Fabrication of BIM CAVE 2: Challenges in Handling 9 Screen Walls

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ABSTRACT

The BIM CAVE developed in 2011 at Texas A&M University, using a commercial building information model reviewing application, has demonstrated that an enhanced user experience in terms of reviewing building information models can be achieved without converting the file format of the model. Any building information models created by most commonly used commercial BIM applications can be loaded on the BIM CAVE without changing their native file format, and users can enjoy reviewing the 3-dimensional model and associated building information in an immersive virtual environment in less than 5 minutes. Although the first BIM CAVE system consists of 3 screen walls, its unique architecture can facilitate the extension of the immersive space by adding more screen walls. The research team at Texas A&M University has recently updated the BIM CAVE application to accommodate 9 screen walls. This paper presents how the BIM CAVE application has been modified. It also demonstrates a new immersive space that a 9-wall BIM CAVE can create.

Keywords –
BIM CAVE; Virtual Reality

1 Introduction

Building Information Modelling (BIM) is now one of the critical technologies that the construction industry uses to enhance decision-making processes and increase productivity. According to the Emerging Construction Technology Catalogue [1] released by FIATECH in 2005, many practitioners in the construction industry acknowledged that construction simulation technology would provide them with an opportunity to increase productivity because it allows them to execute the entire construction process in a virtual environment before real construction starts. By simulating the entire construction process in advance, one can figure out what can be done and what cannot be done in advance, and make some proactive decisions to prevent any rework from taking place during construction.

BIM has attracted many practitioners in the construction industry because of its ability to simulate the construction process in 3-dimension world. Object-based 3-dimensional models can be used to detect clashes between building components including architectural, structural, mechanical, electrical, and plumbing components. It can be used to get the list of the building components and their quantity automatically. It can be used to present the construction sequence visually. By assigning the start-date and end-date of each activity on the jobsite to the associated building component in the model, one can easily produce a 4-dimensional construction simulation model, which can be used to present the sequence of construction visually. According to the SmartMarket Report [2] produced by McGraw Hill in 2009, visual representation of the construction project in 3-dimensional or 4-dimensional world helps project participants better understand the projects and make proactive decisions to prevent many problems from taking place during construction and eventually increase productivity in the course of construction.

When people review a 3-dimensional computer model that is displayed on the computer screen, they seldom feel that they are actually inside the model. They can figure out the spatial relationship between building components when they review the building model displayed on the computer screen, but it is obviously different from reviewing the real building while walking through it in the real world. It may be because the amount of information one can get from the image projected on a small computer screen is limited.

Immersive Virtual Reality (IVR) is a technology inviting users to a virtual space and enabling them to feel as if they are actually in the space. It has been assumed that the feeling of being there, or the sense of presence, in a virtual space may narrow down this gap of human's real experience and virtual experience in terms of reviewing a 3-dimensional computer model. Bochlaghem et al. [3] stated that those who are using the immersive nature of the virtual reality could gain a better understanding of both qualitative and quantitative nature of space. One way of increasing the user's sense of presence in a 3-dimensional computer model is to increase the field of view of the computer monitor, both in horizontal and vertical way [4]. This is the main concept that most CAVE (Cave Audio Video Environment or Computer Aided Virtual Environment) systems use to create an immersive environment.

The original CAVE (Cave Audio Video Environment) was developed in 1991 at University of Illinois at Chicago. It is in essence a 10ft×10ft×10ft cubical theatre made up of three rear-projection screens for walls and one down-projection screen for the floor. It was designed to display the work of computational scientists on high-end workstations attached to large projection screens interactively [5]. The CAVE used a custom made application that understands its own data format only. Therefore, the format of a 3-dimensional geometry data, if the model was created using other authoring tool, has to be converted if one wants to review it in the CAVE. The StarCave, another immersive virtual reality system developed at SEALab, uses VRML (Virtual Reality Modelling Language) format to understand the geometry of a 3-dimensional computer model format [6]. The VRML format does not provide any additional room for containing additional information, which creates a challenge in terms of acquiring "Design Information" while reviewing the 3-dimensional model of a building.

2 BIM CAVE

It is reasonable to speculate that the process of transforming the BIM data into the CAVE system may not be simple, and engineering data attached to the building information model can be lost while they get transformed, mainly because of lack of interoperability between major BIM applications and the CAVE systems. These challenges could hinder practitioners in the construction industry from reviewing the building information models in the immersive CAVE system.

One may be wondering if we can imitate the functions of the CAVE system using commercial BIM applications. If it is possible, we might be able to review the building information models in the CAVE system without transforming data format or losing any data that can be caused by file conversion.

In Fall 2011, a research team at Texas A&M University developed the BIM CAVE, which stands for Computer Aided Virtual Environment for BIM, using a commercial BIM reviewing application that understands as many as 20 different BIM data format. Unlike the original CAVE, the BIM CAVE has 3 walls arranged with 80 degrees of angle between them, which is creating a partial octagonal space. It does not put any images on the floor. Instead of using rear-projection systems that requires a significant amount of space, the BIM CAVE uses the flat screen walls made of 46-inch ultra-narrow bezel LCD displays. Each screen wall consists of 4 LCD displays arranged in a 2 by 2 matrix framework. A total of 12 LCD monitors are used for the BIM CAVE as shown in Figure 1.

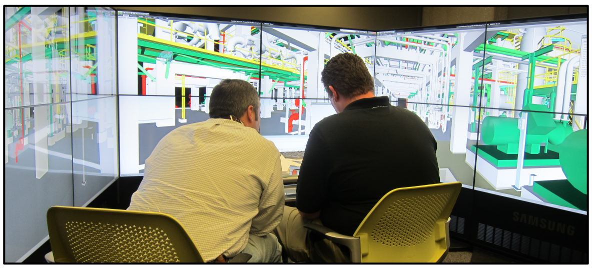

Figure1. BIM CAVE No.1 at Texas A&M University

Unlike the original CAVE system, the BIM CAVE is designed to use multiple computers to generate the images of a building information model for each screen wall independently. The BIM CAVE No.1 uses 3 computers, which are connected to the associated screen wall. Each computer generates the image of the model independently for the specific screen wall it is connected to. In order to synchronize the view of the model between the screen walls in the BIM CAVE, all 3 computers are supposed to load the same building information model and place the imaginary camera inside the model at the same position. The directional vector of each camera's aiming angle is determined by the orientation of the associated screen wall. To bring the cameras to the same position in the models across the computers, these 3 computers are exchanging the camera position in real time over the closed network.

The camera position in the model is basically controlled by the server computer, which is connected to the screen wall in the centre of the BIM CAVE. Two other computers are client computers that are connected to the screen walls on each side. The server computer is the one that interacts with the users to determine its camera location. When the users move the mouse to walk though the model, the server computer constantly collect the camera position and camera's aiming angle in the model. Then it sends the location information to client computers in real time. The server computer also calculates the aiming angle of those two cameras in the client computers using rotational matrix before sending the camera angle data to client computers. Receiving the information of the camera location and the aiming angle from the server computer, client computers are putting their cameras at the designated location with the predefined aiming angle. In theory, this camera synchronization action has to take place at least 30 times a second so that users can feel that they are actually walking through the model in the BIM CAVE. The BIM CAVE No. 1 experiences a slight time delay in synchronizing the camera locations between the computers, which hinders users from getting a full sense of presence while browsing, for example, a big and complex building information model.

3 Challenge

As shown in Figure 1, the BIM CAVE No.1 is not tall enough to fully surround the users. Those who are reviewing the building information model can also see other objects beyond the screen wall, and it prevents them from getting fully engaged in an immersive virtual environment and experiencing the sense of presence while walking through the model. The BIM CAVE No.1 successfully demonstrated its strength in terms of presenting a building information model in an immersive virtual environment in less than 5 minutes without converting its file format. However, users sometimes have hard time to get them fully attached to the model to some extent because of the short height of the screen wall.

The research team at Texas A&M University recently started working on the BIM CAVE No.2, which consists of 9 screen walls. Each wall consists of four 46-inch ultra-narrow bezel LCD displays that are sitting on top of another to make one long column of LCD displays. With 36 LCD displays, the BIM CAVE No.2 is expected to help users get an enhanced sense of presence while reviewing a building information model.

One challenge the research team had to deal with was the workload that the server computer may receive when it calculates the aiming angle of the camera for all client computers. The camera's aiming angle in the client computer is calculated by putting the tilting angle of the camera in the server computer and the angle between two screen walls into a rotational matrix. A significant amount of computing power is required to handle a rotational matrix calculation at least 30 times a second. It is reasonable to assume that one server may not be able to handle the workload when it has to work with 9 computers.

The idea that the research team came up with was to distribute this workload on the server computer to client computers. Instead of depending on the server computer for matrix calculations, client computers should be able to take some of the burdens from the server computer so that the entire BIM CAVE system can be executed with equally distributed workloads across the computers.

4 New BIM CAVE Application

The research team at Texas A&M University recently updated the BIM CAVE application to distribute workloads from the server computer to client computers. Since the server computer does not need to calculate the camera's aiming angle for the client computers any more, there has been some changes in collecting information for setting up the BIM CAVE. Before the BIM CAVE was updated, it manipulated the user's input as follows:

1. Server: collect the angle between the server screen wall and the client screen wall.
2. Server: calculate the directional vector of the client camera using the information collected from step 1.
3. Server: send the position and directional vector of the client camera to the client computer.
4. Client: place the camera in the model using the location and directional vector information received from the server.

With the new BIM CAVE application, the way of handling user's input and calculating the directional vector for the client camera has been changed as follows:

1. Client: collect the angle between the server screen wall and the client screen wall.
2. Server: send the position and directional vector of the server camera.
3. Client: calculate the directional vector of the client camera using the information from step 1 and 2.
4. Client: place the camera in the model using the location information received from the server and the directional vector gained from step 3.

As indicated in the above-mentioned process, major changes took place from step 2 through step 4. Now the directional vector is calculated on the client computer, and therefore the amount of information exchanged between the server and the client computer has been reduced significantly. Before the BIM CAVE application was updated, the server computer transfers 1) the coordinates of the server camera, and 2) the directional vector of the client camera to the client computers. Now the new BIM CAVE transfers 1) the coordinates of the server camera to the client, and 2) the directional vector of the server camera. In summary, there have been two benefits from using client computers for calculating the directional vector. Data traffic between the server and the client has been significantly reduced, which can help to reduce a time delay between the server and client computers. The workload of the server computer has been significantly reduced. Instead, the client computers pick up more computational tasks.

The look of the user interface also has been changed. Figure 2 shows the changes on the server computer user interface. Figure 3 shows the changes on the client computer user interface.

While waiting for 9-wall BIM CAVE getting fabricated, we tested the new BIM CAVE application with 6 screen walls and 6 computers. For this test, the BIM CAVE No.1 has been rearranged with additional 3 computers. Now, each screen wall consists of 2 LCD monitors instead of 4 as shown in Figure 4. Figure 5 shows the new BIM CAVE system with 6 computers. Figure 6 is a diagram showing how the new BIM CAVE is running differently from the old BIM CAVE system.

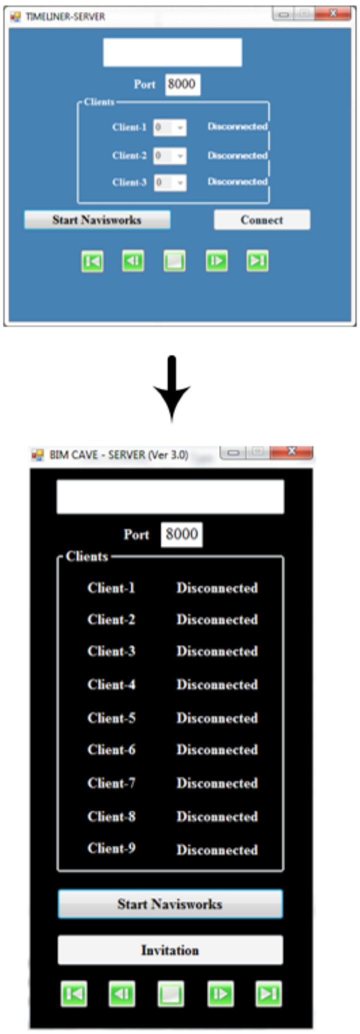

Figure 2. Changes on the server application user interface

Figure 3. Changes on the client application user interface

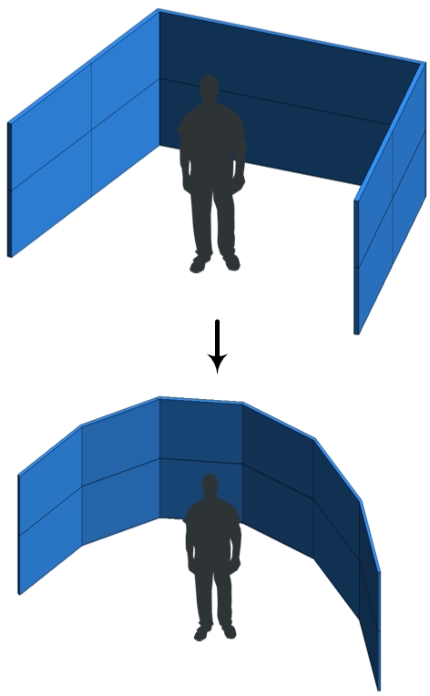

Figure 4. Changes on the BIM CAVE based on the screen wall configuration.

Figure 5. New BIM CAVE system demonstrating a seamless connection between computers

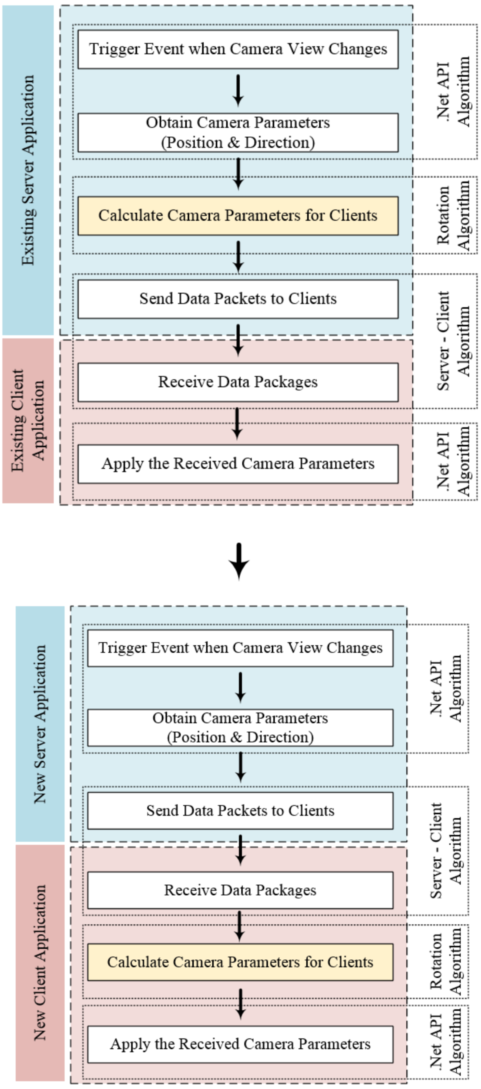

Figure 6. Comparison between the old BIM CAVE and new BIM CAVE

5 Conclusion

This paper presents an enhanced Computer Aided Virtual Environment for BIM (BIM CAVE). The new BIM CAVE application is designed to get the right balance between the server computer and the client computers. The directional vector of the client camera is no longer calculated by the server computer. Instead, the client computers take those tasks and reduce burdens from the server computer.

The test of the new BIM CAVE application with 6 computers and 6 screen walls demonstrated that the server computer application runs faster than before. It also demonstrated that the performance of the BIM CAVE application on the client computers was not affected by the number of client computers.

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