CAD Data Workflow toward the Thermal Simulation and Visualization in Virtual Reality

Yudi Nugraha Bahar [(a,b,c)], Jérémie Landrieu [(a)], Christian Pere [(b)], Christophe Nicolle [(c)]

[(a)] Arts et Metiers ParisTech, UMR CNRS 6306, LE2I, Institut Image 2 Rue T. Dumorey 71100 Chalon-sur-Saône, France
[(b)] Gunadarma University, Jl. Margonda Raya 100 Depok, 16424 Indonesia
[(c)] Université de Bourgogne, Laboratoire LE2I, UMR CNRS 6306, BP 47870, 21078, Dijon Cedex, France

Article Information

Corresponding author:
Yudi Nugraha Bahar
Tel.: +33 602309823
e-mail:
Yudi.NUGRAHA-BAHAR@ensam.eu
or ydnugra@gmail.com
Address:
ENSAM ParisTech, Equipe Gunzo Rue Porte de Paris 71250 Cluny, France

Abstract

Purpose:
This paper presents a CAD transfer method to visualize thermal simulation results in a virtual environment in order to optimize building design determined by energy efficiency.

Method:
As the goal is to present a more immersive thermal simulation and to project the calculation results in projective displays particularly in Cave Automatic Virtual Environment (CAVE), the main idea of the method is to provide a workflow so that the thermal result can be visualized and simulated in the virtual environment (VE).

Result:
The paper shows the experiment results conducted in an immersion room by some respondents. An evaluation of the method has demonstrated that it is possible to conduct a specific data workflow in order to represent building performance data and particularly thermal simulation results in Virtual Reality (VR). With this method, the data flow that starts from the design process is completely and accurately channelled to the VR system.

Discussion & Conclusion:
CAD data in 3D mock-up models composed of basic geometry are usually designed and transferred to other tools particularly if intended for VR. However, CAD data needed for the VE is not simple, it needs to be structured in a workflow method. Challenges in data exchange and interoperability among design, simulation and VR tools used have become an important issue to investigate how the workflow works.

1 Introduction

The modelling and data exchange of 3D CAD models for new interface of computer-aided design systems have been an increasingly varied subject of research. Studies regarding 3D CAD models and immersive environments begin to focuse on VR-CAD integrated systems to evaluate the design process [1][2][3][4][5]. The visualization techniques integrate the simulation results and the CAD model into a VR environment [6]. This paper combines the principle of integration for thermal calculation and visualization. The idea is to use CAD models (extensively used in architectural design) to analyse building thermal performance and visualize it as well as simulate it through VR technology.

Today many thermal simulation tools are available and they differ in their manner of simulating thermal parameters. Thermal simulation software is not always based on digital mock-up and does not necessarily present overall results in terms of geometry, but rather in terms of scales, charts or other notation codes. These formats are sometimes illegible or hard to interpret. Therefore, data exchange methods from CAD tools to thermal simulation tools with high interoperability still represent a very significant challenge to achieving accuracy in simulation. In this research we conducted certain experiments, and tried to keep relying on

calculations based on 3D geometry data and the outcome also in 3D.

The experiment was conducted to simulate object-based data models that are specific to the thermal domain using tools provided by the IFC (Industry Foundation Classes) format. This choice was made to overcome the limitations of general-purpose geometric representations particularly in data exchange among the selected tools used for the simulation.

2 Method

Thermal calculation and simulation of a building through a 3D object begins with the generation of a thermal model in the frame of building thermal simulation. Building thermal simulation is the dynamic analysis of the energy performance of buildings using computer modeling and simulation techniques. In this simulation, a calculation of building thermal loads and thermal consumption are involved in determining the thermal characteristics of the building and its building systems.

Mean radiant temperature (MRT) is a primary factor and should be identified as having the strongest effect of thermal comfort. MRT is simply the area weighted mean

temperature of all the objects surrounding the body. The MRT is a significant factor, especially in buildings whose outer walls were exposed to a strong solar radiation, and where conventional indoor temperature and humidity control cannot guarantee indoor comfort [7].

The radiant temperature can be calculated from measured values of the temperature of the surrounding walls and surfaces and their positions with respect to the person. If relatively small temperature differences exist between the surfaces of the enclosure, the following equation can be used [8]:

$$T_{mr} = T_i F_{p-i} + T_i F_{p-i} + \ldots + T_N F_{p-N} \qquad (1)$$

where T_{mr} = the mean radiant temperature for a person [ºC], T_i = the temperature of surface i [ºC], F_{P-i} = the angular factor between a person and surface i.

This describes that what we feel in terms of thermal comfort comes from the influence of the surface temperatures in the space as well as the dry bulb (air) temperature [9].
Effects of radiant temperature on human thermal comfort of MRT are conducted for this experiment. After completing a long investigation, we determined the use of Autodesk Ecotect. Ecotect thermal analysis provides an optimistic method for this calculation. As perform in Ecotect, Humphreys et.al [10] give equations for calculating the indoor comfort temperature from outdoor monthly mean temperature as follows.

Free Running Building:
$$T_c = 11.9 + 0.534\ T_o \qquad (2)$$

Heated or Cooled Building:
$$T_c = 23.9 + 0.295(T_o\text{-}22)\ \exp([\text{-}(T_o\text{-}22)/33.941]^2) \qquad (3)$$

Where T_o in this case as the monthly mean of the outdoor air temperature and T_c is comfort temperature.
Feasibly, any model can be constructed within the Ecotect environment using its own internal drawing commands, extrusions and other modeling features. Imported models from the design tool will universally fail, unless special care is taken to establish each piece of geometry as floor, wall, window, door, and aperture. The Ecotect will not interpret this on its own with an imported model [11]. Therefore, for this experiment we used Autodesk Revit 2012, one of the leading design tools in the AEC (Architecture, Engineering, Construction) community, because of its high interoperability. The choice of this design tool accounted for various technical considerations, in particular the ease of data organization and the flexibility of data transfer. Most Revit models are quite complicated geometrically compared to other CAD project models. There are two commonly used formats for transferring data from Revit to Ecotect; GbXML and DXF. The IFC format is also accepted in Ecotect (in beta version) as a new opportunity for seamless data exchange [12]. IFC and gbXML are both used for common data exchange between AEC applications such as CAD and building simulation tools [13]. Both IFC and gbXML create a common language to transfer BIM information between different BIM and building analyses applications while maintaining the meaning of different pieces of information in the transfer [15]. Tab.1 describes the required data at each level of the workflow to maintain seamless data exchange.

CAD Modeling	Thermal Simulation	Visualization
- **Site and building location** - **Building orientation including its relationship to the true north** - **The building story information** - **3D Geometry of adjacent building** - **3D Geometry of the building, including walls (exterior/interior), curtain walls, roofs, floor/slabs, ceilings, windows/skylights, doors and shading devices** - **Space objects, including those defined by virtual space boundaries**	- **Building Spaces** - **Spaces (Temperature value, ventilation, building elements, material)** - **Energy analysis zones** - **Annual results**	- **Temperature in scale, text and 2D graphics** - **Radiation value, reflectance, and its transmittance in 3D entity; particles, spray, etc.** - **Animations of thermal simulation and virtual interaction with building elements.**

Tab. 1 Data resulted at each level in the workflow.

2.1   Workflow Concept

The idea of generating 3D models that can be immediately recognized and processed by thermal tools and then VR tools is the main objective. The data flow that starts from the design process strived to channel up to the VR system completely and accurately. Thus the user can immerged, interact, and perceive the impact of the modifications generated by the system.
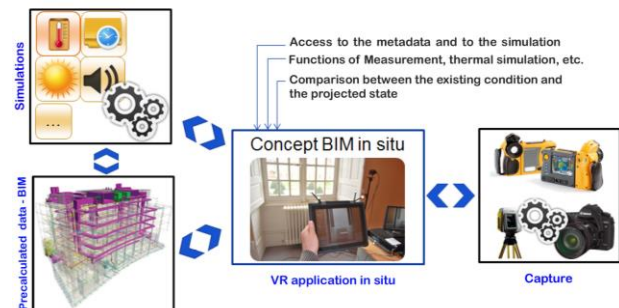

Fig. 1 Generic workflow for visualization in a PC and tablet.

Fig. 2 describes the workflow developed for conducting the experiment of co-located access of a building project which includes the thermal result visualized in a PC and tablet. This is the basic model we developed in the earlier experiment. It illustrates the idea pursued to determine whether to have the entire data in context of the building information modeling (BIM) on site, and a co-located access at the same time, significantly improving the efficiency of an operator on site [16]. This idea became the basis of the principle of conducting CAD workflows toward the thermal simulation and visualization in VR. In this application we share a digital model of the project, which is made from all kinds of simulations i.e. thermal, sunlight, sound, appearance 4D management (planning). The database and the simulation results are available on site via a visualization device. On the other hand, the results from the actual scene capture (i.e. capture topological existing processes through laser scanning and / or photogrammetry; thermal capture at regular intervals). We use this method in the first phase of experiments involving three workshops and 40 participants. In the second phase we use the same principle to transfer the thermal simulation result to the VE. Similar principles are implemented by modifying the basic application, tailored to CAVE requirements for high immersiveness and interactivity.

2.2   Data Workflow
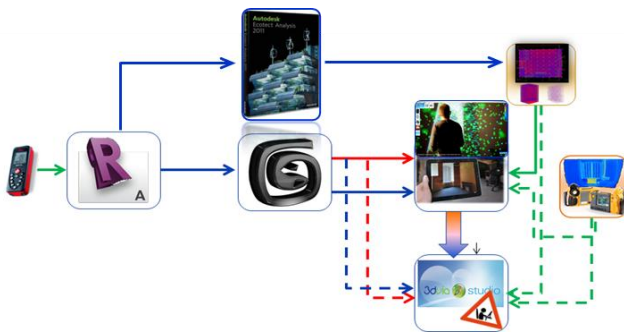
Fig. 2 Detailed process of data workflow. Main applications involved : Revit, (Catia), 3DSMax, Ecotect, (Virtools), 3DVia Studio, and Perl Routine for preformat.

Fig. 3 shows the detailed process of the workflow from the CAD model to VR. A 3D model begins from Autodesk Revit exported (in .Fbx) to be read and textured in Autodesk 3DSMax. At once, the geometry is also exported to Autodesk Ecotect to have a thermal calculation result. Thermal capture with a thermography camera was used just for enriching the interface. Finally, the thermal calculation result converted and coupled into the 3D model to become the virtual model, and then pushed to the 3D engine of Virtools and 3DVia Studio. Thus, the user can interact with the geometry to access metadata of the digital mock-up. As the process involves several tools with different character and data formats, we perform organizations of data exchange according to the workflow mentioned very carefully. We chose Autodesk Revit and Ecotect as construction company choices, which are very popular among the AEC software, and have appropriate interoperability for our application. Last, for real-time rendering in VE we used Virtools and 3DVia Studio, developed by Dassault Systèmes as their flexibility in script. This is optional but we use both simply for comparing their interfaces.

3   Experiment and Results

The experiment began with the background check of the object, the realization of a mock-up model of the existing conditions, followed by the exploration for some alternative models (renovated version scenario). The Gunzo room was chosen as the object of the experiment, located in an old building situated in the historical site of the Cluny Abbey which is also a part of the ENSAM ParisTech campus. As it is typical of old structures, the building consists of rooms enclosed by thick walls and large windows which have been protected. Thermal problems exist in all of the rooms, which can be quite uncomfortable for the occupants.

As in all listed historical buildings, changes are not allowed to be made on the exterior façade. Therefore, the renovation is limited to certain parts of the interior only. In this case, we found that the window was the most crucial factor affecting indoor energy consumption. The interior configuration is adapted to the addition of a partition for a new window. This concept is used as part of interior insulation of a building [17] which has demonstrated its effectiveness, and becoming common practice for window renovation especially in the Nordic countries.

Fig. 3 Gunzo room. Object of experiment located in the historical site of Cluny, France.

The renovated window or the new window consists of two panels; an exterior sash and an interior shutter. Due to the need to preserve the historical façade, no intervention was carry out on the exterior sash. We modified the interior shutter in terms of its position as well as its material. The modification was effected by moving the interior shutter backwards against the exterior sash. This modification required the addition of a shelf under the window sill.
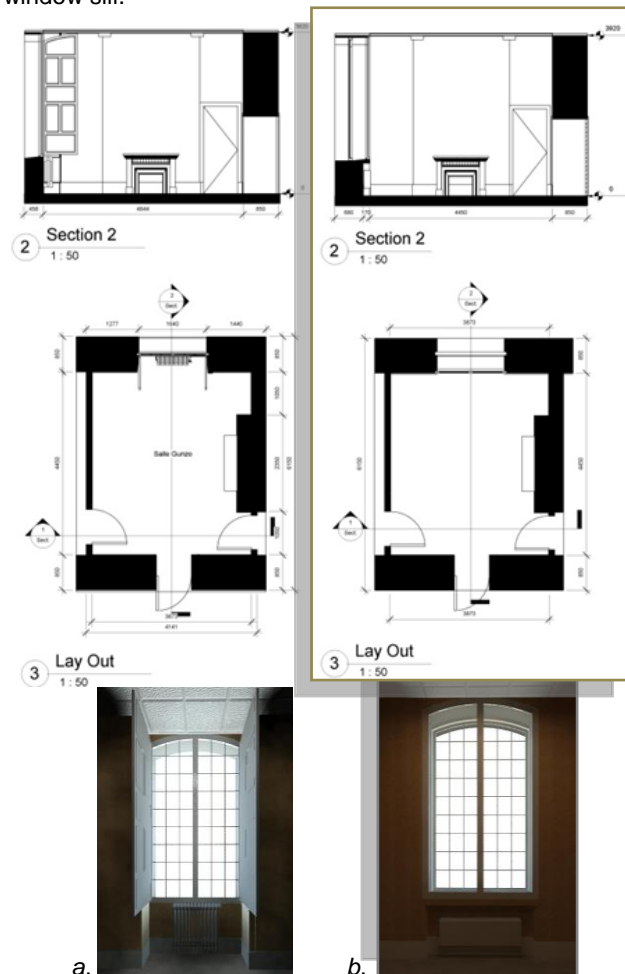
Fig. 4 (a). Revit Model of Gunzo Room (lay out, section and 3D View) in existing conditions (b). Renovated version, changes made to the wall, window components and heater.

3.1   Thermal Simulation and Calculation of the Mock-up model from Revit to Ecotect

To conduct the thermal simulation as required for our first experiment, we performed the data transfer by means of the smooth data exchange between Revit and Ecotect analysis.
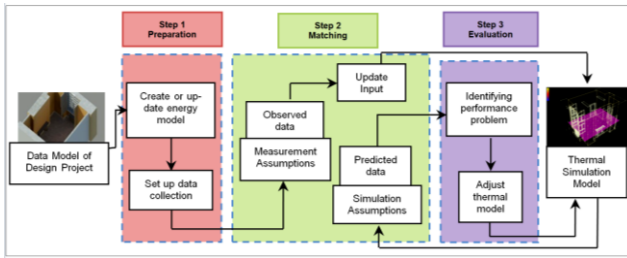
Fig. 5 Initial Workflow to generate a thermal simulation model.

The data contains geometrical, topological, and common surface elements, in real-time and as close as possible to the actual space. The main priorities to handle were the environmental settings (verification of conditions) and the mode of calculation (technical method).
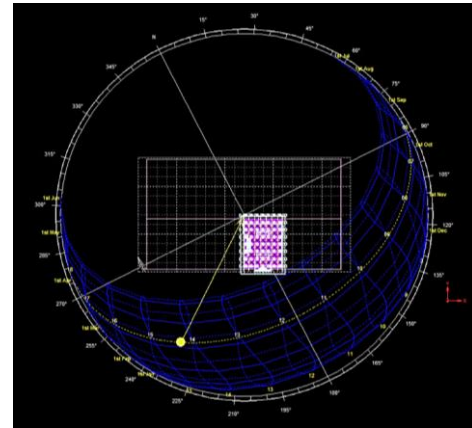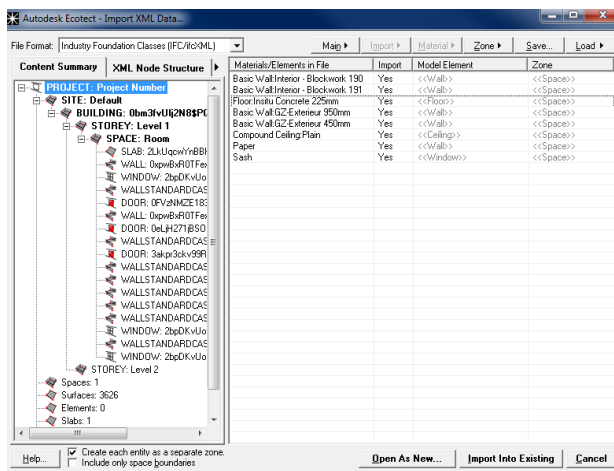

Fig. 6 Gunzo room imported data (IFC/ifcXML format)

Before the object was put into final simulation and analysis in Ecotect, the geometry was already set to an ideal adjustment, to be eligible as an import file.
The principal operations performed to analyze the object (Gunzo room) through Ecotect were as follows:
 1) 3D Model (Import), Adjacency Checks.
    - Building Geometry including the layout and configuration of space,
    - Building Orientation,
    - Building construction including the thermal properties of all construction elements,
    - Building usage including functional use,
 2) Weather Manager / Weather Data Import
 3) Material Properties / Material checks
 4) Zone Settings / Internal Load and Schedules
    - Internal loads and schedules for lighting, occupants, and equipment,
    - Heating, ventilating, and air conditioning (HVAC) system type and operating characteristics,
    - Space conditioning requirements,
    - Utility rates, Heater usage only from November to April.
 5) Thermal Analysis / Calculation Mode.

The thermal analysis is then performed for the selected date/time to determine the air temperature for each zone and the surface temperatures of the object. With this data which provides the MRT, clothing value, metabolic rate and humidity value, it is possible to display comfort values spatially across the grid (along 3 axis).
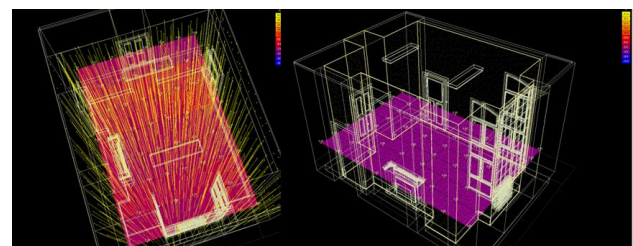

Fig. 7 An Interactive sun-path of the Gunzo room in a projection of the entire sky dome.

Fig. 8 Internal volumes filled up by a series of sampling rays, distributed within the boundaries of the zone.

Fig.8 shows the grid of spatial comfort values mapped over the analysis grid. In this example, the analysis grid of Gunzo room is aligned to the XY axis, displaying comfort values horizontally in flat surfaces. The surface is a 2D slice position, offset 100cm from the floor. When visualized in VE this grid is programmed to exist in all axis (X,Y,Z).

3.2 Visualization and Simulation in VE

There are three steps for visualizing the results in VE. Firstly, mock-up creation in design tools, secondly thermal analyzing in Thermal Calculation tools (Ecotect) and thirdly visual representation in VR tools (Virtools and/or 3DViaStudio). In this case, realistic 3D models from Revit 2012 are used as entry data to generate the architectural model and calculated in thermal tools (Ecotect) and then displayed in a VR, so as to help the simulation user to understand and manipulate the simulation parameters (fig.10). Revit 2012 is used as a design tool due to the various technical considerations, including the ease of data organization and flexibility of data transfer.
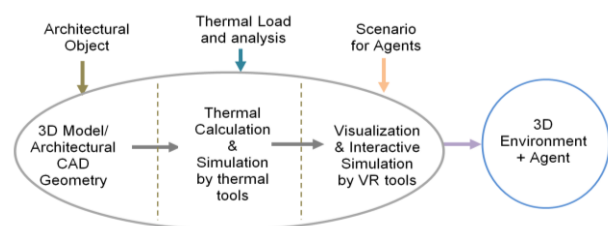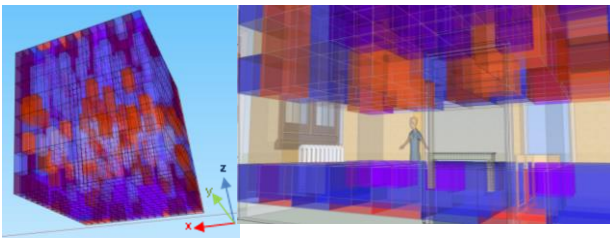

Fig. 9 Illustration of stage composition of the experiment. Final results in VE with interactive agent design.

Data exchange from Ecotect to Virtools and/or 3DVia Studio can proceed with exporting format Txt. However, the data tables of temperature value from Ecotect should be processed so that they can be digested directly by Virtools and 3DVia Studio. This process should pass through a program (Perl Routine) that enables syntax preformat of Txt data which automatically alters the syntax typing without changing the origin data value.

Txt data from Ecotect is a set of values of temperature of the Gunzo room in a 3D position or XYZ axis to be elaborated in virtools together with the Gunzo room 3D model. These data are collected one by one according to time simulation (per hour, days and months) and this input can be detailed more precisely depending on the needs of the experiment.


Fig. 10 Illustration of thermal grid with transparent cubes to be generated inside the Gunzo room precisely arranged on the XYZ axis (left). The scenario to generate thermal visualization using grid transparent cubes (right).

The composition of thermal visualization in 3D volumetric by Virtools meets on the XYZ axis. In the Gunzo room experiment, we tried to divide the interior space into 8x8x8 = 512 parts which contains the temperature values embodied in cube from in each section. The cubes are textured in transparent or in particle 3D and colored according to the temperature value it adopts.
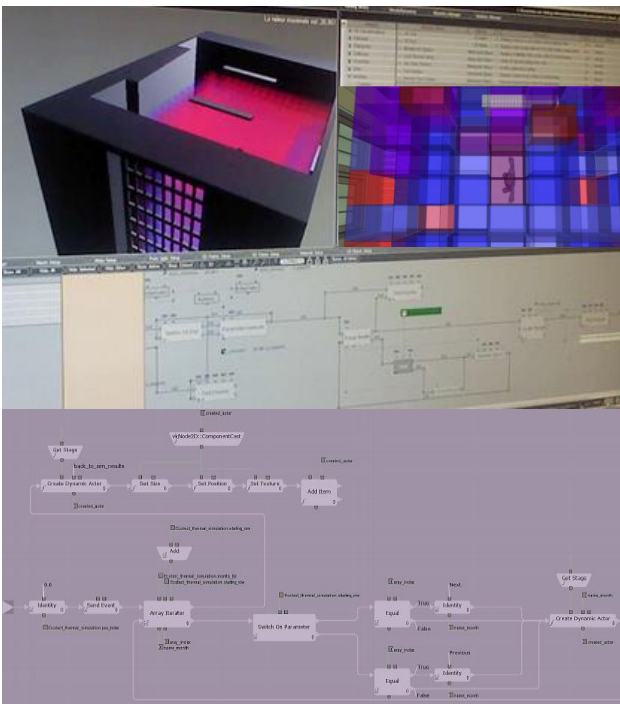
Fig. 11 Schematic Script for interactive menu in Virtools (above) and in 3DVia Studio (below).

Visualization between users and objects in a virtual world are certainly through techniques of interaction metaphors. Each 3D object stored inside the room has its temperature data and interacts in a set of appearance (size, shape, color, etc.). This mode of appearance then elaborates some visualization metaphors to inform the user of the thermal result interactively as well as putting them in high immersion. The application prototype provides an instrument of visualization and interaction in VE, including friendly interface concerning the thermal condition. The interface is designed in such a way that the user can immerge, interact, and perceive the impact of the modifications generated by the system regarding the thermal simulation results.
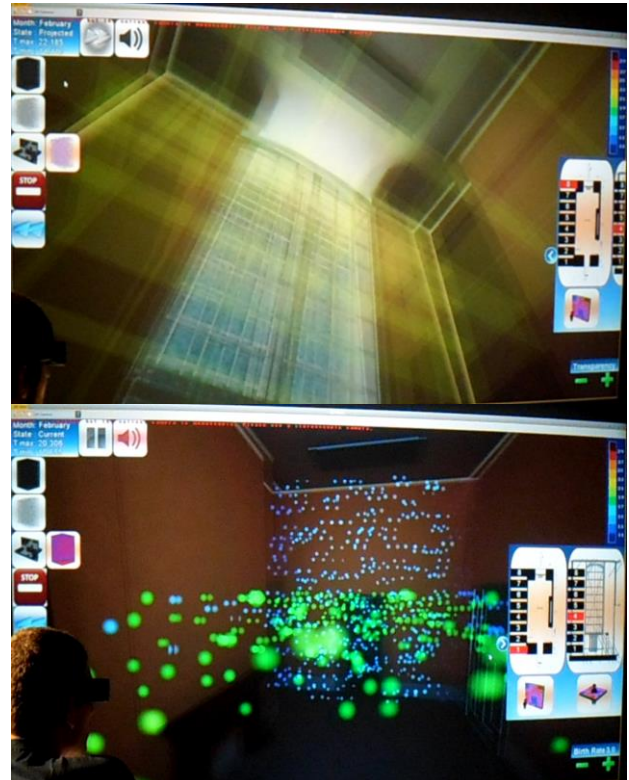
Fig. 12 Thermal metaphors visualized in the immersion room (transparent cubes and particles). In this experiment, some respondents have experienced the simulation in CAVE with stereoscopic visualization and have recorded their responses and opinions in a structured questionnaire.

4   Conclusion

The application prototype has demonstrated that the workflow has optimized the method in improving the representation and interpretation of building performance data, particularly for thermal results using visualization techniques. The system gives thermal sensations by its 3D volumetric visualization in some metaphors to inform and to immerse the user in VE (CAVE). However, there is a workflow behind the scene that is not easy to simplify. The experiment performed the data transfer which was conducted in 3 stages. This relies on the smooth exchange of data workflow between CAD tools, thermal calculation tools and VR tools.

The precise geometrical data from 3D CAD model is necessary to provide as the input of thermal grid position in Virtools and/or 3DVia Studio. Volume size and position

accuracy of the model will simplify the composition of the thermal grid to be displayed in Virtools or 3DVia Studio.

The ability for tools to exchange data is also very important. It offers one solution to the problem of integration. Automated transactions between the tools, however, require that the information data should be improved, not to be fragmented between architectural data and thermal engineering data to guarantee that the tools run in the workflow. These improvements must be evaluated throughout serial tests of interoperability to ensure consistency between all participants in building thermal applications particularly between CAD tools, thermal tools and visualization tools.

Acknowledgement

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