EMPIRICAL EVALUATION OF THREE WIND ANALYSIS TOOLS FOR CONCEPT DESIGN OF AN URBAN WIND SHELTER

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Abstract. The aim of this investigation was to evaluate the performance of three wind analysis programs used in the early design stage (EDS) of a passive windbreak shelter concept for an urban context. This study compared the different workflows of these programs and the respective visualized results, identifying the differences and limitations of these tools, for design exploration. The programs tested were Autodesk Vasari, ODS-Studio, and ANSYS CFX. The results of this investigation indicate that basic computational fluid dynamics (CFD) programs such as Vasari was found to be more suitable for the observation of large-scale wind phenomena through the whole area of the shelter. Moreover, intermediate CFD tools (functions, usability) such as ODS-Studio can be used more efficiently in detailed visualization of wind interacting with design features. Finally, a more sophisticated CFD program like ANSYS CFX can be incorporated in the early design stage workflow for final verification of results.

Keywords. CFD; visualisation; wind; pedestrian comfort.

1. Introduction

Wind analysis in outdoor environments has become relevant in the design process of buildings and public spaces. This is because wind phenomena that are produced by buildings geometrical configurations can affect the level of comfort in pedestrian areas (Stahopoulos, 2011). As a result, architects have incorporated wind expert consulting and simulations with tools for wind visualisation into the design process (Naboni, 2013). However, because of the high cost and complexity of these technologies, experts generally use these tools for validation of final designs rather than form exploration in the
early design stage (Kirkegaard, 2008). The use of wind analysis during the exploration of conceptual designs, for pedestrian wind shelters, is a field of study for architects to develop more sophisticated strategies for wind mitigation. This was the case of the prototype of a canopy developed as part of the initiative CFD-ARCH (2012), in the SUTD-MIT International Design Centre. That project states: "the objective of this research initiative was not to extend knowledge in the field of CFD but to find ways of utilising CFD to support early stages of the architectural design process, where many critical decisions, including those pertaining to the building performance are made" (Kaijima, 2013).

Currently, a new generation of CFD programs is available to be used by architects for wind analysis of concept designs. Tools such as Vasari, and ODS-studio are technologies that are easy to operate and provide rapid feedback for the analysis of wind behaviour in spaces near buildings (Naboni, 2013). However, the performance of these programs to analyse wind on conceptual designs of windbreak screens for pedestrian areas have not been compared.

1.1 AIM AND METHODOLOGY

This investigation was an empirical and qualitative study of the performance of three CFD programs, used for visualizing wind through windbreak screen concepts. The aim was to identify the limitations of these tools for their use by architects to study an outdoor artificial windbreak concept for pedestrian areas. To achieve the research goal, several tests of wind visualisation were conducted with three CFD programs. Two of these programs (Autodesk Vasari, ODS-Studio) have been recently developed for the analysis of wind in the early design stage and a third program (ANSYS CFX) is a sophisticated numerical simulation program used in wind engineering.

2. Case study

The tools were used for an analysis of the wind in a windbreak screen concept for a tram stop. These windbreaks were designed to generate upward deflections of the wind flow at ground level. Thus, each screen produces a wake region as a chain of aerodynamic bubbles that works as protection regions for high speed winds. These screens are organised in five installations along the tram stop, including canopies for a shelter zone. The whole area occupied by the screens had a height of 5m, width of 4m and a length of 80m. The screens consist of four essential elements: (1) a low porous screen with 20% porosity (1.5m height), (2) a double horizontal curved fin as a small deflector, (3) a convex canopy deflector above the
barrier, (4) a roof of canopies. The area of protection is a wind deflection that produces a “wind vault” effect for each bubble of protection created by the screens. These elements are organised strategically so that they define four regions of mitigation within the area of the tram stop and other pedestrian zones (Moya, 2014). Digital models of these screens were elaborated to be imported in the CFD programs (Figure 1).

Figure 1. Windbreak screen shelter concept. Top: screens and canopies with regular geometries. Bottom: screens and canopies with membrane morphology.

2.1 OBSERVATIONS

The use of three different programs for wind analysis allows a comparison for difficulties for their operation and performance, which are explained in the next sections. These comparisons are gathered in two categories: the observations related with the pre-process of wind visualisation (user, workflow and wind parameters) and the results in the post-process stage.

2.1.1 Vasari pre-process:

Vasari is a simulation tool that has CFD functions for preliminary wind analysis of conceptual designs. Following a short tutorial provided enough information to set up the main parameters for an acceptable visualisation of these experiments. The program allows the import of the digital models generated with Rhino3D plus Grasshopper: both screens, with regular geometries and membrane morphology. However, the configuration of the domain of the site for the simulation required to sacrifice resolution of the grid that program uses, to facilitate the simulation for the full tram stop
domain area. As a result, some aerodynamic effects from the screen features are missing; the low definition of the domain grid makes slower and unstable the simulation. Furthermore, it is necessary to consider that Vasari does not simulate the atmospheric boundary layer (ABL) as wind condition and it is not possible to make an adaptation to produce a similar effect (Autodesk 2013). Therefore, the experiments were set up with a flat wind velocity profile; the velocity was 5 m/s and the direction was constant. Finally, the model included a surface as wall to represent the street façade, making more similar the model to the spatial context of the street footpath.

2.1.2 Vasari results

The analysis of the screen group with regular geometries in Vasari showed effects of vertical wind deflection with some clarity. However, it is seen that the screens did not produce the significant change of wind direction that was expected. In fact, the wind flow is deflected below the group of horizontal canopies of the shelter and not above them. Furthermore, below the roofs the second screen did not produce a vertical airflow deflection passing through the gap between the canopies, and the wind flowed horizontally along the shelter zone, where the pedestrians are waiting. In addition, a 3D visualisation of the whole protection region (using isosurfaces) showed the space of aerodynamic protection bubbles with a low wind speed (around 1.5 m/s) and the differences of sizes of these bubbles. On the other hand, the visualisation of screens with membrane morphology looks very similar to the previous Vasari test with regular geometries. Again, the main observation is that the vertical wind deflection from these screens is not enough to produce protection regions between them. The visualisation with a colour pattern slice showed that the area of shelter roofs presents the smallest protection region (Figure 2).

![Figure 2. Vasari visualisation of high wind speed region behind and below screens. Left column: wind visualisation (contour, vector field, isosurfaces) of screens with regular geometries. Right column: wind visualisation (contour, vector field, isosurfaces) of screens with membrane morphology.](image-url)
With a structure of screens with small details, and the area of the whole installation being too large, the resolution of the visualisation is low. Therefore, it was not possible to visualise other adaptations of the small fins, on the screens, that produce changes in the wind flow.

2.1.3 ODS-Studio pre-process

ODS-Studio is a recent tool aimed at rapid design and analysis of commercial and residential building design (Pitman, 2013). This is a script, which works as a link between three open source programs: the 3D modeller Blender (software to manipulate the digital meshes), OpenFOAM (CFD software to run wind simulations), and Paraview (an application for data analysis and visualisation). The software is more complex to use than Vasari (intermediate level). Thus, for these experiments ODS-Studio was used after a short period of training with a tutorial. The digital models of screens with membrane morphology were easily imported and manipulated with Blender; and at the same time it was possible to generate refined digital meshes as domain for the simulation with a high tolerance to the curvatures of these geometries. Therefore, the experiments only addressed this membrane configuration of windbreak screens. From the perspective of wind parameters, ODS-Studio simulates airflow as a simple and constant laminar flow without an ABL effect. However, it was possible to set up a screen and roughness in the domain to produce a minimal atmospheric boundary layer condition with a near wind velocity of 5 m/s at a height of 2 m. The idea was to increase the ground friction and turbulence, following similar methods used by real boundary layer wind tunnels (Cermak, 2003).

2.1.4 ODS-Studio results

The outcomes of the experiments with ODS-Studio demonstrated that behind each group of screen with canopy (installation with a height of 3 m to 5 m), a region of low air pressure is generated. These structures increase the upward deflection of the wind generated from the windbreak screens. However, in contrast of what was observed in the previous Vasari visualisation, the acceleration of wind flow produced a gap between screen and canopy, with a significant vertical airflow deflection above the roofs. The effect keeps the wind velocity at a low level in the pedestrian zone. Thus, an aerodynamic bubble effect is extended along the shelter zone, increasing the wind protection in a whole area, behind the screens and under the roofs. On the other hand, with a refined digital mesh in the domain, it was possible to see how, behind each curved canopy, the wake regions had no significant variations, when small modifications were applied in the canopy design.
Even though these screens have membrane forms, they are symmetrical and the surfaces follow the same profile. Then, the effect of vertical wind deflection was achieved and positively evaluated (Figure 3).

2.1.5 ANSYS CFX pre-process

For these experiments, the operation of ANSYS CFX required expert consulting about how to set up the basic conditions for these simulations, because there were no tutorials available with similar analysis cases to facilitate the preparation. This proved to be the more difficult part of the simulation process. Even though the program allows the import of the digital models, the experiments were only focused for concept designs using regular geometries, because the exploration and development of more complex membrane shapes with porosity requires a more accurate pre-process of elaboration that was not possible to resolve in the time of this investigation (the geometries created with Grasshopper were not useful to generate digital meshes in ANSYS CFX). On the other hand, the Design Modeller module of ANSYS has parametric functions; therefore, it was easier to build the digital models in the program and testing different screen positions (Figure 4).
As pre-process stage, two domains were elaborated for the experiments: the street space and the tram stop site. The first one defines the aerodynamic phenomenon that produces discomfort levels in the site (channel effect). This domain has a width of 30 m (similar to the distance between opposite façades in Swanston St.), a height of 16 m and a length of 101.5 m. The second one is the area of the tram stop, where a hypothetical wind shelter was installed with a height of 10 m, a width of 15 m and length of 80 m. In addition, this smaller domain has a more refined digital grid-mesh. For wind parameters the simulation considers a wind velocity profile with an atmospheric boundary layer effect. This had an intensity of 5 m/s at a height of 2 m.

2.1.6 ANSYS results

After the preliminary simulations, the CFD tests with ANSYS CFX verified that the combination of a porous screen with a horizontal deflector, and a convex deflector over the screen, can generate a significant upward wind flow. This accelerated airflow increases the height of the protection region at the leeward side of the barrier. For these experiments, the protection region reached a height of 3.5 m. This means more than twice the height of the flat screen (1.5 m). Furthermore, a second porous screen below the roofs extended the protection area of the first porous screen increasing the protection region. For the total area of the tram stop, the wind analysis showed that screens with deflectors, in a parallel order, produce a continuous
region of wind low velocity, extending their boundaries along of tram stop site. This area is protected by a succession of "vaults of wind or aerodynamic bubbles", deflecting the high speed of the wind above the screens and the pedestrian's level (Figure 5).

![Figure 5. Wind visualisation of screens with regular geometries, using ANSYS CFX. Top: lateral wind visualisation of the aerodynamic bubbles produced by the screens. Bottom: top visualisation of protection regions with a small protection area after the second screen.]

3. Conclusion:

In general, the observations of each wind analysis program, used in a context of early design exploration, can be summarised in the following table (Table 1).

| Table 1. Summary of the main observation about performance of three CFD programs used for wind analysis of conceptual windbreak shelter. |
| --- | --- | --- |
| **PRE-PROCESS** | **RESULTS** |
| **IBAM** | **OPERATION** | EASY | NORMAL | DIFFICULT | **GRID RESOLUTION AND CONTROL** | LOW | MEDIUM | HIGH | **ATMOSPHERIC BOUNDARY LAYER** | YES | NO | **MODEL AND IMPORT** | YES | NO | **GEOMETRY EASILY TESTED** | REGULAR | IRREGULAR | **VISUALISATION DETAIL** | LARGE | SMALL | **VERTICAL WIND DEFLECTION** | LOW | HIGH | **PROTECTION LEVEL VISUALISED** | LOW | HIGH |
| **ANSYS-CFX** | **OPERATION** | EASY | NORMAL | DIFFICULT | **GRID RESOLUTION AND CONTROL** | LOW | MEDIUM | HIGH | **ATMOSPHERIC BOUNDARY LAYER** | YES | NO | **MODEL AND IMPORT** | YES | NO | **GEOMETRY EASILY TESTED** | REGULAR | IRREGULAR | **VISUALISATION DETAIL** | LARGE | SMALL | **VERTICAL WIND DEFLECTION** | LOW | HIGH | **PROTECTION LEVEL VISUALISED** | LOW | HIGH |
| **FLUENT** | **OPERATION** | EASY | NORMAL | DIFFICULT | **GRID RESOLUTION AND CONTROL** | LOW | MEDIUM | HIGH | **ATMOSPHERIC BOUNDARY LAYER** | YES | NO | **MODEL AND IMPORT** | YES | NO | **GEOMETRY EASILY TESTED** | REGULAR | IRREGULAR | **VISUALISATION DETAIL** | LARGE | SMALL | **VERTICAL WIND DEFLECTION** | LOW | HIGH | **PROTECTION LEVEL VISUALISED** | LOW | HIGH |
Vasari is an easy tool to conduct wind simulation for early design stage, but presents limitations to visualise small details of a large model because of its low grid resolution (flow domain). Furthermore, the visualisation with Vasari performed well to observe the global region of protection with isosurface representation (protection bubble), but showed low vertical deflection of the wind through the group of screens. From this perspective, the analysis invalidates the configuration of screens and canopies. In contrast, ODS-Studio is a tool relatively easy to operate that can be used for a better visualisation of airflow through aerodynamic features of screens, because it has a better control to work with the flow domain grid. The visualisation conducted with this program demonstrated clearly, the effect of protected regions behind each screen and along the tram stop area (chain of protection bubbles). However, the phenomenon appears with a more strong and significant vertical wind deflection from each screen that keeps a low level of wind speed in the shelter zone. In this sense, ODS-Studio validates the conceptual windbreak screen configuration for the tram stop. Finally, ANSYS CFX is a more complex tool to be used in the early design stage. However, the visualisation of wind patterns movements from the windbreak screens demonstrates the significant deflections of the airflow from screens and the effective generation of a protection region along the tram stop. Thus, the analysis conducted with ANSYS CFX validates the configuration of screens and canopies as pedestrian shelter.

In summary, when the analysis involves airflows moving through large configuration of porous screens and canopies, tools for wind analysis in the early design stage, such as Vasari can be less reliable due to the low resolution of its grid domain, as omission of the screen aerodynamic feature effects. In contrast, ODS-studio can be used for this kind of analysis, for a more detailed visualisation of wind interaction with windbreak screens and as validation method for Vasari’s results. Only if the results between them are quite different, a third wind analysis can be incorporated in the workflow with a program like ANSYS CFX to verify results, but its use requires a more complete knowledge and possibly consultation from an expert. These conclusions must be considered by architects if they want to incorporate these tools for design exploration, in the early stage of the design process, with a dynamic feedback level.

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