Tall Building Design Exploration: Designing for Wind Resilience

PhD Thesis

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Date: 2019

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Mohamed Ibrahim Khallaf declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Design, Architecture and Building/Faculty of Built Environment at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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DEFINITIONS OF KEY TERMS AND LIST OF ABBREVIATIONS

Within this research, several key terms and abbreviations may have different interpretations in different contexts. This following section explains these terms as they have been applied in this research.

Air Ventilation Assessment (AVA): A system that includes technical methods for assessment and guidelines for city development promoting better air ventilation.

CFZ: A file format that supports Computational Fluid Dynamic software

Computational Fluid Dynamic (CFD): A numerical simulation method that offers a powerful tool for wind engineering

Design Performance (DP): Assessment of a design's capability according to specified performance criteria.

Design Solution (DS): A geometric model generated and/or optimised from a parametric system. This may also be referred to as a solution.

Development Control Plan (DCP): Provides detailed planning and design guidelines to support the planning controls in cities.

Finite Difference Method (FDM): is a computational method that divides the geometric model into small, interconnected computational Quadrilateral elements in 2D, and into hexahedral elements in 3D.

Finite Element Method (FEM): is a computational method that discretises and subdivides a geometry model into small finite-sized elements of geometrically.

Finite Volume Method (FVM): It discretises the governing equations by dividing the physical space of the geometric model into a number of computational arbitrary Polyhedral in a form of control volumes.

Floor Area Ratio (FAR): Is the ratio of a building's total floor area (gross floor area) to the size of the piece of land upon which it is built.

Generative Design (GD): A design process wherein a flexible model can be varied to produce alternative design solutions.

Innovative Design (ID): Non-routine design that proceeds within a well-defined state space of potential designs by manipulating the applicable ranges of values for design variables.

Leadership in Energy and Environmental Design (LEED): is a green building rating system in the world.

Living System (LS): Consists of eight levels of living systems, each of which is composed of 20 critical subsystems that carry out essential life processes.

Parametric Design (PD): A mode of design practice that utilises a computational parametric design environment.

Performance Driven System (PDS): A parametric system that is driven by performance criteria to explore to a selected performance criterion.

Parametric System (PS): A set of parametric models that are integrated to operate as a whole. This may also be referred to as a design system.

Perfromance-Based Wind Engineering (PBWE): A method focuses on the performance of tall buildings subjected to extreme wind conditions.

Reliability-Based Design Optimisation (RBDO): A framework is based on a directional fragility model that combines the directional building aerodynamics and climatological information.

Council on Tall Buildings and Urban Habitat (CTBUH): The world's leading resource for professionals focused on the inception, design, construction, and operation of tall buildings and future cities.

Abstract

High-density cities can be considered as a matrix of wind obstacles, comprising buildings of different size and forms, arranged at varying angles with different distances between them. Such cities can suffer from poor ventilation and air quality problems, whilst others are subject to strong wind conditions due to their geographical location or improper urban planning. Further, the design of tall buildings plays an important role in the urban microclimate. Tall buildings design envelopes can affect urban microclimate wind flows by increasing or decreasing the wind flow of the surrounding area. Typically, conventional tall building design methods focus on single-objective design exploration techniques and/or produce a small number of design alternatives that explore wind loading and wind flows.

The aim of this research, therefore, is to provide support to planning and building standards authorities to bridge the gap between building code and city design guidelines at the architecture scale and urban scale by developing a computational design method that is able to mitigate the negative impact of wind flow caused by tall building in dense cities. This research extends concepts from generative architectural design into the domain of urban design, focusing on generating a design method to explore the effects of wind load and wind flow caused by tall building envelopes within high-density city fabric. The research presents a novel approach to predicting and providing instantaneous wind pressure data on facades of tall buildings, as well as wind flow data from the surrounding area in early stages of the design process. This performance-based design approach combines building and urban parameters to control the effect of winds on tall buildings at the pedestrian, podium and upper levels of tall buildings. This approach is based on the theoretical foundations of designing for urban resilience, highlighting the different objectives of this approach relative to existing tall building design standards and urban city planning guidelines.

This research provides an overview of related formal regulatory requirements of the building scale and urban scale, including buildings codes and city development design guidelines. In addition, performance-based design methods for generating, analysing and exploring buildings are investigated. The dissertation explores existing performance-based tall building design and the development of an architectural and urban design method that focuses on the effects of wind loads on and wind flows around tall buildings.

Publications

1- **Khallaf, M., & Jupp, J. (2017b). Tall Building Design Exploration: Designing For Wind Resilience**. in *AUBEA 2017: " AUBEA 2017*. RMIT University, 2017.

2- **Khallaf, M., & Jupp, J. (2017a). Performance-based Design of Tall Building Envelopes using Competing Wind Load and Wind Flow Criteria**. *Procedia engineering*, *180*, 99-109.

3- **Khallaf, M. & Jupp, J. (2016). Designing for Urban Microclimates: Towards Multidisciplinary Optimisation of Wind Flow for Architectural and Urban Design**, In name of editor (Ed.), *eCAADE* . Publisher: place of publication.