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An Investigation on Plan and Facade Characteristics of High-Rise Buildings

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Abstract

High-rise buildings are an increasingly common type of commercial and residential buildings because of their large capacity on small lands. These buildings appear with different architectural features with the development of new building materials and technologies. In this study, plan shapes and facade forms used in high-rise buildings are investigated considering the ten tallest buildings in the world. Architectural characteristics of the considered high-rise buildings are briefly summarized based on the results of detailed investigations. Structural systems of the buildings are analyzed, particularly in plan shapes. As a result, it has been observed that different plan shapes and facade forms are determined based on building-specific reasons. High-rise buildings are designed with different architectural plan forms in accordance with the functional requirements. These plan forms are also created with various common areas to strengthen the relations of building users with each other. On the other hand, the most important factor in the current design practice of these forms is the wind load and the forms are generally designed considering the results obtained from wind tunnel analysis. The use of rounded lines in plan and facade forms allows the wind load affecting the building to decrease and the user's comfort to increase. Another important factor in the design is the creation of an aesthetic appearance on the exterior of the high-rise building. In particular, the facade forms of such buildings are designed in accordance with the design principles for increasing the aesthetic perception of the building, as well as the image of the city.

Key words

High-rise buildings, Aesthetic perception, Wind load, Plan shape, Facade form

1. INTRODUCTION

High-rise buildings are generally built in big cities and the number of these buildings is ever-increasing around the world. High-rise buildings are designed with different approaches in plan and facade forms as a result of the increase in building height. One of the most important factors dominating the design approach is the lateral loads caused by wind and earthquake ground motion. Excessive lateral loads acting on high-rise buildings directly affect the comfort and safety of building users. Therefore, the plan and facade forms of high-rise buildings are commonly designed to reduce the potential influence of lateral loads. In addition to structural considerations, the remarkable appearance of the building is another important factor affecting the design of high-rise buildings. As a result, these buildings are becoming the symbols of big cities, and therefore their aesthetic and striking appearance is an important issue to increase the prestige of the city.

The present study evaluates the plan and facade forms of the tallest high-rise buildings in the world. Accordingly, the ten tallest completed buildings in the world are studied. First, the plan shapes of the considered buildings are analyzed in particular and schematic plan views of different floors are drawn schematically by the Authors to clearly illustrate the structural forms. Afterward, facade forms obtained from Council on Tall Buildings and Urban Habitat database [1] are examined. Finally, plan and facade characteristics of the ten tallest completed high-rise buildings in the world are compared.

2. PLAN CHARACTERISTICS OF HIGH-RISE BUILDINGS

There are some considerations commonly implemented in designing the plan of high-rise buildings. One of them is a symmetrical plan shape with a core in the middle. Some buildings have multiple cores inside and asymmetric plan shapes. However, designing the building with a symmetrical plan is more effective in terms of resistance to the lateral forces. Cores are vertical structural elements and, from an architectural point of view, they limit the area of usage in high-rise buildings. Designing a building with multiple cores leads to less usage area than that of a building with a single core. On the other hand, cores are very essential elements to be considered in the structural design of high-rise buildings. For mega tall buildings which are higher than 500 m, floor plan areas are generally observed to decrease.

Table 1 shows the different plans of the lower, middle, and upper floors of the ten tallest completed buildings in the world. All the plan shapes are drawn by the Authors. It is apparent from this table that each high-rise building has specific design aspects. However, some approaches are similar for some buildings. The plan shape of the seven buildings is square or rounded square whereas the other three buildings, Burj Khalifa, Shanghai Tower, and Makkah Royal Clock Tower, stand out with their different plan shapes. Burj Khalifa building has a Y-shaped plan [2]. This plan form provides an advantage in increasing the facade ratio of the building, as well as the resistance against lateral loads. Shanghai Tower has a double-skinned facade system. The form of this facade provides developing atriums at every 12- to 15-floor level and these floors are designed in the shape of triangles. Plans of the other floors are in the shape of a circle [3]. Makkah Royal Clock Tower has a rectangular form and the upper floor plan is not presented in Table 1 since the mechanism of the world's highest clock is located on the upper floor [4].

Three of the listed buildings have sharp corners and straight edges, while the other buildings have rounded corners, concave and convex edges. One World Trade Center stands out with a different design from other buildings. In the plan of this building, the edges are straight, while the corners are chamfered. As the height of the building increases, the corners of the core form are also chamfered [5].

As a result of increase in height of many high-rise buildings, the floor areas become narrow and the building becomes slender. However, in CITIC Tower, the smallest floor area is on the middle floor. The floor area of the building decreases from the ground floor to the middle floor and increases from the middle floor to the top floor. The design of this building was inspired by the "zun" shape that emerged during the Bronze Age of China [6].

On the upper floors of high-rise buildings, the facade is exposed to severe wind loads. For this reason, spaces such as balconies and terraces that open to the outside are generally not designed on the upper floors of high-rise buildings. In Burj Khalifa and Guanzhou CTF Finance Center, terrace areas are created by setbacks. In Burj Khalifa building, terraces have been created by making 9 m setbacks at every seven floors and wind sensors have been used to ensure safe access to these terraces [2]. In this way, more opportunities are provided for building users to have fresh air in open space.

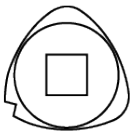
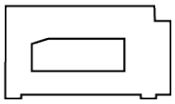
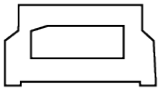
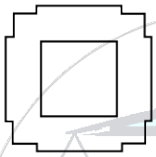
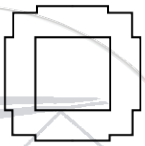
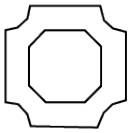
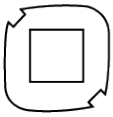
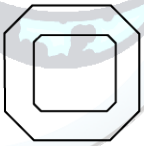
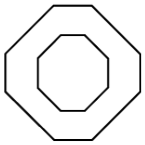
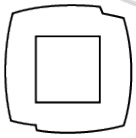
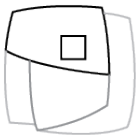
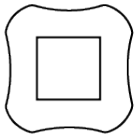
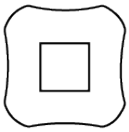
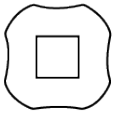
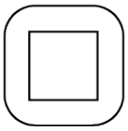
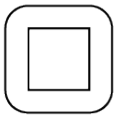
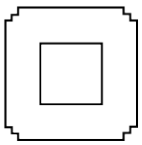
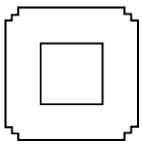
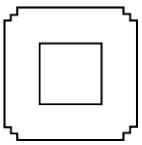
3. FACADE CHARACTERISTICS OF HIGH-RISE BUILDINGS

Different approaches have been used in the design of tall buildings throughout history. Before the development of new structural systems and materials with high resistance and deformation capacity, masonry structural systems were frequently used in high-rise buildings. The ground floor walls of these buildings were very thick and these thick walls occupy a lot of space in floor areas. With the development of new structural materials, structural elements begin to occupy less space in the floor plan. At the beginning of the 20th century, these structural elements were also shown on the facade as a design approach of this period. At the end of the 20th century, design approaches that give a mechanical appearance were applied to the facades of high-rise buildings [7]. In the 21st century, glass curtain wall systems are commonly used in high-rise buildings. It is observed that the facades of the all buildings investigated in this study are also designed with glass cladding.

Mega-tall buildings often become thinner as a result of height increase. Therefore, the mass of the building reduces and inertia forces tend to decrease. The facade forms of the world's ten tallest completed buildings are shown in Table 2, where the total height (H_N) and the floor numbers (N) are also given. It can be seen from the data in Table 2 that except for CITIC Tower, every building tapers as it rises. However, the tapering rates and zones are different for each building. Burj Khalifa building has setbacks on certain floors and it is the building

with the highest ratio of ground floor area to upper floor area. In Shanghai Tower, designers decided a scaling of 55% from base to top according to the analysis. Analyses are also conducted for the rotation ratio and 120° is found to be the optimum rotation angle of the building [8].

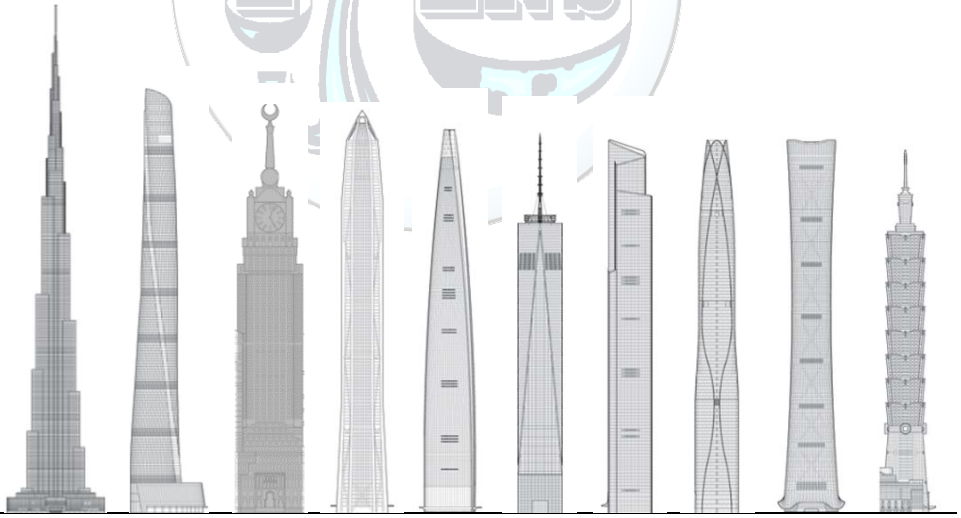
Table 1. Floor plans of the considered high-rise buildings

Building name	Lower floors	Middle floors	Upper floors
Burj Khalifa			
Shanghai Tower			
Makkah Royal Clock Tower			–
Ping an Finance Center			
Lotte World Tower			
One World Trade Center			
Guanzhou CTF Finance Center			
Tianjin CTF Finance Center			
CITIC Tower			
Taipei 101			

Makkah Royal Clock Tower and TAIPEI 101 have the architectural and cultural traces of the region where they are built. Makkah Royal Clock Tower is the tallest clock tower in the world and has a huge crescent at its top. The Taipei 101 building was designed with inspiration from the pagoda architecture and motifs from the Chinese culture were used on the facade of the building [9]. In the facade form, Taipei 101 tapers from the ground floor to a certain height. On the other hand, Makkah Royal Clock Tower and Lotte World Tower were continued with the same floor area up to a certain height from the ground and then tapered. Furthermore, the Lotte World Tower form was inspired by the historical Korean arts of ceramics, porcelain, and calligraphy. The building's curvilinear form and its slender conical form reflect Korean craftsmanship [10]. In the facade designs of Ping an Finance Center and Tianjin Tower, the structural system elements are emphasized on the facade. The braced or curvilinear forms of some structural elements are determined in accordance with the analysis. The word “ping” in Chinese means peace and security, and Ping an Finance Center is designed to give the image of a safe building.

The facade design of One World Trade Center was inspired by the tapering triangular forms of the Chrysler Building and Empire State buildings, which are the important buildings of the city. As the height of the building with cubic floor area increases, its corners are chamfered, resulting in a facade design consisting of eight isosceles triangles.

Table 2. Elevations and perspectives of the considered high-rise buildings

Building name	Burj Khalifa	Shanghai Tower	Makkah Royal Clock Tower	Ping an Finance Center	Lotte World Tower	One World Trade Center	Guanzhou CTF Finance Center	Tianjin CTF Finance Center	CITIC Tower	Taipei 101
N	163	128	120	115	123	94	111	97	109	101
H_N (m)	829	632	601	599.1	554.5	541.3	530	530	527.7	508
Elevation										
Perspective										

4. SUMMARY AND CONCLUSIONS

In this study, the design approaches regarding the plan shape and facade form of the ten tallest completed buildings in the world are examined and compared. The results of this study indicate that the most common plan shape is square. Moreover, the other high-rise buildings have Y-, circular, and rectangular plan shapes. Rounding the sharp corners of symmetrical shapes is a more accurate approach, but sharp corners are also used in some buildings. The chamfered corner design is frequently preferred. Based on the results of wind analysis, it has been understood that the use of rounded or chamfered corners instead of sharp corners reduces the wind loads on the building and increases user comfort. It has been observed that concave and convex edge designs are preferred in some buildings in plan form. This design approach has been determined in accordance with the conducted analyses, as well as the aim of obtaining an aesthetic appearance. It has been observed that the floor areas of the buildings decrease as a result of the increase in height, and only CITIC Tower has a different design approach in this regard.

The results of the investigation on the facade forms of buildings reveal that a design approach that is tapered as a result of the increase in height has been preferred. This approach decreases the building mass and the inertia loads acting on the structural system. The facades of the buildings are designed with glass curtain walls and the structural system elements of some buildings are emphasized on the facade. Approaches reflecting the cultural and architectural characteristics of the region where the building was built are also apparent. Floor terraces are created with setbacks and the relationship of building users with the outside is strengthened. Shanghai Tower stands out with a different approach from other buildings, which is a 120° rotating facade form.

Finally, it can be concluded that high-rise buildings are designed in accordance with the requirements of the country or region where they are built. The designs are dominated by analyses that measure the effect of lateral loads on the building. The differences and similarities mentioned above for the ten tallest buildings of today will continue in the tall buildings to be built in the future. More different design approaches will be possibly as a result of the developing technology and the number of high-rise buildings will gradually increase.

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