COMPUTATIONAL METHOD FOR EARLY-STAGE DESIGN OPTIMIZATION OF NATURALLY VENTILATED TERMINALS

MSc. Thesis | Delft University of Technology
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With the utmost gratitude to my true Father…

Delft University of Technology

AR4B025 Sustainable Design Graduation Studio

MSc. Architecture, Urbanism and Building Sciences

Track Building Technology

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1 INTRODUCTION

This report contains the reflection of my thesis for the Master of Sciences in *Architecture, Urbanism and Building Sciences*, track Building Technology, at the Delft University of Technology. The MSc thesis was carried out in the 2018/2019 academic year and was finalized with the P5 presentation on August 30th, 2019 at the Faculty of Architecture and the Built Environment.

The reflection will focus on the thesis process and final product and frame its wider scope in relation to the masters program, the faculty and socio-technical relevance.

2 PRODUCT, PROCESS AND PLANNING

The primary objective of this Master's thesis was to develop a computational model for early-stage optimization of naturally ventilated terminals. This was performed in a parametric workflow using Rhino/Grasshopper and supported using Python coding, Ladybug/Honeybee/Butterfly plugins and Galapagos Evolutionary Solver. The CFD simulations were conducted in OpenFOAM using BlueCFD Core as the virtual interface.

To achieve this objective, initial background studies (literature review, interview) were followed up by manual designs which were tested using Phoenics CFD. The data gathered from this process was utilized for the development of the computational model, after which it was validated using a case study (Lelystad Airport).

The computational model allows for users to enter a basic floor plan with exclusion zones into Rhino and respective envelope properties and thermal comfort requirements. Additionally, the objective function and design variables are defined after which the genetic algorithm is used to iterate through various design options to find the solution that fits the objective function best. Afterwards, various CFD-based and manual methods are explored to design the final geometry of the terminal.

The primary focus of this thesis was to learn about the various topics that this thesis comprises of. This meant to gain expertise and experience in the fields of airport design, building physics (natural ventilation and thermal comfort) and computational design. Gaining this knowledge was the main reason why I opted for a combination of topics that I had little experience in.

Therefore, the final product of this thesis has been the author's personal development, design knowledge in development of naturally ventilated terminals and the computational design method itself with an applied case study.

The process that led to these products was divided into clear phases demarcated by the various P's: between P1 and P4/5, the design evolved from a conceptual idea to the final optimized variant. The process was divided into the steps of topic selection, background study, model development and finally the summation of the knowledge gained. The planning was also structured along the aforementioned lines.

In reality, the process was a lot less linear and filled with hiccups that influenced the progress; the large amount of time the author had to devote to the Solar Decathlon competition, something he was committed to, led to a decreased amount of time being spent on the thesis. This, even up until this point, is a painful point. If the time planning and task distribution was made more evenly; such problems would have been avoided.

3 METHOD

The methodology implemented for the thesis itself worked well, and was able to cover all of the necessary steps required towards reaching the final objectives stated in the methodology section. Using an example airport as a case study during the whole phase of the thesis, so from background study all the way to final validation, was a very effective choice in breaching many problems that could have arisen otherwise.

The design method itself however has some limitations, meaning it would have more paths for improvement. Firstly, the geometry input and design of the bounding geometry is relatively crude and currently only works with rectangular bounding volumes.

Similarly, the Python script still contains bugs that occur when certain design parameters are combined. Furthermore, the objective function could be improved to attain a better result in terms of thermal comfort, including an optimization function that allows for per space inputs.

4 RESEARCH AND DESIGN

A computational workflow as is proposed in the thesis allows for a clear link between the initial design thoughts and the final results: within a parametric model, it is easy to observe the parameters and constraints imposed on the model. Understanding why such parameters and constraints are applied do require more in-depth knowledge, but can also be understood upon gazing through the literature review and its discussion.

Within that scope, the link between the research performed into the various topics -ventilation, airport design, computational design- and the final result is obvious. The research formed the base on which to design, and the designs added knowledge that is then used to augment the design(s) again.

Especially that element -feedforward design thanks to research, then feedback knowledge for design- is essential to the graduation studio at Building Technology. There is a clear design by research, but also the development of research by design. If we consider the main goal of the thesis to have been a design, however, the research itself has been a supplement to the design process in order to achieve the final goal of an optimized naturally ventilated design.

Specifically within the Building Technology Graduation Studio, this topic therefore perfectly fits in the junction of Design Informatics and Climate Design, two of the graduation directions. This is also reflected in the choice of my supervisors, who are from those two respective directions.

5 WIDER SCIENTIFIC AND SOCIAL FRAMEWORK

As explained in my literature review, the importance of a more sustainable built environment is evident; not merely because of climate change, but also because of depletion of resources. More essentially however, I also believe in an architecture that is based on solid design principles. This means a correct design which does not need correction by building services; putting them in as little as possible, instead of the current trend of increasing services. And all of this should be seen; the performance dictates the architecture, so its performance can be made visible.

In that sense, this research fits into a wider trend of trying to achieve naturally ventilated buildings that have been in development in the second half of the last century after the loss of its importance.

However, as a state-of-the-art analysis, the scientific framework to which the research fits is a small niche of optimization in computational fluid dynamics in the building field, something that has been done relatively scarcely.

The social aspect of the project however is also an interesting one: in an age of ever-increasing awareness of our environment, the aviation and building sectors are under scrutiny. By having been one of the largest contributors to global greenhouse gas emissions, these sectors received much more negative publicity in recent years. Perhaps an approach that creates a 'green' alternative, combined with a hope that in the near future more sustainable means of transport, production and construction can be derived. A green airport; nearly a *contradictio in terminis*. A green design that could perhaps inspire the sector's sustainability as well; a design that is at the crossroads of a hot topic of today.

6 DILEMMAS AND ISSUES

Of course, no design ever goes without problems, a natural part of the whole process. As the thesis topic was demanding for myself -trying to expand horizons on topics I don't know- as well as demanding enough in and of itself -by being a topic that is relatively little documented- I had great difficulties in achieving my final goals smoothly.

Firstly, there are no clearly established software for the usage of parametric design for CFD or natural ventilation purposes, meaning that integration is done through plugins and unvalidated software. Besides being buggy, such a workflow needs to be additionally checked and verified against other results. Such results themselves are often only approximations, as is the case in natural ventilation; only a real experiment is able to validate the design that you envisaged and calculated.

Secondly, the same issue is apparent when trying to analyze your results, but also when putting them into the loop of a Genetic Algorithm. Results are not easy to document and arrange, which makes the whole process longer than is strictly necessary.

Finally, my lack in Python coding also added complexity to what could have been a simple task; as it is all part of a learning process, it is to be expected that everything went relatively slower. It has been thanks to my three mentors -who showed support and lenience towards my activities in the Solar Decathlon- that I actually was able to develop all of my ideas and code them to my abilities within the time allocated to us. In this respect, we also owe a thank you to Peter Teeuw, who supported in allowing for Solar Decathlon members to graduate at the end of August, one to two months later than the regular graduation period.