OPTIMISATION OF COMPLEX GEOMETRY BUILDINGS BASED ON WIND LOAD ANALYSIS

Reflection

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1. INTRODUCTION

This thesis sought to develop a computational procedure for analysing wind loads on complex geometry buildings and optimising the geometry based on those results for use in the early design phase. This was thought necessary and viable to research since present methods such as those in the Eurocode are very complicated and are known to be conservative in the values they give. Moreover, these methods only give guidance for simple shapes such as rectangular and circular cross-sections whereas, many tall buildings today are becoming increasingly complex in their geometry. Wind tunnel tests are the other known method however, these are time-consuming and expensive today requiring specialised technicians to do.

Technology is being used extensively to design the geometry of these buildings, so it is only right that we use this same technology to evaluate building performance and give insight into the design process. This thesis aims to add another tool to the arsenal of performance-based design by giving architects and engineers a way to easily obtain information on the structural performance of a building in strong winds which high-rises are particularly susceptible to. The optimisation more strongly integrates an element of sustainability by allowing the use of the information obtained in the analysis to directly reduce structural mass thus reducing carbon footprint.

2. GRADUATION PROCESS

This project combines the areas of Design Informatics and Structural Design by using computational methods to develop a tool that is easy to use and reuse in the early stages of design. Development took place in Rhino/Grasshopper to prove the concept since it is already widely used and available. This also minimises the export/import of models between different programs. Additionally, existing plugins for Computational Fluid Dynamics (CFD), structural Finite Element Analysis (FEA), and optimisation could be used so that the focus of this thesis would be joining these together in an efficient workflow. However, the aim is that this method can be implemented using any combination of software.

The CFD portion presented significant challenges as it is a complicated field of study and required a lot of background research. In addition, a lot of time was spent getting familiar with the CFD plugins and their various settings and parameters. It was a long process of researching published works, internet forums, and personal guidance from experts. On top of that, the CFD simulations themselves are very computationally intensive requiring a long time to obtain results. Validating the CFD procedure with a standard model and performing sensitivity analyses to try reducing calculation time while maintaining reasonable accuracy was important but required many simulations to be run. Much time was spent simply waiting for simulations to converge. The result of this was a fairly thorough understanding of CFD especially in respect to buildings which allowed the script to be simplified to the point where others with much less experience could use it and obtain good results. All this contributed to the CFD portion of the research and development taking more time than anticipated.

In the end, Butterfly proved to be the best option for this tool giving results that are reasonably accurate and precise with the chosen setting. Fast Fluid Dynamics (FFD), using the GH Wind plugin, was explored as it was said to be a less computationally expensive process than CFD but it proved to be unsuitable for use in this thesis in its present stage of development. The lack of turbulence modelling, using rectangular voxels to approximate the complex geometry, and the lack of mesh grading, along with the inherent lower accuracy of the algorithm were too high of limitations. In the end, the mesh and solver settings would have to be so high to get a decent result that there were no longer any time savings over traditional CFD. However, it was still useful to research and test FFD as this tool has a lot of potential with further development.

The Fluid-Structure Interaction (FSI) portion entailed the joining of the CFD algorithm to an FEA algorithm to obtain the structural effects of the wind on the building. This required a lot of restructuring of the data to get from pressure loads from Butterfly to point loads and moments for Karamba. Nonetheless, the translation worked well and was done within the expected time. The previous knowledge of Grasshopper and scripting in Python and C# was a big advantage to the timely execution of this portion of the thesis. While static results were easy obtained it was noted from research that, especially for very slender high-rises, dynamic deflections can be even more important. Unfortunately, it was not able to be implemented in this work due to the lack of an unsteady turbulence model in Butterfly that could simulate time dependent loading and/or the time required to research a proper way of estimating the dynamic response in a static analytical way that could be scripted to give an objective that could be optimised. This is an area of high potential for further research as it would make the tool much more useful in high-rise design.

The initial planning of the thesis envisioned using a multi-objective evolutionary algorithm. This was mainly because of its popularity in architectural computational design and the fact that the process of building design often has multiple competing objectives. However, after more detailed research into optimisation especially related to CFD and other environmental simulations, it was realised that this may not be the best option for a computationally expensive process like CFD. Given the time constraints, Opossum was selected based on benchmarks and other research to be the most promising algorithm. However, ideally, several different algorithms would have been evaluated and benchmarked to this specific problem. While Opossum and other Grasshopper based optimisation algorithms have been benchmarked to problems like daylight and energy use no research was found specifically for CFD in a structural application. Thus, Opossum, while the most promising from research and performing well in the optimisation tests, may not, in reality, be the best for this tool. Another limitation is that it is a single objective algorithm so while it did work well and achieve the goal of manipulating the geometry to reduce wind actions these actions may make another area of building performance much worse. There is no single optimum in building design so a user needs to see this tool as only for the context of wind actions which then must be combined with the information from other performance objectives to make the best choice for the building as a whole.

Research heavily informed the development of the tool as the concepts, particularly CFD, needed to be understood in depth to ensure a working procedure. The underlying principles of CFD had to be understood but also the settings and parameters of the software and what effects they had on results. This ensured that the tool would be usable for any building design that is input rather than a specific geometry. It was challenging in that regard to make the tool as easy to use as possible. Ideally, even more buildings would be tested so that bugs could be worked out and make it more likely that this tool could be used without error in future. In this sense, design informed the research by the validation, sensitivity analyses, and optimisation tests which helped determine the optimal procedure for this case.

3. SOCIETAL IMPACT

Wind, especially in certain areas in the world, can be a big problem for the structural integrity of a building, as well as the comfort of its inhabitants. This tool allows architects and engineers to see the effect of wind loads on a building at an early stage even if the geometry is highly complex. Present methods based on building codes are usually done at a later stage due to its complexity and limited provision for different shapes. At this stage, counteracting too high deflections or forces would involve increasing the size or number of structural elements. With this tool, however, one would be able to have this information at an early stage when it easier and cheaper to make changes to the design. One can reduce reactions by simply altering the geometry or having the optimisation process of the tool generate the optimal option for you.

This makes practice easier and more efficient. The reusability means it can be used multiple times on a single project to evaluate different design choices and be used with multiple projects. Since it is a discretised computational process it can ideally be used with any geometry without having to depend on conventions for specific shapes like in code calculations. While code calculations now would still be required at a later stage it is hoped that it will be just a verification of what is found using this tool rather than giving brand new information that may require expensive alterations to the design.

As stated, the current methods for wind calculations have been around in one form or the other for decades. However, it has not adapted to the continuing rise in the complexity of building geometry. Presently, the advice given by the Eurocode for non-standard geometry buildings is to do physical scaled wind tunnel tests which are time-consuming and expensive. This thesis brings innovation to this problem using the ever-increasing capabilities of computation in the built environment. Research has been done in this area of computational wind engineering (CWE) mostly seeking to validate CFD packages and establish best practices. However, to the knowledge of the author, a reusable tool to perform this analysis for buildings has not yet been developed.

Central to sustainable design is the gathering of as much information as possible to make informed decisions that result in better building performance. This tool can form part of the suite of other analysis and optimisation tools that are commonly used for energy and structural demands. It allows the improvement of people, planet and profit in the design process. The ability of this tool to analyse nearly any geometry allows for unfettered designs that can be more impactful to the users. It also allows for a more efficient integrated design process for the professionals working on the building. The optimisation tests also show the tools direct ability to reduce needed structural material. This saves cost but also lowers the carbon footprint of the project. Less material needs to be extracted, manufactured, and transported to the building site.

4. CONCLUSION

Overall, the tool has successfully performed its intended purpose. It can, with some limitations, simulate the wind flow and the pressure it imparts on a building, translate that pressure to point loads on a finite element model and analyse the model to obtain results like deflection and mass of the structure. It can then optimise the geometry to reduce wind pressures and thus lower the mass of material needed. Improvements could be made had there been more time including benchmarking optimisation algorithms, running more tests with different case studies, and implementing a calculation for dynamic loading. It should also be noted that that this is for the single objective of wind loading while building projects often have many objectives. Nonetheless, it has the potential to be a very useful tool for design professionals in the pursuit of sustainable performance-based design.