FORMED BY WIND

A workflow for apartment building geometry generation to satisfy pedestrian comfort

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Abstract. The abstract is in 10 pt Times with 11 pt leading and should not exceed 300 words. Wind in the urban landscape is important in reducing urban heat island and humidity levels as well as providing pedestrian comfort, however, the construction of dense high-rise buildings in urban areas changes the behavior of wind. Simulating the behavior of wind in the urban landscape is still a complex process. Digital design tools that engage with computational methods provide efficient ways for designers to simulate, predict and optimize performance for a range of environmental phenomena such as solar radiation, daylighting and thermal comfort. Traditional ways of addressing this issue use wind tunnels and Computation Fluid Dynamic (CFD) calculations that are costly and require time to complete and gain results. CFD is a technique that enables the study of wind in and around buildings and is used successfully in design practices in the aerospace, automotive and many product design industries. In this research, CFD is used to conduct wind analysis computationally. The workflow process is designed in Rhino Grasshopper and uses Grasshopper software called Butterfly that handles the CFD calculations through OpenFOAM, an open source computer program that is used as a simulation engine that connects to Rhino Grasshopper. The research undertakes an action research methodology which involves learning in and through action and reflection. It is an iterative process that aims for improvement with each subsequent cycle. This research demonstrates a holistic workflow in the Rhino Grasshopper environment that sets up geometries, calculates CFD analysis, manipulates geometry shapes according to wind behavior, and re analyses it to determine the changes from the preliminary analysis and the final analysis. This research gives rise to digital design workflows for optimization of environmental phenomena in the computational design field and leads to providing

decision support tools for designers to understand environmental conditions in the early design stages.

1. Introduction: (Research context and motivations)

Digital design tools that engage computational methods provide efficient ways for designers to simulate, predict and optimize performance for a range of environmental phenomena. Yet, while solar radiation, daylighting and thermal comfort performance can be addressed using accessible and accurate digital design tools and workflows, simulating and optimizing for wind in urban environments remains complex. Therefore, optimizing for wind in urban design projects is a way to leverage natural phenomena to, in turn, mitigate issues such as the urban heat island, minimize energy use and enhance pedestrian comfort.

Computational fluid dynamics (CFD) is the primary tool to calculate wind analysis computationally. CFD uses numerical analysis and data structure to analyze and solve problems that involve fluid flow and computers are used to perform the calculations to simulate the wind flow. According to Peters and Peters (2018), "CFD is a technique that enables the study of wind in and around buildings" and is "used successfully in design practices in the aerospace, automotive and many product design industries." (Peters and Peters, 2018). Traditional methods of simulating air movement involve physical models in a wind tunnel which is "time consuming, expensive and offers only a few points of investigation" (Peters and Peters, 2018). Now that computers are more powerful and runs faster, CFD software is more accessible, enabling "multiple studies with greater resolution" (Peters and Peters, 2018). Limited wind analysis and optimization workflows exists, but the analysis and optimization stage are conducted on different software. This research aims to combine the analysis and optimization into one cohesive workflow on Rhino Grasshopper. Butterfly is a Grasshopper software that is used for wind analysis. The scripting using Butterfly turns geometry into meshes and creates a wind tunnel. The analysis is conducted through OpenFOAM within the Butterfly script, which is an open source computer program that is used as a simulation engine that connects to Rhino Grasshopper.

This research undertakes an action research methodology, which involves learning in and through action and reflection. It is an iterative process that aims for improvement with each subsequent cycle of planning, acting and reflecting. The research is done in collaboration with an industry partner, Crone Architect to give guidance and feedback, and to provide the study site. The research aims to design a workflow to generate a geometry shaped by the wind to capitalize on the ventilation and cooling benefits of wind while also minimizing uncomfortable and dangerous conditions of high speed and

channeled winds in urban environments. The anticipated results of the workflow will produce various building geometries that are shaped by the wind to encourage wind harmonization. The final wind analysis of the site will be compared with the initial analysis and the changes to targeted area will show that the workflow works.

This research contributes to scholarship on digital design workflows for optimisation of environmental phenomena in the computational design field, and leads to provide decision support tool to assist designers to better understand environmental conditions in early stage design generation and to potentially mitigate costly re-do work in later stages. Ultimately, a workflow is created from this research that involves CFD analysis and optimization into one platform.

2. Research Aims

This research aims to design a workflow that encapsulates the both the calculations stage and geometry generations stage. Additionally, the research aims to produce apartment building geometries that is manipulated by the behavior of the wind.

3. Research Question

How can an optimisation workflow incorporate wind data and generate apartment building geometry options to satisfy both pedestrian wind comfort and maximise natural ventilation?

4. Methodology: Action Research

Action research is "a disciplined process of inquiry conducted by and for those taking the action. The primary reason for engaging in action research is to assist the "actor" in improving and/or refining his or her actions." (Saygor, 2000). According to McNiff (2013), action research is a way for you to deeply consider what is being done and in turn it "becomes a self-reflective practice". He argues that action researchers have the responsibility to "critique their own practice, recognising what is good, build on strength, as well as understanding what needs attention and taking action to improve it" (McNiff, 2013, pg.28). With the ubiquity of the internet, action research may offer a deeper understanding of the wider community that operates online through network action research (Foth, 2006). Foth explains that network action research is "a method that responds to the shifting quality of community interactions"(Foth, 2006, p17) and "a way to recognise the significance of human networks within communities and society"(Foth, 2006, p17). The principles of action research apply to my project as I am

looking into constructing a workflow that works with optimising building geometries with wind as controller. With this project, I am sourcing information from industry partners and teachers as well as looking to online communities that are associated with the computational design industry to help with designing my workflow and understanding the steps that I must take to finish the task.

To answer my research questions, I look to adopting research action to conduct and structure my project. According to Saygor (2000), the action research process starts from 1)selecting a focus, 2)clarifying theories, 3)identifying research questions, 4)collecting data, 5)analysing data, 6)reporting results, and 7)taking informed action. In my process, I foresee that point 5 and 6, will happen several times in order to have a grounded understanding in the process that is happening in Grasshopper, as well as to receive an overall understanding of wind behaviour in the contextual area. McNiff explains that "action research involves learning in and through action and reflection" (McNiff, 2013, pg. 24) as it is always related to "improving learning" which affects educational, personal and professional growth and is therefore regarded as "a powerful form of educational research". So far in the project, there is constant contact with tutors and industry partners and occasionally peers for them to check what has been done and for them to give guidance and offer solutions if needed. Through this, I have also gained considerable knowledge in the area I am focusing in and applying to the workflow process and is currently in design. This fulfils the educational, personal and perhaps professional growth. The process for this project is not linear, I will have to conduct an analysis, reflect and conduct another analysis again and the cycle keeps going which can be dangerous if there isn't a limit placed. Additionally, aside from knowledge gained from readings, understanding and interpreting the results from the analysis is also important and one that may have a steep learning curve.

5. Background Research/Literature review

Introduction

As the population grows, urban buildings are growing taller and more people move into urban areas. At the same time, climate change is happening, and environmental conditions are becoming more unpredictable (Khallaf et al. 2016). Wind conditions within urban areas can turn extremely dangerous or nonexistent resulting in stagnant air, limited airflow and stuffiness. Reaching a balance between the two extremes to allow for pedestrian comfort and quality air ventilation is important and relies on designers, architects and urban planners to implement methods so that the urban architecture works in harmony with natural forces resulting in comfortable living in urban areas.

Wind plays a key role in the urban climate to ventilate air pollution and urban heat and possible wind energy harvesting (Droste et al. 2018). Elemental considerations in the early design stage may lead to a much more efficient workflow during the design stages resulting in building geometries that are optimized to work well within the urban site and we can see this through multiple investigations regarding solar and shade analysis. The most common methods of visualizing and analyzing wind flows in relation to the environment is conducting computational fluid dynamic (CFD). This literature analysis will look at various research projects that have been undertaken that focus on undertaking CFD simulations and the like that is accessible to designers, architects, and urban planners to use in the early design stages as a way to lead the design progress. Furthermore, this literature analysis will also look at the optimization of geometries that most satisfies the wind conditions of its surrounding context.

5.1 Wind modelling- Computational Fluid Dynamics (CFD)
Computational fluid dynamics is a program used to visualize and analyze wind flows and is "a brand of fluid mechanic that is primarily used to solve problems involving fluid flow through numerical methods" (Kaushik and Janssen, 2015, pg. 1). The software allows the user to examine the model site and give an overview of any issues graphically and has been used to determine comfort levels in relation to wind movements in the site. Conducting a CFD simulation takes time and can be slow as it is a complex calculation and may need to be run multiple times to reach convergence (Kaushik; Janssen, 2015). Designers, architects and urban planners can access this program through various software aimed at providing a version that is not taxing on computers. In a study referenced by Panagiotou et al. (2012), "Hang et al (2012) analyzed the contribution of mean flow and turbulence to city breathability within urban canopy layers using CFD simulations" (Panagiotou et al. 2012, pg.2) in which they found the relationship between pollutant removal and wind in an urban contest, this led to their conclusion that "breathability improves in streets flanked by lower buildings" (Panagiotou et al. 2012, pg.2). Here we see that using CFD simulations in the design process allows for harmonious building between architecture and the people. The results allowed the team to assess the natural ventilation of the area and type of building it works well with. Access to high end CFD simulations may be costly and require high end hardware to run the simulation, additionally it may be difficult for a designer without CDF knowledge to navigate the software dedicated to high end CFD simulation. Several researchers have investigated various applications and other software that either mimic wind simulation or have extended other modelling software capabilities to be able to conduct CFD simulation. For example, Kaushik and Janssen (2015), in their research to develop alternative methods of simulating wind, used the animation software

"sideFX Houdini" which has "a smoke solver that uses an eulerian approach and the software also allows user to have more control over fluid simulation" (Kaushik and Janssen, 2015, pg 5). However while the method succeeds in visualizing wind flows thereby giving early insight into the design, it also takes time to calculate. Kajima et al (2013) developed a tool kit "that combines geometry and data from McNeel Rhinoceros and ANSYS fluent to offer interactive 3D visualization of simulated physical phenomena", thereby extending McNeel Rhinoceros capabilities to allow CFD simulation. Various approaches have been investigated to simulate wind in order to understand the context and create geometries that balance both ends of wind extremities so as to create adequate outdoor comfort levels. "Assessing the effects of urban geometry on the air flow is an important issue for urban and building design in order to plan a more comfortable and healthier city" (Razak et al. 2012, pg 6) as the heights of urban architecture rise, the wind effects may be favorable or unfavorable depending on various factors (Fadl et al. 2013).

5.2 Building geometry optimization

Optimizing a geometry allows for the best possible shape that balances the needs of it. Khallad et al. (2016) looked multi objective optimization as a method to problems through and evolutionary process, and defined by Poloni and Pedriroda (1997), multi objective optimization is achieved through "the art of finding the best compromise" (Khallaf et al. 2016, pg. 7). Kormanikova et al. (2018) looked at changing static geometry shapes which took time to test and repeat. They explored the iterative process of finding the optimal geometry within a specific wind situation site using CFD simulations to continuously test the design performance. The results from the process were evaluated and repeated until the "desired optimal performance in the wind is achieved" (Kormanikova et al. 2018, pg 8), but the process is "time consuming as the meshing, the wind tunnel settings and the calculation setting have to be changed for every new option" (Kormanikova et al. 2018, pg 8). Kabosava et al. (2019) conducted "form finding with the wind" a method that is driven by wind data to generate an architectural envelope with a structure that responds to the wind load. The investigation explored by Kormanikova et al. (2018) and Kabosava et al. (2019) showed that the inclusion of wind data in the design makes it effective in generating geometry shapes that provide optimal wind comfort levels and reducing wind force (respectively).

### 6. Case Study- Formed by Wind

Prior to conducting the analysis, preparations must be done to limit calculation times as much as possible as well as ensuring all the software that is needed by butterfly is downloaded and installed on the computer.

6. 1 Setting up for Analysis
The first step is to import the geometry for testing. I received a 3D model of the city of Sydney from my industry partner, and it is important to select a small section for analysis to not overwhelm the calculation process. In this study, I focused on the building 175 Liverpool street, and used its surrounding context lot. The geometry of the buildings on the envelope are then simplified and ready to analyse.
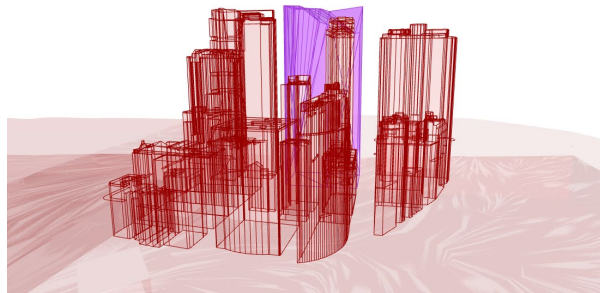

Ladybug's wind rose is used to visualise wind direction in the city, and from this the two strongest wind directions are from the west and from the south. In this project, I looked mainly at the wind coming from the west for the horizontal plane, and southern winds for the vertical planes.
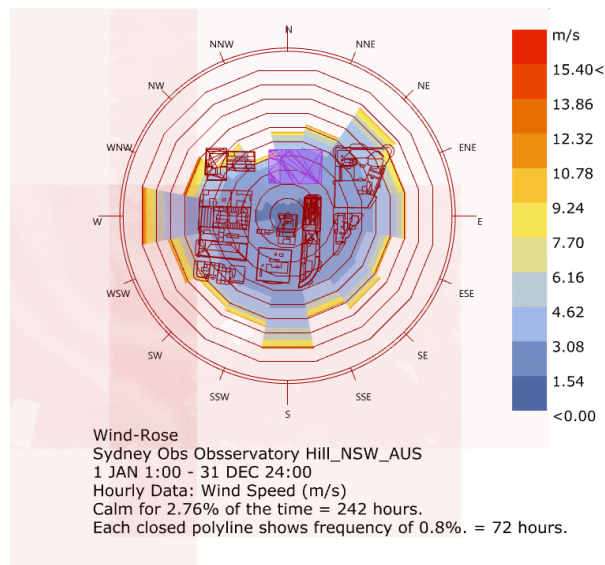
6.2. Analysis:
6.2.1 Planned Plane for analysis: grid

To aim for an accurate analysis, I planned the envelope site with planes for the analysis to occur. The horizontal planes are planned at pedestrian level (3 meters above ground), podium level (10m) and Canopy layer (40m). Vertical planes are focused on proximity to the building of 175 Liverpool Street: the two sides of the building and middle of the building.
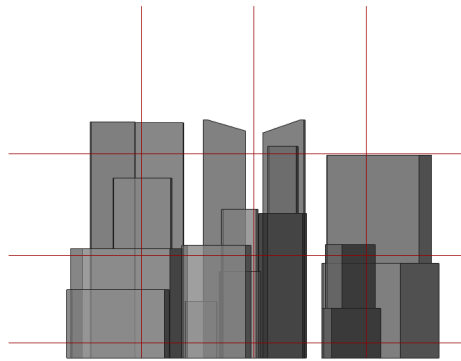

6.2.2 Wind tunnel; wind vector; wind speed

The butterfly software takes the geometries and creates a wind tunnel sized for the site. The default wind vector is north and must be changed to west or south. The vector direction is broken down to three numbers as shown below.
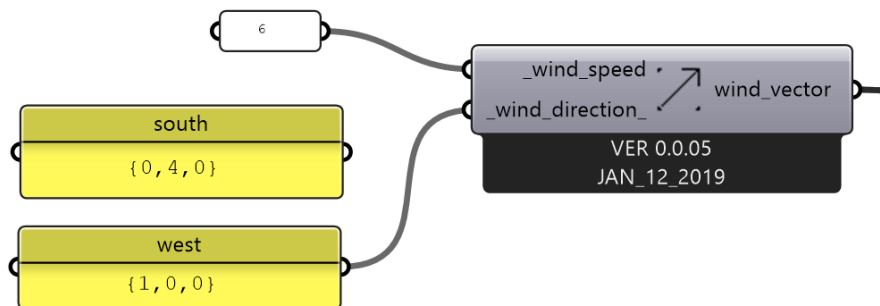
Additionally, wind speed can be changed, and the average wind speed taken from Ladybug's wind rose is used.

6.2.3 CFD calculation: open foam

This is the main process and one that takes the most amount to time to complete. Firstly, the workflow transforms the plane for analysis into a mesh. The plane grid can also be changed, in that the smaller the number the smaller the grid size and therefore takes longer time to process. On the other hand, the larger the number, the larger the grid size and the less time it takes to process, however the results may not be as reliable as it can be as the resulting wind vector will be sparse.
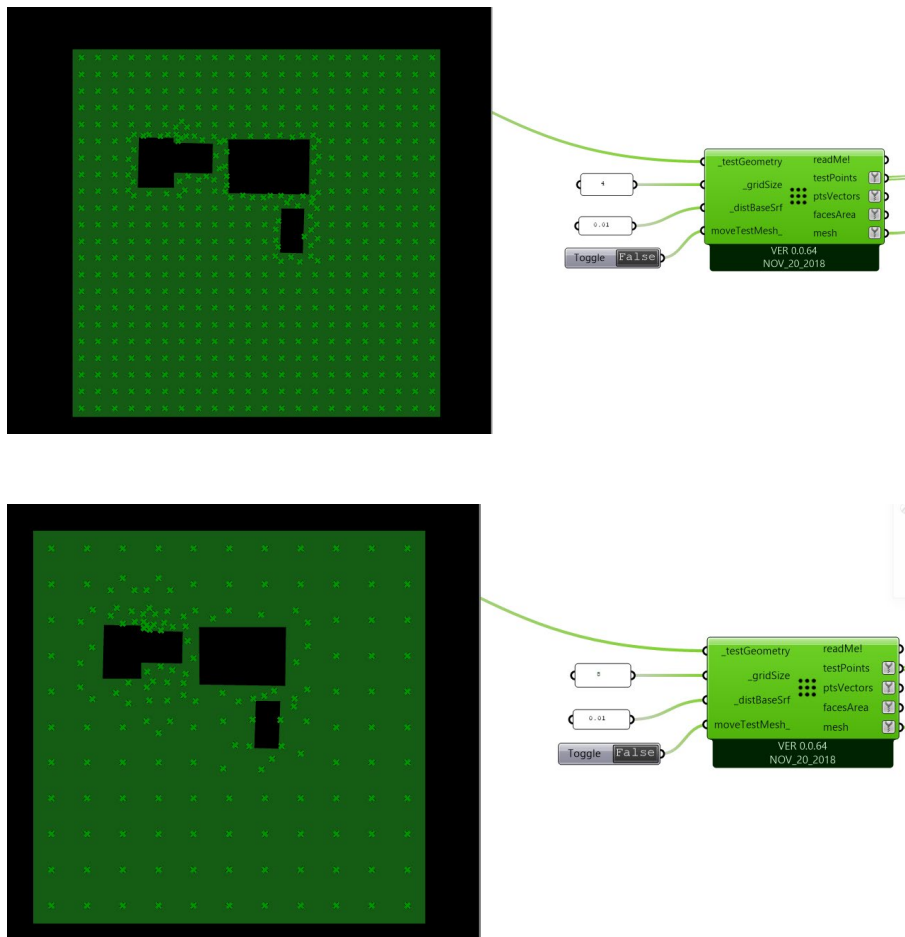
This part of the workflow also involved turning the geometry site into mesh which also takes a considerable amount of time to process.

Another important factor in the calculation process for CFD analysis is the end time, however the consequences are not clearly defined by the creator. The default end time is 600, meaning that the calculation will take 600 steps. For the analysis of the site, it took about 3 to 4 hours to complete. I tried to lower the number to 100 and 300 and found that the results look incomplete, in that the visualised results show incompleteness. Therefore, I have decided to stick to the default end time given. This process was repeated 6 times due to the different planes that have been placed.
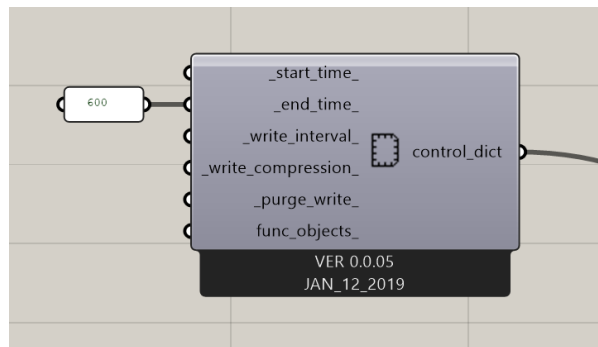
6.2.4 Results

The results of the analysis are coloured vectors that show the wind behaviour in the specified wind direction. The length of the vector depicts the strength/speed, and the colour of the vector shows the pressure of the wind. The legend for the vector colours is also given at the end of the analysis to reference off from.
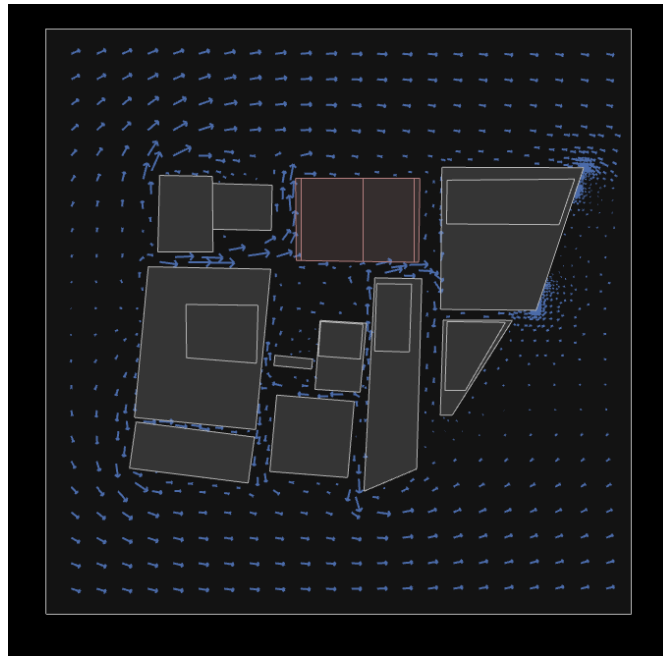

6.3. Geometry generation using wind vectors

In this stage, the focused geometry object that is 175 Liverpool street is manipulated according to the extracted information from the wind analysis that was done before. The focused geometry is made into smaller spheres to visualise the rough shape of the new geometry. Each of the spheres would move individually according to the vector.

The strength of the vector movement is divided between 0.0 to 1.0.
The surface of the resulting geometry is made with the points of the cubes,
turned into a surface, extruded and the sides cut off to fit within the original
175 Liverpool street building envelope.
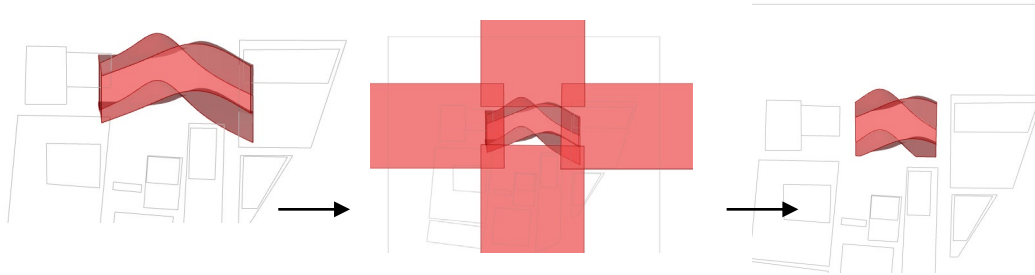
For this project, I extracted 4 geometries for the next analysis:
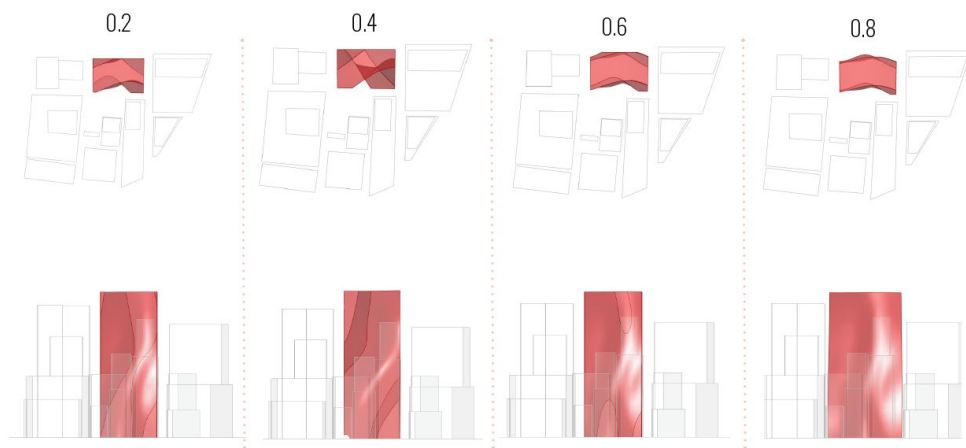
6. 4. Analysis and conclusion
The generated geometries from the wind vectors are labelled 0.2, 0.4, 0.6 and 0.8, signified by their division number. These 4 geometries are analysed again and taken through step 6.2. This was conducted 12 times as each building had to be analysed with the three horizontal planes: the pedestrian level, podium level and canopy level.
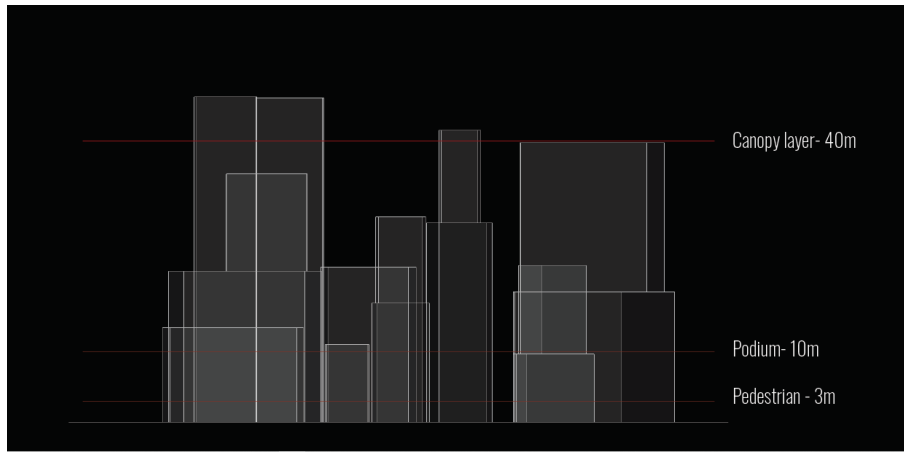
With the analysis done in this project, it is a challenge to identify which geometry is best suited for the site as not enough analysis has been done or exhausted to determine the best geometry.

7. Discussion (evaluation and significance)

Evaluation

The research has produced a workflow tool that analyses the wind conditions in the selected site and produced a building geometry that shapes to work in harmony with the wind and satisfy pedestrian comfort. The analysis relies on using Lawson's wind criteria to make sure pedestrian comfort is achieved. The geometry is then analyzed again to make sure that pedestrian comfort is achieved. The research had two goals: one to generate a building geometry based on the wind flow, and the second to satisfy pedestrian wind comfort and maximize natural ventilation. Wind comfort is a nebulous concept and therefore challenging to quantify it to a specific number. Through the course of the project, I designed a workflow that incorporates wind data to guide the generation of building options for apartments using Grasshopper software, Butterfly and CFD through open foam. Unfortunately due to the lack of time, I was not able to optimally generate apartment building geometries as I was not able to understand and figure out what the optimization objective in relation to the given wind data and the. Additionally, in order to gain reliable

results, ideally, the calculations should be run several times, however this would take more time than given.

Limitations

The main limitation is the butterfly software. The calculation conducted on the given site took on average 3-4 hours to complete. The calculations accounts for the planar surface level that it is on, meaning that, logically, in order to gain data that accounts for the whole site, one would have to conduct calculations at every 'x' step. Data accuracy is also another limitation. The program sets 600 calculation steps as a default. I have tried lowering the calculation steps to 100, which took about 1-2 hours to complete, however, the results differ if it took 600 calculation steps. Visually it's different; the former depicts longer arrows, while the latter shows short arrows and some parts of the grid not accounted for. How much difference would the results be if the calculation steps are set higher? Though the wind analysis workflow is much more accessible and affordable (Butterfly is free) and suited to aid the design process in the early stages, the reliability and accuracy of the data produced is equivocal compared to expensive traditional wind analysis conducted through wind tunnels. Another limitation of this project is that basic knowledge in Rhino Grasshopper is needed to navigate through the workflow, additionally, knowledge in wind characteristics and wind comfort speeds is needed to understand the results gained from the workflow.

8. Conclusion and Significance

Using wind analysis to guide the design of a building geometry is not as common as using solar analysis, and most wind analysis is conducted in separate software which the results are then integrated into a modelling software e.g. Rhino Grasshopper, to generate possible geometries. This research project workflow integrates wind analysis and geometry generation into one platform, allowing users to directly see the impact of the wind data on the building geometry generation. With more time and resources, the workflow would include an optimisation process that satisfies pedestrian comfort levels and wind ventilation in urban landscapes. Possible future directions that build upon this research include satisfying indoor ventilation and multi objective optimisation to work with other environmental factors. Ultimately, this project allows designers to design in harmony with wind conditions to satisfy pedestrian comfort and wind ventilation in the urban landscape.

Acknowledgements

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