TOWARDS WIND-INDUCED ARCHITECTURAL SYSTEMATIZATION

Demonstrating the Collective Behaviour of Urban Blocks as a Design Asset

CHESKA DACLAG NODADO[1], CHRISTINE YOGIAMAN[2] and KENNETH TRACY[3]
[1,2,3]*Singapore University of Technology and Design*
[1]*cheska_nodado@mymail.sutd.edu.sg* [2,3]*{christine_yogiaman|kenneth_tracy}@sutd.edu.sg*

Abstract. This paper presents the premise of collective behaviour of singular units as a design asset in an urban environment. The collaborative effect of building shapes, surface texture and the order of buildings on wind patterns in the urban were explored and analysed. The results revealed that these three factors are imperative to effectively design airflow and air velocity to create cooling effects in warm urban environments. This study intends to solve the problem of compact building blocks which create stagnant air in outdoor urban spaces that worsens outdoor urban thermal comfort. As the study involves a large scale urban area which requires tremendous simulation time, this paper would also demonstrate an attempt for an alternative workflow in studying computational fluid dynamic (CFD) through utilizing Houdini, which is an animation software to predict wind flow patterns in an urban context in a faster way which is highly beneficial for conceptual design stage. The paper explains the setup of Houdini working interface which enables the researcher to compare simulation results of varying models with ease via the switch button, and further improve simulation speed by disabling the need of remeshing the original model.

Keywords. Collaborative behaviour; urban blocks; wind pattern; computational fluid dynamics (CFD).

1. Introduction

Urbanization has increased rapidly in the world and is creating profound effects. The high rate of urbanization in cities has largely affected low-level airflow and high heat island intensity. Compact building blocks create stagnant air in outdoor urban spaces that worsens outdoor urban thermal comfort (Li, 2018). Surface materials and canyon urban structure are the main factors that contribute poor airflow. The impact of the city design over the urban microclimate has been raising concerns about the development of too urban areas. In view of this, the relationship between buildings and their surroundings has become an interdisciplinary challenge for architects and urban engineers. A research group

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 2, 447-456. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

led by Professor Li Yuguo found that it was not enough to solely focus on individual buildings, but that it is important to broaden the analysis to groups of buildings or urban blocks to better analyse the penetration and distribution of air. There is a distinct wind pattern differences when studying the effects of buildings individually and in groups. Individually, buildings cause the downdraught effect which makes the encompassing roads and walkways windier. In groups, buildings can form street canyons which are the roads that have numerous tall buildings on each side and the resulting wind patterns depend on the angle at which the wind reaches the street canyons. Wind behaviours such as channelization, venturi and row effects can only be detected when buildings are studied in groups. As such, once the buildings are laid in clusters, the wind flow pattern of buildings starts to alter. This leads to the idea that studying urban city blocks would further demonstrate a collective behaviour.

2. Literature Review

2.1. SYNCHRONIZATION AND COLLECTIVE MOTION IN NATURE

Collaborative behaviour of urban blocks refers to the relationship between buildings and their surroundings. The main feature of collective behaviour is that tiny movements of an individual unit can add up to an enormous scope. This interesting ordering phenomena can be found in nature where animals in groups have to move in the appropriate formations with an exact spacing between individuals to achieve significant energy savings benefit, create vorticity in their wake or distort the flow patterns (Fish, 1999). For instance, fish school adopts the diamond lattice formation to enable each member to exploit the flow patterns generated by fish ahead of them. In figure 1, the fish used the vortices produced by the leading fish to improve their own thrust performance, lift generation, increase efficiency and reduce drag. The closer the fish to the vortex core generated by its neighbouring fish, the higher the velocity it will experience and the greater momentum it can extract from the moving fluid. However, if the fish follows directly behind the leading fish, it would have to utilize a greater amount of energy instead (Weihs, 1973). Similarly, birds fly in V pattern have the ability to organize the airflow around them and the creation of field around these living beings would be impossible unless they worked together (Fish, 1999). Indeed, a simple set of rules governing the space between each individual and its immediate neighbours could result in changing environmental condition that is interesting to study.

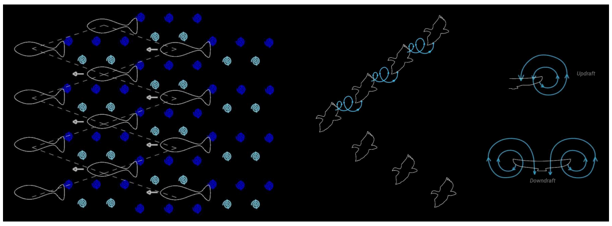

Figure 1. Adapted Diagrams of Synchronization and Collective Motion in Nature.

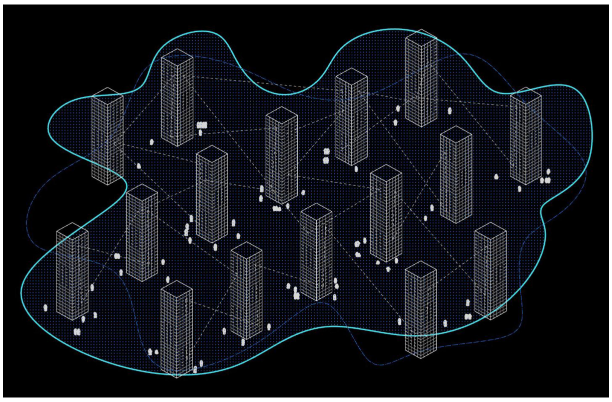

Figure 2. Reimagining cities exhibiting a collective behaviour.

As the air flow patterns around buildings are considerably influenced by buildings around them, the premise of collaborative behaviour of singular units can be applied in the urban environment where there is potential that buildings can work together to build an ambient environment that is good for the collective urban blocks as conceptualize in figure 2.

2.2. URBAN MORPHOLOGY

The air movement within the city depends on its morphology, its street design and orientation, and its form. In the same manner, the shape of the cities is significantly influenced by its local climate to create spaces that are thermally comfortable. For instance, in the town of Harran in Southern Turkey, houses are shaped like beehives. The dome shape design is set up to be resistant to heat and cold. On the other hand, windcatchers in Iran are integrated with building design to trap the wind from high above the building and designs can vary from hexagonal to octagonal depending on the location of different cities. At a street level, aspect ratio is a key parameter that determines the canyon geometry. It pertains to the average height (H) over the canyon width (W). Likewise, different climatic types in the world would have a different ideal aspect ratio or the street design. In a temperate climate, the ideal aspect ratio ranges from 0.4 to 0.6 (Oke, 1988). But in tropical climate, a high asymmetrical aspect ratio of 2-0.8 asymmetrical street aspect ratio was more beneficial (Qaid et al., 2014). In the context of increasing of urbanization especially in Central Business District (CBD) area, these ideal aspect ratios on streets and city morphology are less likely to be followed as streets tend to be skinnier and buildings more compact.

3. Design Methodology

3.1. PROJECT BACKGROUND

The research was carried out during the development of the author's architectural thesis project, which aimed to improve pedestrian-level air flow performance in urban streets. The study will focus on hot-humid regions such as Philippines, which is facing rapid urbanization as well as climatic problems. In Philippines, the leading financial and central business district is located in Makati City. Generally, Makati City has a high humidity level with an average annual percentage of humidity of 75.0% and average wind speed of 3m/s. Throughout the day, it is generally hot and warm. The site study area is highlighted in red in figure 3. The site was chosen as the streets are oriented in parallel with the prevailing wind directions and it is an ideal location to test design strategies at a 3x3 regular street grid. This will allow a way to understand the urban ventilation of the city for decisions related to air paths, urban permeability and site porosity.

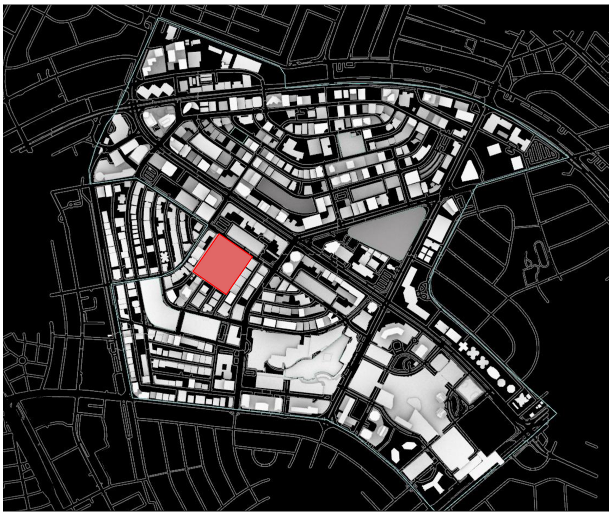

Figure 3. CBD Area at Makati City, Philippines.

3.2. WIND SIMULATION TOOLS

In the context of assessment of natural ventilation in urban areas, a large number of investigations have been conducted in recent years, and CFD method has been introduced as an appropriate approach. CFD is a tool with stunning flexibility, accuracy and broadness of use. The technique has a high consistency with experimental outputs which in turn is the indication of its high accuracy. The most significant imported data for benefiting the CFD method is the amount of wind speed and direction.

3.2.1. Forecasting Wind Behaviour with Ansys Fluent

In any case, the CFD results that provide insights to help optimize designs can be out of reach unless the software is carefully chosen. Ansys Fluent is capable of performing complex CFD simulations, produce reliable technical research and simulation results that are internationally industrial accepted quality standard. Ansys Fluent utilizes a single-window workflow, helping streamline the process from CAD to mesh to accurate results. The workflow in Ansys begins with task-based meshing, continues to a streamlines physics setup and concludes with interactive post-processing.

For a successful CFD simulation, a 3D model must be well developed to maximize its accuracy. Rhino (ver. 6) was selected in this study to develop the 3D model because Rhino is highly compatible with ANSYS (ver. 2021 R1). The models developed in Rhino were exported as Parasolid to ANSYS for CFD study. After which, the boundary conditions of the model were set based on AIJ guidelines, where the lateral and the top boundary should be set 5H or more away from the building and the outflow boundary should be set at least 10H behind the building, where H is the height of the target building (Tominaga et al., 2008).

3.2.2. Visualisation of Results using an Animation Software

CFD simulations of detailed design in an urban scale using Ansys are accurate, however, it is time consuming. To obtain a fast and informative solution to designers during early conceptual design, this study introduces Houdini (ver. 18.0.391) as animation software for simulating windflow. As the paper is studying buildings in an urban context which involves heavy data, it is essential to have an alternative workflow to streamline and amplify the research work by allowing a researcher to consider tens to hundreds of design variations in an urban scale. The Houdini animation software is capable of giving quick and close to accurate CFD results. The wind flow animation in three-dimension in Houdini can be obtained in 1-5 minutes (Kaushik et al., 2015).

Figure 4 shows the details of the components used in the proposed Houdini Working Interface set-up which is an improvement of Kaushik et al. research work. The proposed settings allow the results to stabilize with increasing animation frame instead of spotting the best animation frame. The setup also allows the researcher to only load the mesh model without the need of remeshing or simplifying the original mesh model. This advantage is beneficial as remeshing or finding the correct cell size for the model takes considerable amount of time even before running a CFD simulation. The setup also allows a researcher to have a reusable workflow. At “01 Components in buildings”, users are allowed to load the model at Model_version_1 and another model at Model_version_2 for comparison. This setup allows the user to have as many Model_version_n for comparison just by copying the components and connecting it to the switch button. The switch button allows the researcher to view the CFD simulation results of various 3D models in a single interface and similar settings (ie. incoming wind velocity, boundary conditions, viscous model etc). This reusable workflow in Houdini would definitely help to amplify the research work and output many design variations. Components in 02 are to set up the boundary conditions for the simulation and the incoming wind velocity, where the wind is set as laminar flow. Components in 03 allows the researcher to visualize the output in two options, either via trails or particles. The recommended visualisation output is by particles as the setup allows colour-graded arrows to be attached in each particle for a clear and informative visualisation of varying wind speed and direction. Lastly, components in 04 allows for a recorded flythrough animation of the result.

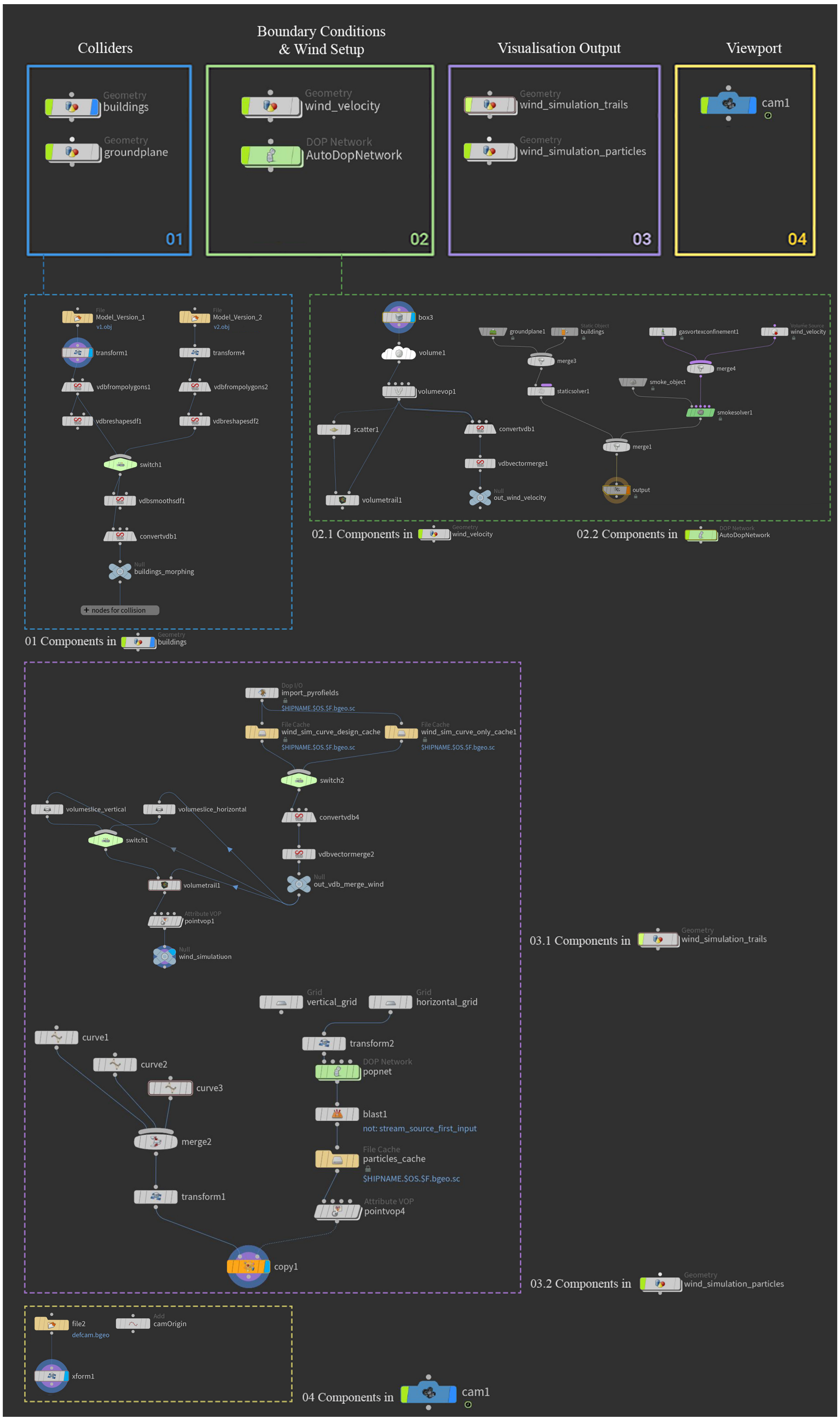

Figure 4. Houdini Working Interface Setup.

4. Design Exploration and Proposal

The project started from investigating the unit behaviour of various forms and surface textures which have the ability to design airflow and air velocity to create cooling effects in warm urban environments (Yogiaman et al.,2018). CFD simulations were conducted to study the shape of the buildings, the texture, and the order of the blocks in the urban setting.

4.1. SHAPE STUDY

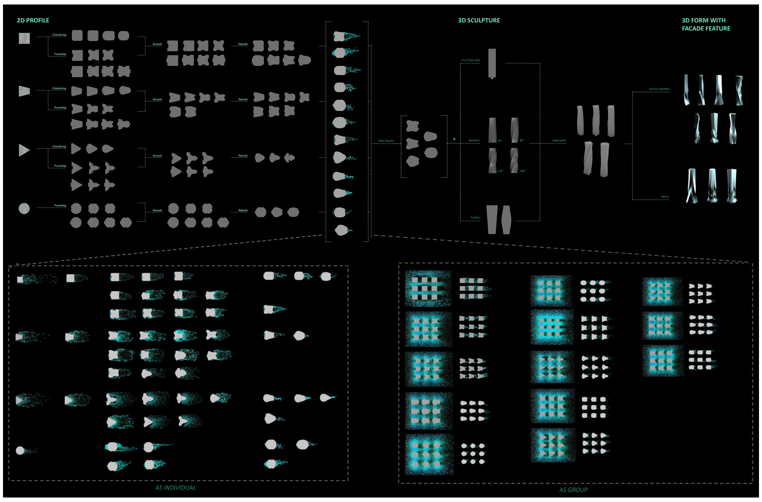

Figure 5. Summary of Shape Exploration and Design Evolution.

Figure 5 shows how the shape has evolved starting from 2D Profile until it was sculptured in 3D. Basic geometries were used as a starting point of the experiment such as square, triangle, trapezoid and circle. Strategies were then applied such as chamfering and funnelling at the first stage. The resulting profiles were then smoothen and rebuilt for second and third stage respectively. At fourth stage, the 2D profiles were filtered based on their performance in the CFD simulation. The results were ranked based on the average wind velocity and percentage of stagnant air for each 2D profile, as individual and as a group. These filtering methods were used until the results were filtered to the best five 2D profiles, which were then used as a basis for 3D sculpturing.

The 3D models were sculptured using the strategies of rotation, scaling and inserting voids. In the same way, the results were ranked and filtered based on the CFD performance by looking at the average wind velocity and the percentage of stagnant air. The results showed that 3D forms which have a twisting character between 135° to 180° displayed the best performance. Subsequently, the forms were then sculpted to have a façade feature that is rotated directly towards the stagnant area to guide the wind and eventually disperse at stagnant areas. This technique would minimize the percentage of stagnant air as the façade helps to direct the wind at areas where wind shadows were prominent. Design variations of 3D form with façade features which demonstrated best performance are displayed at the last stage of figure 5.

4.2. TEXTURE STUDY

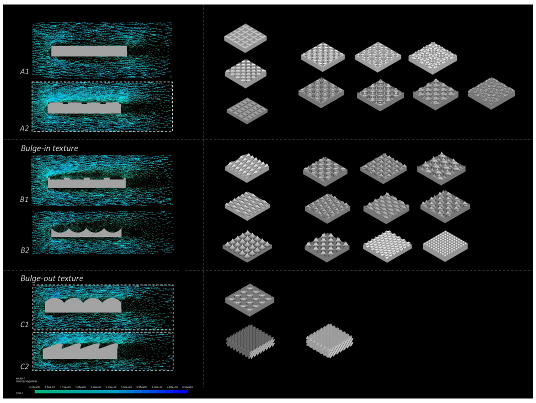

Figure 6. Exploration of Texture CFD Performance.

A total of 25 tiles of different textures were tested for CFD simulation to understand each unit behaviour in relation with the incoming wind of 3m/s. The goal for this exploration is to apply the texture to the geometric form derived from the shape study in the desire that it would amplify the performance of the 3D form and minimize the area with stagnant air in the urban. In figure 6, A1 is the control shape which is a flat texture. From the CFD simulation, the results show that bulging out textures have the ability to let the air stick to the texture closer and maintain the wind velocity as seen from the simulations C1 and C2. This effect is in contrast with the carving in or bulging in textures, which creates turbulence instead and causes the wind to move away as displayed in image B1 and B2. In view of this, bulging out textures are more preferred as it is able to let the wind stick to the geometric form and maintain the original wind velocity, which is highly desirable when combined with the strategy to guide the wind towards the stagnant areas as shown in figure 7.

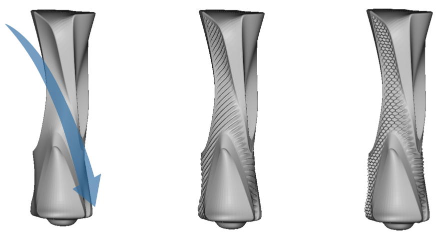

Figure 7. Texture applied on 3D Geometry.

4.3. ORDER AND PLACEMENT OF VOIDS

The form was further developed by creating voids at buildings to allow penetration of air and dispersion to stagnant areas and effectively improve the surrounding wind environment. The voids enabled the wind distribution to be more even around the buildings and eventually lessen the areas of wind shadow at pedestrian level. Figure 8 shows the visualisation of voids at 3D form with integrated façade features. The voids are generally placed at the ground floor level. This creates variations of building core placement at the site area which can be properly arranged and ordered to respond and pattern the incoming wind.

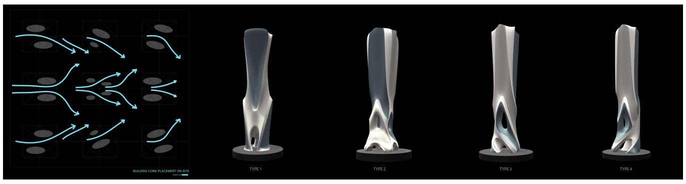

Figure 8. Design Variations of 3D forms with voids .

4.4. PROPOSED DESIGN

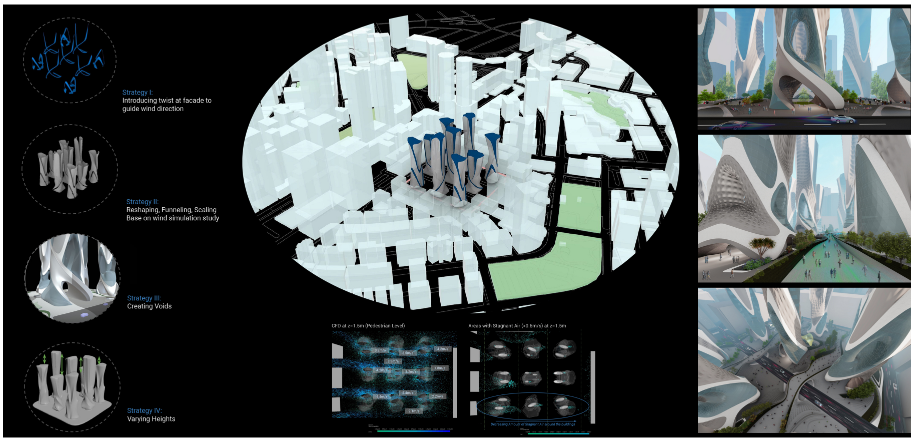

Figure 9. Application of Design Strategies and Design Proposal.

The project explored how urban blocks could display a collective wind behaviour as a design asset in urban environment as shown in figure 9. It utilized the building shape, texture and placement of voids as a way to create a design collaboration of urban blocks as a sustainable approach to improving urban ventilation in between buildings in the CBD Area and, eventually, thermal comfort as compared to individual architectural strategies. The project understood that the design ability and capacity of an individual building to control outdoor airflow movement will not suffice in a large-scale urban setting, and hence, made use of the compact buildings in CBD area to create a coordinated design of building blocks to design an ambient environment.

5. Conclusion

After research and analysis, it can be observed that the shape, texture and arrangement of building cores can be modelled carefully to design wind pattern in the urban. Through an accurate and conscious architectural design that reinforce the design goals of neighbouring buildings, it would be possible to improve outdoor thermal comfort significantly in between buildings. Effective shaping strategies are softening sharp corners, creating openings in the building for the wind to bleed through, funnelling and facade features are essential in the design process. However, shaping strategies should be backed with texture strategies and arrangement of voids to effectively reinforce the design goals and performance of the final form. More advanced simulation should be conducted to test design strategies which include building disposition and various building heights to reveal more insights in the research. Furthermore, the proposed workflow in this research appears to be encouraging with respect to the two key issues of visualizing the wind flow in animation and simulation speed. Although further calibration of Houdini software settings are still required to match with the results from Ansys Fluent, this paper explores the ability of using animation software to aid researchers in the early conceptual design stage and even perform CFD simulations in a large scale urban setting in just a matter of minutes. It should be noted that this workflow is still on its early stage of development and only recommended if the researcher intends to see the general wind flow direction of the design. In-depth calculations and analysis of CFD simulations should still be carried out in internationally industrial accepted quality standard software such as Ansys Fluent.

References

Fish, F.: 1999, Energetics of Swimming and Flying in Formation, *Comments on Theoretical Biology*, **5**, 283-304.

Kaushik, V. and Janssen, P.: 2015, Urban Windflow: Investigating the use of animation software for simulating windflow around buildings, *Proceedings of the 33rd eCAADe Conference*, Vienna, Austria.

Li, Y.: 2018, The Physics in Natural Ventilation of Cities and Buildings, *International Building Physics Conference*, Syracuse, NY.

Oke, T.R.: 1988, Street design and urban canopy layer climate, *Energy and Buildings*, **11(1–3)**, 103–113.

Qaid, A. and Ossen, D.R.: 2014, Effect of asymmetrical street aspect ratios on microclimates in hot, humid regions, *International Journal of Biometeorology*, **59(6)**, 657–677.

Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M. and Shirasawa, T.: 2008, AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings, *Journal of Wind Engineering and Industrial Aerodynamics*, **96(10-11)**, 1749-1761.

Weihs, D.: 1973, Hydromechanics of Fish Schooling, *Nature*, **241(5387)**, 290–291.

Yogiaman, C., Tracy, K., Ghosh, O. and Valdivia y Alvarado, P.: 2018, Aerodynamic articulation: Re-calibrating micro airflow patterns for thermal comfort, *Texas Society of Architects 79th Annual Convention and Design Expo*, Fort Worth, TX.