2006).

Figure 30: The Solaire, Battery Park, New York

8.3.5. The Pearl River Tower

The Pearl River Tower (Figure 31) is a 990-foot (300-meter) tall "Net-zero Energy" mixed-use building, which will be completed in 2010 in Guangzhou, China. Designed by Adrian Smith and Skidmore, Owings & Merrill, it has a curved glass façade that directs air flow through narrow openings in the facade that will drive large, stainless steel wind turbines to generate electrical energy. The building's aerodynamic shape, which resembles airplane wings turned vertically, was developed in collaboration with Rowan Williams Davis & Irwin, Inc. of Ontario, Canada. using the RWDI-Skin suite of proprietary analysis tools, including its Virtual wind simulation modeling (RWDI Group, 2007).

Figure 31: Pearl River Tower, Guangzhou, China, 2010

The design of the Pearl River Tower is intended to minimise harm to the environment and it will extract energy from the natural and passive forces surrounding the building. Major accomplishments are the technological integration of form and function in a holistic approach to engineering and architectural design. The building is designed with energy conservation in mind, including wind turbines and solar collectors, photovoltaic cells, under-floor air distribution, and radiant heating and cooling ceilings. It is one of the most environmentally friendly buildings in the world.

Of Pearl River Tower's accomplishments, many are related to the sustainable design features including:

- The largest radiant-cooled office building in the world
- Most energy efficient super-tall building in the world
- The tower is an example of China's goal to reduce the intensity of carbon dioxide emissions per unit of GDP in 2020 by 40 to 45 percent as compared to the level of 2005.[11]

In a report presented at the 2008 Council on Tall Buildings and Urban Habitat it was reported that the building's sustainable design features will allow a 58% energy usage reduction when compared to similar stand alone buildings.

CONCLUSION

How high the next generation of skyscrapers will go is difficult to determine. Dubai's Burj Khalifa has 828 m of height, it is 60% taller than Taipei 101, the previous tallest building in the world. A number of super-tall buildings will be completed in the next few years. Super-tall buildings are extremely complicated to design, require a very robust leasing and sales market, and take more time to construct than most lenders can accept. In this context, an important topic of discussion would be as to how sustainable a high-rise tower can be. Although the trend to achieve net zero energy buildings, for which a balance between energy flow and renewable supply is established, the way to reach the goal is long. New skyscrapers in dense urban areas are generally greener than other types of commercial and residential buildings. They are typically located near mass transit, minimizing negative environmental impacts associated with road traffic. Vertical living also requires less energy for heat. Designers of skyscrapers continue to go to great lengths to minimize the environmental footprint of new buildings. These efforts take many forms: Orienting the building better to the sun and the wind, expanding the use of natural light and ventilation, providing thermal barriers in curtain wall design, maximizing the use of renewable energy (solar and wind), ensuring better collection and utilization of rainwater, and conserving energy through intelligent building managements systems. The shape of today's skyscraper is particularly notable. The advances in technology and materials have allowed erection not only of very high buildings but also allowed them to take on new and exciting shapes. Today high-rise buildings can twist, lean and turn back on themselves. These shapes are chosen for visual effect, but occasionally they contribute to minimizing wind loads by improving a building's aerodynamic properties.

The skyscraper of the future will have a mixed-use function. The increasing popularity of mixed-use complexes, and in particular the growth in residential towers, has left its mark on every aspect of skyscraper design and construction. In terms of structure, concrete has now overtaken steel as the most prevalent skyscraper material. In terms of construction, mixed-use buildings are more difficult and costly to erect than single-purpose one. In terms of design, mixed-use buildings present the added complexity of segregating users and uses, taken into account pedestrian flows, vertical transportation, loading and other services. In designing these buildings, architects must often deal with multiple building code provisions, as standards for commercial and residential occupancy often differ.

Technological innovations used in high-rise buildings can be manifested in many areas: Geometric form, construction, materials, vibration damping systems and energy efficiency. The development of computer technology has facilitated the design of high-rise buildings with complicated structural and functional solution forms. Increased computing power has allowed the creation of more advanced engineering programs, which for building models better simulate the actual behavior of a structure. This can especially be seen in high-rise buildings erected in the last years. Modern designs have broken the stereotypes of high-rise buildings in terms of history and tradition.

An important aspect in the design of various architectural forms is the determination of the relationship between the shape of a building and the quality of its construction. Very often curvaceous shapes are inspired by various forms, which can occur in nature Capital Gate (Abu Dhabi, UAE) and Burj Khalifa (Dubai, UAE). A tall building, due to its shape, can be a very distinctive landmark in its environment and thus an easily recognizable building.

A very important aspect associated with the technological development of high-rise buildings is the safety of their users. One World Trade Center in New York is the most advanced building in the world when it comes to security technology, setting new standards for the design of high-rise buildings. Sustainability is also a major issue concerning high-rise buildings (Navaei, 2015). It is strongly required to use sustainable concepts and applicable technology for reducing energy consumption and CO2 emissions. Covering the walls of a building with greenery affects the changing of microclimate, produces oxygen, absorbs CO2 and captures particles of pollution (Widiastuti et al, 2016; Kmie□, 2014). Currently, plants are becoming an appropriate facade material in the creation of architecture. Their use is planned and dedicated to achieving both a specific aesthetic and ecological effect.

By the nature of high-rise buildings, it is very difficult to achieve a low energy building. High energy consumption in high-rise buildings has influenced the search for innovative solutions aimed at improving energy efficiency in this area. The research was focused on solutions based on renewable energy sources. Currently, photovoltaic panels and wind turbines are primarily used to produce electricity for a building's own needs. Designing the building together with an integrated wind turbine constituted a major design challenge for the Bahrain World Trade Center building. The project had to take into account the wind speed and direction, which occur in a given area, and as a result change parameters depending on the geometry of the building. There are many factors that affect the flow of wind in these installations. Among them are not only the location and occurring terrain, but also the shape of the building and its dimensions. Skyscrapers not only favor the development of innovative solutions, but also aim to improve human comfort when visiting a building or the safety of people residing in it. For example, the HMS (home management system) system is used, which integrates the majority of installations in an apartment. The organization of operation and modern equipment of high-rise buildings means that they belong to the category of "smart buildings".

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