Aeolian Towers: Designing Aerodynamics

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Abstract. Acknowledging the necessity of designing structures that comply with environmental factors, the main objective of the current project is the morphological investigation of a sustainable dual-tower complex. Considering the force of wind as a basic design parameter, the importance of every design decision is evaluated by calculating its impact on the structure’s performance over its life cycle. Since wind simulation could certify the effectiveness of design techniques that aim to streamline a structure’s form, the proposed approach utilizes computational fluid dynamics (CFD) for the objective and scientific assessment of the complex’s aerodynamic behavior. By altering the design based on the results and comparing the differences of critical variables such as wind velocity, loading and pressure distribution, significant results are extracted. The simulation of the flow field of the final design certifies that the wind’s impact is substantially diminished. Along with a notable decrease in wind velocity and loading, informed decision making takes place and quality enhancement of the urban environment is ultimately achieved. Thereby, wind’s significance as a basic parameter in high-rise design is highlighted. The concept of wind design can, at this point, be further extended. In addition to defining the form of the building’s envelope, energy harnessing techniques are introduced. To ensure its sustainability a nanotechnology-based grid that consists of micro wind turbines is annexed to the structure. For the towers’ cladding, glass that incorporates solar panel technology is also being used, transforming the facades into solar energy collectors. The introduced approach aims at optimizing the complex’s aerodynamic behavior while accomplishing sustainability and energy self-reliance. Although the results are case sensitive, useful design methodologies and techniques can be extracted as guidelines that could assist in future design projects.

Key Words: Architecture, sustainability, high-rise design, aerodynamic design, wind simulation, Computational Fluid Dynamics (CFD)

1 Introduction

The current project is motivated by a preceding theoretical research on Aerodynamics that acknowledges the importance of wind in architectural design. Fundamentally, it attempts to rationalize the interference of tall buildings in wind flows a. by analysing their design’s impact on flow fields and by exploring b. wind tunnel and c. computational simulation methods. Thus, after realizing the significance of considering wind’s action from the initial design phases, the necessity to practically employ and test the effectiveness of such fundamental theories arises. Thereby, the current project undertakes the design of high-rises where wind’s significance can be appropriately showcased and the study of which can yield interesting results.
1. Objectives
With the prospect of establishing the project’s objectives two main themes need to be addressed. In this context, the fusion of both Iconic and Aerodynamic qualities is what the design is ultimately striving for and their simultaneous fulfilment becomes critical as it influences the workflow.

2 Methodology

2.1 Thesis
In the process of determining the ideal shape for the structure, references to previously conducted research are necessary in order to individuate design principles that could support the project’s purposes. This is primarily accomplished through the study of former experiments and the reinterpretation of their conclusions to make them match current contextual specificities. The indicated procedure fuels an abundance of experimentations that examine the interrelation of techniques like rounding the cross section’s corners, deciding on its along-wind orientation and its surfaces’ inclination. The aforementioned act as a starting point for the design’s formation, outlining areas of interest that could later influence the structure’s performance.

2.2 Computational Fluid Dynamics
Main intent of the design process at all stages is the gradual refinement of the buildings’ aerodynamic behaviour. However, theoretical research by itself could not ensure the adaptability and effectiveness of every design operation, thus, moving forward, simulation methods have to be employed to evaluate each distinct application. Since wind tunnel testing is not a cost-effective solution, the use of computational simulation methods comes as a necessity to verify the improvement of the towers’ interaction with wind. That signifies that for the final outcome to be produced a procedure of designing, testing, then reconsidering the design and re-examining the effect of its changes is crucial.

2.2.1 CFD intro
Over the past two decades the building simulation discipline has matured into a field that offers unique expertise, methods and tools for building performance evaluation. To do so, it draws its underlying theories from diverse disciplines, mainly from physics, mathematics, material science, biophysics, human behavioural, environmental and computational sciences (Augenbroe et al, 2004). Although at first it might sound challenging, attempting to introduce such technologies to the field of Architecture carries great importance on a project level. Hence, such simulation methods should be utilized as tools that assist architectural design, especially since interdisciplinary cooperations render the multiplicity and diversity of the required knowledge manageable.

2.2.2 CFD Steps
For practical reasons it is necessary to note that by mentioning computational simulations, reference is made to the analysis of wind and its flow field around structures by calculating numerical models. It is also important to give a brief description of the required procedure which typically consists of the following steps.
Step 1: Collection and Static Analysis of Meteorological Data, to allow their use as input data.

Step 2: Construction of a Mesh that simulates the original geometry in order to compute the surrounding flow field. The mathematical approach used is based on the finite volume method. (ANSYS ICEM software)

Step 3: Mesh Quality Check, to ensure that mesh quality criteria are met so as to minimize the uncertainty of the results.

Step 4: Solver Selection. To ensure the most appropriate solution, which is derived from equations that define this particular mathematical problem. (ANSYS CFX software)

Step 5: Determination of Turbulence Model: Influences the process of solving. In this case, k-ε and k-ω turbulence models were used. They give a general description of turbulence by means of two transport equations (Partial Differential Equations), with the first variable being the turbulence kinetic energy (k) while the second (ε), (ω) being the specific rate of dissipation.

Determination of the Results’ Time Frame: Steady State Simulation can be originally computed, giving results for a steady moment in time. Transient Simulation for a specific time frame can be then initialized by receiving input from the steady state solution, resulting in the visualization of time varying effects over the case study.

By following those steps and evaluating the results, the assessment of the effectiveness of every design decision becomes possible by comparing critical indicators, such as wind velocity, force and pressure distribution with some predefined values. Provided that a lack of compliance with the appropriate standards would occur, the designer would have to resume with the production of morphological variations so as to obtain an improved scenario. In our particular case by computing the flow fields that surrounded the initial and final geometries a comparison between the aerodynamic characteristics of the two designs was enabled and all necessary compliances occurred.

2.2.3 Contrasting Parameters (wind velocity, loading, pressure distribution)

Simulation methods are presented here as tools that assist engineers with decision making processes by evaluating the viability of their demands. So to speak:

By studying the diagram of forces (Diagram 1) that are exerted upon the structure’s surfaces a significant difference can be noted between the two designs. More specifically, as the buildings twist, the windward faces of the towers and their base avoid getting perpendicularly exposed to the approaching wind flow. Instead, as the surfaces smoothly recess and alter their orientation, and thus wind’s angle of attack, the forces’ value range slightly decreases.

Additionally, by considering the shape of a typical wind velocity profile, it becomes apparent that high winds are pushing on the upper part of the building with a lot of leverage. By tapering both towers they become better stabilized, oscillations reduce, while a stiffer and more wind resistant structure is delivered.
Regarding pressure distribution (Diagram 2) on the windward side, areas of high pressures can be clearly spotted on the initial design with red. To achieve a local decompression and partially relieve the final structure, the formation of a central opening on the main tower is critical.

Figure 1: Force Diagrams

Figure 2: Pressure Distribution Diagrams
Furthermore, by analyzing the velocity streamlines’ patterns around the structures (Diagram 3), significant observations can be made. Specifically, their formation in the leeward direction showcases that as the design changes, the flow stays attached to the structures’ surfaces for longer, it becomes less turbulent, more streamlined and vortice irregularities reduce as they get organized. Furthermore, recorded velocities indicate that air speed around the final design is slightly increased. This unsurprising event displays that the structure’s form allows the flow to pass through the bulk shape smoothly and in a less obstructed way. Subsequently, it is suggested that through the evolution of the design a more aerodynamic shape is attained, which in turn enhances the structures’ performance. Additionally, the study of streamlines and their velocity spectrum evaluates the appropriateness of creating livable outdoor spaces. By examining and contrasting flow conditions on exposed roof tops and potential public spaces, flow enhancement is validated. Even local occurrence of turbulence on the highest points of the towers is justifiable, since velocity ranges within acceptable levels securing the viability of local inhabitance.

Moreover, by studying and comparing velocity vectors that lie on two perpendicularly intersecting planes (Diagrams 4,5,6), the one cutting through the tallest tower and the second parallel to ground at a height level of \( z_0=15 \text{m} \), additional data regarding wind’s flow pattern around the alternate designs can be observed. Focusing primarily on the towers’ wakes, in the first scenario they have a significantly wider span which means that a larger area of surroundings gets affected by their presence. The case is inversed in the second scenario where, focusing on the link between the towers’ bases, wind speed is locally increased in the windward side and decreased on the leeward side, which makes sense, since no opening can ensure the flow’s decompression. However, while the base’s wake is larger, the flow’s speed is locally reduced. Indeed, the spectrum of all recorded velocity values is low enough to ensure wind comfort conditions for the structures’ surroundings in general.
Figure 4: Velocity Vectors

Figure 5: Velocity Vectors
The aforementioned analysis ensures that, in the latest design, force and pressure distribution ranges decrease, flow streamlining is achieved, turbulence is mitigated and inhabitable spaces on exposed roof tops are secured. All in all, that means that the structure is undercharged, requiring less structural reinforcement and reducing respective material costs, conditions of wind comfort are attained and wind danger is circumvented. Thereby, through Calculated Design Decisions, a Streamlined and Optimized Architectural Design is achieved, which enhances structural performance, reduces construction costs and ensures public space and urban environment quality enhancement.

Having validated the aerodynamic effectiveness of the proposed design, further developing the project becomes meaningful. In this context, the incorporation of technologies that would further advance the structures’ sustainability emerges as a necessity.

### 3 Energy Harvesting Techniques

An increase in energy requirements is expected for a building of such scale. Since the utilization of sustainable energy resources, as well as design techniques, is essential, the project reasonably seeks methods to achieve its sustainability. Examining the main concept, sailing boats, it appears that they collect energy from wind and utilize it for their movement by transforming it to kinetic energy. The complex is inspired in this way to utilize wind power, that is aeolic energy. The study of different wind turbine typologies accommodates the discovery of an innovative system which, combined with nanotechnology, will aid the energy harvesting process. A nanotechnology-based grid (Diagram 7) in the form of sails is found and annexed to its exterior steel columns (Otegui, 2008). It consists of micro wind turbines whose exterior surfaces act as solar panels while their interior surfaces absorb carbon dioxide from the atmosphere. Additionally, glass that incorporates solar panel technology is being used for the towers’ cladding, transforming the buildings’ exterior into solar energy collecting surfaces. Ultimately, the implementation of the above technologies aims at achieving the construction’s energy self-reliance.
Figure 7: Energy Grid
4 Results and Discussions

The recognition of the fact that the physical state of a building is dependent upon the complex interaction of a very large set of physical components poses numerous theoretical challenges. Major modelling and computational challenges are set when one attempts to integrate all these interactions in one behavioural simulation. Ultimately, the ability to manage the resulting diversity of components and complexity of scale makes building simulation tools critical for the assessment, verification and prediction of buildings’ performance (Augenbroe, 2004).

Another important aspect when modelling fluid dynamics phenomena, is the advancement and use of supercomputing. The various fields where such phenomena take place vary in number and context (modelling of urban environments, weather and climate, aerospace vehicles, solar physics, universe formation). Since high-fidelity numerical modelling, as well as the detailed analyses and visualization of large-scale data are required in all disciplines, supercomputing possesses a critical role in enabling this processes and, thus, in advancing technology and human knowledge (Dunbar, 2017).

To facilitate the aforementioned processes, enable their direct interrelation and partial automation essentially rendering the presented complexity more manageable, the integration of simulation and design software applications comes as a necessity. Establishing a neutral language and a common style of representation is an important aspect that consists the basis of software development. Through it, more accessible technologies are created and their wider employment is ensured.

5 Conclusions

This project emphasizes that the use of computational simulation tools can prove critical in the context of architectural design. By testing and evaluating the structure’s performance under wind loading and examining its surrounding flow field’s characteristics, significant results can be extracted, both about the structure and its environment. Computational fluid dynamics (CFD) is recognized as a tool that can assist designer’s by guiding them in decision making processes.

From the behavioral study of the structure’s form in this specific case study, valuable observations can be made about design techniques that improve the aerodynamic behavior of tall buildings. Although some are case sensitive, by reconsidering their applicability and adjusting them to different cases a wider context can be influenced by their frame of reference. Thus, through the evaluation of wind’s action in urban environments and existing structures, the establishment of design methodologies and techniques that will ensure streamlined design for future structures is enabled.

Regardless of the criticality of wind’s incorporation in the initial stages of architectural design, to ensure that every project reaches the desired level of sustainability additional measures need to be considered. In this scene, employing ingenuity can initiate the discovery of new technologies that enhance the structure’s energy self-reliance. Thus, the incorporation of such technologies will enable the substantial improvement of pre-existing potential, certifying the structure’s sustainability.

All things considered, the employment of computational fluid dynamics that simulate and predict the structures’ performance, the establishment of design methodologies that assist architects and engineers in building design and construction, as well as the incorporation of innovative technologies, all work towards ensuring sustainability over the life cycle of buildings and especially of high-rises. Therefore, the importance of wind engineering is accentuated, as now, more than ever, human, urban inhabitancy patterns and demands necessitate its employment.
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