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Tall Buildings Preliminary Deign Criteria for Architects

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Abstract

Tall buildings, according to the progress of human societies are increasing dramatically in different parts of the world. The point that distinguishes a high-rise building from the other ones is the prominent role of structure in the tower design. So, the structure in the design process and architectural final design not only heading its main task, means bearing and transmission forces, but also accepts other roles to cover other design criteria including aesthetics, energy and etc. The reason for combination of these roles is in a high-rise building due to the reduction of the weight of the building in order to bear lateral and gravity forces, structure must accept multiple roles to reduce additional elements. In this paper, by studying effective measures in designing of tall buildings and identifying the characteristics of each one, suggestions are offered towards appropriate integration of these measures in order to design a high-rise building. These suggestions can help architects at the beginning of the way of designing a tower. In fact, considering these measures lead to create options that other design teams (like structural team) will not face the great problems in the rest of the way.

Keywords: High-rise Buildings; Design Criteria; Structure; Aesthetics; Energy; Urban Design; Skyline; Design Process

1. Introduction

These days due to the fact that population has been increased, countries tend to build tall buildings and this tendency increases day by day. There will be, of course, those who oppose such developments arguing that tall buildings are unwelcome intruders that drain the financial resources of a city. They also argue that these tall buildings are the product of the greed and grandiosity of

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wealthy developers and power-hungry politicians (Kheir, 2011). This particular debate has been going on for a long time with no end in sight. One thing is certain: people who criticize high-rise developments have no alternative credible solution to the problems of overpopulation and overcrowding of future cities.

In tall buildings because of gathering numerous items inside the building, they have many complexities in design and construction. Different criteria have effects on the process of designing a high-rise building. These criteria, sometimes are aligned and some other times they are opposite. That is the reason that responding to one of them needs violating the other one. The main goal of the design team is concentrating on criteria and make a priority of them and then making responses for all or at least most of them according to designing priorities. The most important thing is getting to know features of each criterion to have the most integration with other design principles.

In this article, we are going to check out different criteria in designing tall buildings in five categories; Aesthetics, Energy, Structure, Urban and Other criteria. After that we will talk about interactions between criteria and at last, we will suggest what to do to have all criteria together peacefully.

1.1. The History of Tall Buildings

A series of tall buildings that were tall and big at the time of their construction were built at the turn of the twentieth century. These included the Wainwright Building of 1890 in St. Louis, the Guaranty Building of 1895 in Buffalo, New York, and the Reliance Building of 1895 in Chicago. This trend continued in New York with the Flat Iron Building of 1903, continuing to the Chrysler Building of 1930, and the Empire State Building of 1931. Following a pause in construction during the Great Depression and the Second World War years, tall building construction re-appeared in Chicago (Beedle et al., 2007).

In 1926 Frank Lloyd Wright developed a series of drawings called “Skyscraper Regulation,” after his visit to New York (Schipporeit, 2000). In these drawings, he offered his concept of accepting the grid and planning several cities blocks together. He created a second-level bridging over the streets for pedestrians and provided landscaped gardens and terraces on horizontal surfaces. Parking and commercial and retail services were placed within the base of the towers that were integrated with vegetation. This was an attempt by him to make sense out of the city before he embraced the idea of spreading the city out (Kheir, 2011).

Immense progress was made in the development of tall buildings after the Second World War, first in the United States and then by the Pacific Rim countries, parts of Europe, and the Middle East. Although technology has advanced and the architectural style of tall buildings has changed, their architectural planning concept of stacking a series of floors vertically and achieving spatial efficiencies by increasing the net-to-gross floor area has remained the same (Kostof, 1995). Despite architecturally ambitious thinking and technological and structural innovation, the focus of these buildings has remained on economic viability, and technological and constructional capabilities (Yeang, 2002).

1.2. Literature Review

About tall buildings designing there are several reference books and lots of papers. Most papers talk about just one or two criteria that seemed more important to writers to search about. In the paper, In Evaluation of Parental Satisfaction of Children’s Spaces within High Rise Apartment Environments (Sharghi et al., 2014), the authors have examined the importance of outdoor spaces

and playing space for children in high-rise buildings, and by examining a few examples of high-rise buildings, the level of satisfaction of parents and adults living in the building has been measured by a questionnaire asks about the available facilities in the building and the highest marked deficiency was open spaces. At the end of the research, suggestions were made to locate these spaces on the site. In another research, A Causal Analysis of the Sense of Community for High-Rise Residents in Bangkok Metropolitan Area (Rujibhong and Upala, 2017), the authors examined the sense of community in high-rise buildings, particularly in a high-rise neighborhood in Bangkok, and a group of people was selected as the test population, using a survey form in which sense of community in that area was asked. The results showed that in the neighborhood with tall buildings, the sense of community is far less in other areas. There are many articles about having a sustainable system and structure in tall buildings. One of them is, Observance of the principles of environmental sustainability in tall buildings (Mohammad Hosseini and Yousefi Tazakor, 2016), in which the authors after introducing tall buildings, stated the necessity of energy sustainability, and at the end, it offers solutions to make tall buildings more sustainable from an energy perspective. About the reference books some most important ones are Tall Building Guidelines City of Toronto (adopted by city council, 2013), Designing Tall Buildings Structure as Architecture (Sarkisian, 2011), The Tall Buildings Reference Book (Parker and Wood, 2013) and London Borough of Tower Hamlets Tall Buildings Study (Assembly and Parliament, 2017). Sarkisian in his book "Designing Tall Buildings Structure as Architecture (Sarkisian, 2011), this book is a comprehensive guide to what is important in the design of tall buildings. In this book, he talks about one of the criteria in each chapter in order to provide the reader with enough knowledge to design tall buildings. Sarkisian is a structural engineer, and this book is the result of his personal experience in designing and building tall buildings. Due to the fact that the main field of the author is related to structure, this book examines tall buildings and its design criteria more than the aspect of structure and construction, and no attention is paid to the impact of these criteria on architectural design. Dave Parker and Anthony Wood have also written a reference book for designing tall buildings. In this book, The Tall Buildings Reference Book (Parker and Wood, 2013), they discussed the importance of tall buildings and the need to use them in modern cities and studied high-rise buildings about their social, human and urban criteria. They have also addressed future high-rise buildings and provided solutions to the sustainability of these buildings. But while this book is a comprehensive guide to the design of tall buildings, it was not mentioned anything about designing limitations in design process. In another reference book, London Borough of Tower Hamlets Tall Buildings Study, which was published in London in 2017, authors decided to write this book due to the expansion of the use of tall buildings. They pointed out the important criteria in the design of these buildings in London. In a separate chapter, the authors discussed the architectural design criteria of these buildings and mentioned some points to be done and not in general. In the book published by Pontarini on May 2013 named Tall Building Design Guidelines, the authors mentioned most urban criteria that affect the architectural design. Site organization and context are the first two chapters in this book. It started with urban criteria because of its large scale and then by reviewing more criteria it got closer to architectural criteria. In this book it had been tried to give some advice which are not only conflicted with city discipline, but also make the most communication with it. As studied and mentioned some of references briefly, there are not many articles and also books in which the requirement of structure, Architecture and MEP are examined at the same time and try to solve contradictions between them and be a reference to help the designers the most in design process. For this reason, we decided to write this paper and gather the most effective and important

criteria and explain them literally to start the way that will make tall buildings a better place for its habitats and other users.

1.3. Research Aim and Question

This research by reviewing some tall buildings' design provides design principles for assessing the design guidelines for tall buildings in a more productive way for designers and users. The main objective behind this research is to provide a framework for tall buildings' designers to avoid unnecessary and repetitive design process during the design process. However, considering that we could not measure all design criteria in one research, we finally decided to find the main and the most effective criteria. The main question addressed in this paper is: How can we design tall buildings in a way that the final result be able to solve most problems? To answer this question, some sub-questions should be answered: a) What are the main criteria; and b) How to answer these criteria?

1.4. Research Methods

To clarify the main factors affecting the design of tall buildings, we use contents analyze method, based on our research question. After reading the articles and consulting with specialists and experts in the field of high-rise buildings, the criteria used in this research for content analysis were selected. Next, by an analytic network process (ANP) based assessment model was constructed to assess the effectiveness of tall building design criteria. We defined the units and categories of analysis and then the number of keywords that were the most related to the tall buildings' design criteria were counted and the first five of them which were the most used ones in the selected researches were chosen. The results indicate that the most critical factors that have the most impact on tall buildings' design are: Aesthetics, Energy, Structure, Urban, and other criteria. As the use of the fifth to the tenth criteria is close, we gathered them in one group named "the other criteria". Later, by using library research methods we reached the information about how to answer problems for each criterion and what is the appropriate way to combine them in the design process.

Finally, it should be noted that since the five categories examined are all important and none of them can be considered insignificantly, we have reviewed these five criteria without considering the ranking obtained from the ANP method. We used ANP result ranking to reach first 5 ones that are more important among 30 items.

2. Designing Criteria

2.1. Aesthetic Criteria and its effect on the Skyline

Designing of high-rise buildings is a comprehensive process, and it is impossible to consider feminine or aesthetic features apart from technological requirements and structural improvements. To examine high buildings, we divide them into three sections, the tower top and the ceiling, the middle or the shaft and the base building.

The base building is a part of the building, which is 40 degrees from the level of view of the pavement in the cone. It has a little impact on visions and the construction of a city landscape, and its greatest impact is on the scale of the pedestrians and the vision that they have close to the building. In fact, the most important task of the base building is to coordinate with the site and its neighbors, and create a human scale to link with the context and interaction with the audience better.

The middle part or the shaft that starts from the base and goes up to the upper part of the building. This section has a significant impact on the interaction with surrounding environments. The most important thing is how to guide the wind stream in this area. In fact, the shaft is designed as a stem for the upper part.

The tower top must not only be used in conjunction with environmental conditions and wind flow, but also has a great impact on the skyline of the city. For this reason, among the various sections of the high-rise buildings, the last section has the opportunity to display architectural and aesthetic ideas for architects (Fig 1).

The aesthetic quality is not taken too seriously by professionals, but evidence suggests that from the perspective of workers and urban residents, aesthetic elements are the most important factor in the assessment of the cities (Karimimoshaver and Winkemann, 2018). The impact of the aesthetic dimension of architecture, especially for cities (e.g., Sydney and Kuala Lumpur) that intend to upgrade their universal positions, is inevitable (Charney, 2007). Buildings are divided into three main parts including top, shaft, and base. The top of tall buildings is related to social values, and are an important component in studying the aesthetic role of tall buildings in the city (Sev, 2009). The relationship between the top and the base of the tall building is like a dialectical discourse in which the top has a greater opportunity to express the aesthetic role (Ali and Armstrong, 2006). However, the height, top, and color of tall buildings are the most important physical features, respectively (Samavatekbatan et al. 2016).

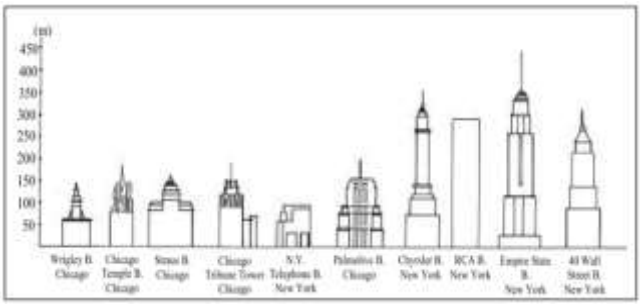

Fig 1 Around line of tall buildings in the Art Deco period (1920-1940) (Source: Sev, 2009)

In the International Style, the buildings were made of simple cubes, but the main reason was the economy and also the performance of the building (Figure 2). In fact, in each era, buildings were built in response to the circumstances of that time and they were leading in the field of beauty and technology. As a result, the definition of beauty, regardless of other conditions affecting the construction of the tower, is not accurate.

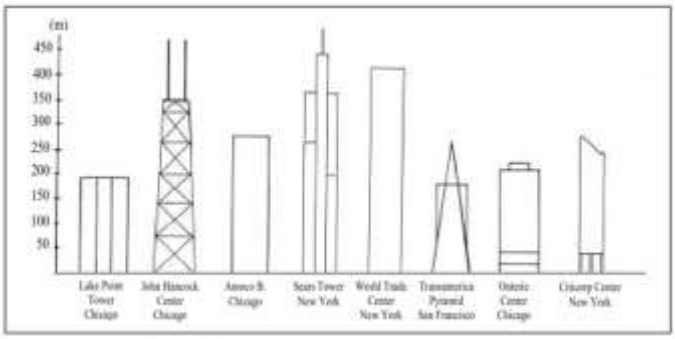

Fig 2 Around line of tall buildings in the Art Deco period (1965-1980) (Source: Sev, 2009)

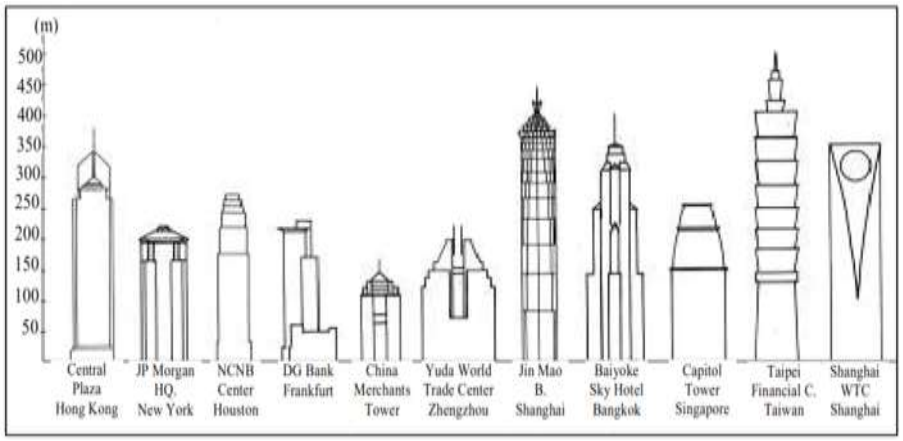

Fig 3 Around line of tall buildings in the Art Deco period (after 1980) (Source: Sev, 2009)

Of course, where there are only economic issues, in some cases, simple tower designs with simple cubes can be the right answer. A tall building without having a specific idea on top section and just having a simple and flat roof has less impact on the environment and the skyline from the point of view of aesthetic criteria. Most of the early skyscrapers had a flat roof, and over time, the necessity of paying attention to the upper part of the building was raised (Sev, 2009). Finally, the upper part of the tower has the greatest impact on the scale of the city and in fact, it is the connection between the tower and the sky. As you can see, in Figures 1, 2 and 3, over time, the attention to the upper part of the buildings was raised.

Finally, regarding to the aesthetic criteria, although there are not any clear standards, by examining the buildings that are most considered it is possible to mention the following issues. Here we suggest some design technics to improve aesthetic diversity in tall buildings. However, the following may conflict with the structural criteria that should be considered.

Lack of symmetry in plan and in height, the column-free plan, requiring wide openings with wide entrance areas on all floors and especially on the ground floor, and in some cases, straight-line forms with non-90-degree angles.

Morphogenetic planning of the future tall building will consider weighted parameters for design beyond individual buildings. Form, building material, embedded and operational carbon, daylight, use efficiency, site placement, and other important parameters will be considered even on the district or city scale at early conceptual stages (Sarkisian, 2016).

In tall buildings the connection between the building and the city is quite important. The height of a tall building is often dictated by economics. Research shows that the economic height for most tall buildings' ranges between 40–50 stories. Within this range, tall buildings are most energy efficient in a residential typology and can be built with advanced construction technology in a minimum time schedule. However, the height of a tall building is also dictated by market-driven real estate considerations; environmental and aviation factors; ego-driven prestige and a sense of competition; as well as practical considerations such as elevators, fire safety, energy demand, structure, etc. (Kheir, 2011). In tall buildings we have a large height instead of width; so, these kinds of buildings have poor communication with their adjacent urban space around them. So, designers have to try hard to improve this connection by heightening gradually from the base part of the tower toward the center of the site.

Optimum height depends upon pragmatic considerations of which the market economy is the most important. The economic height reflecting optimality is a dynamic value depending upon a city: its construction infrastructure, labor cost, etc., and the time of construction. As building height increases, wind forces control the structural design of tall buildings and the energy demand also increases. As a result, the cost per square foot will increase (Kheir, 2011).

As we mentioned before, it is important to have a base part in designing tall buildings. The minimum height of the base building should be 10.5 meters or 80 percent of the length of the adjacent street, the maximum height should not exceed 24 meters and the minimum height of the ground floor should be 4.5 meters (Pontarini, 2013).

Considering the practicality of all these factors, the 2,000 ft (610m) height limit seems to be a reasonable one for the present and foreseeable future. This may, however, change with the intervention of unpredictable circumstances (Kheir, 2011).

Understanding and utilizing the tall buildings environment conditions are two essential factors to have a self-sufficient building. Winds at the site can be used to generate power or control the behavior of the building or the both. Holes introduced into the tower along the height of the building can also (Sarkisian, 2016):

1. Allow winds to pass through the building lessening the surface area subjected to winds while minimizing across-wind dynamic effects.

2. Allow power to be generated at each opening location. A reduction in the opening diameter within the structure increases wind velocity and power generated.

3. Incorporate an airfoil concept where forces can be developed to counteract overturning by generating upward forces on the leeward side of the structure.

4. Incorporate windcatchers to funnel air into cooling systems where air is moved over a reservoir of water.

2.2. Energy Related Criteria in the Design of High-Rise Buildings

About energy and sustainability criteria, the following issues are recommended, by following these issues having a sustainable building at the end of the design process is more possible.

It is better to place important spaces in both the North and the South facades and the less important areas on the East and West. We should also try to have the fewest views on the eastern and western sides. Therefore, the ground floor plan can be a square, a circle and etc. but when it goes to the upper part gradually stretches along the east-west direction (Fig 4).

Fig 4 Proper shape of the tower according to the direction of the appropriate light (Source: authors)

Soft edges provide a better and easier wind flow control and help the building to reduce the compression of structural members that are resistant to lateral force (Kareem, 1999) (Fig 5).

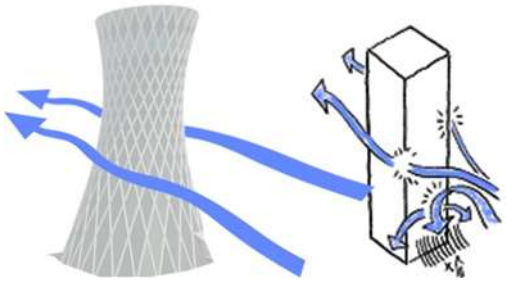

Fig 5 Proper shape of the tower to create the least effect of wind on the structure of the building (Source: authors)

In hot areas in the southern and western facades, the heights of shading and the amount of that should be increased. Having a circular form to reduce the disturbing light, also reduces the surfaces which attract sunlight and the heat (Rezazadeh, 2014). Also, in cold areas, high-capacity walls are good choices that can be used to save the heat for more hours and it is better to be used on the western facade. In general, live spaces that have permanent or semi-permanent use are located on both the northern and southern fronts and other spaces on the western and eastern facades. Orienting more than 25 degrees to east or west reduces the effect of horizontal shading (Rezazadeh, 2014).

Placing short buildings in south part of the site and tall building in north causes more light to be penetrated into the interior spaces. Note that this point can be used in the Northern Hemisphere.

Another factor which is related to energy is Photovoltaic Cells. About how to use them and the impact of them on the form of the building, it can be said that sloping down the place and also the cells to the south can be effective in absorbing the energy of the sun. A wide view of a tower is a great opportunity for maximum sunlight usage.

Generally, the organization of the main and broad areas of the building towards the north and south (East-West stretching) is greatly beneficial in reducing the insulation rate and as a result the effect of ventilation would be better. It should be tried to reduce the number and the surface of the windows in eastern-western walls as much as possible. And if this is not possible, the windows should have retreat and awnings.

Whenever the wind blows at the 45 - 90-degree angle to the front side of the building, it has a significant impact on the air flow. The impact of the wind which blows at a 25-to-45-degree angle to the front side of the building is negligible. And if it blows at less than 25-degree angle it has no effect on flowing the indoor air. On the other hand, although the best angle of wind blowing to have the best ventilation is 90-degree, vertical blowing of the wind imposes a large horizontal force on the structure of the building. One solution to organize this contradiction is designing some holes on the surface of the building to have a better leading of wind-flowing. These holes help the ventilation system of the building and also, they can be designed in a way to place a turbine in them.

In designing the form of the building, after determining the proper height for the turbine, it is necessary to place the installation and service spaces around it. The most important point about the form when we have turbines is that the form should be concave to direct the wind to the turbine and reduce the turbulence of the wind stream (Rezazadeh and Balador, 2014). The difference in designing the views of a tower is the answer of the sun's movement directions. The degree of

transparency of the facade, the location of the balconies and the arrangement of interior spaces are all organized according to the direction of the sunlight and to increase the amount of passive solar power.

Mechanical, Electrical and Plumbing (MEP)

Mechanical, Electrical and Plumbing (MEP) also known in the industry as Building Services that are the active systems in a building that makes the buildings livable by providing electricity, communication, heating/cooling and ventilation, supply and disposal of water (Barton, Fryer, and Highfield, 1983). Tall buildings inherently require infrastructure within strumentation and automation to support basic activities such as; vertical transportation, building services, and communication systems. They have unique scale and role in interacting with infrastructure systems that are built to support them (Burton, 2017).

In tall buildings, the best specialists in different fields (architecture, structure and MEP) are gathered and cooperated together. Specialists are basic resources for this operation. In order to have an eligible design all relevant specialists must be joint from the beginning to the end of the project and during the design, they must pay enough attention to the maintenance after the construction of the project is finished (Aminmansour and Moon, 2010).

MEP's (Mechanical, Electrical and Plumbing) work in high-rise construction can be very challenging due to the different crews involved during the installation. Conflicts between the crews generally cause delays in project schedule and result in additional cost due to rework (Samarasinghe et al, 2017). Besides technical issues, there are some challenges those tall buildings are involved with. These challenges include stacking, mechanical systems, stack effect and heating and cooling systems. For stacking in high rise buildings, we need MEP engineers to work collaboratively with the architect and also with the vertical transportation consultant to organize the building into independent, vertically stacked zones (Fig 6). In mechanical systems It is common for a single technical floor to support between 15-20 floors, either above or below its location. Technical floor spacing beyond these parameters will increase losses from friction and gravity forces, which diminish energy performance and give rise to ongoing operation and maintenance issues. Stack effect is another challenge that displays itself in the movement of buoyancy driven air flow and it can create some issues like door closing at the base of the tower, uncontrolled moisture ingress, excessive noise, discomfort and difficulty in controlling temperature from airflow through elevator lobbies. The last challenge that the building is involved with is heating and cooling systems. Distribution of chilled water/condenser water and/or heated water from the basement, midrise technical floor or rooftop, along the height of the tower is planned to minimize overall system pressure and typically requires the use of heat exchangers located at technical floors to transfer energy and separate hydronic zones (Burton, 2017).

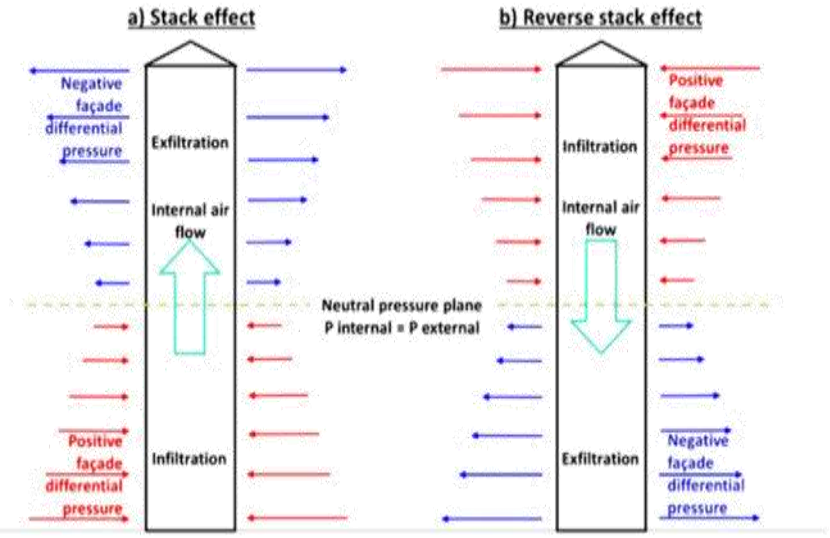

Fig 6 Principle stack effect diagrams (Source: Mijorsky and Cammelli, 2016)

2.3. Structural Criteria

Here are some suggestions on how to design an architectural form from a structural perspective. Circular buildings have a higher resistance than angular buildings and smooth surfaces to the wind. In fact, it is better to have a circular shape at high altitudes where the wind flow is stronger; and in the lower floors according to the shape of the site and functional requirements, the plan can be determined.

Having a cone form (or the one which is similar to the cone) is another factor that is compatible with structural principles.

In the part that the building connects the ground, we have the most possibility of shearing and bending forces. Therefore, it is better to have the strongest shape in that part. On the other hand, in the upper floors of the building, the less obstacles to the wind will cause the least force to the building. That is the point that the area in the plan in lower levels is more than the upper ones.

Another principle is that at the bottom of the tower, the percentage of the openings should be less than the upper floors. It is because of the most shearing force at the base of the tower. In fact, the tower's view, which has a structural function, has to be more congested in order to transfer lateral forces better (Rezazadeh, 2014). Thus, ground floors of the tower require a wide range of transparency to invite people and it is possible with collector columns.

As we approach the top of the tower, due to the increase in the intensity of the wind, the tower form should approach aerodynamic forms in order to create the least barrier against the wind force. Round and curved shapes with soft corners are considered as aerodynamic forms (Burton, 2015).

The insertion and percent of cores, shear walls and basically, the supporting structures in the two perpendicular directions in the plan should be symmetric (Charleson, 2012), even if the form or plan is asymmetric. In fact, if we had to create an asymmetrical shape according to the requirements of architecture, the method of locating the structural members against the lateral forces should be symmetrical in both perpendicular directions.

Tower cylindrical shape, makes a real tubular structural system which has 3D structural behavior against lateral forces. Cylindrical tower shape besides structural advantages has fewer facade areas

against perpendicular wind load direction, so in comparison with a triangular tower, the wind pressure will be decreased. Oval plan shape tower acts like the cylindrical one against wind lateral forces. Prismatic tower shape is the other optimal structural shape against wind forces that by increasing the height to length portion, its lateral tolerance will be decreased .

The other factors that will be desirable for the structural team are: near columns and lower span (especially in the ground area), symmetrical plan and façade (will act equal against lateral forces and prevent torsion), for conduct the wind flow with the least effect, the conical, narrowing and curved shapes is desirable.

By reviewing the above, we understand that the structural ideas lead us to a symmetrical plans, facades, volumes, and structural elements, while cubic forms, from an aesthetics point of view, are not acceptable. The concept that can be expressed here is the desirability factor (Heristchian, 2010).

The desirability factor of a design is the ratio of its aesthetic to its structural efficiency. In other words, sometimes architects design an extraordinary form that is not acceptable by structural principles, here the question is that how important or beautiful this form is; Is it worth building exactly this idea or we should make some changes to it to make it logical to build? Despite the fact that some extraordinary designs have additional costs, it is worth to be built. But in some other projects, although the designer designed an unusual form which is certifiable from an aesthetic point of view, the profit is not worth to be paid.

Structures will become self-reflective, capable of undergoing state changes of materials where component properties can be temporary altered to efficiently resist abnormalities in loading. Ultimately structures will exist in a true state of equilibrium in which umbilical reliance on services from other sources is eliminated and regeneration of resources is possible; structures will contribute to the environment rather than challenge it. This goal will only be achieved through innovative processes of collaboration, invention, and integration. Structures in tall buildings of the future should be designed to have two or more purposes. For instance, the structural system could be a conduit for fluids that can be used for heating and cooling buildings. Structures can be carefully integrated into the exterior wall systems where superficial enclosure elements are eliminated (Sarkisian, 2016).

2.4. Urban Criteria

For the multifunctional towers, it is recommended to make a difference between the residential and commercial entrances. The location of the entrance should be designed due to have an access to the public transportation stations; Moreover, to save the privacy of the entrance (in residential parts), it could be placed upper than the pedestrian realm or it can go in to the building. In private entrances, using garden in front of the entry can preserve the privacy.

The maximum surface area for each floor in towers is 750 square meters. This limitation includes all closed spaces of each floor and the open spaces (such as traces and roofless parts) can exceed this limitation (Pontarini, 2013). These limitations are proposed because of two reasons, first, if we have more surface area than 750 square meters, we will miss the access of natural light as we have a long depth. The Second, by having larger area in each floor, we have bigger shadow and as a result the neighborhoods will be deprived of natural light most of the day times.

The distance between each tower and its own land boundary line should be at least 12.5 meters. For towers were located in one land this number changes to 25 meters from each tower (Pontarini, 2013). This distance is measured from the outer walls of the two buildings. Balcony lines are not included in this measurement. By keeping the minimum distance between the two towers, the

undesirable effects of each tower, such as shading, creating an unfavorable wind flow and wind turbulence, decreased visibility to the sky, lack of privacy (due to vicinity), are minimized.

The width of the pedestrian realm could be at least 6 meters (Fig 7).

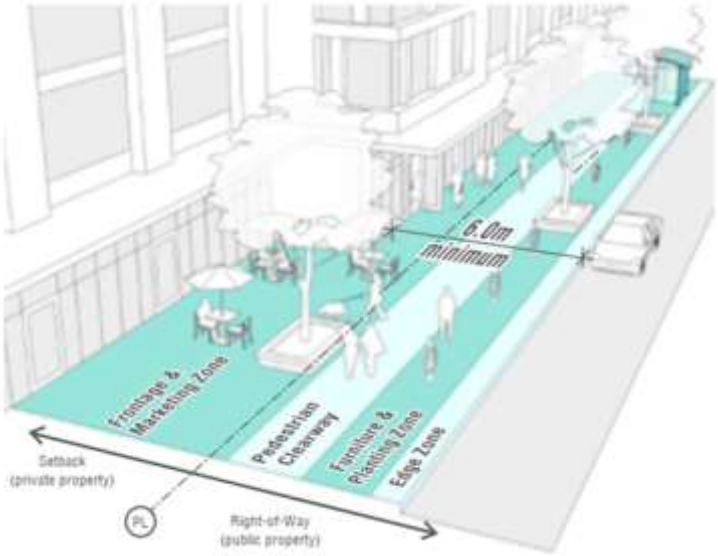

Fig 7 Pedestrian realm requirements in tall buildings (Source: Pontarini, 2013).

2.5. Other Criteria

To consider other criteria, we mentioned some important clues that knowing them can improve the design quality.

The green space presence for each floor or each unit brings a positive effect and a sense of vitality for residents. The minimum portion of open and green spaces in tall building sites, to be satisfied with the green space, is 25 percent. The appropriate location of green spaces in tall buildings' plan is east and west since green spaces in these areas will decrease the adverse effect of unwanted east and west lights. Proper lighting and fresh air are other factors that increase the quality of life in the space.

In tall buildings, it is necessary to provide at least two separate exits as far apart as possible for each floor.

The maximum length of exit access in tall buildings is 30 meters, in special cases where the building or structure has been approved against fire, this length can be increased to a maximum of 45 meters (Pontarini, 2013).

It should be considered that stairs and elevators should be designed in such a way that not cause torsion around the vertical axis (Golabchi and Masteri Farahani, 2013).

The appropriate interior height range for administrative-commercial tall buildings is 2.6 to 2.75 meters. The level height range is 4.1 to 3.8 meters that the floor's mechanical fixtures and wirings are hidden in the suspended ceiling and floating floor in the level (Pontarini, 2013).

Balconies with a rectangular shape and a depth of more than 1.5 meters are suitable to be used as dining room. Opening balconies provide a better privacy and visual security for users.

In fact, it should be seen to what extent the asymmetry in the plan, the facade, the long cantilevers, and the forms that is against the wind (such as the straight lines) contribute to the

beauty of the building and its other needs. Finally, in a situation where it has a great impact on improving the design and performance of the building, spending money on such projects may be justified. In general, it is necessary to try as much as possible to consider the common characteristics of the contradictory cases, for example: creating large openings on the ground floor with high floor height (about 6 meters) is an architectural and functional needs of the design. However, large openings reduce the number of columns and do not properly transfer the gravitational and lateral forces to the ground. On the other hand, by increasing column height and span length, we provide soft floor condition which is vulnerable against lateral forces. To solve the large span problem on the ground floor, we can use the gathering column and the reinforced column. Although these techniques need more expenses, architectural desirability compensates these expenses (Fig 8). Moreover, using a base building and connecting columns at regular heights will help to solve this problem.

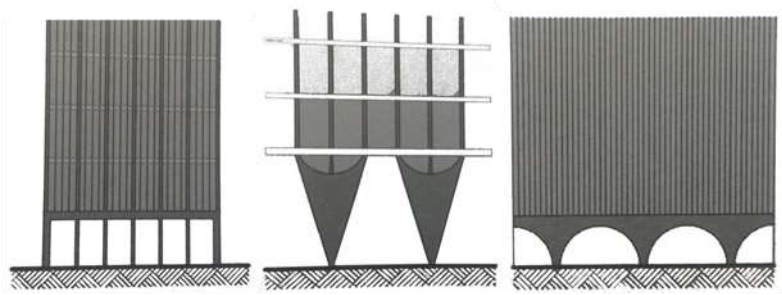

Fig 8 Methods of transferring the power of the upper floors and reducing the columns in the ground level in the tower; From left to right: main beam, columns and retractable arches (Source: Schueller, 1977)

3. Conclusion

Tall buildings, in combination with other low-rise and mid-rise buildings, can become an integral part of urban planning as they provide the opportunity for the large-scale creation of open space and views, and simultaneously reduce the collective cost of the built environment through agglomeration and clustering (Kheir, 2011).

The first step in each project is studying and recognizing. Afterwards, the design of a tall building is based on five main categories; these five are: Structure, Architecture and Aesthetic criteria, MEP (Mechanical, Electrical and Plumbing), Energy related criteria, Urban criteria and other criteria which is consisted of criteria we should consider them during the design process. Although architecture starts and ends the design process, the importance of the role of all five branches is equal. Indeed, by creating an appropriate architecture, these three branches can be coordinated. It should be considered that all these five topics must be considered at the same time in order to prevent facing a major problem in the project. It is an important point in designing high-rise buildings as we have a large scale of structure and MEP.

3.1. Architecture and Aesthetic Criteria

The architecture of a high-rise building has a direct relationship with the form, facade, cover, programs and needs of the project, green space and finally the structure and installation. For example, although the main core shape of the building is defined by the architect, this shape must

be the location of the MEP arteries and bearing structural forces. So, it is necessary to consider the structural and MEP requirements in the design of the core form. It should also be noticed that in a short building, the structure can be hidden with decorations, but in towers, it is not acceptable to impose more forces, which will be caused by using decorations in order to hide the massive tower structure. Moreover, according to the formula (F = MA†), we can conclude that by increasing the weight of the building, the forces on the building will increase. As a result, we should try to eliminate the elements that can be removed as much as possible and give their role to non-removable elements such as structures and installations. With this trick, the finished weight of the building will be greatly reduced.

3.2. Structure

The cases that affect the structure of the building include foundation, formatting, core, thickness, and the form of the members that tolerate lateral and gravitational forces in the facade, inside the building, in the architecture and in the MEP. Although the high-rise building facade shaping pattern is exposed to the vision, it must be chosen in a way that it plays an effective role in tolerating all the forces. Therefore, the best case is structure acts as architecture and architecture acts as structure.

3.3. Importance of MEP and Energy related Criteria

The MEP in a tower is like its vessels. The entry of light, air, water, etc., and the disposal of sewage and garbage have made MEP as an important organ during the life of a tower. MEP is directly involved with cooling, heating, air conditioning, electrical and mechanical equipment, plumbing, cores, elevators, water resources, structure and architecture. It should be considered that designing the MEP in parallel with the design of structure and architecture increases the life of the building. The way of providing the basic needs of the MEP and its consumption should be in a way that the consumption of water and other energies is optimal. Due to the large scale of the building, this wasting repeated in all units in the tower and the small wasted amount becomes larger. Moreover, designing the MEP equipment should be in a way that repairing and replacing them cause no damage to the building and no disturbance to the residents.

The concept of sustainability is usually introduced in the form of MEP issues. This is because of the most of the sustainability requirements depend on the installations in the building. For example, the supply of light, water, the use of new energies, and also the disposal and use of wasted water depend on MEP equipment.

To achieve a sustainable building, many things must be considered in different areas. The possibility of energy production in tall buildings due to the large surface area in front of sunlight and the intensity of wind flow at height is a matter that should be considered in tall buildings. Moreover, as mentioned before, we should try to involve other areas of design, including structure and architecture, in order to achieve sustainability goals.

In closing, it should be noted that each criterion is used to perform especial tasks and at the beginning, each criterion must be considered independently. The more we give a criteria different role, the more successful we are in providing a proper answer. As mentioned before, architecture,

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† Newton's second law of motion describes the relationship between an object's mass and the amount of force needed to accelerate it. Newton's second law is often stated as **F=ma**, which means the force (**F**) acting on an object is equal to the mass (m) of an object time its acceleration (a).

structure and MEP are the basis of designing a tower. In the combination of these three criteria, we should try to establish a good interaction between the tasks of each organ. For example, the facade of the tower must withstand the horizontal forces caused by wind and earthquake and can also have architectural and aesthetic roles. Researching on finding a pattern for the facade which has a good performance against forces and also is aesthetically significant that can help to optimize the facade of the building and reduce the load caused by additional elements.

Beyond sustainability in tall buildings, resiliency also can propel designers to design environmentally sensitive buildings perhaps consist of recycled materials and can adapt itself with climate change. Systems in these buildings require a design based on performance in which each component has multiple uses: structural systems capable of heating and cooling, exterior wall systems capable of absorbing and storing energy, and building systems capable of operating with site-based water collection, power generation, and distribution. Buildings should be completely self-sufficient, not relying on their neighbors. Advances in energy storage will be provided to bridge periods of limited or lack of solar power, while on-site water reclamation, purification, and reuse will reduce demand on our most important resource.

So, to achieve a self-sufficient tall building we should combine structure, architecture, and MEP systems (Fig 9). Considering the aforementioned criteria and points, as some systems have conflicts with each other, according to the project priority, we should balance them in a way to have the most interaction with each other. Next to these criteria, there are some more criteria which are local that because of different climate in each zone, it should be analyzed specifically for each project according to its site.

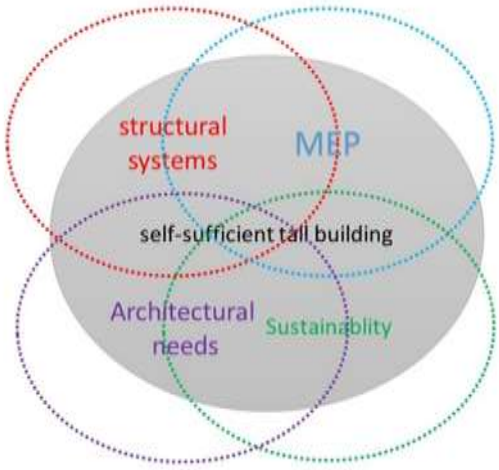

Fig 9 Self-sufficient tall building factors (Source: authors)

3.4. Urban Criteria

As a designer you should make a difference between the residential and commercial entrances. Access to the public transportation stations, minimum distance between each tower and its own land boundary must be considered as an important factor to locate tall buildings. The unwanted impacts of each tower, for example, shading, producing an unwanted breeze stream and wind turbulence, decreased the visibility to the sky and lack of privacy, can be minimized by providing the appropriate distance between the towers. To determine maximum surface area for each floor,

besides practical and economic matters we should assume maximum space depth for access of natural light and the tower's shadows effect in our neighborhoods that may deprive them from natural light most of the day times.

To sum up, a tall building in the city must pay attention to the privacy of historical zones, the skyline and the neighbors' rights, to access natural light, the sky and the city visibility, to have the best constructive interaction with other tall structures.

3.5. Other Criteria

Local small gardens convey lots of opportunity for preserve the privacy, refreshing air, balancing sunlight and act as filters for interior spaces. Having an access to green space for each floor or unit has a positive impact and a sense of vitality for the residents. The optimal place for green spaces in high-rise buildings' plans are east and west sides of the building, as green areas in these places would mitigate the detrimental effects of unnecessary western and the eastern rays. Natural light and natural ventilation are other variables that make life better in tall buildings. The structure as well as its Framework must be certified against fire. Stairs and lifts should be constructed in such a manner that they do not twist the vertical axis. Simply, the basic characteristics of conflicting situations should be considered as far as possible. For instance, by increasing column height and span length, we have a soft floor state that is sensitive to lateral forces. We will use the series of columns and reinforce them to overcome the wide span problem in the base building. Although these strategies lead the project to extra costs, architectural desirability balances these expenses. In addition, the use of base building and connected columns in a standard height are efficient to cope with this issue.

However, it should be noted that in addition to these criteria that we have mentioned here as the main criteria, there are many more that is not possible to review them in an article. These should be put together in the high-rise buildings guide line for each city. Finally, the lack of information and rules about criteria in designing tall buildings does not bring freedom for designers and they are responsible for our design and its costs brought to the project and the city and they should reduce it.

References

Al-Kodmany, K. (2011). Tall Buildings, Design, and Technology: Visions for the Twenty-First Century City. *Journal of Urban Technology, 18*(3), 115-140.

Ali, M. M., & Armstrong, P. J. (2006). Strategies for integrated design of sustainable tall buildings. *AIA Report on University Research, 14*.

Ali, M. M., & Armstrong, P. J. (Eds.). (1995). *Architecture of tall buildings*. McGraw-Hill, New York.

Aysin, S. E. V. (2009). Typology for the aesthetics and top design of tall buildings. *Gazi University Journal of Science, 22*(4), 371–381.

Aminmansour, A., & Moon, K. S. (2010). Integrated design and construction of tall buildings. *Journal of Architectural Engineering, 16*(2), 47-53.

Assembly, L., & Parliament, E. U. (2017). London Borough of Tower Hamlets. *Politics, 1*, 1.

Barton, P. K., Fryer, B. G., & Highfield, D. (1983). *Building services integration*. E & FN Spon.

Beedle, L., Ali, M., & Armstrong, P. (2007). *The Skyscraper and the City: Design, Technology, and Innovation*. Lewiston, New York: The Edwin Mellen Press.

Burton, C. (2017). Designing High Performance MEP Systems for Supertall Buildings: A Review of Challenges and Opportunities. *International Journal of High-Rise Buildings, 6*(4), 301-306.

Burton, M. D., Kwok, K. C., & Abdelrazaq, A. (2015). Wind-induced motion of tall buildings: designing for occupant comfort. *International Journal of High-Rise Buildings*, *4*(1), 1-8.

Charleson, A. (2012). *Seismic design for architect*. Routledge.

Charney, I. (2007). The politics of design: architecture, tall buildings and the skyline of central London. *Area, 39*(2), 195-205.

Golabchi, M., & Masteri Farahani, N. (2013). *Conceptual design of tall Buildings*. University of Tehran Press.

Heristchian, M. (2010). Desirability factors in structural design. *International journal of space structures*, *25*(3), 159-167.

Kareem, A., Kijewski, T., & Tamura, Y. (1999). Mitigation of motions of tall buildings with specific examples of recent applications. *Wind and Structures*, *2*(3), 201-251.

Karimimoshaver, M., & Winkemann, P. (2018). A framework for assessing tall buildings' impact on the city skyline: Aesthetic, visibility, and meaning dimensions. *Environmental Impact Assessment Review*, *73*, 164–176.

Kostof, S. (1995). A History of Architecture: Settings and Rituals. New York: Oxford.

Mijorski, S., & Cammelli, S. (2016). Stack Effect in High-Rise Buildings: A Review. *International Journal of High-Rise Buildings*, *5*(4), 327–338.

Mohammad Hosseini, P., & Yousefi Tazakor, M. (2016). Observance of the principles of environmental sustainability in tall buildings. *First International on Rethinking the Sustainable Development.*

Parker, D., & Wood, A. (Eds.). (2013). *The Tall Buildings Reference Book*. Taylor and Francis, Routledge. ISBN13: 978-0415780414.

Pontarini, H. (2013). Tall building design guidelines. *City of Toronto*.

Rezazadeh, M. (2014). *Recognition criteria in tall building design by using algorithmic architecture design Principles*. M.Sc. Thesis in Architectural Technology, Faculty of Fine Arts, University of Tehran.

Rezazadeh, M., & Balador, Z. (2014). The effect of wind turbines in architectural design of high-rise buildings. The *first national conference of green building*.

Rujibhong, S., & Upala, P. (2017). A Causal Analysis of the Sense of Community for High-rise Residents in Bangkok Metropolitan Area. *Asian Social Science*, *13*(10).

Sarkisian, M. (2016). *Designing tall buildings: structure as architecture*. Routledge.

Samavatekbatan, A., Gholami, S., & Karimimoshaver, M. (2016). Assessing the visual impact of physical features of tall buildings: Height, top, color. *Environmental Impact Assessment Review, 57*, 53–62. https://doi.org/10.1016/j.eiar.2015.11.008

Samarasinghe, T., Mendis, P., Aye, L., Gunawardena, D., & Karunaratne, R. (2017). BIM and modular MEP systems for super-tall and mega-tall buildings. *8th International Conference on Structural Engineering and Construction Management*.

Schipporeit, G. (2001, November). The Future of High-Rise Buildings. In *Proc. of the 6th World Congress of the Council on Tall Buildings and Urban Habitat (London, UK: Spon Press 2000* (pp. 1343–363).

Schueller, W. (1977). *High-rise building structures* (Adeli, H. Trans.). Dehkhoda publisher.

Sharghi, A., Maulan, S. B., Salleh, I. B., Binti, A. S., Salim, S., & Sedghpour, B. S. (2014). Evaluation of Parental Satisfaction of Children's Spaces Within High Rise Apartment Environments. *Journal of Landscape Ecology*, *7*(2). 10.2478/jlecol-2014-0016.

Yeang, K. (2002). *Reinventing the Skyscraper: A vertical theory of urban design*. Academy Press.