Visualizing Building Performance in a Multi-User Virtual Environment

ALI MALKAWI
University of Pennsylvania

ELENA PRIMIKIRI
The University of Michigan

INTRODUCTION

During the past few years, many research projects were conducted to develop various tools that allow users to visualize a building in a three-dimensional (3-D) environment. These efforts are usually related to modeling and rendering the building itself, or in other cases, to the visual and lighting characteristics of the building. One of the main objectives of these approaches is to facilitate the collaboration of the people involved in the design and the construction of a building (Clarke, 1993), (Mahdavi, 1998). Very little work has been done in the area of building performance visualization, and in particular, thermal behavior of buildings (Linden et al. Linden, 2001). Most of the tools provide one or two-dimensional representation of the data derived from a building thermal simulation. This has always been an important challenge, since only experts can precisely understand the data, and hence are always required to interpret them. Consequently, this introduces the problem of time and cost that has always been an issue in Architecture, not only in terms of hiring these experts, but also in terms of establishing communication among the participants. This communication is not only dependent on their physical presence, but it involves issues of representation as well as of semantics.

The aim of this project is to generate a prototype technique that will allow users to visualize various building thermal analysis data in a virtual 3-D environment that can facilitate multi-user interaction, such as the CAVE (CAVE Automatic Virtual Environment). The CAVE environment provides the illusion of immersion by projecting stereo images on the walls and floor of a room-sized cube. Several persons wearing lightweight stereo glasses can enter and walk freely inside the CAVE and share the information presented.

It is expected that this approach will facilitate the awareness of thermal problems inside the building. In addition, it will enhance the communication among the design participants and as a result, improve both project cost and design time.

PROJECT OVERVIEW

The space modeled in this project was a thermal chamber that was designed to investigate the dynamic thermal behavior within spaces. The chamber has dimensions 8'*8'*8'. This is approximately the size of a one-person office. The chamber has its south face exposed to the outside. The other surfaces are under typical indoor conditions, figure 1.

This office size thermal chamber was modeled and analyzed using Computational Fluid Dynamic Software (CFD). CFD provides the opportunity to analyze flows in rooms at a highly detailed level – something that is too cumbersome to do through experimentation and not possible by lower level simulations. FLUENT 5.4.1 (FLUENT, 1999), is used for the CFD analysis. The three-dimensional model and mesh are constructed using GAMBIT 1.3 (FLUENT, 1999) – a modeling tool developed specifically for FLUENT applications. The advantage in using FLUENT is that it has an extensive GUI and post-processing abilities that allows several options for data output that can be customized and read in any desired format. Actual data from the chamber was compared to the simulated

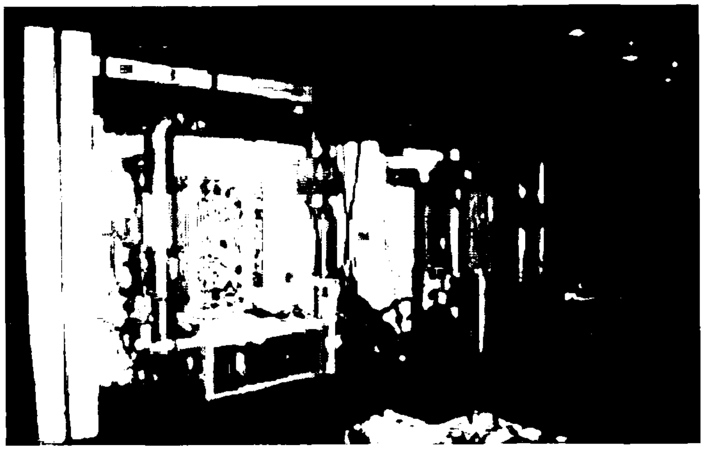

Fig. 1.a. The thermal chamber.

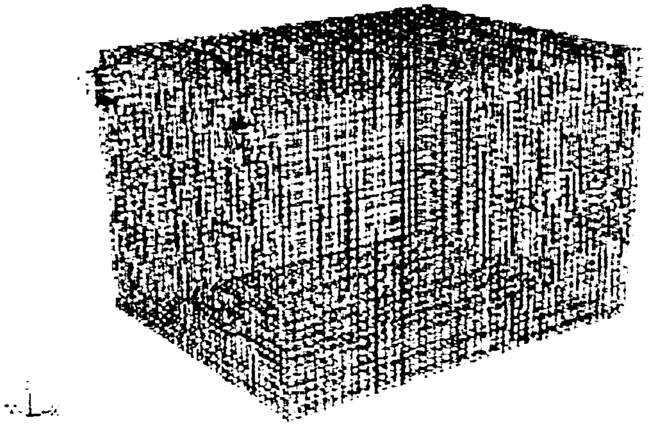

Fig. 1.b. The thermal chamber mesh.

results to provide accuracy and achieve model calibration, figure 2.

The space was then translated into the CAVE format and the CFD data output was programmed to be visualized inside the model and within the CAVE environment.

THE CAVE

The CAVE is a projection-based Virtual Reality (VR) system that surrounds the viewer with 4 screens. The screens are arranged in a cube made up of three projection screens for walls and a projection screen for the floor, figure 3. The projectors (1) and the mirrors (2) for the sidewalls are located behind each wall. The projector for the floor is suspended from the ceiling of the CAVE, which points to a mirror that reflects the images onto the floor. A viewer wears Stereographics' CrystalEyes liquid crystal stereo shutter glasses (3) and a six-degrees-of-freedom head-tracking device. As the viewer moves inside the CAVE, the correct stereoscopic perspective projections are calculated for each wall. The glasses will not function if the user is facing away from the emitters. The stereo emitters (4) are placed around the edges of the CAVE. They are the devices that synchronize the stereo glasses to the screen update rate of 120Hz or 96Hz. A wand (a 3D mouse) (5) with buttons is the interactive input device. The primary wand has three buttons and a pressure-sensitive joystick. It is connected to the CAVE through a PC, which is attached to the supercomputer serial ports. A server program on the PC reads data from the buttons and joystick and passes them to the supercomputer. The CAVE supports several different tracking systems. The primary system is an Ascension Technologies Flock of Birds. There are also "simulated" tracking options available, using either the keyboard and mouse or a spaceball. The current implementation of the CAVE runs using a Silicon Graphics Onyx (6) with three Reality Engines (7). Each Reality Engine is attached to a CAVE wall.

The standard CAVE is a 10-foot cube. The origin of the coordinate system (0, 0, 0) for the CAVE is normally located at the center of the floor, that is, 5 feet away from any wall. This means that the programmer has from +5 to -5 feet horizontally and from 0 to 10 feet vertically to define objects inside the CAVE. All the walls of the CAVE share the same reference coordinate system, as shown in Figure 4.

DATA INTERACTION AND SYSTEM DESIGN

The chamber was modeled for both CFD and the VR analysis. After the model was simulated using CFD, the output data was

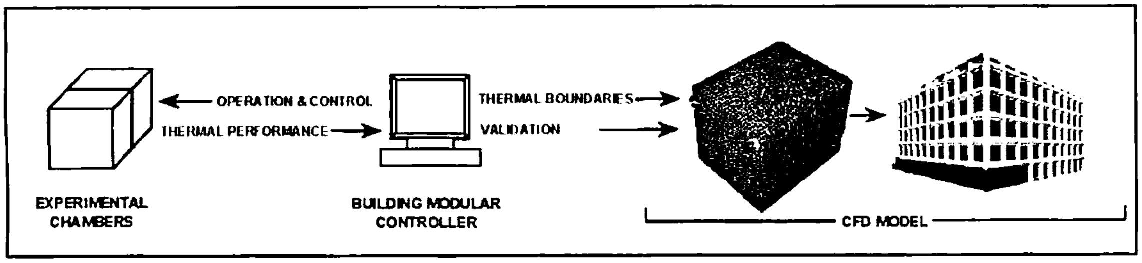

Fig. 2. Calibration between the thermal chamber and CFD analysis.

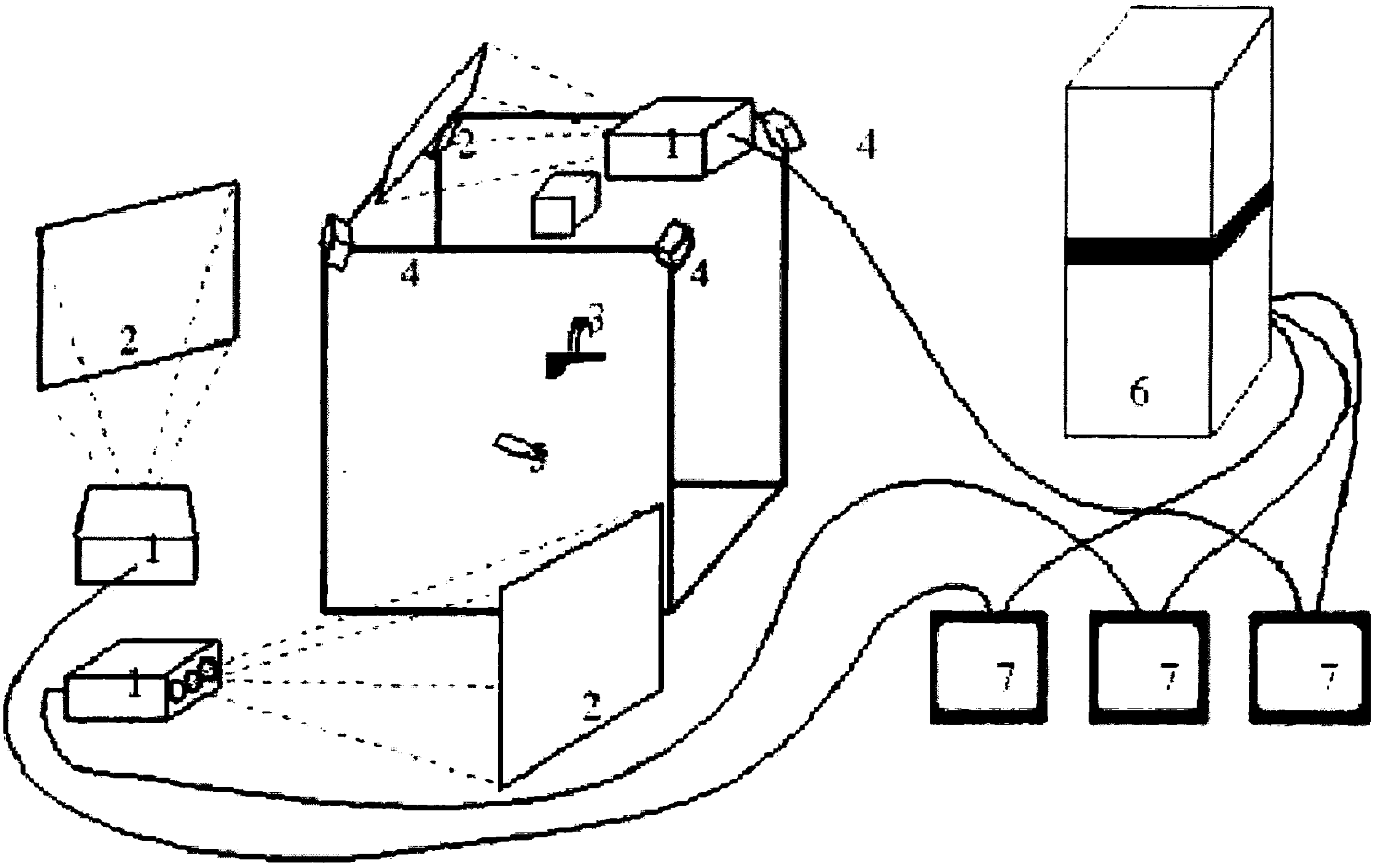

Fig. 3. A diagram of the CAVE environment.

saved in a text file. The data included indoor air velocity, radiation and temperature values. For the purposes of this project, only temperature values were utilized. In order to construct a VR model, the space was first built using 3-D Studio Max and then it was exported into Virtual Reality Modeling Language (VRML) format. The VRML model was then transformed into Inventor 2.0 format. Inventor is a computer program that allows objects to be displayed in a 3-D format that the CAVE can display. Once the model became CAVE compatible, an engine was created to operate the CAVE to allow the interaction between the space and data visualization to be displayed. The computer language used to program the CAVE was the Performer. It is a computer graphics language that allows real-time communication among several programming languages, such as C+, and openGL. The engine designed relies on several files that behave as the source files for it to be executed in the CAVE. These source files are connected to the CAVE libraries. Hence, they provide the specifications for some of the basic configurations of the CAVE such as the speed of navigation, the buttons functions and the interaction with the space, figure 5.

When executing the engine, two different calls occur at the same time. The thermal data plotting and the model of the space, which is functioning as the background of the thermal analysis. The data are then mapped onto the space as one object using the performer functions in the CAVE. This allows

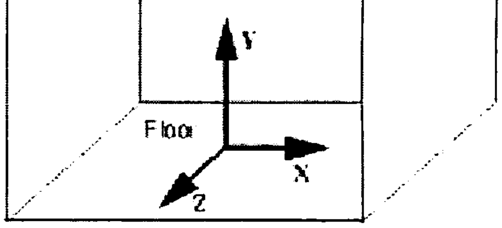

Fig. 4. CAVE Coordinates.

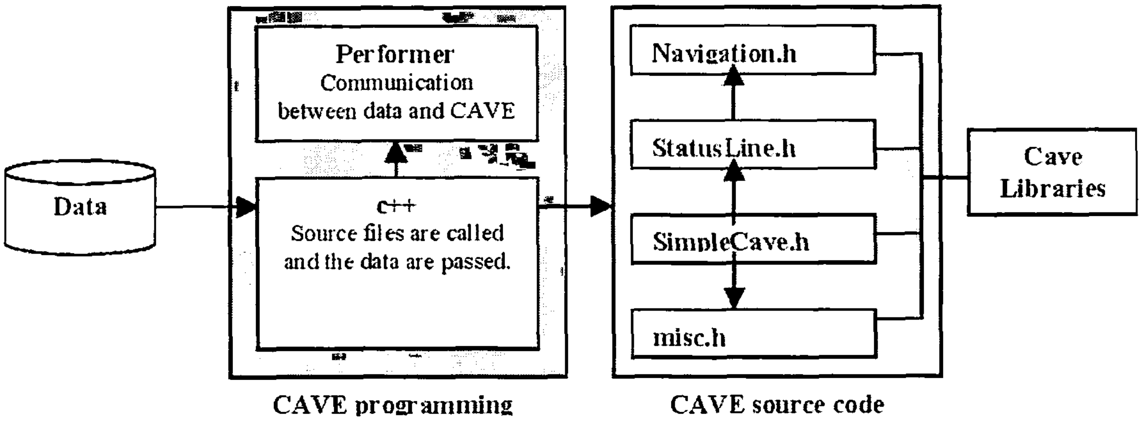

Fig. 5. Engine framework.

the user to move around both the data and the room at the same time, figure 6.

For the given dimensions of the room, three different 2-D meshes were created, one in each direction (xy, yz, xz). The main technique used for the meshes was tristrips. This technique allowed some flexibility in terms of the mesh control, and thus enabled the possibility of manipulating the nodes of the mesh more easily. Once the temperature data from the CFD analysis is sent to the Performer, It is stored in a 3-D array and then assigned to each of the 2535 nodes of the mesh. According to the temperature value, a color range was assigned and displayed, figure 7.

One or more users can then navigate through the space, change some of its parameters such as window size or materials and visualize the resulting thermal conditions. These conditions are displayed by choosing the desired mesh to be deployed. This means that the user can decide exactly which slice to be shown with the click of the buttons on the wand, visualize this information and share it with other users. Simulation information regarding that condition are extracted and displayed in a 3-D format, figure 8.

CONCLUSIONS

Translating information from the CFD simulation to the CAVE proved to be a challenging task. Issues of mapping information between the different software were resolved by creating the engine discussed in this paper. The CAVE language is also restrictive regarding the primitives it allows to use. Only basic shapes can be used, such as cubes, or spheres. Thus it makes it difficult to map information with complex shapes to the output of the CFD simulations. In addition, the more detailed information a user requires regarding the space performance, the less likely that the engine will adapt to providing the information.

The method illustrated the feasibility of visualizing thermal information, in particulate, CFD data in the CAVE environment. Using the CAVE allowed multi-users to virtually navigate through a 3-D environment and share information regarding its performance. The method demonstrated the potential of expanding such a system to a real-time visualization and simulation system. This can be accomplished by having a simulation engine feeds its output to the system as the users change the parameters and properties of the space. The method showed that performance information about the building could be visually represented in three-dimensional format. This allows information to be shared easily among the different

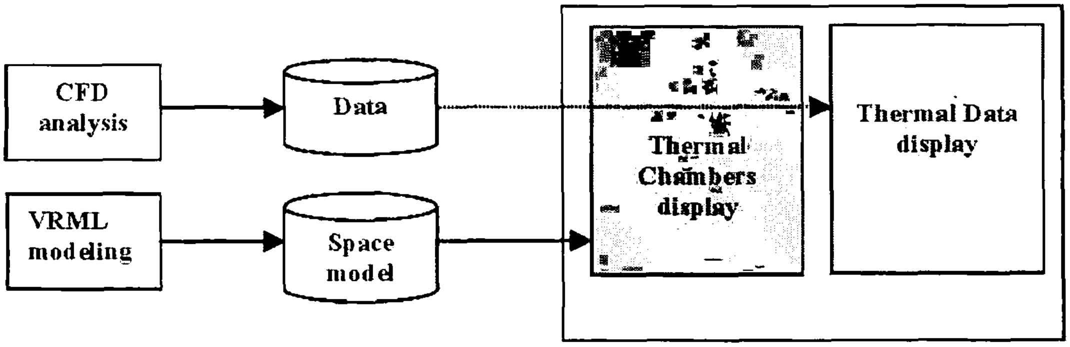

Fig. 6. Data Coupling Procedure.

Fig. 7. CAVE display of CFD thermal data as seen by participants.

Fig. 8. Participants inside the CAVE.

design participants. As a result. it provides a different and a new approach on how architects and engineers share information regarding architectural spaces and its performance.

REFERENCES

Clarke, J., "Assessing building performance by simulation." Building and Environment. V.28. 1993. pp419-427

FLUENT Inc., "Fluent User's Guide." Fluent Inc., NH, USA. 1999.

Linden, E., Hellstrom, J., Cehlin, M. and M. Sandberg, "Virtual Reality presentation of temperature measurements on a diffuser for displacement ventilation." In Proceedings of the 4th International Conference on Indoor Air Quality and Energy Conservation in Buildings. October, 2001 Changsha, Hunan. V.II, pp849-856

Mahdavi, A., "A comprehensive computational environment for performance based reasoning in building design and evaluation," Automation in Construction. V.8. 1999. pp427-435