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Innovation and Technological Advancements in High Rise Buildings "In search of enabling the most flexible space in Architecture"

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Abstract – Since the design of the first high rise building, the "Home Insurance Building" erected in Chicago in 1884-1885 only with 11 floors, new technologies encourage the designers to build taller and slender buildings penetrating through the sky. In the history, high rise buildings are the results of the complex interaction of innovations in structural and mechanical systems, as well as artificial lighting, curtain wall systems, and etc. The high rise building typology developed with the office function mainly in New York and Chicago in 19th century. As people will be living in more dense cities in the near future, high rise is mainly accepted as achieving more sustainable cities.

Structural system plays a significant role in determining the overall form and efficiency of a high rise building. The building typology in the globe in the last two decade, the most significant trend related to high rise constructions are iconic and competitive within each other. These new forms are the results of the technological developments and innovative structural systems, such as diagrid systems, mega frames, light concrete systems, high-strength concrete tubes, core and outrigger structures, butressed core, etc. Considering the wind load, lateral load earthquake and gravity high rise buildings' slenderness ratio is related with its structural efficiency. The success of designers is related mainly facing these issues by optimizing these facts wihin the design itself. The developments in technologies enrich the opportunities for the architects and structural designers to create flexible spaces with slender buildings of the future.

The developments in material and technologies in structural design the foot prints of the high rise buildings are using less space in cities and allow the architects to use more free spaces apart from floor plans filled with thick columns and shear walls. This paper focuses mainly on how the developments take place in recent projects in the world. Residential high rise examples from United States such as 432 Park Avenue designed by architect Rafael Vinoly and 111West 57 Street (Steinway Tower) by Shop Architects and Herzog De Meuron's 56 Leonard Street buildings will be evaluated in detail in terms of the new technologies such as structural systems and engineering services.

Keywords – High Rise, Technology, Flexibility, Architectural Design, Innovation

I. Introduction

This paper focuses on mainly about the technological advancements in high rise building regarding the structural and architectural design. The developments in high rise design in terms of engineering and the effects to create the most flexible and the effective space in high rise buildings.

Since the design of the first high rise building, the "Home Insurance Building" erected in Chicago in 1884-1885 only with 11 floors, new technologies encourage the designers to build taller and slender buildings penetrating through the sky. In the history, high rise buildings are the results of the complex interaction of innovations in structural and mechanical systems, as well as artificial lighting, curtain wall systems, and etc. The high rise building typology developed with the office function mainly in New York and Chicago in 19th century. As people will be living in more dense cities in the near future, high rise is mainly accepted as achieving more sustainable cities.

Structural system plays a significant role in determining the overall form and efficiency of a high rise building [1]. The building typology in the world recently, the most significant design trend related to high rise constructions are iconic and competitive within each other. These new forms are the results of the technological developments and innovative structural systems, such as diagrid systems, mega frames, light concrete systems, high-strength concrete tubes, core and outrigger structures, butressed core, etc. Considering the wind load, lateral load earthquake and gravity high rise buildings' slenderness ratio is related with its structural efficiency. The success of designers is related mainly facing these issues by optimizing these facts within the design itself. The developments in technologies enrich the opportunities for the architects and structural designers to create flexible spaces with slender buildings of the future.

II. Materials and Method

The developments in material and technologies in structural design the foot prints of the high rise buildings are using less space in cities and allow the architects to use more free spaces apart from floor plans filled with thick columns and shear walls. This paper evaluates mainly on how the developments take place in recent projects in USA. Residential high rise examples from United States such as 432 Park Avenue designed by architect Rafael Vinoly, 111West 57 Street (Steinway Tower) by Shop Architects and Herzog De Meuron's 56 Leonard Street buildings are evaluated in detail in terms of the new technologies such as structural systems and engineering services.

The evaluations of these three buildings were examined according to their sizes, their structural engineering approach and architectural concepts.

Brief Background of the High Rise Buildings

Throughout the history, high rise buildings are the result of the complex interaction of many events and innovations in structural and mechanical systems, as well as artificial lighting, curtain wall systems, and etc The high rise building typology has developed mainly with the office function in 19th century in New York and Chicago. The first examples were constructed by load-bearing masonry walls, which makes them very heavy, so they necessiated stronger foundations piled into the stiff bedrock. The invention of steam powered drilling and digging machines in the 1830s allows to construct these foundations. [7]. Also the early high rise building developments were based on economics; increasing rentable area by stacking office spaces vertically, and introducing as much natural light as possible was the prior task. In order to achieve this task, new technologies were developed upon the conventional load-bearing masonry walls that had relatively small openings. The result was the iron/steel frame structure, which minimized the depth and width of the structural members at building perimeters. Economically favorable, mass-produced rolled steel became available after 1856 through Henry Bessemer's invention [2].

The invention of the elevator in late 19th century, the firefighting systems and ventilation systems were the main developments who supported to raise the height till mid of the 20th century to make the life in those buildings more comfortable Before the mid of the 20th century the height limit passed over 300 meters with the Chrysler Building of 1930 and Empire State Building of 1931, in New methods rather than technological developments.

After the World War II, the era of mass production came and the International Style emerged by the architects educated in Europe and influenced by Bauhaus. . Mies van der Rohe's 860-880 Lake Shore Drive apartments (Chicago, 1951) and Seagram Building (New York, 1958) were the significant examples of this new approach. The International style continued until the late 1960s, the time of the construction of collapsed World Trade Center twin towers (New York, 1969).

Technological Developments in High Rise Buildings

Developments in structural systems such as diagrid, outrigger structures mega frames, light concrete systems and high strength concrete tubes, core and outrigger structures, buttressed cores are the new systems that provides more flexibility to architects in their design. Out of box aerodynamic forms and tilted, twisting forms are the results of the digital era. The advances in concrete construction technology, such as self-climbing robotic formworks, reusable forms, prefabricated reinforcement cages, and state-of-the-art concrete pumping systems for ultra heights, allowed the speed of concrete construction to compete with steel. In addition Very High Strength Concrete (VHSC), Self-Consolidating or Self-Compacting Concrete (SCC), Lightweight concrete, and other concrete mixtures led the concrete to be the only alternative structural material for ultra high rise buildings,

Inventions in elevator systems, smart materials and nanotechnology the electro mechanical systems provides comfortable and flexible working and living spaces.

Façade solutions among the high rise building are the use of double skins, occasionally triple skins, adaptable or responsive facades, but most significants are the facades with operable windows or openings, which enable Natural Ventilation (NV). Another recent approach in façade technologies is the responsive skins. This new generation of high-performance envelopes have contributed to the emergence of sophisticated assemblies combining real-time environmental response, advanced materials, dynamic automation with embedded microprocessors, wireless sensors and actuators, and design-for-manufacture techniques [2].

432 Park Avenue

Design architect behind 432 Park Avenue is Rafael Viñoly, who envisioned the building on the basis of the square, a purist geometric form. With its identical width and length of 28,5 m and a total height of 427,5 m the slenderness ratio of the building is 1:15. (see figure 5)

The architectural concept, the aspect ratio of the building, and its specified structural performance resulted in interesting challenges which required the pioneering of several structural engineering solutions. The design incorporates energy efficiency and renewable technology approaches which have made the building LEED certified.

The main architectural attributes of 432 Park Avenue are symmetry and simplicity. The regular 4,72 m to 4,72 m by grid defined by exposed structural members is perfectly matched by large squared glass windows, which allow for amazing views of Manhattan. The orthogonality of structural members further conveys a sense of strength and stability to a slender structure. The compact footprint of the project, in combination with its extraordinary height, has permanently changed the paradigm of economical design of high-rise buildings. [3].

The structural concept consisted of a dual tube-in- tube system formed by an exoskeleton of perimeter moment

frames integrated by spandrel beams and columns, which were interconnected to the interior
Shear wall core by outriggers placed at key elevations. ftis configuration allowed for unobstructed open spaces at practically every floor (Figure 3-4).

The open drums in certain levels allow the wind load to flow through these openings and with the support of the tunned mass damper at the top performs the best comfort for the residents in the building.
With these structural engineering solution the architects uses the opportunity to use the unobstructed space in terms of spatial design.
The main structural engineering challenges of 432 Park were not only triggered by the aesthetics of Rafael Viñoly's vision but also by the financial considerations of such a unique and ambitious project. Nevertheless, the structural approach developed for the project was able to address the requirements of the client while providing the most cost-effective solution and maintaining a balance between aesthetics and functionality.

56 Leonard Street

Inspired from the famous jenga game (see fig 7) the architect Herzog De Meuron defines the architectural idea like as follows : "The project is conceived as a stack of individual houses, where each house is unique and identifiable within the overall stack" . The architect mentions that the towers are solely artifacts that the residents might be uncomfortable living in such heights. Quoting from the designers expalanations architect is saying that *typical residential towers, while successful in aggregating the living unit, often fail to improve upon the living environment. The multiplication of units within simple extruded shapes produces repetitive and anonymous structures with no extra benefits or architectural qualities despite the incredible densities they achieve. For those who live in these structures, this experience of sameness and repetition can be relatively unpleasant. 56 Leonard Street acts against this anonymity and repetitiveness, emanating from so many towers of the recent past. Its ambition is to achieve, despite its size, a character that is individual and personal, perhaps even intimate.*

The structural solution to allow this kind of architectural concept is to use a very strong concrete structure, concealed to allow a completely glazed exterior with views from almost every angle. The central core is linked to the external columns by outriggers at the mechanical levels 32 and 46. At the top is the 'swimming pool' – a slosh damper filled with 130,000 litres of water to temper the building's movement in the wind.

Supporting the cantilevers was one of the biggest conundrums for structural team. For the smaller ones, the thickness of the concrete floor slabs provides sufficient support. For the larger ones above 4,72 m there are additional beams, and for the very largest, a Vierendeel truss – a perpendicular column that engages two floors, without obstructing layouts or views. Throughout the structure, there are many 'walking columns', where loads are transferred from one location to another as they progress down the building (Fig 9). There are no dividing shear walls in the apartments at all, to allow residents to lay out their living spaces as they wish, or to combine apartments horizontally or vertically.

The greatest cantilevers are at the top of the building. The uppermost 10 floors each comprise just one apartment, known as 'sky villas'. "It won't feel as if each occupant is living in a high-rise building but in a house in the country," says the designer.

111 West 57 Street

111 West 57 street is one of a new residential tower that are pushing that ratio to previously higher levels. The designers argue that far from being a new typology for New York, super-slender is a return to its classic era of skyscrapers. "Pre-war, before air-conditioning, buildings tended to be thinner to get people closer to light and air. In these new buildings, because they're residential, light and air again becomes an issue and we have an opportunity to look back to historic buildings and what makes those so special."

Designers approached 111 West 57th Street with the ambition of creating a classic Manhattan skyscraper. In fact, while the building's super-slender form may look startlingly new, it is itself a heritage project. As well as the construction of the tower, the scheme involves the complete restoration of the 1923 Steinway building, an Art Deco landmark for the city.

As a slender building such as 111 West 57th Street it is mandatory to have a stiff and strong structure to endure wind and seismic forces. Structural designers have achieved the necessary strength with two shear walls running the height of the east and west elevations of the building. This leaves the others completely clear, so that residents can comfortably live uninterrupted vistas of Central Park to the north and Midtown and downtown Manhattan to the south. There is also a tuned mass damper at the top of the building, concealed by the lightweight steel structure that completes its delicate tapering form.

Fig. 1 432 Park Avenue, 111 West 57th Street High Rise Buildings shaping the silhouette of upper Manhattan

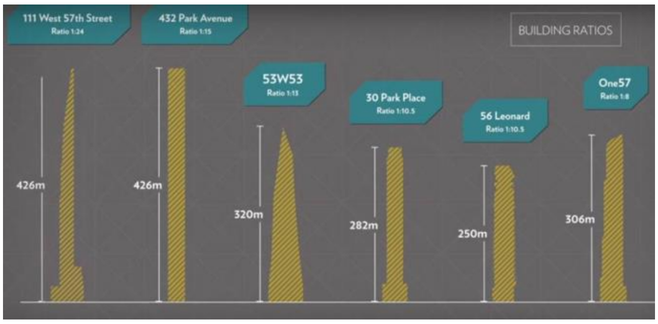

Fig. 2 Slenderness Ratio Comparison for high rise buildings

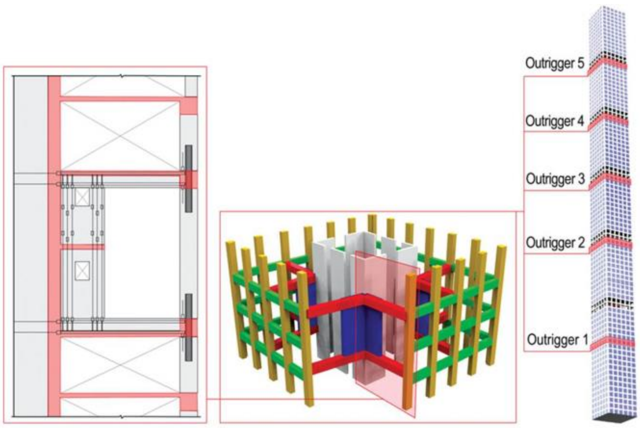

Fig. 3 Outrigger Structural System of 432 Park Avenue

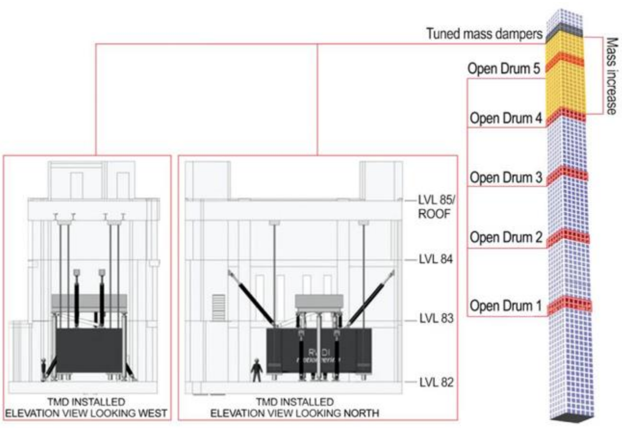

Fig. 4 Open Drum and Tunned Mass Damper Diagram

Fig. 5 Slenderness And small footprint of 432 Park Avenue

Fig. 6 Structural System Allows Architect to use unobstructed free space

Fig. 7 56 Leonard Street By Herzog De Meuron inspired From Jenga Game

Fig. 8 Strong Concrete Use For Cantilevers of 56 Leonard

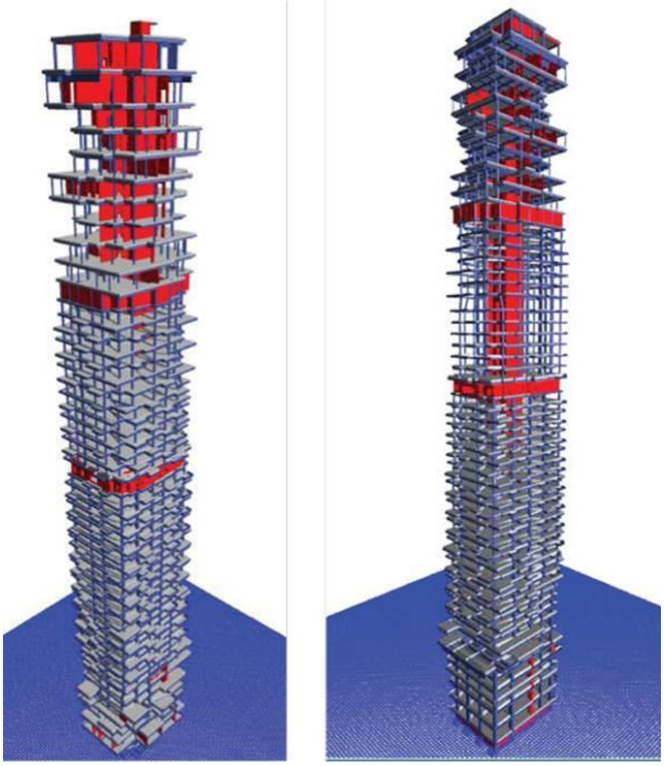

Fig. 9 Diagram for walking columns carrying the loads to shear walls and to the foundation

Fig. 10 The Entrance and the Street Connection

Fig. 11 111 West 57 Street will be the most slender residential building after its completion

Fig. 12 The perfect gridal façade of Vinoly's 432 Park Avenue

III. Results

Regarding these three high rise buildings which have carried the slenderness ratio to a higher level all three designers worked closely with structural engineers using high quality strong concrete technology, outrigger systems, dealing not against the wind load instead accepting it passing through the buildings as in 432 Park Avenue.
Considering their foot prints in comparison with the former ones they use small traces in the city ground. All electromechanical systems have been used as energy saving and the buildings are energy efficient.

IV. Discussion

The foot prints of the high rise buildings and the slenderness ratios in the near future are going to be developed further with technological improvements and interventions. The discussion will follow the line if these high rise buildings of the future will be used by individuals for residential functions further or will they be left unused to their destiny. The structural developments will ensure the architectural designers won't be considering the loads as an issue as today. Will these high rise buildings create the natural environment that the individuals live comfortably.

V. CONCLUSION

As mentioned previously the technology allows the designers to build 1000 m or taller buildings. Regarding the skyscraper building list for the upcoming high rise building it is seen that this will be realized soon. However, designers shall not forget that these ultra high buildings will be used by individuals and will accommodate people. Ironically it is related that the future of these buildings are combined with real estate market charts which will define their future. The question is if these buildings are going to be occupied by their users.

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