Flexing Wind

Aerodynamic study of architectural windbreak

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Abstract. *The aims of the Flexing Wind project, investigated in an intensive cross-disciplinary course, were twofold. First was to learn about aerodynamic phenomena around buildings. Second was to explore ways to observe, measure, and control the negative effects of wind around specific pedestrian areas, tram stops, and public sites in Melbourne City. Using tools such as a weather station to collect data and CFD software to simulate aerodynamic phenomena students could study the wind conditions in one of the windiest areas in the Melbourne downtown. Various do-it-yourself tools such as mini wind tunnels, handheld probes and sensors were used to evaluate the performance of potential design options, which lead to prototyping full scale adaptive architectural windbreaks.*
Keywords. *Urban aerodynamics; windbreak; wind tunnel simulation; Computational Fluid Dynamics; architectural prototype.*

INTRODUCTION

A better understanding of urban aerodynamics will positively influence design decisions in architectural and urban projects. The wind flow and dispersion through a city determine environmental air quality, wind pressures on buildings, urban heat islands, pedestrian comfort, and ambient noise level in the surrounding environment (Boris, 2005; Zaki et al., 2010). However, only a few existing techniques have been developed to deal with the habitability and comfort issues due to strong wind conditions on pedestrian areas (Cochran, 2004). These are mainly done on the urban planning level or by introducing trees and shrubs as vernacular shelterbelts. Studies have been done on how aerodynamic characteristics of windbreaks can be used to resolve pedestrian comfort issues (Gandemer, 1981).

This project was conducted as an intensive three-week cross-disciplinary elective in the School of Architecture and Design, RMIT University, offered to architecture, landscape architecture, and engineering students. The outcomes of the explorations include:

- Wind maps of the sites (a major intersection located at the northern axis of Melbourne and the alleyway at the rear-entry of the RMIT University Design Hub building), derived from data captured using handheld probes and a weather station
- Analysis and evaluation of the performance of a series of windbreak options designed for

each particular site performed using a small-scale wind tunnel test and Computational Fluid Dynamics simulation.

- Three prototypes as a system of mitigation for conflictive wind environments (deflector and diffuser devices). Two of these prototypes are reported in this paper.

The main task was to investigate the design and performance of architectural windbreaks as design interventions on the prevailing wind conditions (directions, pressure, speed) by controlling eddy areas around a building. Eddy is a turbulent wind condition caused by the changes of wind pressures [1]. The key outcomes were design prototypes of adaptive architectural windbreaks, which were installed on public footpaths. Feedbacks were gathered around issues such as the performance of the proposed windbreaks and the impact of installing the windbreak on the windy sites.

METHODOLOGY

The research and design aspects of the elective projects was conducted by a group of students (11 masters and undergraduate students) and highly guided by investigators (the teaching staff in the elective, authors of the paper). At the beginning, the students had access to a wide range of literature on the theory of windbreak design. Topics included studies about aerodynamics in urban contexts and wind comfort using Beaufort scale criteria where wind is considered as a function of speed and sensations felt (Gandemer, 1978); and systems to wind control such as windbreaks (Cochran. 2004). The students were also presented with introductory lectures on the technical aspects of the project by the teaching staff as well as an external industrial expert. During this stage the students learned about causes and effects of more common aerodynamic phenomena in cities produced by the wind flow interacting with buildings and affecting public areas.

In the second stage, students were introduced to the methodology and tools on windbreak design. The literature included the authors' earlier research projects, such as the parallel wind analysis method and the mini wind tunnel (Salim and Moya, 2012) and methods of designing kinetic façade prototypes (Sharaidin et al., 2012). Digital technologies such as Computational Fluid Dynamics (CFD) were also used to simulate the aerodynamics of the external environment. Additionally, using a mini wind tunnel, physical experiments such as erosion test (wind flow visualization using particles on a dark-coloured background) and smoke test (Salim and Moya, 2012) were applied to evaluate the different designs of the windbreak systems. Through these methodology and tools the students could run different experiments focused on the analysis of wind phenomena.

The proposed methodological experiments were divided into several tasks:

1. Build a system to quantify and visualise wind data (wind speed). The tools made available to the students were: a low-cost commercial weather station, scientific indoor condition measuring probes, low-cost electronic sensors and development platform (Arduino). Through a selection of the above tools, the students will develop a system to collect and visualise the data from the public space. The intention is to develop a wind map of the urban zone using instruments to measure the movement of wind.
2. Construct both a physical and digital module of the selected site. Conduct simulations to understand the effect of wind in an interactive fashion.
3. Design an artificial windbreak prototype for public space (passive or kinetic structures). Students were encouraged to test their design iteratively through both physical and digital simulations.
4. Build and install a full scale windbreak prototype. Students built a representative part of their design in a scale one by one. This prototype was installed in a windy site in the city to evaluate impact on public space and performance to mitigate wind problems.
5. Evaluate the wind mitigation achieve after of the prototype installation.

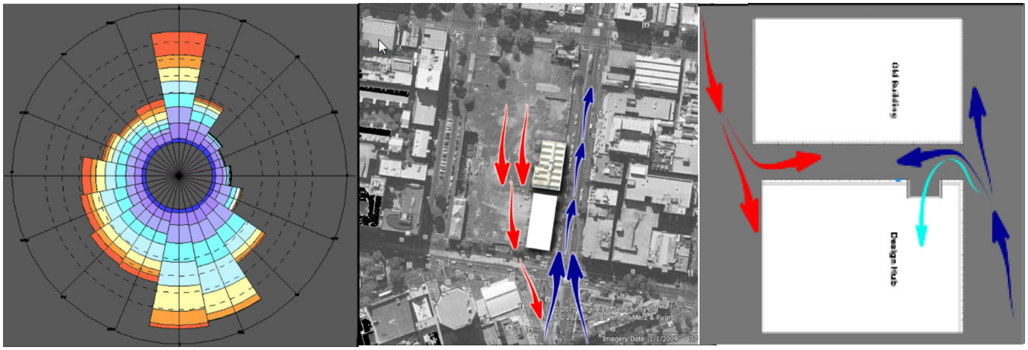

Figure 1
From the left to right: the wind rose from Vasari and wind map derived from the site observation.

PROJECTS: ANALYSIS, DESIGN AND OUTCOMES

The two main approaches to develop a wind control structure were the exploration of porous patterns as a wind filter and the concept of a shell as a wind deflector. The challenge was to not only design a structure to control the negative effect of wind detected in the site, but also produce low impacts in the surrounding space. This meant that the aesthetics is an important element alongside the functional aspect of the windbreak.

Milk.Crate.Break Project (by Tamara Cher, Xuan Son Nguyen, Romy Peterfreund)

The site for prototype 1 *Milk.Crate.Break* is at the rear entry of the RMIT Design Hub (Swanston Street entrance). It is a narrow alleyway close to an alcove with an operable door opening. Through a study of the historic data of the site it was found that there is a prevailing wind blowing through the site, direction alternating depending on the season (Figure 1). When the door is opened the sudden pressure difference produce a noticeable wind gust into the building.

The study of the site (Figure 1) was focused on the investigation of the differences of wind conditions between summer and winter seasons, as well as analysing the impact in this area.

The first finding of this study showed that wind has two predominant directions (north and south). This meant that wind passing through the passage leading to the entrance changes its direction throughout the year. The effect on the entrance is the same but the design of the windbreak should deal with both wind directions.

Using Vasari as CFD software it was possible to visualise how the gust of wind had a curved movement producing two separation zones with low pressure areas. One of these areas coincided with the entrance of the building, producing an input of wind when the gate was opened. These simulations were validated with measurements of the wind speed using the anemometer on the low-cost weather station. On the day of data collection it was found that the wind coming closed to the façade had an average speed of 3.7m/s at 2m height, but this velocity increased up to 4.4m/s when was blowing through the passage (Figure 2).

The first approach was to use a shell or canopy to deflect the wind to maintain the low pressure area in front of the entrance. Later the design process progressed to the design of a skin with some kind of porosity to control the wind speed. This porosity concept evolved from a surface with simple patterns of holes to different patterns with a variable density of porosity (Figure 3), following the indications of the studies by Gandemer (1981) on windbreaks.

As part of the project the students were required to construct a section of their design in full size and install it on site. The *Milk.Crate.Break* team decided on the front section of the design to be constructed

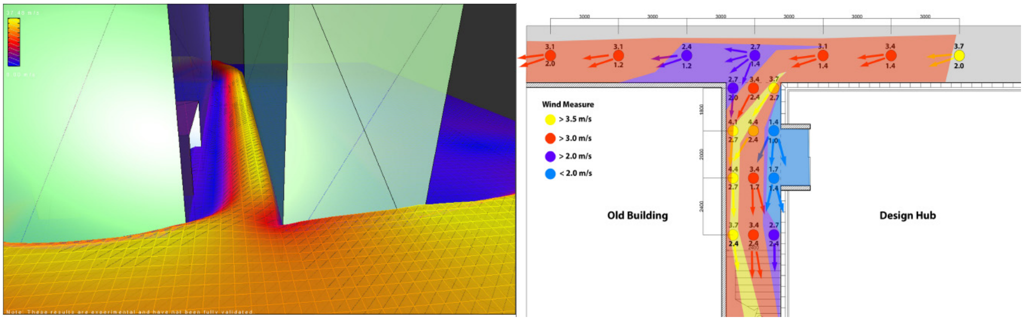

Figure 2
From the left to right: CFD visualisation and windmap of the site done in Vasari.

at the full scale. This had the implication that a new structural system is required for the design. Through further exploration the students decided on using milk crates as the main building material, factors influenced their decisions included: structural (modular self-supporting, easy to assemble and disassemble), sourcing (free and readily available), a cultural significance (Melbourne's laneway). The inherent structure and porosity of the milk crates also offered the students additional design possibilities: The design was adapted to take advantage of the crate volume to produce a design with a double skin. The students explored several options of patterns for an adaptable second skin through CFD analysis. The first option had a pattern of Venturi funnels working as a diffuser to decrease the wind speed in the outcome side of the wall. The second version was a pattern of triangular petals with a more simple system of petals aperture for the density control. The final design was a pattern of triangle flaps based on the shark skin. This was the options chosen because the parallel triangular surfaces deflected the wind more efficiently to produce an upward air through the wall. The experiments compared these different patterns with 20%, 40% and 60% of porosity. For each case, the pattern moves depending on the pressure of the wind, where used to deflect the wind upwards as well as absorbs a fraction of the wind energy (Figure 4 and 5).

The final concept was a structure with a double layer of porous skin. The first porosity layer was a regular graph design which ameliorated the wind speed. The second shark-skin pattern layer reduced the wind flow close to zero. Between both layers, the internal chamber in the structure was designed to deflect the wind vertically. In this way the pressure on the structure was reduced to maintain the structural stability.

The students' final design was a windbreak that spans the full width of the alleyway, 2.5 meters in height, offering protection for a large area in the proximity of the door. The design form is symmetrical to work with both wind directions. There is one opening at each end to allow access through the

Figure 3
From the left to right: the first version of shell, the second version of a porous shell, the study of porosity density.

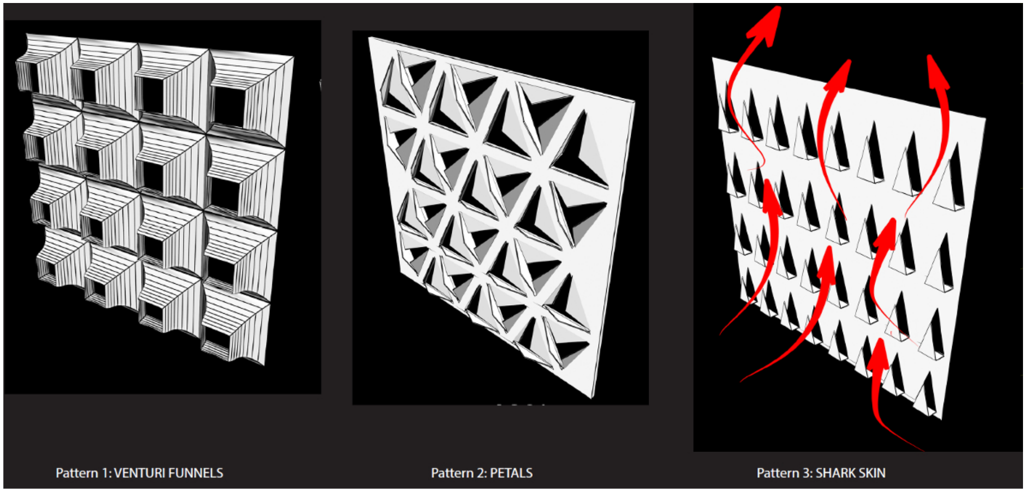

Figure 4
From the left to right: Venturi funnels, petals and shark skin.

site and into the building. The porosity system is designed for the surface of the windbreak, with lower density at the lower part the design to offer more protection (Figure 6).

Further testing (both simulation and in the physical mini wind tunnel) were conducted to confirm the functionality of the adapted design. Measurements were taken to evaluate the design.

Lyrebird Project (by Mikhail Kochev, Sara Metanios, Daisy Leung, Rico Shuyuan Zhang)

The site of prototype 2 *Lyrebird* is located close to a street level entrance to RMIT University Building 14 (Swanston Street). The onsite data measurements revealed a predominant wind direction from the south to north. The students noticed a strong and

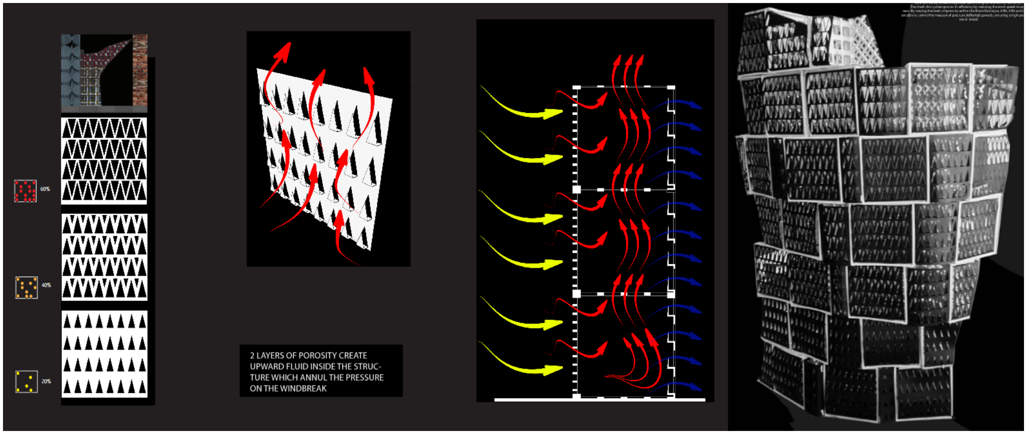

Figure 5
From the left to right: porosity variations and effect of wind passing through the structure, final installation.

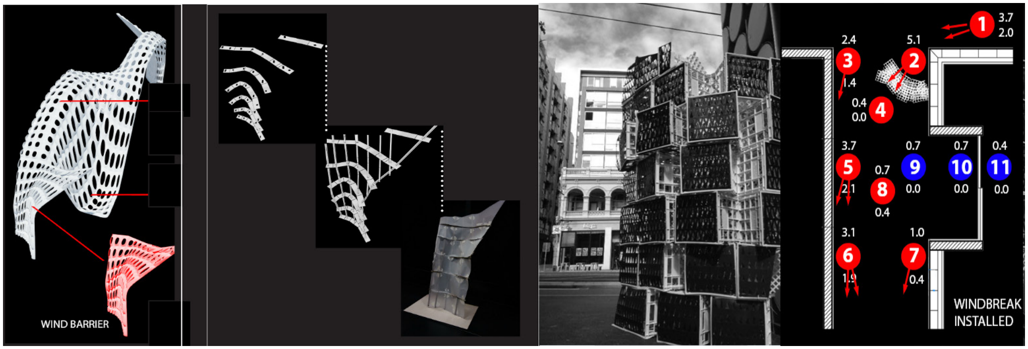

Figure 6
From the left to right: design process from the concept to the installation and measurements in the site.

turbulent wind close to the building facades side of the pedestrian sidewalk. Although a number of trees are present on the street near the site, it was evident that the wind conditions were not improved for pedestrians. Erosion test of the site model was conducted in the mini wind tunnel to reproduce the more relevant phenomena. The phenomena observed were: the wind blowing along the street, the wind effect around the corner on the building, and the effect that could be produced by placing structures over the entrance (Figure 7). These simulations demonstrated a channel effect occurring in this area with a high level of turbulence from the friction with the buildings' walls. This was identified as an issue for the building entrances and other points around the pedestrian circulation routes. The design objective was to protect the street level entrance from the prevailing and local wind conditions.

The student drew their design inspiration from bird feathers, in particular the fan-like tail of the Australian Lyrebird. The idea was to mimic the natural curvature of the feather to form a curved shell for the entrance (Figure 8). Design iteration of the form and dimension of the windbreak was mainly conducted through physical wind tunnel tests and CFD experiments. These digital tests were focused to find the more efficient curvature for this roof to deflect the wind. This exploration found that a double curvature performed a very good protection rather a single curve (Figure 9).

In the wind tunnel test, a simple curved canopy shows a good performance to deflect the wind without significant loan on the structure: the arched shape was able to deflect and guide the wind over the building opening. This final version was chosen as the structure shown to be a more effective windbreak. These tests demonstrated that the structure does not produce lateral strong gusts and the protection area was large enough to provide shelter against strong winds around the entrance of the

Figure 7
From the left to right: mini wind tunnel and erosion test of the proposed windbreak design, wind map of the site.

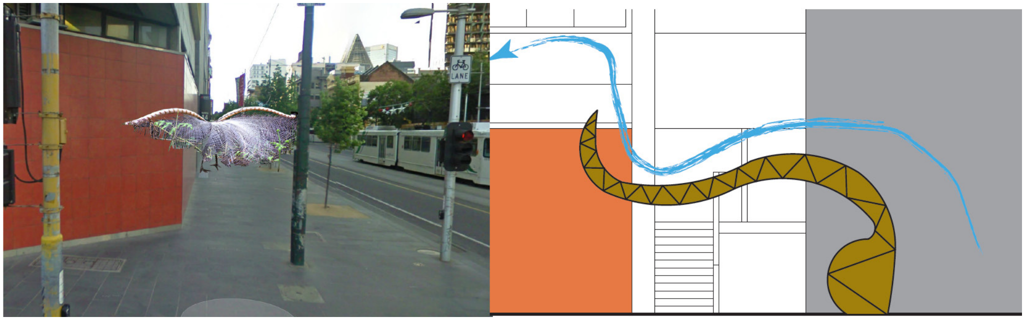

Figure 8
From the left to right: concept based on tail of the Australian Lyrebird and hypothesis of wind deflection.

building (Figure 10).

Detailed porosity exploration was also carried out using smoke test to study the best sequence of gaps and thickness of the barrier with different wind velocities (Figure 11).

The final design was a frame and infill system with triangular “slot-in” panels on vertical structural frames. Each triangular panel contains a movable flap with functions similar to prototype 1. As these panels are more visually prominent compare with prototype 1, the students worked to adapted them as a visual wind indicator to increase public interaction with the windbreak. This was done through installing an Arduino controlled LED display, where the display was driving by wind data from an electronic sensor (anemometer). This was not installed

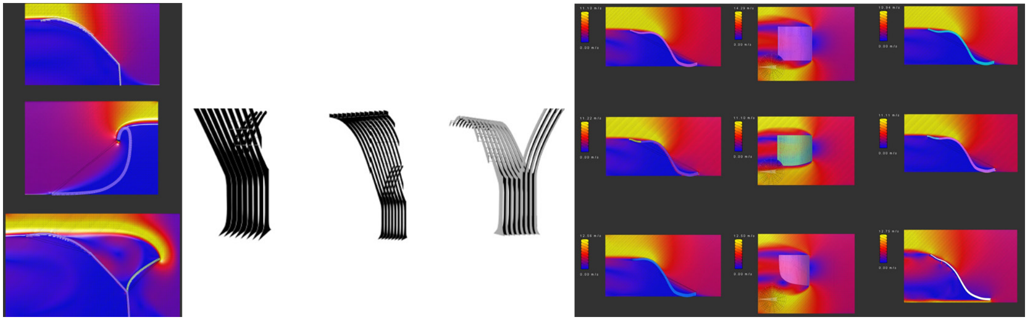

Figure 9
From the left to right: CFD tests for different curvatures, first project design and wind test of curve profiles.

Figure 10
From the left to right: CFD test and wind tunnel test for the final design.

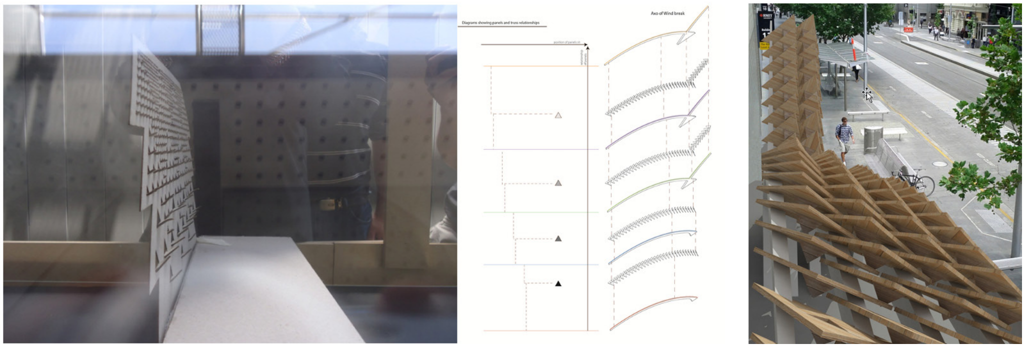

Figure 11
From the left to right: smoke test, axonometric of panels and final render.

on the final installation due to time constraints. Many factors such as site permit restriction and fabrication constraints dictated that only approximately 2 meters by 2 meters by 2 meters of the design was constructed and evaluated on site. The students applied bright paint to observe how colours have a relevance to intensify the visual aesthetic of the structure in the public area (Figure 12).

GENERAL EVALUATION

One positive outcome of this academic project was the opportunity to share knowledge from different fields that conduct work on the city and its current problems. The use of technology helps us to understand the dynamic phenomena like wind in cities, through collecting data (both in the physical and virtual realm, on site and through simulations) and make sense of that information. This was the intention of this project: to teach students to work with methods and technological tools to study complex phenomena.

This first part of the objective was fully complete for the students. In the short three weeks, through the study of the literature available in the field of wind engineering and the tools such as Vasari CFD and a low-tech mini wind tunnel, the students were able to gain a good understanding of the basic aerodynamic effects to begin their own design exploration in this field. The potential of these tools for pedagogic purposes was evident. The visual interactive feedback helped the students to gasp with the comprehension of these complex phenomena, and as a platform for discussion the design performance. The visual documentation of the design testing process (both still images and videos) formed a large part of the presentation material for the students

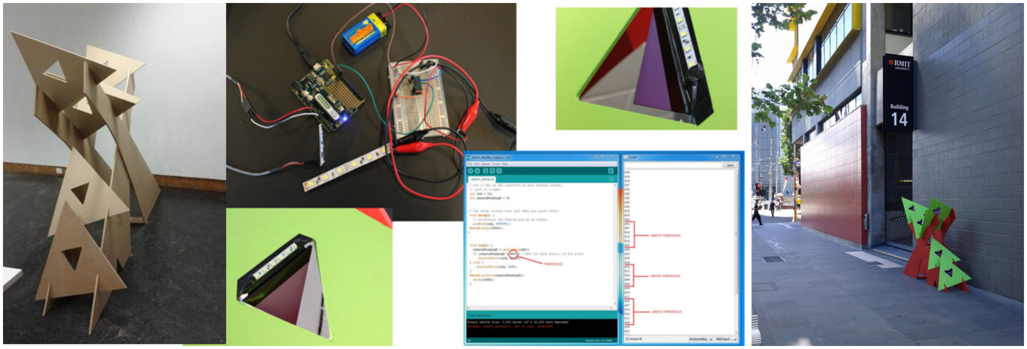

Figure 12
From the left to right: prototype, Arduino platform and installation.

to communicate their design intent to the teaching staff and invited critiques.

The ready-to-go low-cost commercially available weather station, with its simple interface, was quick to be adapted by the students to be used for site analysis and to prototype performance evaluation tool.

Arduino Platform and electronic sensors have proven to require a learning curve too steep for most of the students to be able to utilise them in their design. The Arduino and sensors induction were provided as part of the course material, but whether to incorporate it within the design was a choice left for the individual student team. All of the students welcomed the half day hands-on session exploring Arduino sensors and motors. The students were guided through a series of selected examples that introduced the concept of Arduino microcontroller and a collection of electronics. With each example its possible application to the windbreak design was discussed. Following the demonstration, a proportion of students actively sought additional equipment and assistance to experiment it further. This demonstrated that new technology was easily taken up students when it is presented as a useful resource to extend the possibilities for their design proposal.

Apart of the design aspect of the windbreak, the challenge of a built prototype was a very positive learning process because students were encouraged to deal with physical problems and technical solutions. Even if the prototype was not a fully functional model, many issues concerning scale, materials, and cost were considered and evaluated for each project. This dialog of material and constructability also opened up new design exploration. Take the intention of the *Milk.Crate.Break* project to use recycle plastic boxes as an interesting example. The decision to use milk crates as a building material led the team to explore the features of a double-layer windbreak. This project studied the performance of different porous patterns when a simple plastic mesh may be functionally sufficient. This demonstrated that performance and constructability should inform each other in design.

The task of constructing a physical prototype and installing it on site helped students to understand how an urban intervention can also have a visual impact in the space. For instance, the colour in the structure of *Lyrebird* project was considered as a parameter of communication. Additionally, the project also considered to use an anemometer driven LED display which could be activated with the wind, sending a live visual signal to the passers-by when the wind speed increases over the comfortable levels. Thus, the performative aesthetics of a windbreak as an urban element can also have a functional aspect that informs people of the surrounding environmental conditions.

CONCLUSION

Wind around buildings and in public spaces can produce negative effects that are necessary to mitigate. This paper reports on a design-construct cycle of a site specific architectural windbreak, conducted in the form of a design studio taken place over an intensive three-week period at the RMIT University, Melbourne Australia. After a detailed study of the site, the students successfully incorporated aerodynamic theory into their design thinking and demonstrated the use of CFD simulation tools and physical wind testing to assist their design process. The impact of the windbreak on the site was quantitatively measured and evaluated. This is done by assimilating the studies of local wind conditions and vernacular systems and testing the design in wind tunnel simulations.

The results and prototype designs are preliminary, however they demonstrated the possibilities of designing windbreaks that have aesthetics features as well as the functional capacities to provide comfortable pedestrian areas.

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