Configuration-Based Classification of High-Rise Buildings, a Procedure for Sustainable Design of High-Rise Building’s Form

Seyedpooya Seyedinnoor¹, Mahmood Golabchi²

1. Master of Structural Engineering, Islamic Azad University South Tehran branch, Tehran, Iran, pooya_seyedin@yahoo.com
2. Professor of Civil Engineering and Architectural Technology, University of Tehran, Tehran, Iran, golabchi@ut.ac.ir

Seyedpooya Seyedinnoor

He is a structural engineer interested in high-rise buildings.

Abstract

With the world increasing need to tall and super tall buildings and considering their energy efficiency, a procedure for sustainable design of high-rise building from configuration point of view (especially against wind) could be defined. Primary global schemes including completely separate, entirely connected through the height and connected but partially detached for clustered configurations and regular traditional, regional and also creative free form for single configurations are described. Fresh proposals of innovative engineered forms are proposed and described. They are designed based on the principles of integration of structure, architecture and energy efficient principles (especially related to wind power). In fact they have the characteristics of a sound structural system to resist gravity and seismic loads and meantime they reduce wind load on global body of structure, they are efficiently able to produce energy in creative ways by their innovative configuration. For each configuration, main possible functionalities, best structural alternatives to meet the architectural and configuration requirements, energy efficiency potentials and also attractiveness potential of high-rise architecture are stated and global advantages and limitations are discussed. A procedure for sustainable design of tall buildings is proposed. Final step of designing the tall building’s form which needs a great collaboration between structural engineer, architect and wind engineer, comes out from blending wind engineering-based architecture with structure-based architecture resulting in high degree of sustainability in high-rise building’s form. Both structural engineer and architect should be aware of the principles of sustainability and apply them into their design from the first steps and blend them together to achieve final sustainable configuration.

Keywords: tall building, configuration-based classification, sustainability in form
Introduction

The relationship between form, structure and architecture has made the procedure of design interesting and somehow complicated. A powerful architect designs the global form with considering all design principles including primary purposes of the design and main functionalities, energy efficient principles, structural principles and architectural expression and this is the power of rich architecture to have all the design principles behind the beautiful and attractive appearance [14]. In the case of tall buildings, the global form of early tall buildings was followed by structural systems. Structural engineering developed as complex forms have been rapidly creating by architects. In this era, complex forms could be structurally sound but were not usually energy efficient [3]. Energy efficiency and environmentally friendly subject has become an absolute design principle as fuel resources are at their end of age and its importance is much more when designing a high rise building. There are many ways to take the principle of sustainability into account in the design procedure such as natural ventilation, double skin façade and high-performance glazing, daylight controlling, solar and fuel cells and wind turbines. These alternatives do not usually involve global configuration but their efficiency and performance will greatly increase when global form and configuration of a tall (and especially super-tall) building is designed based on the principles of sustainability at the first stages of architectural design. This strategy also opens up new vision in aesthetic of tall buildings. To achieve this, a great collaboration of wind engineering and creativity is needed. Previous researches show that with using wind resistant forms or some modification in shape such as setbacks, tapered and twisted forms, softened corners, varied cross section and opening and porosity, wind load on the structure will be greatly reduced. But innovative configurations and forms have the characteristics of a sound structural system to resist gravity and seismic loads and meantime they reduce wind load on global body of structure, they are efficiently able to produce energy in creative ways by their innovative solutions. Thanks to above description, a procedure for sustainable design of high-rise building from configuration point of view (especially against wind) can be defined taking into account primary purposes of the design and main functionalities, energy efficient principles, structural principles and architectural expression. For this purpose, at first a configuration-based classification is defined and then the procedure is explained based on the new classification of high-rise buildings.

Configuration-based classification

The classification of high-rise buildings based on their configuration consists of six primary global schemes and each one includes several samples of previously designed and fresh proposals. The emphasis will be on fresh proposals which show sustainability in form.

Primary global schemes

Clustered towers

Separate clustered towers

These systems are not structurally connected to each other but pedestrian linkage is recommended for quick evacuation and comfort of occupants (not recommended for residential types). Also if using innovative forms and considering site climate situation, wind turbines can be placed between the towers preferably at higher levels of tower or specific places allocated in the tower surface in which funnel effect can be formed in order to harvesting energy from wind power. Primary purposes of the design can be making condominium complexes in big scales. Main possible functionality is residential but it is clear that for such a great complex, the commercial and entertainment centers should be planned to make the occupants free of want to go out of the complex for daily affairs. The common form for this system is simple configuration without any complexity and architecture of every single tower is expressed by its structural system but the architecture of the cluster is expressed as a whole so that the coordination and cooperation of each tower, their arrangement, dimensions and shape and directions thanks to global shape concept of the cluster express the architectural concept. The state-of-the-art clusters consist of complex forms which can be both extremely attractive and wind resistant by modification in their forms (E.g. tower 29 in Dubai, figure 1). The principles of energy efficiency should be considered for each tower alone but when using innovative forms (innovative
forms and fresh proposals will be defined and explained later), there is a potential to harvest wind power by installation of appropriate wind turbine in right place (figure 1, right).

Figure 1. left: Tower 29, Dubai [13]; attractive, structurally sound and aerodynamic but not featured with an energy efficient form. Right: Bahrain World Train Center; wind turbine and its influence on the global form

**Entirely connected towers through the height**

Entirely connecting towers through the height can bring many benefits. In this system the tall buildings can have their own central core or a condominium one which will be the intersection of tower. For the system with one condominium central core, the stabilization of each connected tower against lateral loads is ensured by the other towers and the system works as single structure if global plan of the system allows (E.g. a star with three wings. Figure 2, left). The system has the potential to greatly reduce the vortex shedding effect if in addition to global plan shape, tapering through elevation is considered. The system can be useful for super-tall buildings also in different ways by connecting a numbers of towers through their circumference resulting in structural form called bundled tubes (figure2, right). The condominium core can consist of vertical circulation, atria, garden and green spaces, sport clubs and ceremony halls. The structure-based architecture can be well done by using the concept of bundled tubes with different height and connected towers with single core.
Figure 2. connecting towers results in more stability and more potential for structural and also energy efficiency; (explanation in next page)

left: Russia tower, (Halvorson and Partners, 2007) [12]. Right: author’s proposal, combined structural systems; (main system: Bundled tubes), external diagrid, internal core and outriggers, belt truss at the level of setbacks, perimeter mega columns, funnel effect for harvesting wind power, ability of every single tube to have different height thus making attractiveness, Height potential: more than 150 stories

Connected towers with partially detached areas

In this system the towers are connected to each other but detached in some areas through their height. In opening areas, pedestrian linkage could be used. This option can also be useful in rapid evacuation. Through vertical opening areas, natural light could penetrate to the floors located at these levels. Wind power is also reduced by creation of these opening [5]. The openings can also be used as a place to install wind turbines (if innovative forms are applied) in the way that overall form of the building direct the wind to the areas equipped with vertical or horizontal turbines so that the whole system can produce partial of its usage energy by its own while the effect of wind load on the structure is reduced because of the nature of innovative forms. The linked areas help to maintain overall stability of the whole cluster especially against wind load. Each tower has its own core system. The cores can conventionally contain elevator systems, mechanical areas, sport clubs, green spaces (preferably in opening levels), essential equipment and security systems and condominium areas. Since the towers are structurally connected, the overall slenderness ratio is relatively low thus having higher height potential but with applying appropriate structural system. The tower itself can has a twisting and tapered form to ideally reduce wind power and the cluster of towers could be intertwined together to achieve higher levels of attractiveness in global form based on wind and structural principles [5]. The appropriate structural system for the proposed cluster could consist of an improved diagrid with core system because of natural complexity of the towers cluster. (figure 3).
Figure 3. Left: Wave-form tower cluster (land.P, CTBUH 2008). Wind and light flows through openings thus reducing wind loading on tower clusters. Balance between transparency and thermal performance. Pedestrian cross over points and double story landscaped atria are located at each of the three structural links between towers [10]. Right: clustered towers for wind harvesting; taper, twisted, curved corners, aerodynamic, condominium central multi-purpose core between three towers (engineering-determined places for implementing wind turbines, vertical garden or typical partially suspended stories, pedestrian linkages for both more structural stability and occupants comfort), funnel effect, best place for turbines between three tower where wind flows are accelerated [4], balancing light penetration and thermal performance by creating curvature in surface at height, the schematic hand drawing of the cluster shows smaller windows at lower levels for more publicity and larger ones for upper levels for open views [18]. Structural alternatives; exterior diagrid with sloped mega columns, separately core shear wall for each tower, interior outriggers at those level which diagrid system shifted, resistant against overturning moment by using the concept of connecting towers through the height, resisting both gravity and lateral loads on one series of elements (efficient structural design), functional, innovative and attractive but resistant and self-sufficient.

Single tower

Regular forms

Traditional forms of tall buildings have been usually inspired by their conventional structural systems (figure 4). These structural systems consist of framed tube, braced tube, bundled tube, tube in tube and outriggers and belt trusses which shown an exterior expression of architecture [2]. In these systems the major collaboration should have been between structural and façade system to achieve a structure-based architecture. There was always a problem that the structure which had good performance from structural point of view, had disadvantages of obstruction of view (E.g. braced tube) or interior planning limitations (E.g. bundled tubes). With the development of structural engineering and advent of state-of-the-art structural systems such as Diagrid, space truss, super frame and Exo-skeleton the architectural expression of high-rise buildings with more attractiveness was unfold, super tall buildings were feasible to design and construction, the problem of obstruction of view could have been partially solved and The architect was more free to generate hybrid and mixed-use tall building but construction cost and complicated joints were problem in addition to lack of innovation in energy efficient systems.
Regional forms

Regional forms can be offered in both clustered and single tall buildings. The most significant trend of tall buildings constructed in various Asian countries is that they use their own regional architectural and cultural traditions as main design motives [2]. These forms range from basic cultural concepts to climatic condition (figure 5). They can be designed in creative ways to present a regional architecture in addition to benefit a sustainable design procedure for highly engineered tall building’s form if the global regional concept has the potential to conform to innovative configuration (which is going to be described by author). The best structural alternatives for the regional forms should be selected upon specific configuration but to achieve complete architectural concepts, composing some structural systems may be the best alternative.

Figure 4. 21st Century Tower, China, structural action in primary columns and braces

Figure 5. Left: Burj al arab, Dubai. Right: Taipei 101 Financial Center, Taiwan
Creative free forms
Architects keep trying to design free forms to introduce their initiatives but in the case of tall building they should follow some basic structural rules and because the nature of complexity in tall buildings. A good architect uses these structural concepts in a creative ways to come up with a structurally sound free form but now they have another tool which is wind-originated concepts. In fact these concepts lead the architect to create innovative forms which produce and conserve energy of wind while reducing overall wind load on structure (figure 6, right). Innovative configurations are definable with Wind engineering Architecture through Wind-Originated Concepts. With the developed power of structural engineering, tall and super tall buildings with creative engineered free form can be designed structurally sound covering every desired functionalities. (Figure 7).

Figure 6. Left: Nordhavnen Residences Copenhagen. Right: Pearl River Tower, funnel effect and influence on the form, both accelerating wind flow and decreasing turbulence

Figure 7. Author’s proposal; 30 story conceptual tower; the tower proposes new visions inspired by natural forces like sun, wind and earthquake. The tower is twisted, taper and aerodynamic thus reducing wind power on global configuration. The global form expresses the lateral deformation of a high-rise building under lateral load; the western side shows the deformation of braced frame while eastern side remembers the moment-resistant frame thus reaching Earthquake Architecture from seismic principle theories to aesthetics in architecture. At the top of the tower multi-purpose plates are installed for both funneling wind and on the opposite side for installing passive solar cells. In fact because of the nature of the form and dominating wind direction (which is west-east in Tehran) wind is conducted to especial areas which are better to be at the
highest levels where wind power is increased. Last story includes a great garden where rain water has the shortest way to be used for garden and then it can easily move downward to be reused in landscaped areas. The windows on the south face are large to absorb the energy of sun in the winter but small and relatively high on the north to avoid escaping heat and reaching natural ventilation. The eastern and western windows also are planned to have sun shading featured with solar cells. The lowest levels of tower have relatively smaller windows for privacy while upper levels have wider windows for having unobstructed view. The western façade consists of innovative partially glassed systems for both avoiding glare sunlight and increasing the stiffness for first, resisting wind and conduct it upward and second, concentrating the center of mass and center of rigidity. The whole façade is not completely glassed because of making balance between natural light (transparency) and thermal performance (around 50% window).

Procedure of sustainable design of tall building's form

The procedure of sustainable design of tall buildings should be started by defining the main purposes of the design thus selecting the primary global scheme and then developing the scheme thanks to climate situation through solar and wind engineering-based architecture approach which varies from project specific situation while meantime considering structural principles of high rise buildings. Considering wind (and also solar) power and employing their principles at the first stages of the design, greatly affects the global form. Final step of the designing tall building's form which needs a great collaboration between structural engineer, architect and wind engineer, comes out from blending wind engineering-based architecture with structure-based architecture resulting in high degree of sustainability in high-rise building's form and configuration. In fact innovative forms which are sustainable from wind and solar aspects of view and usually complex and attractive can have a potential of sound primary structural system because of the nature of these form if the architect know the structural principle of high-rise buildings and their primary structural system in addition to state-of-the-art means of sustainability in the global form. Both structural engineer and architect should be aware of the principles of sustainability and apply them into their design from the first steps and blend them together to achieve final sustainable configuration.

Conclusion

For the new age of high-rise buildings, the term sustainability should be referred to whole aspects of building. In addition to natural ventilation, double skin façade and high-performance glazing, solar and fuel cells, wind turbines and etc. (which is better to be applied in a multi-purpose way to achieve a sustainability-in-sustainability) and structural sustainability, sustainability of form is undeniable fact of new age of high-rise sustainable design. Like the other rich architecture, design of form needs a great integration of structural engineering and architecture but in the case of high-rise buildings, to achieve real sustainability in form wind engineering (and sometimes solar power) also need to be entered in this collaboration. In this paper, a configuration-based classification was introduced, potential of each configuration for sustainability discussed and some example and fresh proposal illustrated. Innovative forms for super tall buildings reduce the wind load on global structure but conduct and then funnel it to the special engineering-determined places to earn energy from wind. At the end, the procedure of sustainable design of tall building’s form was explained and its conclusion was that, in order to achieve real comprehensive sustainability, a procedure of design which involves wind and solar power is needed. This procedure leads the architect to create innovative forms which can be usually more attractive and sometimes complex but structurally sound because of the nature of innovative forms if a great collaboration of architect, structural engineer and wind engineering expert is performed at the first stages of the design like those examples and proposal specified in the classification.
Reference


