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Determining The Structural Criteria and Form Finding of High-Rise Building and Low Rise Wide Span Steel Structures

Dr. Bhagirathi Tripathy

Asst Prof, Civil Engineering, Igit, Sarang

Abstract

Recently, complex geometries appeared increasingly especially in mega cites as a symbol of power and as indicator of urban society development. In addition to the latest advances in digital and computational tools that encourage designers to explore finite number of iconic and complex forms. The design, fabrication and construction of gigantic structures of these forms is becoming increasingly difficult with the increase in geometric complexity. Also, the cost of constructing these complex buildings increases, as a result of the increase in demand for steel usage in the past years and its expensive cost. And as known, self-weight of these structure increase with the increase in the building height and its increasing complexity.

So, it is of importance to utilize structural analysis in the early stages of the design process, so as to generate forms that are structurally efficient and then the structure performance is considered the main deriver in form generation of these projects. This study focuses on studying form finding process of two types of buildings: high-rise buildings and complex wide span steel structures (low rise), that adopt an integrated design approach: generative structural performative approach to gain a detailed understanding of its capabilities and to capture the complexities of utilizing it, therefor, evaluating its effectiveness in generating forms that achieve balance between aesthetic aspects and structural efficiency.

Keywords: Generative design, Performance- based, Structural analysis, Optimization, High- rise building, Aesthetics.

I. INTRODUCTION

Architectural forms and complex structures represent an important value in architecture even before the development and advance of today's computers. Complex ornaments are more pleasing and simplified if they are built in order, not only from a perceptual point of view but also in terms of structural analysis and fabrication aspects. Therefore, many architects and engineers have sought to design buildings that appear very complex but at the same time are relatively simple to understand, calculate and build [1,2].

The advent of computer-aided design (CAD) technologies in the past twenty years has helped to improve these types of structures using an iterative algorithm based on specific performance criteria, building material properties, fabrication and execution determinants. Currently, the design of complex structures is becoming increasingly dynamic with the development of real-time generative tools based on building structural performance which allows the designer to start with an initial model and then search for more optimized forms [1].

As a result of advances in computational techniques and rapid prototyping technology over the past years, a new design methodology has emerged, allowing architects to generate forms based on the structural performance of the building in the initial stages of the design process [3]. Then the structural system can be simulated, evaluated and developed to reach the optimal solution from a structural point of view. These techniques helped the process of cooperation between the architect and the engineer, which in turn increases architectural creativity [4].

Structural performance- based design is no longer limited to the application of structural principles and rules only, but has many potentials:

- Form finding for a large number of creative design solutions from an aesthetic and structure point of view.

- Provides highly efficient construction solutions.
- Create a new and distinct spatial experience.
- Improving the quality and efficiency of the building implementation process in the advanced stages.
- Compared to performance-based structural design in the past, computational technology has enabled architects to build structural knowledge in a more dynamic and evolving environment.
- It also helped facilitate the process of cooperation between the architect, who is concerned with achieving aesthetic and functional dimensions, and the structural engineer, who is concerned with achieving structural stability, through analysis, statistics and structural calculations.
- The process of optimization and access to the optimal solution includes integration between design and structural decisions, through a specified number of parameters or variables. In this direction, these decisions are structural and aim to reduce the amount of building materials used and expand their scope and can also be applied to reach the optimal solution on the project program, functional relationships or building form [5].

II. GENERATIVE STRUCTURAL PERFORMATIVE DESIGN FOR TALL BUILDINGS

High-rise buildings represent a great symbolic value in the urban community, which receives wide attention and scope on a professional level. The human aspiration has always been to build taller and taller structures. Where ancient structures such as the Tower of Babel, the Colossus of Rhodes, the pyramids in Egypt, the Mayan temples in Mexico, the Books of Minar in India and many more were built as symbols of power and control. It was huge, protected, and rarely used. Today, the factors determining the height of buildings are mainly economic and social factors in addition to the increasing horizon of competition, architectural innovation and modern technologies [6].

One of the recent approaches in the design of high-rise building forms is the promotion of diverse architectural styles through the continuous search for new forms, in response to the increasing demand for “iconic” buildings due to new urban developments, and the newly emerging approaches, that do not use traditional geometric forms and orthogonal to produce differences and new design possibilities. This approach has spread significantly which reflects increasing degrees of geometric variance [7].

In the design process of tall buildings, there is a great attention to aesthetic and artistic considerations and architectural style, while showing less concern for structural issues, that are usually left to be dealt with after the building form has been well generated and articulated. This approach requires that the form undergo a severe rational process that limits the role of the structural design in solving the design problem instead of integrating the structural solution in the formulation of the idea and architectural composition. While such an approach may enable the structural stability of the building, it will not lead to solutions that are “ completely performing intellectually, plastically, technically, financially and physically”, particularly with regard to the structural performance of the building [8,9].

Due to the increase in structural costs exponentially with the increase in height, mainly due to the significant increase in the amount of building materials required to withstand lateral loads. These costs can represent up to 30% of the total building construction cost (Fig1). Therefore, to increase constructability, the structural performance must be taken into consider from the initial stage of the design process while conceptualizing the architectural form [10].

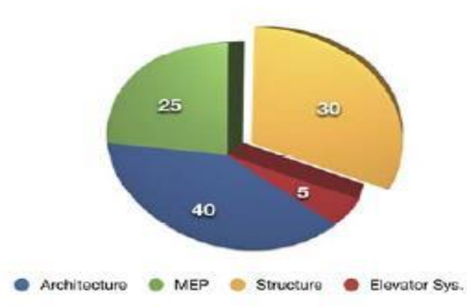

Fig 1:The cost of the structure relative to the total cost of the building [10].

Therefore, through an integrated design approach that generate tall building forms based on it' s structure performance in the initial stage of the design process, by integrating the tools of generating, analysis and simulation, which resulted in a more informed design decisions based on structural criteria. In addition, providing a large number of possible solutions away from traditional solutions that are concerned only with aesthetic considerations [8,9].

Currently, non-orthogonal tall buildings with complex geometric shapes are appearing all over the world at an accelerating rate particularly in major cities, which aim to be mega-city for political, cultural, social and economic reasons. Bored with traditional tall building designs, non-orthogonal tall buildings are now the latest trend. There are many contemporary iconic high-rise building design trends, resulting in many different architectural forms, such as twisting, tapering, rotating and freeform. To design distinctive buildings and unprecedented building forms, the architects moved away from the standard forms and simple and traditional geometry such as pyramids, boxes, cylinders and cones. This has resulted in the emergence of non-orthogonal tall buildings globally with an increasing degree of geometric asymmetry. The design, manufacture and construction of gigantic structures of unusual and unconventional shapes increases with engineering complexity [11].

Generative performative design of tall buildings may include multiple types of performance according to the nature and conditions of each project, even environmental, functional, structural, economic and others. The structural performance is one of the most important factors affecting the form and behavior of a building, especially tall buildings and skyscrapers. This is based on the fact that most of them tend to be relatively tall and slender, so the main element is height, which plays a major role in the formation, selection of the structural system and building materials for the structural structure. The height of skyscrapers also affects the loads, whether horizontal or vertical, to which the structure is exposed, which must also resist the initial loads of gravity and lateral forces to achieve stability and stability. A good understanding of these loads leads to the selection of the most appropriate structural system[12].

2.1 DUBAI TOWERS

The 550m Tower 2, was the tallest of the proposed Lagoon Towers project to be built in Dubai, 2007. Dubai Towers is a mixed-use project consisting of four towers of varying height and geometric configuration (Fig3). So that the design of the towers is structurally effective, economical and feasible. These goals require the seamless integration of the structural and architectural design and can only be achieved through early and continuous collaboration in the initial stages of the design process [13].

▪ PARAMETRIC MODELLING

The shape of the towers was created by taking an octagonal shape in the horizontal plane and tapering the extruded form in the vertical direction. Then a rotation is made for each horizontal projection at a fixed angle along the height of the tower. Finally, the tower is curved in two perpendicular directions. These operations (taper, rotation and curve) for towers of full height have had the following effects:

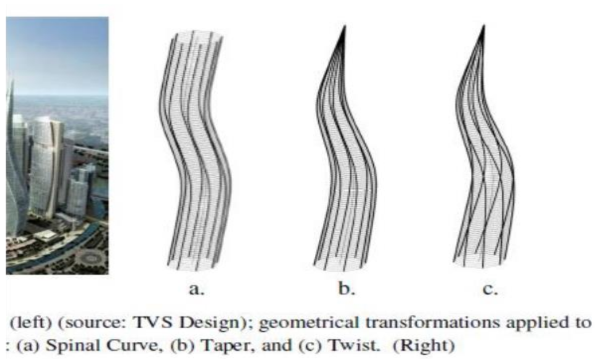

Fig 2Building geometric modifications: a. The axial curve, b. taper and c. Rotation[14] Fig 3: Dubai towers[14]

- TAPER: Helps reduce floor space on upper floors, reducing cumulative gravity loads. It also reduces the impact of lateral winds and provides an irregular vertical section for the full height of the tower, reducing cross wind effects.
- ROTATION: The rotation of the tower causes the perimeter columns to slope, which in turn causes gravity loads to cause a torsion. This torsion can be countered by inserting inclined perimeter braces opposite to the columns. A perimeter diagrid system was created by balancing the axial area of the elements with the forces caused by the inclination of the columns and the braces. A balanced system will have only vertical displacement due to gravitational load.
- CURVE: The curve moves gravitational loads away from the center of the tower at its base and creates eccentricity and inversion moments. Curvature also results in a slope between one floor and the other, resulting in an average slope of all structural elements on the perimeter of the building. This inclination creates a horizontal shear force from gravitational loads that must also be resisted at each periodic level in which a change in the geometry occurs. This horizontal shear must be resisted by perimeter braces or core [13].

The structural system that resists lateral loads and gravity loads is a compined system that consists of: Reinforced external tubes, Core shear wall, Outriggers, Interior columns Interior columns, Floor framing. Comprehensive optimization improvements have been made to the design process to achieve the best results in terms of cost reduction, constructability and implementation of towers. The aim was to generate building form based on structural criteria while preserving the architectural concept. The main focus was on the balance at the base of the tower as well as the reduction of the inner shear resulting from the slope between each roof slab.

The impact of twisting on the building's structural behavior was also studied, with a 360-degree rotation applied to the architectural form, an increase of 30 degrees per trial. 13 cases of different alternatives were studied and tested. lateral displacement was used here as a key performance indicator and in each trial the resulting external structural system is analyzed using ETABS [15].

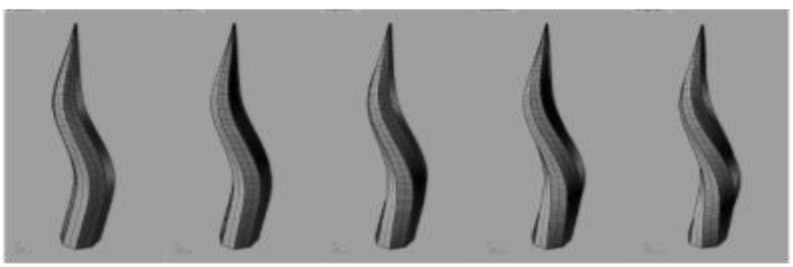

Fig 1: Parametric changes as a result of changing the rotation angle[15]

- FINAL GEOMETRY

Each tower's architectural form was subtly reconfigured to balance the gravity load of the tower with the center of the tower at the base by tilting the top of the tower, changing the central axis, and reducing rotation. A simple spreadsheet was created based on the first principles, which controls all configuration transactions and provides preliminary results for any proposed modifications.

Each attempt is evaluated based on the balance of the tower, reducing the inner shear forces, and aesthetics. The figure shows the overall effects of the improvement process [16].

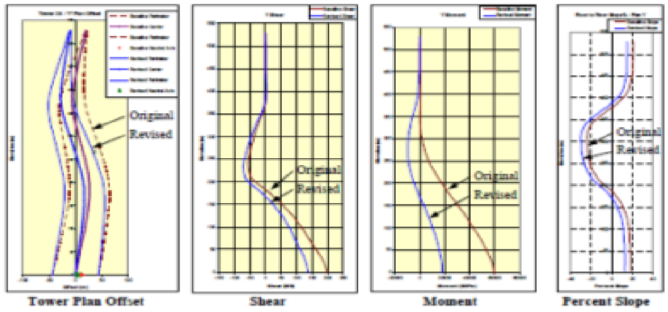

Fig 1: Geometry spreadsheet[16]

2.2 SHANGHAI TOWERS

Shanghai Tower is 30,370 m2, which stands at 632 meters high with 128 floors above ground designed by Gensler, 2015. Designed for high energy efficiency and sustainability, this tower offers multiple separate areas for administration offices, commercial spaces and recreational use, providing an integrated community [17].


Fig 1: Shanghai Tower [18].

- PARAMETRIC MODELLING

Shanghai Tower has a unique design, with a spiral form that extends vertically at a rotational angle at about 120 degrees and is tapered by 55% and double façade. In the initial phase of the design, Gensler's team anticipated three important design strategies: asymmetry of the tower's shape, tapering, and rotating angles, which would allow the building to resist the forces of shanghai popular hurricane winds [18].

- STRUCTURAL ANALYSIS and SIMULATION

The structural system of the building consists of a central reinforced core with an area of 30m, 8 huge columns on the perimeter and 4 large columns in the corners, in addition to supporting trusses connecting the columns to the central core of the work in an integrated manner [19,11].

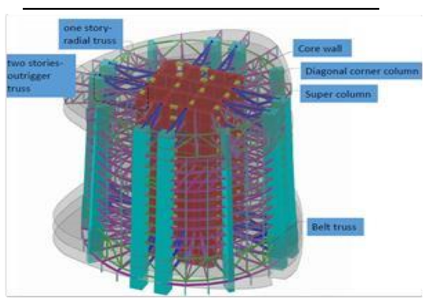

Fig 1: 3D model of shanghai tower structure system [19]

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▪ OPTIMIZATION PROCESS

Using wind tunnel tests, Gensler and structural engineer Thornton Tomasetti improved the tower's shape, ultimately reducing the building's wind loads by 24%. The result is a simpler, lighter structural body with unprecedented transparency and a 32% reduction in expensive materials [20]. The Gensler design team expected that a significant reduction in both the tower's structural wind loads and the wind stresses on the building's cladding could be achieved if its geometry was further optimized. To create the best possible case for reducing these loads, several different alternatives were proposed:

1. Rotation at 90°, 120°, 150°, 180° and 210°.

2. Then reduce the scale by 25%, 40%, 55%, 70% and 85%. All these alternatives are analyzed against each other and then compared to the base case - in the
form of tapered box [17].

▪ FINAL GEOMETRY

According to [18], when designing high-rise buildings today, the building form should not only reflect the aesthetic dimensions and architectural concept but should also lead to the reduction of wind effects on the structure resulting from aerodynamic effects, where some aerodynamic modifications in the architectural form is one of the effective design methods that greatly reduce the impact of lateral wind force and thus the movement of the building [21,22].

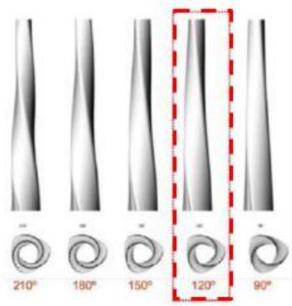

Fig8 : Wind tunnel study rotation models[18]

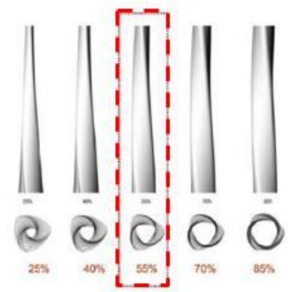

Fig9 : Wind tunnel study scaling models [18]

Wind tunnel tests determined that the most effective scaling is about 55% and rotation at 120°, which reduces wind loads on the structure by 24% compared to the tapered box in the base case [19], which equates to a saving of about $50 million. American in only the building structure. although a 180° rotation would reduce loading by an additional 9%, but was not selected for aesthetic considerations [23].

III. GENERATIVE STRUCTURAL PERFORMATIVE DESIGN FOR LOW RISE WIDE SPAN STEEL STRUCTURES

Architectural forms and complex structures represent an important value in architecture even before the development and advance of today's computers. Complex ornaments are more pleasing and simplified if they are built in order, not only from a perceptual point of view but also in terms of structural analysis and fabrication aspects. Therefore, many architects and engineers have sought to design buildings that appear very complex but at the same time are relatively simple to understand, calculate and build [1].

3.1 WATER CUBE PROJECT

It is located in the Olympic Village in Beijing,China, a sports building, designed by Arup, CSCEC, PTW in 2008, with a total area of 31329 and a height of 30 m. [24]

Fig 1 : National aquatic center (Wtaer Cube) [24]

- PARAMETRIC MODELLING

At the end of the 19th century, the mathematician Lord Kelvin proposed a problem in which he asked how to divide space into cells of equal volume with the minimal surface area between them. This was the first time Lord Kelvin's foam bubble theory had been applied in architecture, and it is also the largest public building in the world completely enclosed in an air-filled ETFE membrane [25]. In the design process, engineers adopted an integrated, multidisciplinary approach. The main disciplines that were incorporated into the design were Structural Engineering, 3D Documentation with CAD, Fire Fighting, and Environmental Engineering, Building Services, and Acoustic Engineering [26].

- STRUCTURAL ANALYSIS and SIMULATION

The structural solution is based on the strengthening of the building by arranging the structural elements at the boundaries of each bubble, expressed in the Superstructure 3D Vierendeel system.

It is difficult to calculate sizes of all the structural elements and to design a stable structure in the traditional way, and then a new program was developed that selects the sizes of the structural elements in an iterative optimization method, which resulted in a highly efficient structural framework [27]. The structural design of the building is linked to several considerations related to achieving strength and durability, which are as follows: The roof structure was designed under the influence of live load, snow loads, wind loads, and three levels of earthquakes were taken into account during the design in addition to the self-weight of the structure system [28].

- OPTIMIZATION PROCESS

The structure of the building consists of 22,000 structural elements, each of which must meet the strength requirements of 11 different clauses of the China Metallic Design Code, which includes 5 points for each element for 190 different loading groups. This equates to 230 million design constraints that must be met by changing 22,000 separate strength improvement variables to reduce the overall weight of the steel used in the structural frame. This problem is too big for gradient- based optimization methods, and therefore solving this problem requires the use of probabilistic optimization methods, genetic algorithms or an alternative method to reach a satisfactory design with high structural efficiency. The use of this method resulted in a significant reduction in the total weight of the steel used through an iterative approximation process with all design parameters being met [24].

3.2 HANGZHOU TENNIS CENTER

The Hangzhou Tennis Center is a 10,000-seat tennis stadium located in Hangzhou, China. designed by NBBJ with CCDI. Digital computation plays an important role in the form finding process of the project, which encouraged designers to search for new approaches to expand their capabilities and derive unconventional ideas and solutions in an infinite number [24]. The building is made up of 24 truss modules arrayed around a circular arc, called "petals", which create a large-scale repeating pattern that surrounds the seating areas of the stadium. In addition to giving a distinctive visual dimension to the building, the outer shell plays an important functional role in providing shades and protecting the seating from rain. This structure also houses the building's technical equipment such as lighting elements [25].

Fig 1: Hangzhou Tennis Center [29]

- PARAMETRIC MODELLING

The design based on an integrated parametric system to generate the building form, formulate the architectural concept, simulate and document its complex engineering systems: To conceptualize the initial form, a parametric system was set to define the control surfaces of the geometry and study the various configurations through a number of parameters to change and modify, which results in the exploration of a large number of different configurations of the building's outer envelope[30]. The generation and evaluation of these different alternatives and the comparison between them depends not only on the aesthetic considerations, but also introduces a number of key transactions, which are considered among the main elements to conclude the final configuration of the building, namely: shading elements, rain drainage, structural performance, sports technical systems [31].

Fig 1: The different alternatives to the outer shell of the building [31].

- STRUCTURAL ANALYSIS and SIMULATION

Physical simulation tools were used to test the structural behavior of the building. For detailed and structural analysis, custom scripts were used to automate the delivery of central line information to the structural design team, coinciding with additional functionality for concept simulation has been added to the Grasshopper algorithm. Gravitational loads on the steel truss structure were tested as shown in Fig. Tensile and compressive forces can also be expressed as well as areas of maximum stress. By incorporating these capabilities into the design model at the initial stage of design process, the design team was allowed to make more informed decisions and generate forms based on the building's structural performance [24].

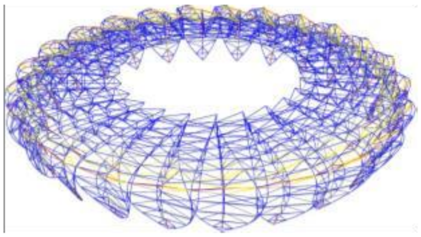

Fig 1: Using the Kangaroo List in Grasshopper to visualize the gravitational loads on the centerline model of the truss [24]

- FINAL GEOMETRY

As global demand for steel has increased - by 78% in the past decade - so is the cost, which has increased by 217% since 2007; For this reason, parametric design with it' s potentials, is used to reduce waste in form finding process. The

steel structure and the concrete structure are bonded to achieve stability and optimum use of steel. The possibility of making changes in the architectural configuration flexibly in a very short time. The parametric model has been used as a basis for interdisciplinary collaboration with the structural engineer and building materials consultants, where they can directly use the design outputs to perform specialized analyzes, helping to ensure quality control and create opportunities for further improvement. Reducing the percentage of steel used by
67% compared to projects of the same density and size [32].

IV. COMPARATIVE ANALYSIS BETWEEN DIFFERENT POTENTIALS OF EACH DESIGN APPROACH

As a result of the development in digital technologies and computational design, the opportunities for architectural creativity increase, as well as enrich form finding process, and provide opportunities to generate complex forms that are hard to design, calculate and implement using traditional methods.

Currently, tall, non-orthogonal buildings with complex geometric shapes are emerging all over the world at an accelerating rate, especially in cities, which aim to be megacities for political, cultural, social and economic reasons. Architects seek to create iconic and unconventional forms that reflect the evolution of urban society and technological and technical development, as well as a symbol of power and control. The design, fabrication and construction of gigantic structures of unusual and unconventional forms is becoming increasingly difficult with the increase in geometric complexity. In addition to difficulties in the implementation process, which is difficult by traditional methods.

The research focuses on studying form finding process of two types of buildings: tall buildings and complex wide span steel structures (low rise). With the increase in the demand for the use of steel in the past years, and also the high cost, the cost of constructing these complex buildings increases; These costs can represent up to 30% of the total building construction cost, the structural elements used and the self-weight of the structure increase with the increase in the height of the building in tall buildings. Also, complex wide span steel structures, the weight of the structure and the amount of materials used increase with the increase in geometric complexity.

This requires the use of a design methodology that depends on the inclusion of the structural performance of the building during the initial stages of formulating the design idea, which provides a number of solutions that take into account aesthetic considerations as well as generating form based on structural criteria. So, it is of importance to investigate the adopted design approach to evaluate its effectiveness and to gain a detailed understanding of its capabilities and to capture the complexities of utilizing it as shown in (TABLE **I**).

TABLE I COMPARATIVE ANALYSIS BETWEEN EACH DESIGN APPROCH

		HIGH RISE BUILDING		**WIDE SPAN STEEL STRUCTURES (LOW RISE)**	
PROJECT		DUBAI TOWERS	SHANGHAI TOWER	THE WATER CUBE	HANGZHOU TENNIS CENTER
DESIGN APPROACH		Integrated approach: Generative structural performative design approach			
PER FOR	STRUCTURAL	✓	✓	✓	✓
	ENVIRONMENTAL	✓	□	□	□
	FUNCTIONAL	✓	✓	✓	✓
	COST	✓	✓	✓	□

EVALUATION CRITERIA	STRUCTURAL	- Efficiency of the structural system. -The equilibrium of overturning moment of at the base of the tower. -Reduce the internal shear caused by the slope between each floor slab.	-Reducing wind loads on the tower and reducing wind pressure on the outer cladding. -Reducing the building materials used.	-Resist live loads, wind, snow, earthquake, rain and dead loads. -Reducing the total weight of steel used in the ceiling and walls. -Increasing constructability.	-Achieving the lowest self-weight of the structure system represents the architectural concept. - structure efficiency.
	AESTHETICS	Generate iconic building form that takes into consider aesthetics and visual aspects.			
	FUNCTIONAL	Functional considerations vary to meet the requirements of each project			
SOFTWARE USED		Rhino3d Grasshopper ERABS	Rhino 3d &Grasshopper Karampa plugin tool	Rhino 3d &Grasshopper Strand7, Autodesk Revit	Rhino 3d & Grasshopper Kangaroo physics engine
Opti	SHAPE	✓	✓	✓	✓
	TOPOLOGY	□	□	✓	□

POTENTIALS OF DESIGN APPROACH	AESTHETICS	Taking into account aesthetic considerations and achieving the architectural concept.	During the optimization process, although a 180- degree rotation in the tower's mass configuration reduces wind loads by an additional 9%, it was not selected for aesthetic and optical considerations.	The building is the world's first application of the Kelvin theory of foam bubbles in architecture. - The building looks complex but at the same time is simple and modular facade design.	The building envelope design was innovative and distinctive based on a modular system of sculptural repeating steel trusses.
	STRUCTURAL	**-Structural Efficiency:** Improving constructability and structural efficiency. **-Economic Efficiency:** - Reduction in building materials equivalent to 95,000 tons of steel and 96,000 m3. -Reduction in construction resources exceeding 600 million US dollars[13,15]	-The final form achieved a reduction in wind loads in the building by 24%. Which resulted in a simpler and lighter structural structure with unprecedented transparency. -Saving about 50 million US dollars in the building structure. -32% reduction in expensive building materials[17,18].	-The structure is of a high degree of efficiency. -The sizes of 22,000 structural elements and 12,000 detailed diameters were calculated to reach the least possible area that can respond to the pre-set construction goals, which is impossible to implement by traditional methods.	-Reducing of steel used by 67%. compared to projects of the same density and size. -Reducing constructi-on cost of the struct-ure and thus reducing the total cost. -Using parametric modeling enabled project document- ation and increased constructability efficiently[21,22].

				total cost. - Computational modeling helped to estimate the quantity of each steel type accurately and thus estimate the cost[20]	
PROBLEMS		The difficulty and complexity of the design process, which requires cooperation between architects and structure engineers experts in with the use of modern parametric techniques.			

Comparing the previously explained projects in terms of design approach, criteria for evaluating design alternatives, software used, the different adopted performance, the potentials of the design approach and the significance of using it, in addition to capture its complexities. An integrated design approach is adopted: form finding process based on the evaluation of the structural performance of the building, in the initial stages of the design process.

Generative and computational tools allow exploring an infinite number of different design solutions by defining different design parameters and factors according to each project concept and the architect's desire to create an iconic, distinctive and unconventional form.

These projects have many pre-determined design and construction objectives, find the most appropriate structure system that achieves the highest efficiency, taking into account reducing the self-weight of the structure to the lowest permissible limit, as well as reducing the building materials used and reducing the waste of resources, increasing the constructability and thus increasing construction efficiency of the building. To achieve this, the structural analysis of the building was included during the early stage of the design process, which provides infinite design solutions, through the optimization process, the architect compares between them and the select of the optimal solution that achieves balance between aesthetic, technical and structural considerations.

Some approaches are single objective, that generating forms based on structural performance, while others are multi objective design approach that utilizes other performances as functional, environmental and economic in the early stages of the design process.

It has been found that, some of the major advantages of using this integrated design approach are related to the aesthetic and visual aspects, while others related to the structural and economic aspects, as follows:

- Aesthetic potentials:

- Exploring an infinite number of design solutions that fulfill the designer's desire to create a distinctive iconic building away from typical traditional forms that cope with modern digital and technological developments as well as the current urban development.

▪ Structural advantages:

- Generation architectural forms that achieve the structural efficiency.
- Reducing the cost of the structure system and reducing the building materials used, thus reducing the total cost of the construction process.
- The possibility of designing complex geometric forms and high-rise buildings in a way that is difficult to calculate, analysis and implement by traditional methods.
- Increasing constructability.
- The design process consumes less time compared to the traditional processes for the same project types.

▪ Complexities:

- One of the main findings is that, the design approach includes some complications such as the difficulty of the design process, as you need a design team fully aware of the use of modern digital technologies and design algorithms. In addition to the need to cooperate with different disciplines (structural engineer - acoustics engineering, ...) in the initial stage of the design process.

V. CONCLUSION

The following conclusions can be drawn from the present study, complex geometries and high-rise buildings appeared increasingly especially in mega cites as a symbol of power and dominance, that also reflects the urban society development. In addition to the striking development in digital media and computational tools that enables designers to explore finite number of iconic and complex forms away from the traditional forms.

Through investigating the design process of some case studies of these projects, that enhances our understanding of its different stages and adopted design approach, then tracing its significant potentials as well as capturing complexities in order to evaluate its effectiveness and to what extent the designers could adopt it to achieve a pre-defined design objectives. The most obvious finding to emerge from this study is that these types of buildings adopted integrated design: generative structural performative design approach, that integrates structure analysis in the early stages of the design process, that resulted in decision making being informed with structural criteria.

This approach has many potentials in common:

- exploring an infinite number of design solutions that fulfill the designer's desire to create a distinctive iconic building in no time.
- generating architectural forms that achieve the structural efficiency.
- reducing the cost of the structure system as well as reducing the building materials used, thus reducing the total cost of the construction process.
- In addition, the possibility of designing complex geometric forms and high-rise buildings in a way that is difficult to calculate, analysis and implement by traditional methods, therefor, increasing constructability.

On the other hand, this approach has some complexities lies in the difficulty of the design process, as you need a design team fully aware of the use of modern digital technologies and design algorithms. In addition to the need to cooperate with different disciplines (structural engineer - acoustics engineering, ...) in the initial stage of the design process.

It could also found that, the design process generally goes through three iterative stages: parametric modeling, performance simulation, and computational optimization algorithms. The combination of modular modeling and rapid assessment tools allows for the rapid generation of a large number of design alternatives and their numerical evaluation. This can be well combined with optimization algorithms to obtain an optimal performance simulation-based design. The findings of this study suggest, utilizing this integrated design approach, that integrates structure performance in form finding in the early stages in the design process, to achieve the pre mentioned potentials which approved the effectiveness of this approach in designing such complex and high-rise buildings.

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