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RESEARCH ARTICLE

Parametric wind design

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Abstract
Although gradual, the changes in the weather patterns are also noticeable and impactful to architectural design. If the local microclimate is taken into account early in the conceptual stage of design, the longevity of the ultimate structure can be greatly enhanced, despite challenging environmental factors. Parametric designing enables to discover the optimal architectural shape based on specific weather data. The paper intends to investigate how this design approach, coupled with Computational Fluid Dynamics simulations, can be used to create a wind-induced architecture. Both the benefits and the limitations of this approach are explored in detail. The interaction between an architectural shape and wind flow is tested in a study called 'FlowBrane'. The process of (1) designing a parametrically changeable geometry, (2) testing its behavior in the wind, and (3) evaluating the results allows looping back to the initial geometric design, continuing to improve the design and ultimately the performance of the architecture in the specific wind conditions of the chosen site. However, the need to test multiple geometries separately and to adjust the wind simulation for each test (and for every wind direction) remains a disadvantage that should be addressed in further research.

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1. Introduction

After the second industrial revolution, the trend of expanding cities, growing industry, and a forgotten relationship with nature dominated architectural and engineering designs. During the most recent decades, society and architects alike have concluded that those building strategies are not sustainable. Warnings about the changing climate, global warming, and the resulting extremes have sent a clear signal for architects, engineers, and planners to start thinking differently about design. It is probable that if we keep building the way we are building now, with architecture as a static element placed in a dynamic environment, we will be unable to fit into and influence the ever-changing surroundings. Reacting to the citation of Charles Darwin, Edwards noted that also buildings, as everything on the planet, need to be capable of adaptation in a larger or a shorter timescale if they are to survive (Edwards, 2010). Without considering the changes in the environment, an adaptation is not possible. This is one of the reasons why architects are focusing on designing in regards to nature and utilizing computer simulations, as well as the benefits of parametric design, in early design stages in order to create architecture which is adapted for the future environment.

Designing with the wind as a factor has already long history, but incorporation in the architectural design process is still quite recent. Wang et al. (2016) mentioned that despite the wind-related optimization in industrial design, there is still no such standard in architecture. Integrating the wind and lighting performance criteria into the form-finding process could, based on the simulation results, continuously improve the design and lead to an excellent environmental fitness. The parametric architectural design based on the specific wind conditions helps to test different design options to find an optimal placement of buildings, an optimal building's shape or an optimal material to be used to benefit from the wind factor and to improve it using architecture. In short, two main research directions have been explored in architectural research: i) passive cooling and emission reduction using the wind, and ii) mitigating the wind and ensuring the pedestrian wind comfort.

Guo et al. (2015) emphasized the relevance of designing the site plan, the building's shape and the building's envelope using Computational Fluid Dynamics (CFD) simulations over the conventional design approach. “Natural ventilation not only plays a crucial role in energy conservation and emission reduction but also greatly enhances the comfort level and air quality of the built environment”. Chung and Malone-Lee (2010) similarly suggested that CFD is not only useful for exploring air flow in the interior of a building or around high-rise buildings, but it can be successfully used on a greater scale of the urban design proposals, in order to target the improvement of larger inadequate urban spaces early in the design process. A CFD analysis of a planned zone in Singapore was proposed as a solution to the urban heat islands and uncomfortable urban pedestrian spaces, particularly the case of high-density and high-rise contexts. The use of the wind for passive cooling of houses was proposed in the case study in Dubai (Taleb and Musleh, 2015). This site-specific parametric approach considers the non-humid, desert environment with the scarcity of water and proposes how to benefit from the ‘Shamal’ winds squeezed between the buildings. In like manner, Chronis et al. (2012) developed an algorithm that enables achieving the best buildings’ distribution based on the integrated wind and sun data.

In different climates, on the other hand, strong wind gusts and high wind speeds are a source of concern in the built environment. “High wind speed occurring between buildings can be, in extreme cases, the source of wind-related accidents…or it can disturb and/or disrupt recreational, cultural or social activities taking place at urban outdoor locations” (Szűcs, 2013). Moya et al. (2014) explored shape optimization of a permeable structure proposed as a windshield for a tram stop to mitigate the strong wind gusts and hence to improve the wind comfort in the public space. Other studies were carried out to examine the effects of different wind speeds on pedestrians and their comfort in an outdoor environment and explore different wind situations to determine the right wind conditions (Stathopoulos, 2009; Blocken et al., 2016) and influence the wind using architecture (Janssen et al., 2013).

As early as in 1998, Tsou proposed the CFD technique to be integrated into the architectural design by establishing an online CFD teaching project for architects (Tsou, 1998). More than ten years later Hartog et al. (2009) described the use of CFD as a “rather new technique in building design”. Today, it is still not a common practice to include wind analysis in the early stage of architectural design (Chronis et al., 2017). There are new attempts to include this technique into the early design education. Students from RMIT University in Melbourne tested their windbreak designs using CFD simulations and then verified the results on the prototypes (Moya et al., 2013). Texas A&M University made a step towards introducing the wind simulations into the common design strategy. Students observed the behavior of their designs of building skins for affecting the wind and blocking the sand, situated in UAE (Kalantar and Borhani, 2017).

The above-mentioned examples show that the wind tests in the early conceptual stage of design provide an understanding of the frequently occurring natural phenomenon that is influenced by shapes of the buildings and the urban outlay, albeit there are still some disadvantages of the process. Kaijima et al. (2013) pointed out the problems of using the CFD simulations, particularly regarding the mesh geometry for the analysis. He commented the drawback of the need of repetitive CFD solving for multiple options of geometries. Therefore, when a parametric study of possible buildings’ arrangements or of possible buildings’ shapes is carried out, simpler design loops are searched for (Taleb and Musleh, 2015).

In this paper, the general wind-changing patterns, complete with realized architectural examples, are identified. Specific wind characteristics of Loudden Docks in Stockholm are the basis for the following case study. The dense silos’ configuration causes the wind flow to accelerate and create both turbulence and wind-induced vibrations. With the changing climate, more extreme wind scenarios can occur. The site was chosen to address the unique wind situation caused by the present urban structure and to propose a design way how the wind conditions of the site can be altered. We describe an integrated approach of using CFD analysis in the parametric design of wind bracing membranes for a brownfield site in Stockholm, Sweden. The