Wind sensing with real-time visualisations for Designers

An approach to understanding wind phenomena for pedestrian comfort using low cost wind sensors

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The evaluation of a low-tech wind sensing platform for urban aerodynamic simulations relevant to pedestrian comfort. In this paper, the wind canyon effect is simulated with two different building morphologies. The platform provides conceptual knowledge of the dynamics in wind relevant for designers, architectural practitioners and students of design. Low-cost hot wire anemometry is utilised for the design of an Experimental Fluid Dynamic (EFD) wind sensing network interface. This paper explores the validity of the sensing platform for a new approach for non-wind engineers to gain a better understanding of the dynamics of wind. The influence of real-time feedback from quantified wind on the understanding of wind phenomena for non-wind engineers is discussed and compared with post analysis data. It was found that real-time quantified feedback from wind intrigues and stimulates the intuitive notion of wind dynamics through discussion, however post analysis remains critical to evaluate building design performance.

Keywords: *Wind Sensing, Real-time feedback, Experimental Fluid Dynamics, Hot-wire Anemometry, Atmospheric Boundary Layer*

INTRODUCTION

The study and knowledge of urban aerodynamic phenomena is very important in the fields of sustainability, environmental design and human comfort (Boris, 2007). The aerodynamic phenomena produced by wind in the built environment and its effects on the level of pedestrian comfort usually require complex and expensive technologies to quantify the wind condition and visualise the effects in the built environment. Tools such as: Computational Fluid Dynamics (CFD) or the use of various high cost and complex wind sensing techniques i.e. multi-hole pressure probes coupled with Experimental Fluid Dynamics (EFD) can be overly complex (Watkins, 2002). The nature of wind is beautiful and majestic, though chaotic which creates difficulties when attempting to introduce the topics of observation and analysis of complex wind flow phenomena in built environments to architects and designers. Architects and designers should have a broader knowledge about the more important and fundamental concepts involved in wind around buildings so they may understand the parameters involved at the conceptual design stage. Wind phenomena around buildings has strong relevance in urban planning and architectural design and is imperative for an architect's ability to share common knowledge with disciplines such as wind engineering in their professional careers in design (Wisse, 1988).

The Wind Sensing Platform

The wind sensing platform proposes an improved method of phenomenological exploration and observation of the dynamics of wind by quantifying empirical experiments in real-time. The platform provides real-time feedback of the changes in wind speed in understandable units (metres per second) at strategic points around a scaled building design with a direct digital interface to visualise data. The sensing platform was tested with two scaled buildings in two different wind flow scenarios to show the capabilities of the sensing technology to identify the predicted wind phenomena surrounding the buildings.

Empirical observations of wind dynamics are the most informative and stimulative way to understand the dynamics in wind, which is suggested as a good introduction method for architects (without a wide theoretical background in fluid mechanics) to understand aerodynamic phenomena in built environments. The sensing platform presents an opportunity to add value to and actually quantify the empirical experiment in real-time for on-the-fly discussions and decision making. Rapid feedback about the dynamics of wind improves a designer's ability to choose the most effective design based on the wind speeds around a building (a good indicator of pedestrian comfort levels) (Gandemer, 1978). It has been found that using empirical explorations and digital sensing technology is much faster when iterating through multiple design concepts in comparison with virtual simulations (Williams, 2013). This is just as evident in the specific realm of fluid dynamics where CFD is notoriously enigmatic.

The sensing platform integrates three main technological approaches: physical simulations of wind with a wind tunnel, micro anemometer sensors connected to an Arduino board and a digital interface to visualise data using Grasshopper3d (0.09.0056) with the Firefly plugin and Rhino5.0 software.

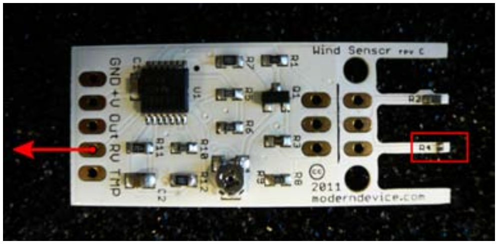

Figure 1
Hot-wire anemometer ModernDevice (revC)

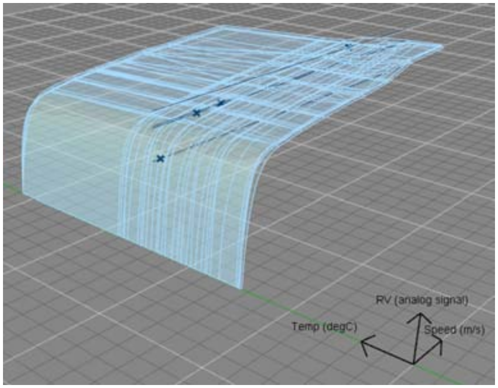

Figure 2
Hot-wire anemometer calibration surface in Rhino 5 using Grasshopper3d

The adaptation of the wind sensors

The wind sensors were acquired from ModernDevice (see URL in references). These particular sensors were originally designed for the purpose of recognising if someone was breathing. Five wind sensors went through a calibration process within the low-turbulence aerospace wind tunnel at RMIT University. The anemometers are dependent on temperature changes in the ambient conditions as well as the temperature difference created by the change in wind speed (figure 1). The dependency on the orientation of the sensor with respect to the wind direction was also tested. A surface was created in 3D space to relate ambient temperature, analogue signal and wind speed (figure 2).

EXPERIMENTATION IN THE WIND TUNNEL

The low-cost anemometers were utilised in two main scenarios within the industrial wind tunnel at RMIT University, Bundoora. Firstly, the sensors were used to measure the Atmospheric Boundary Layer (ABL) wind velocity profile at a 1:100 scale. The second set of experiments involved two different building forms that would display interesting wind phenomena. A second building was placed windward to the building in question to simulate a canyon wind effect in subsequent experiments.

Wind Velocity Profile Measurement and Calibration

The first task was to set up a group of sensors to measure the wind velocity profile of the 1:100 ABL condition (Aynsley, et al. 1977). An existing rig to create the 1:100 ABL condition in the industrial wind tunnel was used (figure 3). The wind velocity profile was measured with the anemometers and plotted against the ABL power function. The wind velocity profile and turbulence intensity profiles are documented from previous experiments with a cobra probe. These results were used as a reference for the hot-wire anemometers, though detailed analysis of the hot-wire anemometer performance for turbulence intensities will be well documented in further research. The scope of this paper covers an exploration into techniques to calibrate the wind tunnel boundary layer condition for wind speeds in real-time (figure 4).

The ABL calibration process is usually an arduous and time consuming task. The hot-wire anemometers used in this wind sensing platform show promise in this area of wind measurement. Basically, a theoretical boundary layer condition should be calculated and plotted on an elevation verses wind velocity graph. A reference velocity should be chosen relative to the height which is of some significance - commonly taken as 10m above ground level for urban conditions. However, these experiments are focused on the effect of pedestrian comfort around buildings, so a reference velocity is taken at 1.5m above ground level (head height). The sensor positions are then chosen and values along the theoretical ABL power curve equivalent to their elevation are noted for reference during the real-time calibration process.

Timber of various sections were used as wind barriers to configure the wind dynamic to achieve the ABL. Each effect of each additional timber element was measured in real-time. The aim was to achieve the reference wind speed at each elevation. Though when one wind barrier is added, the effect on the wind measurements were dispersed amongst surrounding measurement points. A major advantage of multiple sensor measurement creates the opportunity to observe these de-localised effects and immediately take action to balance the distributed effect. The resultant configuration for the 1:30 profile included one additional slat and a series of 90x45mm timber sections to alter the 1:100 ABL profile into a 1:30 ABL (figure 4).

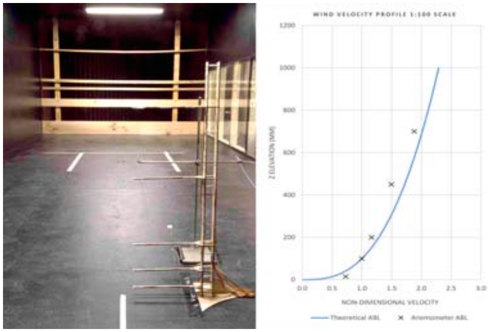

Figure 3
Wind velocity profile anemometer measurements (Scale 1:100)
Vertical slats were used to create the ABL condition

The red curve in the Rhino 5 screen capture moves with the wind along the wind speed axis (figure 5). It was possible to observe the dynamic fluctuating effects of the wind as the curve snaked around its theoretical counterpart, the blue curve, which describes the theoretical ABL wind velocity profile. The values represented virtually at the location of the sensors were a display of the target speed and real-time speed measured by the anemometers. It was difficult to understand the nature of the velocity profile curvature with these measures alone, but proved to be useful when trying to reach the target velocities during the calibration process (while adding or altering timber elements).

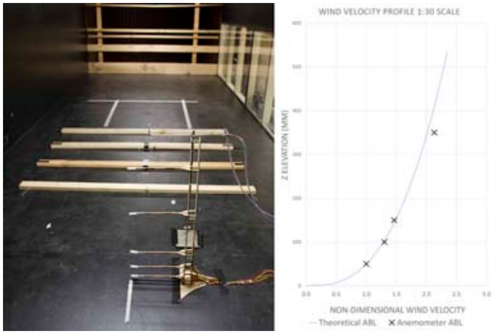

Figure 4
Wind velocity profile anemometer measurements (Scale 1:30) A combination of vertical slats and horizontal wind barriers were used to create the ABL

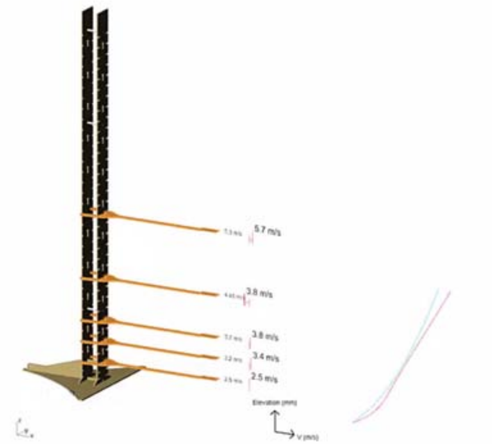

Figure 5
An example ABL wind velocity profile measurement real-time visualisation (calibration of the 1:30 velocity profile (Castro et al., 2014))

The methods of visualisation had a strong impact on how one may understand or interpret the quantified wind data. For measurement of wind at various chainages along a vector, a continuous curve has shown to be the most useful. ABL measurement requires the measurement of a reference velocity and should match the ABL power law (Walshe, 1972). Relative wind velocities or turbulence intensities need to be quickly compared with respect to one another - the curvature of the velocity profile is critical since the results are represented non-dimensionally and in non-compressible fluid flows the geometry of the wind flow should not change with respect to the magnitude of the wind velocity.

The instantaneous ABL curve representing the anemometer measurements appeared to move too and fro about the theoretical ABL curve. During observation, discussion and manipulation of the timber elements it was possible to see the change in the wind velocity profile using this curve, however, as a time dependant visualisation (45.7Hz sample rate with 20 point weighted smoothing applied). This removes the abstraction of the static depiction of post analysis velocity profile plots. The decrease in abstraction of the reality is proportionate to the increase in understanding of the reality. In this sense the process is valuable to the non-wind engineers whom are interested in observing and understanding wind dynamics.

It was possible to estimate the wind velocity profile of the ABL through real-time observations of the hot-wire anemometer measurements. The observed data was strategically logged and quite readily averaged over a one minute sample to plot the wind velocity profile. It only took one attempt to achieve a very reasonable resultant ABL condition. The entire process of calibrating the wind tunnel from a 1:100 profile to a 1:30 profile was achieved in approximately an hour.

Measuring Wind Speeds around Buildings

The following building examples were chosen to create some interesting, but clear wind effects and in some cases quite well known in the wind engineering literature. Effects, such as: the canyon effect and channel effect were created with the two building morphologies (Penwarden, 1975). It was possible to check the wind speed at various locations around each building model and project the quantified wind values in real-time to the observers. Some interesting discussions about the wind phenomena displayed began to change how we approached the experiment, but also allowed us to reflect directly on the data which we saw in real-time on the digital interface.

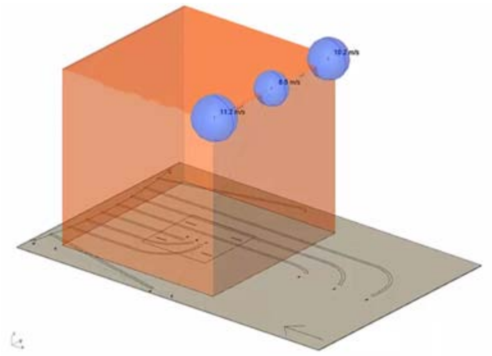

Figure 6
Virtual visualisation of quantified wind: Cube building example

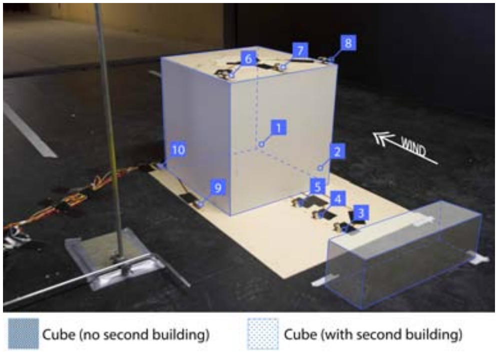

Figure 7
Cube building example 45(W)x45(L)x45(H)cm Two scenarios depicted: 1. without smaller building 2. with the smaller building

The experiment to test the sensor platform was designed to simulate of the canyon effect, an accelerated vortex of wind in the space between both a high building and lower building. The phenomenon is produced by a downward wind flow deflected by the high building facade to the ground level. The wind effect around a building could have a strong impact on the pedestrian comfort level. For this reason, it is relevant to study the relationship between geometry of a windward facade and the wind speed deflected from the facade to the ground.

The aim of the experiment was to detect the differences of the wind flow produced with respect to the two buildings, one of a regular shape and another with a twisted hyperbolic form. The sensors were installed in specific points in front of the building facade, at the corners and on the top of the building to detect the main variations of the wind flow (Penwarden, 1975).

Digital Interface and Real-Time Feedback

Using Grasshopper3d with firefly and Rhino 5 it was possible to develop a digital interface to directly receive the analogue signals from the sensors, calibrate them through a surface in 3D space and translate this data into graphical information. This allowed an easy comparison between physical and virtual realities. Additionally, this information can be overlapped on a 3D digital model of the building shape (figures 6 and 8) or urban configuration to help define zones of turbulence and wind speed variations.

The anemometers were placed in regions chosen with reference to ratios of the building geometry (Penwarden, 1978). These configurations were matched with theoretical wind patterns which are well known in the field of wind engineering. These were very relevant in the case of the cube building example, in contrast to the hyperbolic building morphology. So, a smoke machine was used for direct observation of the turbulent characteristics around the hyperbolic building (video footage is available). It was evident that the wind was channelled and accelerated along the facade down towards sensor 10. Diagonally skewed eddy vortices were also observed on the leeward hyperbole surface. A similar and slightly more intense effect was observed in the region of sensor position 2. Though, this was a combination of wind channelling and wind shedding about the acute building edge condition.

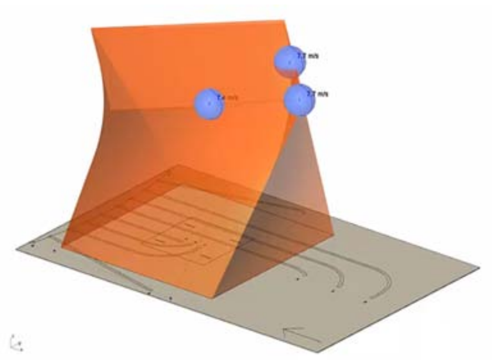

Figure 8
Virtual visualisation of quantified wind: Hyperbolic building example

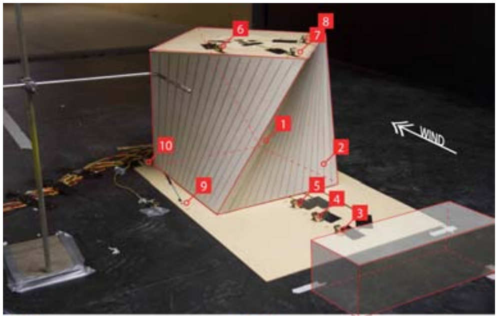

Figure 9
Hyperbolic building example Base-Roof: 45(W)x45(L)cm Height: 45(H)cm Twist: 45deg Two scenarios depicted: 1. without smaller building 2. with smaller building

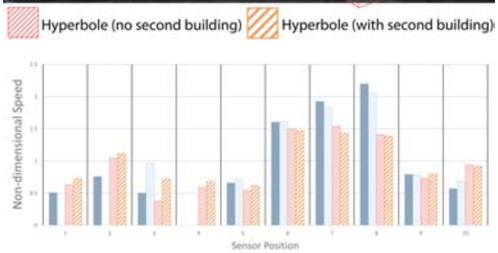

Figure 10
Wind speeds at various locations

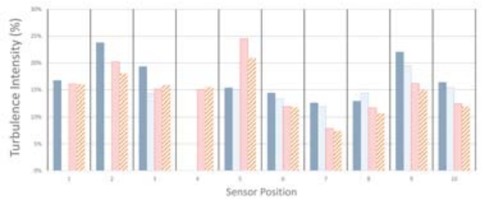

Figure 11
Turbulence intensities at various locations

The sensors were strategically placed around each scale model building. During on-the-fly discussions it was possible to identify the accelerations in wind due to wind shedding on the windward corners of the buildings, the amplified effects of the wind within the region between the smaller building and the larger (canyon effect) and the differential effects of the wind on the leading edge of the rooftop. It was also possible to identify that there are asymmetries in the wind flow within the wind tunnel. The observation of the asymmetries in the wind flow became very useful knowledge for the post analysis process - something which would not have been readily concluded during post analysis. These observations were recorded through video and audio recording during the experiment. A selection of these recordings will be presented at the conference.

Post Analysis Results

An interesting example of the canyon effect has been observed in the above results. The canyon effect is created by the differential wind speeds simulated by the ABL condition in the wind tunnel. One would assume that when one *blocks* the wind with another building the wind speed should decrease at sensor position 3. However, we observe the contrary. The effect of the ABL and low pressure systems in-between the two buildings creates an accelerating effect (Penwarden, 1975).

It is evident that after post processing the collected data, the average speeds surrounding the two building morphologies expressed very similar patterns to those inferred from the real-time observations.

This is the first application for the measurement of turbulence intensities for these particular wind sensors. So, it is not possible, at this early stage to verify the measurements' accuracy. Though it may be within reason to speculate that the measurements observed are in-fact quite relevant - as is observed in "Aerodynamic strategy applied in an urban shelter design"(also presented in this conference) (Moya Castro, 2014). These observations are merely selfreinforcing evidence at this stage, however further tests will be conducted prior to the conference proceedings to clarify the accuracy of turbulence intensities and wind speeds measured with the low-cost anemometers.

The application of the sensor platform for rapid visualisation and comprehension of physical simulations can improve the observation and analysis of wind dynamics in the built environment for architects and designers, potentiating the communication with other specialists. This tool has the potential to be used in the study and design of microclimatic conditions for pedestrian areas near buildings.

CONCLUSION

This research presented a technological platform which integrated different techniques of simulation and visualisation of wind phenomena and analysis of aerodynamic simulations of wind flow around built environments. This technology has the potential to help non-engineers to better understand the dynamics of wind around buildings. It is a practical tool to analyse problems of discomfort produced by wind in areas near buildings, but also, it is a tool that can assist architectural practitioners and designers to explore aerodynamics through quantifiable empirical observations. It is a cheap, relatively low tech, reliable and quick method of measuring wind effects around buildings. This approach to wind visualisation is relevant because architects and designers should share (at least) a basic knowledge of wind with engineers to have a discussion about the problems related with the factor of wind in design.

OUTLOOK

This wind sensing platform is very relevant for use in the design industry and wind engineering. The fact that this sensing platform is a low-cost, reliable and quick feedback tool for the measurement of wind speeds within reasonable accuracies promotes this research as an option to adapt the sensors to any conceptual design challenge where the effects of wind are relevant.

ACKNOWLEDGEMENTS

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