Performative Approaches in Tall Buildings: Pearl River Tower

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ABSTRACT

21st century has become prominent with two main concepts in architecture; the first one is "sustainability in architecture" which has been seeking for a less environmental footprint in the ecosystem and the second one is digital technologies that drive a novel approach in all kinds of man-made products including architecture. Potentials of digital solutions (CAD/CAM/BIM) in the design of "energy efficient" buildings can be considered as innovative way of thinking/designing/simulating/optimizing for the actors working in all levels of discipline of architecture. In other words, integration of these tools with the design process offers designers many alternatives through the analysis of both climatic and physical data usage during the optimization process of architectural forms and structures, especially, designing unique/extreme buildings like, tall buildings, wide span structures and buildings having complex forms. From this context, this paper discusses and exemplifies the term "performative architecture" as a melting point of the concepts mentioned above. It is aimed to present and discuss how cutting edge technologies help designers to design not only the building but also the "design of design process" in a sustainable way. For this purpose, tall buildings are examined within the light of performative approach. After presenting the theoretical framework of the concept of performative design; Pearl River Tower, (Guangzhou, China) an energy efficient tall building, in which digital design and optimization tools are integrated with the design process, is exemplified and the criteria of performance based design used in the case study is discussed.

Keywords: Energy efficiency, Pearl River Tower, performative architecture, tall buildings.

TALL BUILDINGS

"Tall building", "high-rise building", and "skyscraper" are difficult to define and distinguish solely from a dimensional perspective because height is a relative matter that changes according to time and place. The term "high-rise building" has been recognized as a building type since the late 19th century, while the history of the term "tall building" is very much older than that of the term "high-rise building". As for the use of the term "skyscraper" for some tall/high-rise buildings reflecting social amazement and exaggeration, it first began in connection with the 12-storey *Home Insurance Building*, built in Chicago towards the end of the 19th century (Harbert, 2002, Peet, 2011)

Definition

There is no general consensus on the height or number of storeys above which buildings should be classified as tall buildings or skyscrapers. The architectural/structural height of a building is measured from the open-air pedestrian entrance to the top of the building, ignoring antennae and flagpoles (Gunel and Ilgın, 2014a) According to the CTBUH (Council on Tall Buildings and Urban Habitat), buildings of 14 storeys or 50 metres' height and above could be considered as "tall buildings"; buildings of 300 metres' and 600 metres' height and above, are classified as "supertall buildings" and "megatall buildings" respectively. According to the Emporis Standards, buildings of 12 storeys or 35 metres' height and above, and multi-storey buildings of more than 100 metres' height, are classified as "high-rise buildings" and "skyscrapers" respectively (Emporis Data Standards ESN 18727, ESN 24419).

Tall buildings are defined: by structural designers as buildings that require an unusual structural system and where wind loads are prominent in analysis and design; by architectural designers as buildings requiring interdisciplinary work in particular with structural designers, and with experts in the fields of aerodynamics, mechanics and urban planning that affect design and use; and by civil engineers as buildings needing unusual and sophisticated construction techniques. César Pelli (1982) defines a skyscraper as a supertall building and highlights the word "super" within this definition as changing according to time and place. Structures such as *The Eiffel Tower* (Paris, 1889) cannot be classified as skyscrapers because of the lack of a habitable interior space.

In the view of the authors of this paper, "tall building or high-rise building" is a local concept and "skyscraper or supertall building" is a global concept. To be able to define a tall building as a skyscraper or supertall building, it is not sufficient for it only to be tall in its own region; it is necessary for it to be recognized in the world as a skyscraper or supertall building (Gunel and Ilgın, 2014b).

Emergence and Historical Development

Architects contribute to the social and economic changes of the age, reflecting the environment they live in with their designs and creating a development/evolution by developing new styles or building types. In addition, underlying the first appearances of skyscrapers in Chicago was a social transformation triggered by the economic boom of that era and by the increase in value of urban building plots. The advance in construction technology has played a much more important role in the development of tall buildings than in the case of other types of structure. At the end of the 19th century, beginning with the discovery of the elevator for the vertical transportation system, and structural metal beam-column framing system, the construction of tall buildings commenced as an American building type owing to innovations and developments in new structural systems, high-strength concrete, foundation systems, and mechanical systems; this continues to drive the race for height in skyscrapers that is spreading across the world.

The *Home Insurance Building* (Chicago, 1885) (Figure 1), designed by engineer William Le Baron Jenney with 12 stories, is recognized as being the first skyscraper. The use of a structural frame in the building won it the title of the first skyscraper, marking a new epoch in the construction of tall buildings, and it became a model for later tall building designs. When 800m was passed at the beginning of the 2000s, heights have been reached that could not have even been dreamed of in engineer William Le Baron Jenney's time. In other words, while 10-storey buildings were classified as skyscrapers in the 1890s, about 40 years later the *Empire State Building* (New York, 1931) (Figure 2) exceeded 100 stories, and about 100 years later the *Burj Khalifa* (Dubai, 2010) (Figure 3) exceeded 150 stories.

Figure 1. Home Insurance Building
Figure 2. Empire State Building *(photo courtesy of Antony Wood)*
Figure 3. Burj Khalifa *(photo courtesy of Adrian Peret, adrian.peret@gmail.com)*

PERFORMATIVE ARCHITECTURE

Today, the use of digital technologies in architecture has been shifted from being a tool of representation to media of design, optimization and manufacturing. There is no doubt that, CAD/CAM/BIM applications have been rapidly changing the conventional architectural design and construction process since the end of last century. In this process researchers and practitioners have been seeking for new tectonics, materials, systems producing its own energy, more efficient, more comfortable *etc*. revealing the beauty of using cutting edge technology in a sustainable viewpoint.

From this respect, thanks to these technologies, some parameters like being recyclable, being convertible, security, interaction and circulatory systems have been taken into consideration and more holistic approaches have been used under the umbrella of sustainability. It possible to argue that the increasing number of design parameters can only be turned out into an economical, aesthetical and performance based/optimized “design” by the help of computational technologies. In this context, recent studies reveal that these two main concepts can be melted in a pot and called **performative architecture.** It is possible to claim that performative design in architecture represents a combination of two critical characteristics of computational design. First, generation of a solid model that enables all kind of analytical evaluation of environmental performance based upon simulating physical conditions such as solar or structural loadings etc. Second, helping designers to create "architecture” performing as an art, with the surroundings, acting as the stage on that the building can perform and be on show via computational model that enables from file to fabrication.

Followingly, in the discipline of architecture “parametric design and performative architecture" has been discussed and published by Kolarevic and Malkawi to describe the idea of performance as a guiding principle in architectural design (Kolarevic, 2003, Kolarevic and Malkawi, 2005). Menges and Hensel (2008) highlight that being performative is usually associated with sustainability and complex digital models analyzing the structural and environmental behavior of buildings. This limits performance to a merely technical interpretation. Hagan (2008) argues that performative architecture must also consider other aspects, because architecture has always performed socially, semantically, ideologically, and in a basic manner as a shelter. Therefore, the question “what is architectural performance in the digital age” gains importance: "Is this performance comparable to the performance of a machine or a theatrical performance?"

Oxman (2009) argues that, there is no single answer for this question because of the multiplicity of the meanings and connotations of the word performance have. Albayrak (2011) concludes that, determining different performative aspects in a particular project and reconciling conflicting performance goals in a creative and effective way are key challenges in performative architecture. Accordingly, performative architecture can be considered as a paradigm that defines complex and ill-defined design problems, identifies constraints/criteria and goals of design, evolves the designing process to an optimizing process. This definition reflects the “architectural design process for sustainability” accurately. More lightweight structural system, less energy, more day lighting, more natural material, interactive building systems... all these “more” constitutes the themes of performative architecture and provides them being realized through digital designing and manufacturing techniques. Even, as transforming to a meta discipliner identity, architecture is only possible to construct smart/intelligent buildings via smartness/intelligence of the design process. Therefore, it is possible to claim that architecture is already an action for sustainability.

PERFORMATIVE TALL BUILDINGS: PEARL RIVER TOWER

China has very little in a way of oil and gas reserves and coal represents the solution to providing 80% of electricity demand. The countries’ developing economy has increased the energy consumption and resulted with rapid growth in carbon emissions (Tomlinson *et.al* 2014). Therefore, Chinese government set a goal of reducing carbon emissions by 10% by 2010 and Guangzhou was the focus of this policy. Furthermore, China sets 15% non-fossil energy consumption target by 2020. According to Frechette and Gillchrist (2008) performative approaches in the design of built environment has become a necessity in this way.

The Pearl River Tower designed by Skidmore, Owings & Merrill LLP (SOM) (completed in 2013) is one of many sustainable or green tall buildings that have recently developed (Figure 4). The project’s site area: 10,635m^2 project area: 214,000m^2 number of stories: 71 building height: 309m) Karlatornet Tower in Sweden, Pertamina Energy Tower in Jakarta, Al-Bahar Tower in Abu Dhabi, Agile Corporation Headquarters Tower in Guangzhou, Shanghai Tower, Guohua Financial Tower and Nanjing Keyne Centre in China can be mentioned as performative tall buildings recently completed with the help of computational design optimization and manufacturing tools and technologies.

Figure 4. Images from The Pearl River Tower [URL1] [URL2]

Performative Quests in the Design Process of Pearl River Tower

Selected through a competition in 2005, Pearl River Tower with its 214,000m^2 usage area and 309m building height (71-story) is an important case to demonstrate what is possible in performative design by integrating the latest green technologies and engineering advancements. The tower's sculpted form directs wind to a pair of openings at its mechanical floors, where passing winds trigger turbines that generate energy for the building. Other integrated sustainable elements including double-skin curtain wall, a chilled ceiling system, solar panels, under-floor ventilation, and daylight harvesting, all of which contribute to the building's energy efficiency. As completed the building uses approximately 30% less energy than would be used by a similar structure built to China stringent energy codes (Tomlinson *et.al* 2014). These quests are examined in detail starting with the "performative structural design" in the following sections.

Performative Structural Design

The lateral load resisting structural system of Pearl River Tower utilizes both reinforced concrete and structural steel to resist gravity and lateral loads, seismic and wind loads. The Tower's structural system is outriggered frame system[1] which is composed of reinforced concrete core (supercore), steel perimeter columns and composite corner mega columns, outrigger and belt trusses and steel end bracing. The rectangle-shaped central core, namely "supercore", consists of reinforced concrete shear walls with thickness varying between about 150cm at the bottom and 70cm at the top through height of the building (Tomlinson *et.al* 2014, Smith, 2012, Gonchar, 2015) Closed form of shear wall provides torsional stiffness.

The "supercore" shear wall system, which is linked to the *steel perimeter columns* by a system of *outrigger* and *belt trusses,* at two mechanical equipment floors at levels 23-27 and levels 49-53, and *composite corner mega columns* linked by *steel end bracing*. Figure 5

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[1] An "outrigger" consists of a horizontal truss or shear wall. It is a lateral extension of the core shear truss / shear wall to the perimeter columns in the form of a knee. An outriggered frame system is formed by the addition of an outrigger to a shear-frame system with a structural core. To make them effective, outriggers are at least one storey deep, and have a high flexural and shear rigidity. They are generally located at the mechanical equipment floors in order to not to hinder the use of normal floors. At the levels of the outriggers, connecting the perimeter columns to each other with belts consisting of a horizontal truss or shear wall. By means of the belt, the column connected to the core by the outrigger, distributes the axial load effect of the outrigger to other columns.

represents how this structural elements work together to achieve structural performance in a wise and economical approach (Tomlinson *et.al* 2014, Smith, 2012, Gonchar, 2015

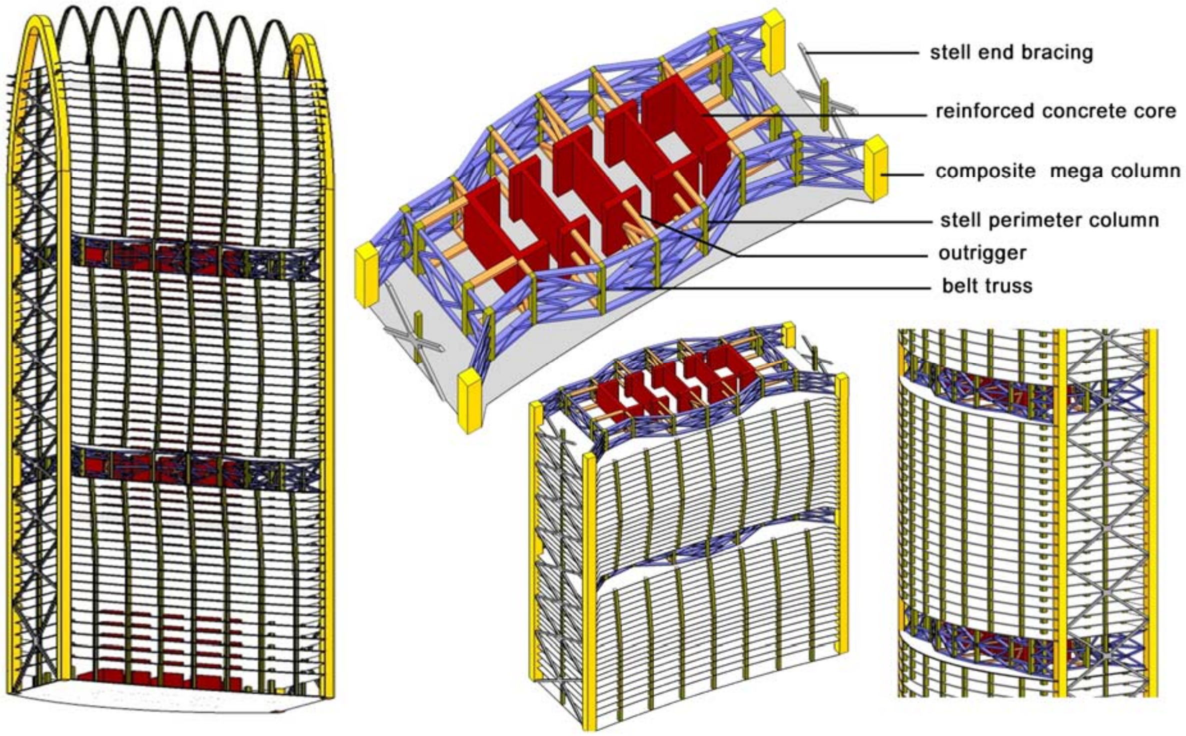

Figure 5. Structural system of the tower[2]

More Green Energy

Integration of wind power into the design of the building is one of the tower's distinct features. The towers location is shifted from the city's predominant grid to help capture the wind for energy generation. In the building design it can be easily seen that the east and the west elevations are straight while the south façade is concave and the north façade is convex. The building has four large openings in the concave face, where mechanical floors and four -2m wide 5m tall- wind turbines are placed (Figure 6). As Epstein (2008) highlights wind speed in Guangzhou is usually a mild 9 mph at that elevation, but the air is literally pulled through the holes in the envelope by the negative pressure on the protected south side, accelerating winds to speeds of about 18 mph (Epstein, 2008). (Figure 7). The turbines are estimated to provide 1% of the building's energy needs (Sharpe, 2010) It can be concluded that together with the design of building mass and its facade the geometry significantly enhances turbine performance.

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[2] Drawings for structural system of Pearl River Tower are made by ***Havva Nur Tümbaş*** in the MSc course of ***BS 536: Studies on Tall Buildings: Design Considerations***, spring 2014-2015, Department of Architecture, METU

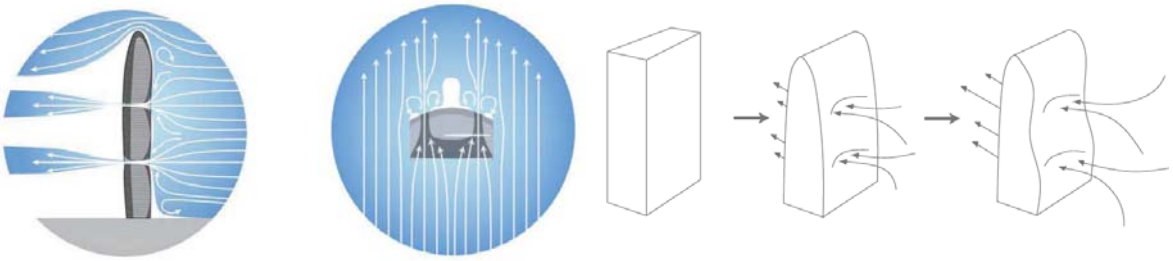

Figure 6. Principles of building design in terms of wind energy use (Choroba, Siemen, 2012.)

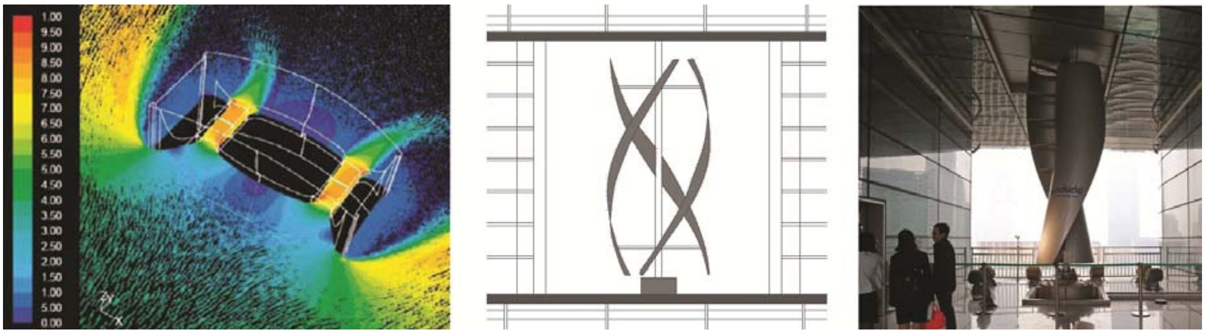

Figure 7. Wind tribunes[URL3] [URL4]

More Effective Building Skin

The tower's smooth, aerodynamic form was developed through analysis of solar and wind patterns of the city. The achieved design optimizes the solar path and utilizes the sun to the building's advantage. Similarly, façade design is performed according to energy saving principles. For example, the façade has an insulated exterior layer and an inside layer - with air space sandwiched in between the two layers (Epstein, 2008)

Figure 7. The principles of double façade design and PV panels on sunshades[URL5]

Furthermore, a photovoltaic system is integrated into Pearl River Tower's external solar shading system and glass outer skin. Motorized sunshade devices are provided within cavity for solar shading and glare control, and are controlled automatically in response to photocells that track the sun position relative to the elevation. Building Management Systems controls the angle of the sunshades automatically in response to solar intensity, solar altitude angle and solar azimuth angle to minimize solar heat (Tomlinson *et.al* 2014). Similarly, a low energy