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Visualization of CFD Simulation Results in VR Environment for Design Feedback

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ABSTRACT

In the tropics, where air-conditioning consumes around 50% of the electricity, natural ventilation is a primary passive design strategy. Due the complexity of natural wind flow, Computational Fluid Dynamics (CFD) simulations are used to evaluate the efficiency of applied natural ventilation, however, architects and designers find it difficult to visualize the results provided by these simulations, something that can be improved with the use of better visualization tools. This research project uses a BIM created unit as a case study for CFD simulation of natural ventilation displayed in a VR environment, in order to improve design feedback and the visualization of simulation data for natural ventilation.

KEYWORDS

Computational Fluid Dynamics (CFD), Virtual Reality (VR), Augmented Reality (AR), Passive Design Strategies, Natural Ventilation, Building information modelling (BIM), Design Feedback.

INTRODUCTION

When designing an energy efficient and sustainable building, passive design strategies are the most reliable way to save energy and provide maximum comfort for the occupants. Common practices in passive strategies in architecture include the evaluation of the wind's predominant direction against the building's orientation in order to achieve an optimal natural ventilation, this is done by assuming that the wind will enter the room and exit through the openings. This basic assumption is based on principles that have been tested and confirmed though practical applications (Stavridou 2015).

Figure 1 Sketches illustrating the natural ventilation principles applied in architecture (CIBSE 1997).

Highly dense developments such as high-rise housing and office towers in urban areas, present a challenge when applying passive design strategies. The interaction between built volume and natural airflow becomes more complex and difficult to prognosticate by the architectural designer, however, technology in Computational Fluid Dynamics (CFD) simulation allows us to understand the complexity of air movement outside and inside of a building, and the interactions with objects and openings that conform the architectural space.

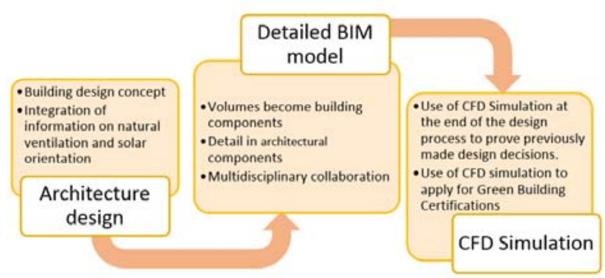


Figure 2 Current Professional trends and practices for CFD simulation integration in architecture design.

The design stage in which the CFD simulation is created presents relevant aspects that will affect the complexity of the calculations and the impact of the results in the design output. Therefore, the importance of integrating CFD simulation studies at early stages of design allowing room for modifications to the geometry of a building in order to provide suitable orientation and openings to incorporate natural ventilation and optimized air flow. Making these changes at more advanced levels of design, will involve more restrictions and a higher cost.

Advances in visualization tools are instrumental in the integration of CFD simulation and architecture design. The most common visualization tools such as photorealistic renders and building's walkthrough animations, are used to display the final design to clients who might not be familiar with the 2D language used in construction blueprints. In recent years Virtual and Augmented Reality (VR & AR) have done an appearance in the architecture design market as new ways to display three dimensional information. Tools with such power present great potential to display more complex information, beyond colors and shapes in a more involving way and based on the building's geometry and materials. Considering the potential of displaying analytical Information in a VR and AR environment, a design professional can understand in a more holistic way how the simulation results interact with the building's geometry. Furthermore, visualizing complex CFD simulations in a VR environment can take advantage of the work done creating the simulation results to extract detailed data, expose each component of the building interacting with the simulated information in different and more interactive ways. CFD simulations are pretty much a field on its own, interpreting results from this type of calculations requires highly skilled professionals with the capacity to create the simulation atmosphere and proper settings. In many cases the complexity of the results is not fully utilized due to interdisciplinary gaps between professionals not allowing architects and building designers to make their own conclusions and design related estimations due to the lack of familiarity with CFD simulations. In view of the many advantages of the technology in visualization, building information modelling and CFD simulations; and the intricate contributions they have in the architecture design process; establishing a primary platform for coherent integration of data sourced from these three platforms, represents a first step in the implementation of BIM and CFD simulation that eventually can be transmitted to mobile, web based and software integrated tools. Background and previous studies

BACKGROUND AND PREVIOUS STUDIES

The need for better visualization tools in the computer aided design market had brought important developments in the way buildings are visualized and how we interact with them before they are constructed. Tools such as rendered realistic images, the enhancements in colors, lights, surrounding environments; and the possibilities to navigate the space at a human scale level, are now commonly used resources. Are these tools in human interaction with virtual objects and environments, what is allowing a better understanding of design conditions as close to reality as we have come so far (Langevin 2015).

Buildings existing only in the computer as CAD files and realistic setups are, so far, the trend in complex 3D and virtual representation, all done with the purpose of allowing non-design related professionals, a better access to this information. For any architect or engineer, a set of blueprints in 2D is more than enough to visualize the general and detailed aspects of a building; however, for many non-related professionals, picturing 3D information from a 2D sources is represents a difficult task. The same happens for complex data generated in simulation software when presented to a professional without the proper raining in CFD data analytics. Is in this type of scenarios where a better way to display CFD simulation results is needed. The common practice for evaluating CFD simulation results is to "slice" volumes filled with simulation information and present them as 2D images of the simulation results (Figure 3).

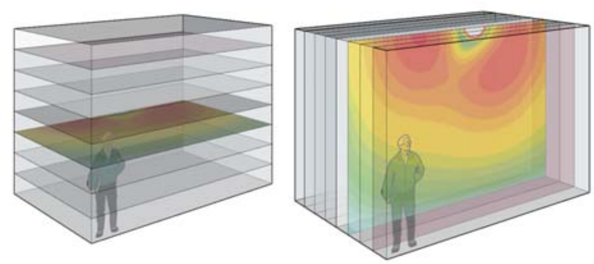


Figure 3 Evaluation of CFD simulation results by creating 2D sections in horizontal and vertical planes.

Previous research projects have done VR integration for CFD simulation applied in architecture, with very positive results, creating a better understanding of the need for such platform and awareness of its potential to include factors such as: positional data, scaling, time intervals and correct-realistic perspective (Berger et al. 2015). By allowing a coordinated integration of data with the user in a 360° surrounding environment the understanding of the simulated data can be improved and therefore lead to a better use in design feedback.

In some studies, the focus is on the Graphic User Interface (GUI) created also to interact with previously calculated simulation data and the VR space. VR platforms have also been created to provide design feedback for thermal simulation (Hosokawa et al. 2016), allowing changes in the HVAC system and creating new simulation results to evaluate different possible design options (Fukuda et al. 2015). Additionally, in cases where the emphasis is the create the better information display for large and complex data, the results are good enough to allow types of navigation that are not possible in CFD visualization platform such as Paraview. Using tools from the video gaming industry –most of the previously done research relies on the use of UNITY3D as main software for the creation of a VR platform- brings better and more controllable navigation and realistic graphics, all in first person perspective.

METHODOLOGY

Bearing in mind the multidisciplinary nature of this project, settings for the components has to be done separately using different software applications (Figure 4).

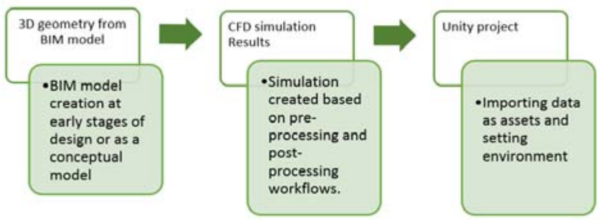


Figure 4 Overview of content development for VR Platform

Next is a description of the three main settings:

BIM based geometry and mesh for CFD simulation.

The current practice of architecture design relies heavily on BIM workflows to create the computer files on a building. In this project we have taken the geometry for the CFD simulation from a BIM file created in the software Revit. Since Revit geometry is not suitable to run a simulation in a CFD application and contains several objects that are not necessary for the mesh creation, the model was edited leaving only relevant components such as walls, windows, doors and floors. An additional file conversion step was done using the software Rhinoceros 5.0.

CFD simulation for natural ventilation

To analyze natural ventilation around/in buildings, CFD is a widely used tool to study the flow field. The main idea is to divide the space into small volumes/elements with a mesh, and solve the Navier-Stokes equation numerically on each mesh point. The two-equation k-ε turbulence models is one of the commonly used numerical methods to solve the mean velocity, pressure and temperature in the Navier-Stokes equation, it is accurate enough for natural ventilation study. With the CFD simulation results, one can understand the air movement, temperature and pressure distribution in the space.

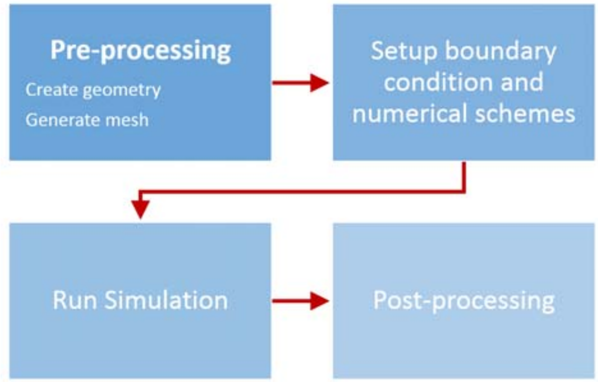


Figure 5 CFD simulation settings workflow

Unity3D environment and VR settings

One way of seeing the environment created in Unity is to consider it as an empty space where files from two different products can coexist and interact in a flawless way. After the simulation results are exported as FBX files (for visualization purposes), the file is added to the Unity project in the form of an asset, the same is done for the 3D architecture model from Revit. The 2 files can be scaled and positioned, using Unity's positioning, scaling and rotation tools. The 3D mesh used for the simulation works as a reference for coordination with the architectural model. After the 2 assets are coordinated, VR supporting options have to be selected in the project's settings. In order to enter the VR platform a Head Mounted Device (HMD) is needed, for this experiment an HTC's Vive HDM was used, however the platform is compatible with many other brands and models of HMD.

Figure 6 VR equipment used at the Building Modelling and Simulation Lab of NTU's ERIAN

SIMULATION AND EXPERIMENTATION

In this paper, natural ventilation in a bedroom of a residential building is taken for the case study. There is an exterior window facing North and a door in the opposite side of the room, assuming that the wind enters the room through the window, and exits the room from the door. Thus, the boundary condition for window is a velocity inlet, wind coming in from Northeast direction with a speed of 1.2 m/s and the door is a pressure outlet. Flow field of the air volume in the room is of interest and heat is not considered in this simulation. Figure 6 shows the top, front and isometric views of the room with arrows pointing the direction of the wind. Two isometric views of the 3D mesh generated for the simulation is illustrated in Figure 7.

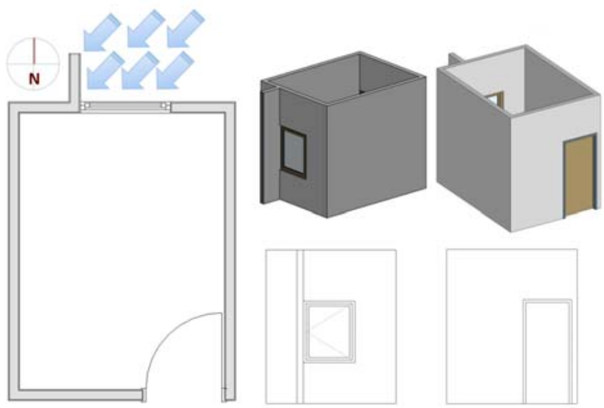


Figure 7 Bedroom unit floor plan with diagram of wind direction (NE to SW).

Room description:

- Common single bedroom at a residential unit in Singapore
- Measurements: 3.2 x 2.4 meters
- Area: 7.2 m2
- External façade with vertical element to block West sunlight, element length: 0.6m
- Predominant wind direction: Northeast
- A vertical element is located next to the window in order to reduce the impact of direct sunlight in the afternoon. The same element helps capturing more wind flow into the room

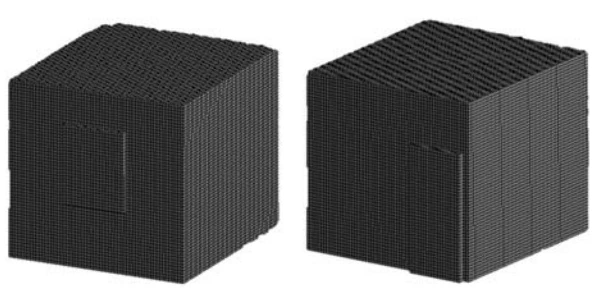


Figure 8 Mesh of the bedroom unit for CFD simulation.

The mesh of size 0.05m was adopted with a total number of 213,772 elements generated for the air volume. The results can be presented with velocity contours and velocity vectors on cross sections. Following the mesh creation and CFD simulation both sets of data were added to a Unity3D project as assets.

RESULTS

Figure 8 shows the data collected from the CFD simulation is displayed in a conventional 2D sectioned image at different heights, this technique can be used for vertical sectioning in order to create similar images in a vertical view. The highest speeds recorded happened in the center of the room from the window to the corner and the side of the door (up to 1.5 m/s).

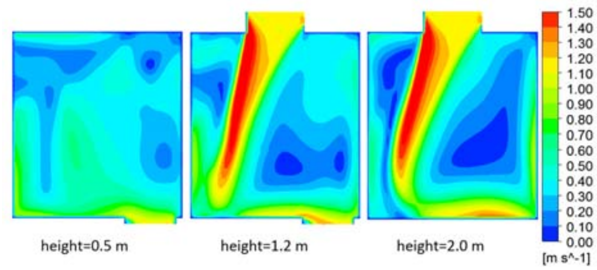
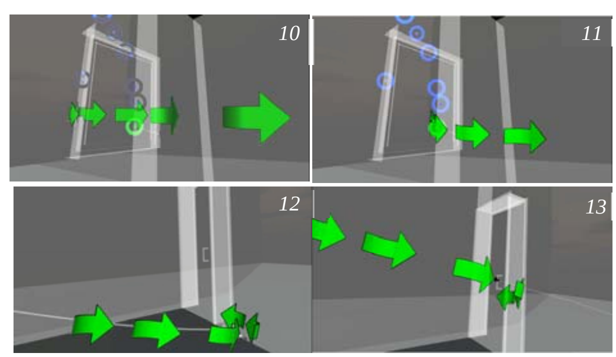


Figure 9 Velocity contour on the horizontal plane at three heights from the floor level

Figures 10 to 13 show the same results obtained during the simulation, now from a human perspective in a VR environment, arrows represent the vectors indicating the origin and path followed by the wind entering the room from the window and moving to the corner of the room and the side of the door.



Figures 10 to 13 Bedroom unit created in Revit and mesh generated for CFD natural ventilation simulation

It is technically impossible to present the VR experience achieved in this study using images, what is presented in this paper is just part of the potential of using VR and advanced visualization tools to bring a better understanding of the results obtained using CFD simulation in designs relying on passive ventilation. For designers in general having a clear picture of complex air flow dynamics and interactions with the interior space of a building brings a case by case understanding of the specifics air movement, space and comfort. The architecture example used in this study is basic and with limited complexity, however the model proposed can be adapted to elements that are more intricate where the visualization can make much valuable contribution. Is worth to say that the VR platform does not eliminate the need for a 2D sectioning evaluation of the CFD simulation results. The two methods can coexist and help providing understanding and data analytics. In some cases the data representation might be more illustrative to represent the basic concepts –in this case natural ventilation- within a mode graphically developed model, like it is illustrated in Fig. 14.

Figure 14, a final VR with illustrative natural ventilation arrows as it is used in architecture design

The image of the building (at design stage before construction) is integrated with arrows that illustrated the incoming airflow to the open balconies. In a more technical context arrows are not represented in such graphical way, this is a more “architectural” graphic representation. However the arrows are not the result of a conceptualized natural ventilation system, but the result of a CFD calculations.

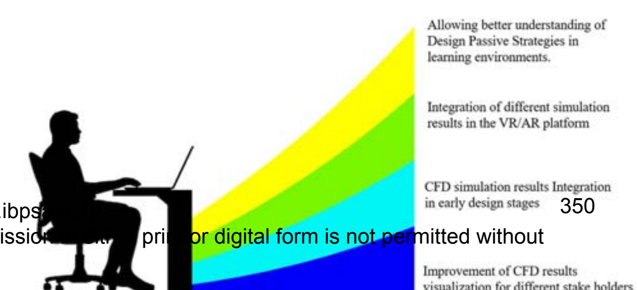
Figure 15 and 16, a comparison of a final VR image and the actual building. There are differences in the design and the final construction, however , the process was enriched by the simulation work done.

INTEGRATION WITH DIFFERENT PLATFORMS AND FUTURE WORK

The study presented in this document is the first step of an effort to provide a multiplatform visualization tool for CFD and simulation results for sustainable buildings. As part of this effort we are working to provide more practical and responsive tools that will allow a faster feedback, better understanding of the complex data provided by simulation software in building design and better interdisciplinary collaboration. Following the VR visualization platform, a series of studies are planned to integrate similar tools to a web based platform with a first-person realistic perspective for BIM models and CFD simulation results.

This paper presents the first attempt to integrated CFD simulation results in a systematic way, however eventually more data can be integrated in the platform and new workflows in the design field will be proposed, among them:

- In-house CFD simulation for early stages of design in sustainable buildings
- Natural ventilation and natural light in buildings can become a more discussed topic by representing it in more visual ways for better understanding of the design team and the clients.
- Building evaluation of applied design strategies can be better visualized



Figures 17 Potential benefits of including CFD simulation results integration in VR & AR environments

REFERENCES

Berger, M., Cristie V. 2015. CFD post-processing in Unity3D, ICCS 2015 International Conference on Computational Science, Reykjavík, Iceland

CIBSE Application Manual AM10.1997. Natural ventilation in non-domestic buildings, The Chartered Institution of Building Services Engineers, London

Fukuda T., Mori K., Imaizumi J. 2015. Integration of CFD, VR, AR and BIM for Design Feedback in a Design Process - An Experimental Study, The 33rd eCAADe Conference, At Vienna University of Technology, Vienna, Austria

Hosokawa M., Fukuda T., Yabuki N., Michikawa T., Motamedi A. 2016. Integrating CFD and VR for indoor thermal environment design feedback, 11th International Symposium on Architectural Interchanges in Asia

(ISAIA2016), At Tohoku University, Sendai, Japan

Langevin, J. 2015. Simulating the human-building interaction: Development and validation of an agent-based model of office occupant behaviors, Drexel University, Philadelphia, PA, United States

Stavridou, A.D. 2015. Breathing architecture: Conceptual architectural design based on the investigation into the natural ventilation of buildings, Aristotle University of Thessaloniki, Greece