Science Arts & Métiers (SAM)
is an open access repository that collects the work of Arts et Métiers Institute of Technology researchers and makes it freely available over the web where possible.

This is an author-deposited version published in: https://sam.ensam.eu
Handle ID: .http://hdl.handle.net/10985/9290

To cite this version :

Yudi NUGRAHA BAHAR, Jérémie LANDRIEU, Christian PÈRE, Christophe NICOLLE - Integration of thermal building simulation and VR techniques for sustainable building projects - In: Confere 2013, France, 2013-07-04 - Confere - 2013

Any correspondence concerning this service should be sent to the repository Administrator : scienceouverte@ensam.eu

INTEGRATION OF THERMAL BUILDING SIMULATION AND VR TECHNIQUES FOR SUSTAINABLE BUILDING PROJECTS

Yudi NUGRAHA BAHAR[1,2,3], Jérémie LANDRIEU[1], Christian PERE[1], Christophe NICOLLE[3]

[1] Arts et Metiers ParisTech, UMR CNRS 6306, LE2I, Institut Image 2 Rue T. Dumorey 71100 Chalon-sur-Saône, France. Yudi.NUGRAHA-BAHAR@ensam.eu
[2] Gunadarma University, Jl. Margonda Raya 100 Depok, 16424 Indonesia
[3] Université de Bourgogne, Laboratoire LE2I, UMR CNRS 6306, BP 47870, 21078, Dijon Cedex, France

ABSTRACT

The importance of energy efficiency and integration of advances in building design and VR technology have led this research to focus on thermal simulation results visualized in a virtual environment to optimize building design. This paper combines the principle of integration for thermal calculation and scientific visualization in VR. The method is to use CAD models (extensively used in architectural design) to analyze a building's thermal performance and visualize it, as well as simulating it through VR technology. Interaction between users and objects in a virtual world are certainly through techniques of visualization metaphors. The object of the experiment was the Gunzo room, located in an old building on the historical site of the Cluny Abbey in France. An application and an experiment scenario of a thermal simulation was created to interactively visualize the results in the immersion room, and tested by some participants. The experiment was conducted to simulate object-based data models that are specific to the thermal domain, using tools provided by the IFC 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. Analyzing the application 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 VR. With this integration method, the data flow that starts from the design process is completely and accurately channeled to the VR system.

Keywords: Data integration, Building performance, Thermal simulation, Scientific visualization, Virtual Environment

1 INTRODUCTION

Integrated building energy simulation programs have been used in various ways by building professionals in order to respond to the challenges of energy efficiency and to improve building designs in the aim of sustainability. This paper presents a new approach to integrating thermal building simulation and VR technique in order to transform numerical data into a visual representation within high-dimensional and in a 3D volume, to be more understandable for building stakeholders. The object of experiment takes place in a historical building, aimed to optimize building performance as well as design review and to explore its large potential for another sustainable building project. The VR technique used since it becomes an important support in the building performance domain, which the emphasis is on the perception of a room's thermal data simulated in a VE. Its interface concepts allows the rapid and intuitive exploration of the 3D volume containing the data, enabling the various phenomena at various places in that volume to be explored, as well as providing simple control of the visualization environment through interfaces integrated into the environment.

The idea of generating 3D models that can be immediately recognized and processed by thermal tools and then VR tools is the main objective as today many thermal simulation tools are available and they differ in their manner of simulating thermal parameters. In fact, only few thermal simulation tools can present their calculations and simulation results in 3D which is still limited for PC use, and none of them has been satisfactory when applied to VR. 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 or charts, and resulted in different format. Therefore, data exchange methods from design tools to thermal simulation tools and VR tools with high interoperability still represent a very significant challenge to achieving data integration. An experiment scenario of a thermal simulation was created to interactively visualize thermal results in the immersion room where users can "walk" through the room, observe the dynamic temperature exchange, and simulate the thermal visualization during a certain time.

1.1 Related work

The study of thermal building simulation is commonly related to design tools that are used in the AEC (Architecture, Engineering, Construction). Several studies have been conducted using design tools to represent design results in VE. Studies regarding 3D CAD models and immersive environments, for example, try to focus on VR-CAD integrated systems to evaluate the design process [Toma et al., 2012; Bourdot et al., 2010; Weidlich et al., 2007; Ingrassia et al., 2009; Sampaio et al., 2012]. These works were carried out to develop concepts, methods and tools for integrating VR as a user interface into the process of geometric modeling and detailing. They focused on CAD data workflows and design review, and became initiate concepts for the visualization of thermal building simulation in VE.
With regard to the integration of thermal building simulation and VE, Fricoteaux (2010) has studied the creation of thermal information in VE called Thermic3D. He proposes different solutions to retrieve information regarding thermal data and re-transcribes thermal calculation results in a virtual building. In the workflow: thermal calculation used TRNSYS, modeling used 3Ds Max, and the simulation is realized in Virtools. The experiment made some excellent progress concerning solution on perception of thermal data and especially visual and thermal feedback in VE. However, problems in representing the thermal calculation results in 3D volumetric with friendly interface still remain.
Crouse et al. (2002) demonstrated the modeling of convective flows based on a 3D lattice Boltzmann approach. This technique used moved 2D translucent in the EVE. The workflow integrated within a CAD environment, the geometric model, based on an IFC building product data model, is discretized using a Cartesian grid based on a tree topology. These data then reading from a VRML file. The thermal visualization using a cutting plane was very interesting, however there are difficulties regarding workflow in translation of thermal data into the VE and presenting it in a friendly interface (with interactive system, suitable metaphor etc.) as close as possible to the real environment.
Van Treeck et al. (2006) presented the work on the development of an interactive computational steering environment (CSE) for interactive indoor thermal comfort simulation by utilizing high-performance supercomputing facilities. They integrated an interactive user interface with a context-based 3D menu to provide an intuitive front-end in the application. The approach to thermal visualization concept is very comprehensive. However the calculation only focused on single task simulation and the interface was not considered for immersive sensation.
Malkawi et al. (2005) have worked on an interactive speech and gesture recognition-based, immersive Augmented Reality (AR) model designed to visualize and interact with buildings and their thermal environments. The workflow include: design feasibility, meshing, CFD analysis, export and store VRML models. The thermal metaphors presented were colored fluid dynamics and particles in isoplane through HMD. However, while projected in VE the user is still burdened with the number of sensors and other heavy equipment.
As can be seen from the previous projects, the integration of thermal building simulation has been applied in a number of VR applications. However, they are complicated in workflow and no previous work adapted the integration for CAVE task and tablet. In addition, their VE is less similar to the real environment. This could lead to misinterpretation of the user. Therefore, it is necessary to find out the method applicable for seamless workflow that takes into account the nature of the data and the characteristics of the human perceptual system. These are the areas that we are addressing in this paper.

1.2 Thermal Building Simulation in the context of this study

Thermal building 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. From an AEC (Architecture-Engineering-Construction) perspective, advanced analysis of building thermal simulation in building modeling programs has become a critical part of high-performance buildings. The conceptual design phase of thermal modeling is used to provide the designer with first order of magnitude feedback about the impact of various building configuration on annual thermal performance [US GSA, 2010].
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 [Atmaca et al., 2006]. 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 [ASHRAE, 1993]:

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

where T_{mr} = the mean radiant temperature for a person [ºC], T_i = the temperature of surface i [ºC], $F_{P\text{-}i}$ = 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 [Bean, 2010].
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.

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. The Ecotect will not interpret this on its own with an imported model [Wagner, 2010]. Therefore, for the experiment we used Autodesk Revit 2012, one of the leading design tools in the AEC 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. IFC and gbXML are both used for common data exchange between AEC applications such as CAD and building simulation tools [Dong, 2007].

2 METHODS

The study began with a 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 on the historical site of the Cluny Abbey which is also a part of the ENSAM ParisTech campus. 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 the interior insulation of a building [Ter Minassian, 2011] which has demonstrated its effectiveness, and has become common practice for window renovation especially in Nordic countries.

Figure 1. Gunzo room. Object of experiment located in the historical site of Cluny, France.

We re-create the room in a digital mock-up in two conditions; actual condition and renovated version. Several alternatives of the renovated version were created to adapt the needs of an efficient environment situation.

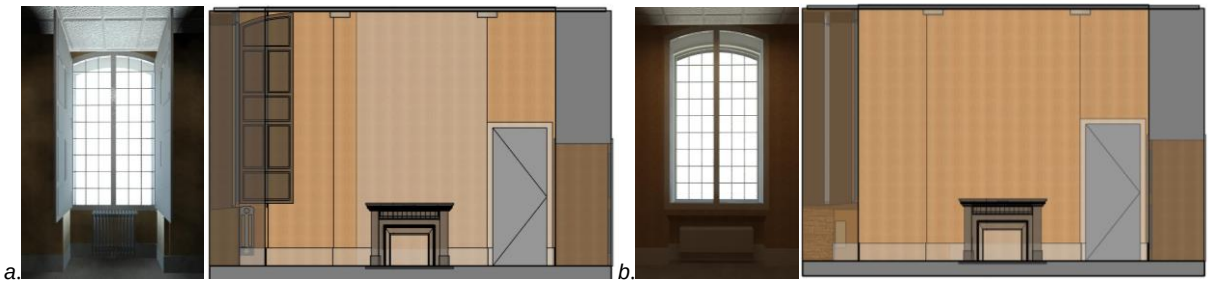

Figure 2. (a). Revit Model of Gunzo Room (3D View and section) in existing conditions (b). Renovated version, changes made to the wall, window components and heater.

2.1 Data integration

On the first phase of experiment the workflow was 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 with 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, which significantly improving the efficiency of an operator on site [Landrieu, 2012]. This became the basis of the principle of conducting the workflow. 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). In the second phase which is the focus of this paper, we use the same principle to transfer the thermal simulation result to the VE. Similar principles as well as similar model are implemented by modifying the basic application, tailored to immersion room /LITE (CAVE-like) requirements for high immersiveness and interactivity.

The application was developed in three stages: planning, modeling, and the integration of the first two stages:

- The planning has to take into consideration the final purpose of the presentation. The definition of the tasks and their details has to be done according to this idea.
- The geometric modeling needs to relate correctly with the tasks defined in the planning stage. We used some popular software in each field, from 3D modeling solution, thermal analysis, and 3D game engines commonly dedicated to integration and management of VR devices (CAVE and tablet) Three selected software involved: Revit Architecture (a BIM software, used to design a building and its components in 3D), 3DsMax (a 3D computer graphics software for making 3D animations, models, and images), and Ecotect (an environmental analysis tool that allows designers to simulate building performance). The modeling and calculation do the different tasks and the elements are formed for the simulation.
- The third stage, the integration into the VE, makes use of two optional programs: 3DVia Studio and/or Virtools (a 3D game engines very popular used in VR), where the first takes the 3D model

created with Revit Architecture, 3DsMax and Ecotect. In terms of simulation and visualization, we include interactive scenario with navigation keys for the user. A true three-dimensional perception is achieved using stereoscopic projection techniques.

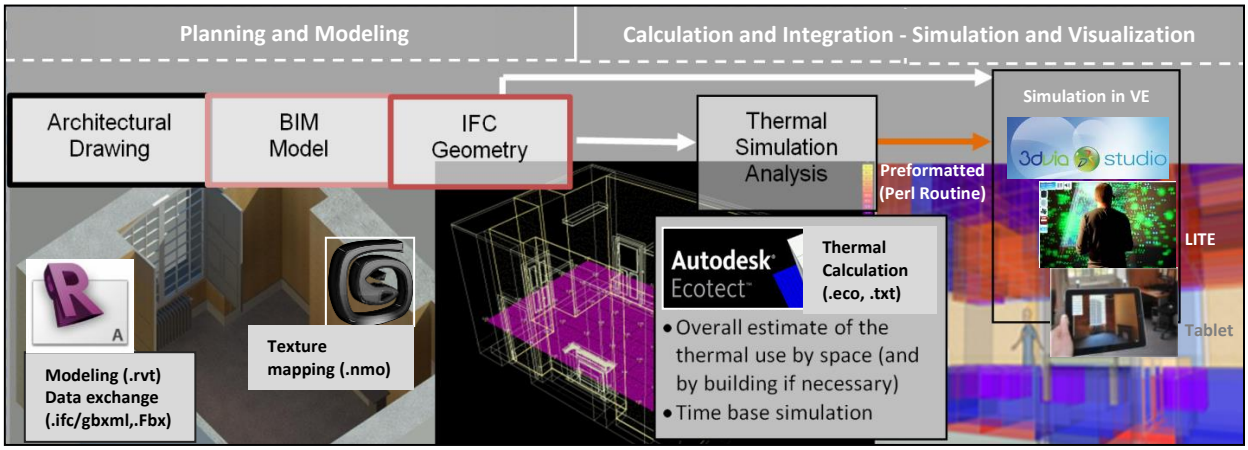

Figure 3. Detailed process of data workflow. Main applications involved: Revit, 3DSMax, Ecotect, 3DVia Studio (or Virtools), and Perl Routine for preformat.

Fig. 3 shows the detailed process of the workflow from the 3D 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 (ifc/gbxml) to have a thermal calculation result.
Data exchange from Ecotect to 3DVia Studio can proceed with exporting Txt format. However, the data tables of temperature value from Ecotect should be processed so that they can be digested directly by 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 original 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, day and month) and this input can be detailed more precisely depending on the needs of the experiment.

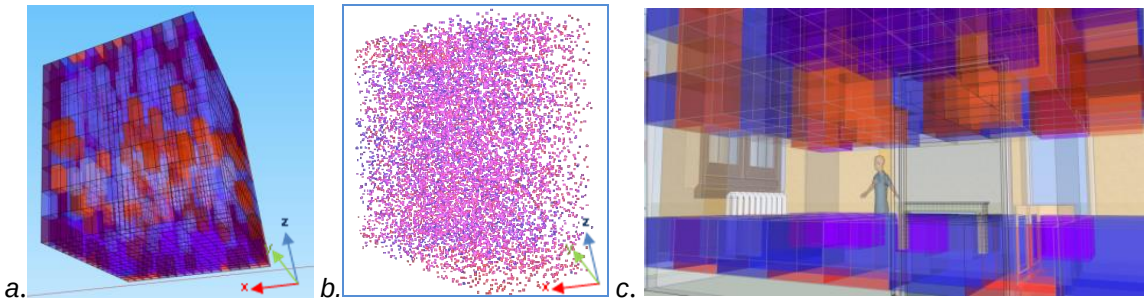

Figure 4. (a). Illustration of thermal grid with transparent cubes to be generated inside the Gunzo room precisely arranged on the XYZ axis. (b). The cubes filled with particles (c). The scenario to generate thermal simulation and visualization using grid transparent cubes.

The composition of thermal visualization in 3D volumetric by 3Dvia Studio meets on the XYZ axis. In the Gunzo room experiment, we tried to divide the interior space into 512 parts (each axis divided into eight) which contains the temperature values embodied in the cube from within each part. Once the simulation has been updated to the current simulation time, colored cubes and/or particles are created at every part and textured in transparent as well as colored according to the temperature value it adopts. The data workflow and the visualization metaphors principle are then integrated in the interface which present information and interactions in a fashion that suits the task at hand and give a visual clue to the user to find the functions easily. User interface-level integration with real-time data of MRT (Ecotect) is designed toward the mode of appearance (visualization metaphors) to allow the users conduct their tasks via the navigation menu.

2.2 Integrated simulation through CAVE

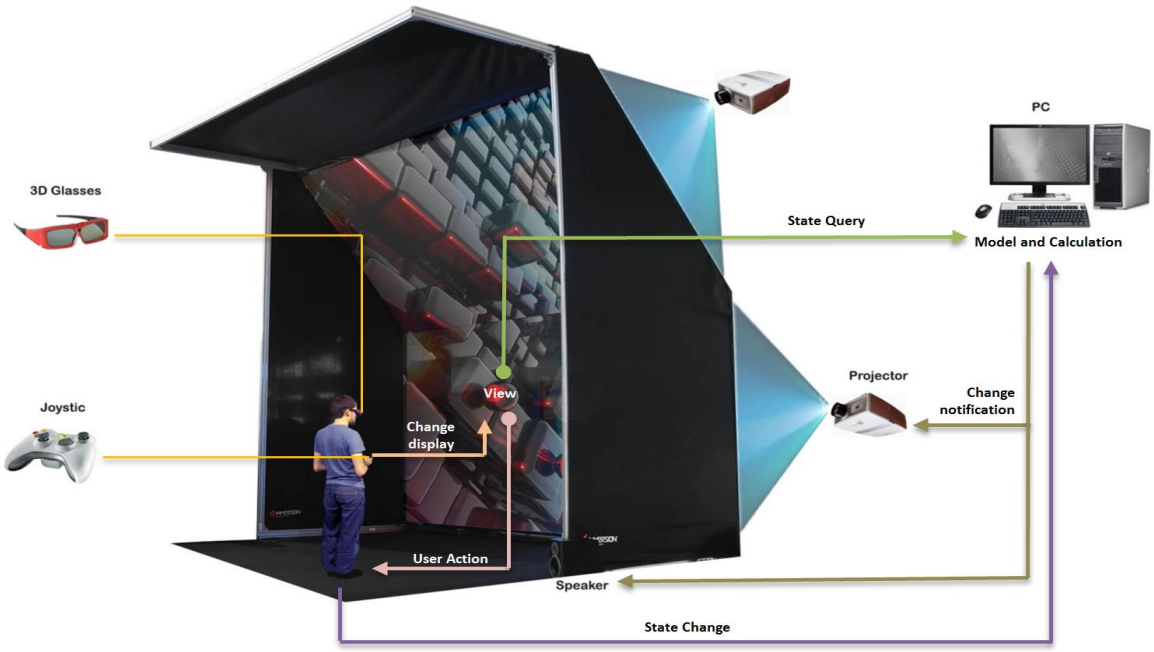

Figure 5. The instruments and system of the interface within the immersion room.

The application prototype provides an instrument of visualization and interaction in VE, including friendly interface concerning the thermal condition. The interface adopted is Model-View-Controller (MVC) architecture [Reenskaug, 1979] that is suited for iterative design.
The advantage of the MVC is that the resulting application is modular. The coupling is flexible between the three blocks: Model, View and Controller. This implies that the change of a block does not affect the overall structure, which makes changes easier. Thus, the user can immerge, interact, and perceive the impact of the modifications generated by the system.
The system in the VE is divided into three main parts:

- Data: These data are dynamically loaded into the environment. They are: thermal and geometric data (3D model of Gunzo room);
- Data translation: An intermediate step between the raw data and the data represented (returns in visual and thermal).
- Interaction: This is to give the users visual feedback and provide them the ability to navigate in the environment, as well as to conduct the simulation tasks interactively.

3 SIMULATION RESULTS IN VE

The monthly temperature graph displays the internal temperatures of the Gunzo room thermal zone over a one-year period as measured by Ecotect (Figure 6). These data are based on the average daily minimum and maximum temperatures, for each month and as an annual statistic, are preformatted into a 3D entity, and transferred in VE. The 3D data is attached in the geometry stored in the scene volumetrically.

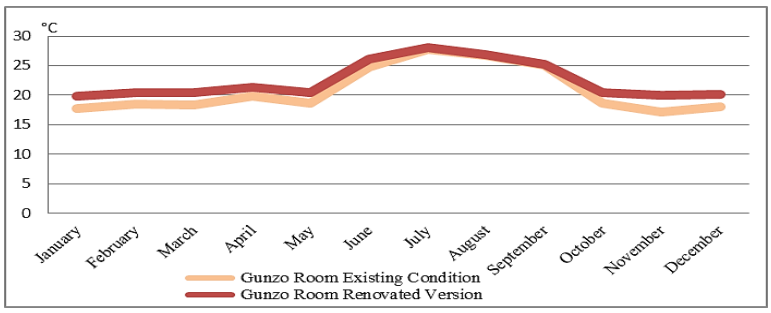

Figure. 6. Monthly Mean Radiant Temperature results between the two versions of the Gunzo room.

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 with a friendly interface, to inform the user of the thermal result interactively.

Type of Simulation Display	Description
Colored cubes	Each of the 512 areas of the room will be occupied by a cube to which the color is assigned depending on the temperature area. The transparency of the cubes can be modified by the user from a small "Transparency" menu, on the right-bottom corner of the display.
Colored particles	The cubes used in the first case will become completely transparent and will be filled with small particles. The color of the particles will also depend on the temperature of the area it occupies. Each particle has a life span of 3 seconds. The "life span" menu in this part is used to control the number of particles in each cube. It is composed of 0-16 particles / cubes.
Layer cubes	As mentioned earlier, the room is divided into 8 zones on each axis. In the previous cases, while the room is completely filled with cubes or particles that indicate the temperature of the area they occupy. In this simulation, only 2 layers are shown at a time, a horizontal layer (HL) and a vertical layer (VL). A "slide-in" menu is available, where the user can choose which HL or VL to be displayed. It also provides an option to hide or to show the layers, and to switch between displaying a simulation by cubes or particles.
Layer particles	

Table 1. Experiment stage description according to the four types of thermal metaphor

Figure 7. Thermal metaphors of transparent cubes and particles simulated in the immersion room with stereoscopic visualization tested by some participants. (a). Simulation results of renovated version in June 6th,14:15 with colored cubes (b). Simulation results of the Gunzo room in existing conditions in January, using particles (c). Simulation results on February 6th,14:15, using layer particles in vertical and horizontal (d). Simulation results of the renovated version using layer cubes in vertical and horizontal.

4 CONCLUSIONS

The paper describes the integration of thermal building simulation and VR techniques, in particular thermal data workflow toward visualization in VE. A VR application and scenario of a thermal simulation were created to have intuitive exploration of the VE, support visual representations and measurements on the data. Thus the user can immerge, interact, and perceive the impact of the modifications generated by the system, regarding the thermal simulation results. The application is intended to facilitate building stakeholders evaluate their design decisions where they can “walk” through the room, observe the dynamic temperature exchange, and simulate the thermal results during a certain time. The visualization of metaphors developed was intended as an alternative presentation of the simulation results of thermal calculations. This method is very effective in an immersive room as it can deliver the real temperature of a room before and after construction. Future research needs to set the thermal simulation result delivery in VE to be more integrated to the user. Moreover, the application needs to be equipped with some tools to present the impact of thermal changes made by the user directly in the visualization system, and to improve the technical services offered by software platforms.

ACKNOWLEDGEMENTS

This work is a part of the CORDOBA (COnsortium pour la Rénovation Durable des Ouvrages et Bâtiments Anciens) project. The author would like to thank Guillaume Schotte, Xavier Herissé, Andrei Rist, and the Gunzo Team of Ensam Paristech Cluny for providing assistance during the development of this work.

REFERENCES

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). (1993) Handbook—Fundamentals, Physiological principles and thermal comfort, Atlanta, USA. (Ch. 8).

Atmaca, I., Kaynakli, O., Yigit, A., (2006). Effects of radiant temperature on thermal comfort, *Journal Building and Environment*, Elsevier, 42 pp 3210–3220.

Bean, R., (2010). Mean Radiant Temperature (MRT). Available online: http://www.healthyheating.com/Definitions/Mean Radiant.htm#.UTB1sFcySpA (accessed on 16 February 2013).

Bourdot, P., Convard, T., Picon, F., Ammi, M., Touraine, D., Vézien, J.M., (2010). VR-CAD integration: Multimodal immersive interaction and advanced haptic paradigms for implicit edition of CAD models, *CAD Computer Aided Design*. 42, Issue 5, 445-461.

Crouse, B., Krafczyk, M., Kühner, S., Rank, E., Van Treeck, C. (2002). Indoor air flow analysis based on lattice Boltzmann methods. *Journal Energy and Buildings-Elsevier*. 34 (9), 941-949.

Dong, B.; Lam, K.P.; Huang, Y.C.; Dobbs, G.M. (2007). A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments, Proceedings: *Building Simulation*, pp.1530-1537.

Fricoteaux, L. (2010). Conception d'un environnement virtuel informé: Application à la restitution de calculs scientifiques. Rapport d'activités Stage TN10/ST02, UTC Compiègne, France.

Ingrassia, T., Cappello, F., (2009). VirDe: a new Virtual Reality Design Approach, International Journal on Interactive Design and Manufacturing Springer-Verlag. 3 (1), 1–11.

Landrieu, J., Nugraha B.Y., Père, C., Merienne, F., Nicolle, C., (2012). Pertinence D'une Representation 3d D'un Projet de Renovation de Batiment en Realite Augmentee Mobile, *Proceeding CONFERE ENSAM-CESI*, Venice, Italy.

Malkawi, A.M., Srinivasan, R.S. (2005). A new paradigm for Human-Building Interaction: the use of CFD and Augmented Reality, *Automation in Construction - Elsevier*, 14 (1), 71-84.

Reenskaug, T., (1979). A note on DynaBook requirements, Xerox PARC, Available on http://heim.ifi.uio.no/~trygver/themes/mvc/mvc-index.html (accesed: 21 March 2013)

Sampaio, A.Z., Gomes, A.R., Santos, J.P., (2012). Management of Building Supported on Virtual Interactive Models: Construction Planning and Preventive Maintenance, Journal of Information Technology in Construction (ITcon). 17, 121-133.

Ter Minassian, H. (2011). La réhabilitation thermique des bâtiments anciens à Paris : comment concilier protection du patrimoine et performance énergétique? Cybergeo : European Journal of Geography, Aménagement, Urbanisme, article 536. Available online: http://cybergeo.revues.org/23737 (Accessed : 21 February 2013).

Toma, M.I., Gîrbacia, F., Antonya, C., (2012). A comparative evaluation of human interaction for design and assembly of 3D CAD models in desktop and immersive environments. *International Journal on Interactive Design and Manufacturing*, Springer-Verlag. 6 (3), 179-193.

US GSA, Statsbygg and Senate, (2010). Information Delivery Manual (IDM) for BIM Based Energy Analysis as Part of the Concept Design BIM. Available online : www.blis-project.org/IAI-MVD/IDM/BSA-002/PM_BSA-002.pdf (accessed on January 12, 2013).

Van Treeck, C., Wenisch, P., Borrmann, A., Pfaffinger, M., Egger, M., Wenisch, O., Rank, E. (2006). Towards interactive indoor thermal comfort simulation, *European Conference on Computational Fluid Dynamics ECCOMAS CFD*. TU Delft. 1-15.

Wagner, A.D., Revit Architecture + Ecotect, Revit to Ecotect Workflow: Daylighting, BIM/CAD Camp 2010 Honolulu. www.uscad.com, www.uscadbim.com. (accessed: 22 January 2013).

Weidlich, D., Cser, L., Polzin, T., Cristiano, D., Zickner H., (2007). Virtual Reality Approaches for Immersive Design CIRP Annals - *Manufacturing Technology*, Elsevier. 56, Issue 1, 139–142.