IMMERSIVE REPRESENTATION OF BUILDING INFORMATION MODEL

A Thesis

by

HUSSAM NSEIR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Civil Engineering

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Approved by:

Co-Chairs of Committee,	Stuart Anderson
	Ho-Yeong Kang
Committee Member,	John Walewski
Head of Department,	John Niedzwecki

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ABSTRACT

Immersive Representation of Building Information Model.

(May 2011)

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Co-Chairs of Advisory Committee: Dr. Stuart Anderson
Dr. Ho-Yeong Kang

Building Information Modeling (BIM) is an emerging technology that utilizes 3D graphical representations to improve communication, collaboration, and data exchange. Immersive Visualization Environment (IVE) is another promising technology that enhances the 3D graphical representation to achieve a higher level of a sense of presence. The connection between the BIM technology that utilizes the 3D graphical representation and the IVE technology that enhances the 3D graphical representation has led many professionals to visualize BIM in immersive environments. This study is an attempt to overcome a systematic issue presented by available immersive visualization systems. The problem is that in order to visualize an information-rich BIM model from a commercial BIM application in an immersive visualization environment, the BIM model needs to pass through a tough conversion process and loss a large amount of its information. This research study utilizes the Application Programming Interface (API) of a commercially available BIM application to develop an immersive visualization environment. This approach was applied on Autodesk Navisworks software by developing a software program that utilizes Navisworks' API to control Navisworks' camera angle and generate an immersive visualization environment. A prototype of the approach was built in the Department of Construction Science at Texas A&M University and named BIM CAVE Prototype.

The overall goal of this research was to prove that it is possible to transform a commercial BIM application into an immersive visualization system. A phenomenological study was utilized by interviewing subject matter experts from the construction industry. The intent of this effort was to explore and develop a phenomenological understanding of how research participants perceived the BIM CAVE system. The results show that the BIM CAVE can be considered an immersive visualization environment because it contains a majority of the immersive visualization environment features. However, a variety of technical limitations must be overcome before it can be called a fully immersive and functional visualization environment. Moreover, even though this investigation was to some extent successful, this research approach needs to be tested on other commercially available BIM applications before generalizations are made.

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1. INTRODUCTION

In recent years projects in the Architectural, Engineering and Construction (AEC) industry have become increasingly complex. Much research has focused on developing visualization techniques that improve the communication of project information. According to Eastman, “external representations, optimizations and simulations of a design are needed because of human limitations in mental ability to carry large amount of complex information” (Eastman 2003). In the past, visualization techniques, such as Computer Aided Design (CAD), utilized the two dimensional (2D) graphical representations to communicate design information. Recently, the focus has shifted to the use of three dimensional (3D) graphical representations to facilitate the communication of information among partners in the AEC industry.

Building Information Modeling (BIM) is an emerging technology that utilizes 3D graphical representations to improve communication, collaboration, and data exchange. The National Institute for Building Sciences (NIBS) defines BIM as the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes (NBIMS 2007). Several studies show that BIM technology offers the potential to improve productivity and efficiency in the AEC industry.

This thesis follows the style of *Journal of Construction Engineering and Management*.

According to Fischer, “the advancement of Building Information Modeling (BIM) and analysis methods now allows engineers to accurately simulate the performance of structural, mechanical, lighting and other building systems in a virtual environment” (Fischer 2006). BIM leads to a reduction in change orders and design errors, more collaboration between project teams, and more efficient and reliable delivery process which reduces project time and cost (Eastman et al. 2008). “BIM represents a shared knowledge resource, or process for sharing information about a facility, forming a reliable basis for decisions during a facility’s life-cycle from inception onward (Suermann and Issa 2009).”

On the other hand, immersive visualization environment is another promising technology that enhances the 3D graphical representation to achieve a higher level of a sense of presence. The sense of presence is tied to experiencing the computer-generated virtual environment and is the key to defining virtual reality in terms of human experience rather than a technological hardware (Zikic 2007). The sense of presence is improved by the level of immersion the visualization environments offer. Immersive visualization systems enhance the sense of presence by making users feel surrounded by the virtual environment. The enhanced sense of presence results in a better understanding and deeper learning of spatial information. The immersive visualization systems can be categorized into full immersive, semi-immersive, or non-immersive depending on the level that users feel surrounded by the virtual environment. One of the significant applications of the fully immersive visualization system is the Computer Automatic Virtual Environment (CAVE). CAVE is a fully immersive visualization system that facilities real time navigation and interaction with the virtual objects. Many researchers have recommended the use of immersive visualization systems in the AEC industry to improve communication and reduce error. There are many potential benefits to the application of immersive visualization systems in facility design and construction management. One of the most important benefits is improved communication that can be facilitated through improved visualization of facility product and processes via shared reference to interactive, human-scale, virtual facility prototypes (Otto et al. 2005).

The connection between BIM and the immersive visualization has driven several researchers to examine the representation of BIM technology in an immersive visualization environment. In the AEC industry, the use of an immersive visualization system would allow the project team to gain an increased sense of presence within the 3D or 4D model. This additional immersion can provide an experience where people feel embedded in the design, and they can gain a better sense of scale since they can visually navigate the model at full scale (Messner 2006).

1.1. Research Problem

In order to implement BIM, companies in the AEC industry are utilizing commercial software packages such as Revit, Navisworks, or Bentley. These applications use various file formats such as RVT, NWC, NWD, IFC or DGN to contain parametric digital models. However, immersive visualization system such as CAVE, Head Mounted Devices (HMD), Workbench, or Panorama keep the digital model using formats such as VRML (Virtual Reality Modeling Language) or X3D (Extensible 3D). To represent a building information model in an immersive visualization environment, the model needs to be converted into VRML or X3D. No immersive visualization systems can take the building information model stores in the proprietary format developed by commercial BIM application vendors. The file conversion process would normally be long and may cause the loss of information in the model. Most of the time, only geometry related information survives the conversion process. This problem has been addressed as a limitation by other researchers. For example, according to a researcher in the Immersive Environments Laboratory (IEL) at Pennsylvania State University:

> "We have encountered several impediments to the efficient development of information rich models for use in virtual environments. One problem is the lack of support in mainstream applications for stereo display and/or interactive techniques specific to virtual environments. For virtual reality (VR) use of facility data developed within industry leading applications, we must transfer that data to an appropriate VR toolset. Robust transfer of models or data from these applications often is non-trivial at best (Otto et al. 2005) ."

Similarly, while exploring the benefits of applying immersive visualization environment to architectural education, a group of researchers from the Faculty of Civil Engineering at Czech Technical University in Prague stated that:

> "One of the principal technical problems is the conversion from formats suitable for the concept of Virtual Building to data suitable for VR. The IFC format is intended for semantic and 3D data and does not carry such information as a level of detail, potential visibility sets, etc. The roughly transformed data is huge and it is frequently difficult to process and display (Dvorák et al. 2005) ."

1.2. Motivation

Like other commercial software vendors, some BIM applications facilitate users to add additional functions using Application Programming Interface (API). API is an interface that allows the interaction between user's application and a set of primitive functions of the commercial software application. The main motivation of this research is to investigate if it is possible to transform a commercial BIM application to a BIM CAVE. The concept behind the BIM CAVE is to establish an immersive visualization environment by having a commercial BIM application installed on multiple computers and utilizing API to control and coordinate the camera view in every computer by placing the camera at the same location in all the computers and aiming it to a slightly different angle in each one. Ultimately, the BIM CAVE system will facilitate an immersive visualization environment without the need to convert the file format of BIM models to VRML or X3D file format.

1.3. Research Objective

The objectives of this research are:

1. To prove the concept of developing a BIM CAVE using a commercial BIM application.
2. To evaluate the BIM CAVE as an immersive visualization environment.

1.4. Limitations

To achieve the research objectives, a BIM CAVE prototype was built in room 445 in the Department of Construction Science at Texas A&M University. The BIM

CAVE prototype works only with three computers and three screens. What works on the BIM CAVE prototype might not work on a full scale BIM CAVE system.

1.5. Benefits

There are several anticipated benefits of the immersive visualization environment that will be developed using the BIM CAVE concept. Like other immersive visualization environments, BIM CAVE system would enhance the visualization of BIM models. It would also facilitate effective communication of BIM information such as 3D geometry, construction sequence, and other BIM attributes. Unlike the rest of the immersive visualization environments, the use of BIM CAVE system will eliminate the time consuming task of model conversion, and it will eliminate the loss of BIM information that results from the conversion. Information rich BIM Models will stay rich before and after the visualization. The proposed BIM CAVE system is very affordable because it will be built using commodity-off-the-shelf computer products. The BIM CAVE system will be beneficial for the use in the AEC industry, in teaching, and in research. This research provides knowledge that could contribute to advancing the Building Information Modeling technology and the immersive visualization technology. Also, this research will provide valuable information for the future improvement and development of the BIM CAVE system.

1.6. Thesis Outline

This thesis consists of six sections. Section 1 provides an introduction to the BIM CAVE concept and explains this research problem, motivation, objective, limitations, and benefits. Section 2 summarizes the existing literature that is relevant to this study. This includes literature on virtual reality in the AEC industry and Building Information Modeling. Section 3 describes hardware components, software programs, mechanism, and interface of the BIM CAVE prototype. Section 4 describes the research technique used for this study. Section 5 presents the research findings and provides and analysis of the collected data. Section 6 provides a research summary, describes research limitations, and outlines future research about the BIM CAVE concept.

2. LITERATURE REVIEW

This section presents the literature review performed for this research. The literature review covers an introduction to the virtual reality technology, the characteristics of this technology, a review of virtual reality applications in the AEC industry, and a review of building information modeling technology and applications.

2.1. Virtual Reality

Virtual Reality (VR) is a technology that utilizes computers to generate a virtual environment. This technology allows humans to visualize and interact with the generated environment through interaction devices. VR gives the users the chance to visualize, experience, and interact with the modeled objects in the virtual environment. The degree of interactivity the Virtual Reality provides goes beyond what can be found in traditional visualization techniques. VR allows the user to control how the modeled environment is explored so he or she is no longer a passive receiver. Virtual Reality creates a dynamic visualization that simulates the reality rather than static imaging in the traditional media.

CAD and VR could be regarded as complementary technologies in design visualization. However, the 3D systems have limitations when it comes to conveying an understanding of complex virtual environment (VE), since these systems are made for a different purpose. The distinction is that a 3D CAD system is developed for a design specialist to create precise three-dimensional representations of real objects, while VR is developed to allow users to display and interact with these objects in a VE. A 3D CAD object is represented as an object with features, such as volume, weight, et cetera; the same object is modeled with surfaces in the VE in order to minimize the required computing power. In this way, the strengths of both systems can be utilized to improve the information creation done by the different design specialists and the coordination and communication of the design to a wider audience.(Woksepp 2007)

2.2. Characteristics of Virtual Reality

According to cognitive psychologists, depth perception is an important component of spatial cognition. By means of large displays that cover the user's field of view and the simulation of depth, VR technology has the capability to present spatial information in a more engaging manner, allowing for interaction with designed spaces at a human scale. The content of the displayed information can further augment the richness of information and possibly enhance the visualization process. Large screen size and wide field of view are identified as very useful VR components in that they allow for more spatial information and alleviate the scale problems characteristic of traditional media. Stereoscopy, texture, lights, shadows and objects contribute to the overall VR experience, but even more so, they act as depth cues affecting the perception of spaces. (Nikolic 2007)

Depending on the way the user interacts with the VR, VR systems can be divided into three types: non-immersive, semi-immersive and immersive.

- Non-Immersive VR

Another name of the Non-Immersive VR is the Desktop VR. The Non-Immersive VR system consists of a three dimensional environment viewed on a graphics monitor and navigated and controlled by a mouse, stereo glasses to give a stereo viewing from the monitor, stereo projection systems, and others. An example of a Desktop VR is the Autodesk Navisworks Model. It visualizes the model in a 3D environment on a computer monitor. It also allows the user to explore and walkthrough the model using a regular mouse. The low cost and portability are the advantages that a Non-Immersive VR system has over the other VR systems. However, a Desktop VR system has many limitations such as it does not fill the complete view of the user and it does not give a feeling of the immersion in a vertical space.

- Semi-immersive VR

Semi-Immersive (also called partial immersive) VR system is used to describe projection-based VR systems. Examples of the Semi-Immersive VR systems are Reality Centers and Immersive Workbenches. In the Reality Center system the view is projected on a large curved wall based screen while in the Workbench the view is displayed on a large table based screen. Usually, a Semi-Immersive VR system consists of several projectors and large screens. The advantage of the Semi-Immersive VR system of the Desktop VR system is it provides a wider field of view and a greater sense of immersion.

- Fully immersive VR

The fully immersive VR system provides the users with a 360 full view of the environment. The fully immersive VR system could be achieved by wearing a head-mounted display device that changes the view by moving the head. Head mounted displays are known for being uncomfortable and hard to handle if several people are trying to visualize the same model. Another way of achieving a fully immersive VR system is by employing Cave Automatic Virtual Environment (CAVE). All fully immersive VR systems provide a sense of presence in a virtual environment that cannot be achieved by other VR systems. The sense of immersion comes from the ability to display a new view wherever the user is looking. The fully immersive VR system provides a full-scale reproduction of the artificial three-dimensional world.

2.3. Virtual Reality in the AEC Industry

In the AEC industry, VR techniques have the potential to enhance the efficiency and effectiveness of all stages of a project, from initial conceptual design through detailed design, planning and preparation, to construction completion. The ability to review the design and rehearse the construction of the facility in a 3D interactive and immersive environment can increase the understanding of the design intent, improve the constructability of the project, and minimize changes and abortive work that can be detected prior to the start of construction. Unlimited virtual walkthroughs of the facility can be performed to allow for experiencing, in near-reality sense, what to expect when construction is complete. (Thabet et al. 2002)

An evaluation of the industrial applications of virtual reality in the AEC industry in the USA and UK was performed by Jennifer Whyte from the Business School at the Imperial College London in 2002. The researcher studied the approaches of eleven companies using virtual reality technology to identify business drivers and the strategies that were implemented. The research found that the business drivers for utilizing virtual reality included demonstrating technical competence, design review, simulating dynamic operation, coordinating detail design, scheduling construction and marketing. Moreover, the study found that the implementation strategy of virtual reality on a specific project was directly affected by the size of the project. The bigger the project the more likely virtual reality will be used. (Whyte 2003)

A research in the Department of Architecture at Pennsylvania State University led by professor Kalisperis in 2002 explored the potential of using an affordable immersive virtual reality environment in the early years of architectural education. The developed system, VR-Desktop, allowed the students to check and test their conceptual designs in an immersive virtual reality environment. The research, which was carried out, was a usability study in which thirty five students evaluated the different attributes of the immersive virtual reality system. The study concluded that the immersive virtual reality system communicated design information more efficiently than traditional visualization system. The immersive virtual reality environment included two six-by-eight foot screens. The display method was rear projection with passive stereoscopic. The system used high-end graphic cards that support OpenGL and stereo view. Input devices included a joystick and a SpaceOrb. The system operated on a software program called Navigational Loader that was developed using Java. The 3D model must be converted to VRML format before it is loaded to the software. (Kalisperis et al. 2002)

In 2003, the VR Desktop initiative in Department of Architecture at Pennsylvania State University was upgraded by adding a third screen to the system. The goal of the upgrade was to increase peripheral immersion and to accommodate more audience. The three-screen system consisted of three projection structures. Each projection structure included two mirrors, two projectors and a screen. Also, the navigation software was upgraded to achieve an immersive experience across the three screens. The upgrade included shifting from a continued display on two-screen using windows, into a coordinated display on three-screen using Linux. However, 3D models had to be converted to VRML format before it could be used in the VR-Desktop system. (Otto et al. 2003)

A study was conducted in the Applied Research Lab (ARL) at Pennsylvania State University to determine if the utilization of a full scale virtual mockup of a nuclear plant in a CAVE-Like environment would reduce the cost of its construction and maintenance. The immersive virtual reality environment that was used for this research was a surround screen virtual reality system. The system generates 3D stereoscopic views on four walls and a floor which completely surround and immerse the user in the virtual model. To visualize a 3D model on the system, the 3D CAD model had to be converted to VRML format. The research was carried out in the form of two experiments. The first experiment involved two groups of students while the second experiments involved two groups of industry professional. Each group was asked to develop a construction schedule while utilizing the immersive virtual reality system. The research results showed that a full mockup in this CAVE-Like immersive virtual reality caused a 25 percent reduction in the scheduling time over the traditional scheduling methods. (Whisker et al. 2003)

Another study was carried out in the Faculty of Civil Engineering at Czech Technical University in Prague in 2005 to explore the pros and cons of the implementation of a virtual reality, VR Center in Architectural and Civil Engineering education. The VR Center is based on two windows-based computers equipped with powerful graphic cards that support stereo views. Views generated by the two computers are projected on one large screen using two 3D projectors. The views are synchronized over the local network to achieve stereoscopic views. The system can operate with a single computer where only one computer is generating the stereoscopic views. In this case, 3D models had to be converted into VRML format to be visualized using the VR Center. Otherwise, if two computers were to be used, 3D models should be converted to OpenFlight format before they can be displayed on the VR Center. Several professors and more than twenty graduate and undergraduate students participated in the research. This study concluded that the VR Center improved the students' understating of the conceptual design. And it helped professors examine students' projects and detecting design errors. (Dvorák et al. 2005)

2.4. BIM and BIM Applications

Building Information Modeling has become a topic of great interest throughout the Architecture, Engineering, and Construction (AEC) Industry. Building Information Modeling (BIM) is the process of designing, analyzing, integrating, and documenting a building's lifecycle by developing an intelligent virtual prototype of the building using a database of information (Leicht and Messner 2007). Three-dimensional models and 4D simulations produced from building information models are far more communicative and informative to lay people than technical drawings. The direct benefits of BIM include easy methods guaranteeing consistency across all drawings and reports, automating spatial interference checking, providing a strong base for interfacing analysis/simulation/cost applications and enhancing visualization at all scales and phases of the project (Eastman et al. 2008).

BIM allows for an accurate geometrical representation of the different components of a structure in an integrated data environment. Therefore, the implementation of BIM technology implies several advantages. BIM facilitates an easier way to share, modify, add, and reuse building information which makes the construction process faster and more effective. Utilizing BIM leads to a better design process because building proposals can be analyzed more thoroughly, construction simulations can be performed quickly, and innovative solutions can be reached easily. BIM provides a way to control life cycle costs and access environmental data. BIM improves production quality because its output is flexible which enables automation. Automated assembly and manufacturing is much easier with BIM. BIM also allows for better customer service through the accurate visualization. Additionally, design, conduction, and operational data available through BIM are very useful for facility management. BIM achieves an integration of planning and implementation processes. Ultimately, BIM means a more effective and competitive industry. (CRC Construction Innovation 2007)

A study was conducted in the School of Building Construction at University of Florida to evaluate commercially available BIM applications for general contractors. The research studies 33 different software packages from 11 BIM software developing companies. The study looked at general contactors’ expectations from building information modeling technology, and attempted to develop a BIM software evaluation model which recommends the top five BIM software packages based on the general contractor needs. Four of the major developers included Autodesk, Bentley Systems, Graphisoft, and Solibri (Ruiz 2009).

Autodesk is an American multinational corporation that focuses on 2D and 3D design software for use in architecture, engineering and building construction, manufacturing, and media and entertainment. It was founded in 1982 and it became popular due to its software AutoCAD that was and is still wildly used in the construction industry. Nowadays, Autodesk has developed a broad portfolio of digital solutions to help users visualize, simulate and analyze real world performance. The most known software packages from Autodesk using BIM in building construction sector are: Autodesk 3ds Max Design, Autodesk Design Review, Autodesk Navisworks, Revit Architecture, Revit Structure, and Revit MEP. These software packages offer different types of features that go from drafting and modeling capabilities of blending different types of models and to developing clash detection analysis allowing for a better understanding of the building before it is built (Ruiz 2009).

Bentley Systems is another important software developer in the market, providing solutions for the building, plant, civil and geospatial vertical markets in the area of architecture, engineering, construction (AEC) and operations. The company was founded in 1984 and its most popular software solution for the building construction is Microstation, an important competitor for AutoCAD. Nowadays the company's solutions are evolving through BIM and they just released a new line of packages that are object based parametric. The most used software packages for the building construction include: Bentley Architecture, Bentley Structural, Bentley Building

Electrical Systems, Bentley Building Mechanical System, ProjectWise Navigator (Incorporated Project 4D from CommonPoint), and ConstructSim (Previously part of CommonPoint). The company is still offering their Microstation software, but is trying to move forward with the market trends by implementing BIM tools into their solutions. The previously listed software packages offer tools from drawing and modeling capacity to design rules reviews and bidirectional capabilities with power and lighting analysis software. The new addition to the Bentley team of Common Point allows them to offer 5D solutions as part of their portfolio and they are making changes into ConstructSim to upgrade its capabilities (Ruiz 2009).

VICO Software is another new company in the CAD Design world that used to be part of Graphisoft Company. The company offers a very complete set of programs that link the design of the project with the construction phase, offering programs that allow to create the model from scratch and simulate construction process inputting cost, creating earn value analysis and "what if" scenarios. VICO programs include Vico Constructor, Vico Estimator, Vico Control, Vico 5D Presenter, Vico Cost Explorer, and Vico Change Manager (Ruiz 2009).

Solibri was founded in 1999 to develop and market solutions that improve the quality of BIM and making the design process more effective. With this in mind they offer the following software packages, Solibri Model Checker, Solibri Issue Locator Solibri Model Viewer, and Solibri IFC Optimizer. With the goal of optimizing BIM processes the different Solibri solutions allow the user to analyze the models for integrity, quality and physical security. It also allows for the checking of clash detections and code verification, with a function locating the error on the original model. Solibri also allows the user to see models from any IFC standard and to combine them as one model using an IFC optimizer eliminating any redundant information (Ruiz 2009).

2.5. Summary

The literature review was performed to present the extent to which the virtual reality and the building information modeling can be utilized in the AEC industry. Virtual Reality technology allows humans to visualize and interact with a computer generated environment and enhances their understanding of spatial information. Several features of virtual reality systems could affect the spatial cognition such as the size of the displays, the field of view, the depth perception, and the level of immersion. The application of virtual reality technology in the AEC industry improves communication between project participants. Therefore, it could lead to an increase in construction efficiency, a reduction in errors, and a save in time and money. BIM technology facilitates an easier way to share, modify, add, and reuse building information which makes the construction process faster and more effective. Utilizing BIM leads to a better design process because building proposals can be analyzed more thoroughly, construction simulations can be performed quickly, and innovative solutions can be reached easily. BIM provides a way to control life cycle costs and improve production quality.

The next Section describes how this study attempts to transform a commercial BIM application to an immersive visualization environment.

3. BIM CAVE

The main motivation of this research is to investigate if it is possible to transform a commercial BIM application to a BIM CAVE. The concept behind the BIM CAVE is to establish an immersive visualization environment by having a commercial BIM application installed on multiple computers and utilizing API to control and coordinate the camera view in every computer by placing the camera at the same location in all the computers and aiming it to a slightly different angle in each one. In a fully immersive environment, the camera view should cover the 360 degree view around the user. So if eight LCD screens were to be used to achieve the 360˚ view and to prove the BIM CAVE concept, each screen will take 45˚ Field Of View (FOV). However, because of the limited budget, only three screens were used to develop the BIM CAVE prototype with the assumption that what could work on three screens will work on eight screens. Therefore, the BIM CAVE Prototype includes only three LCD screens, each one of the three screens will take 45˚ FOV, as shown in Figure 3.1.

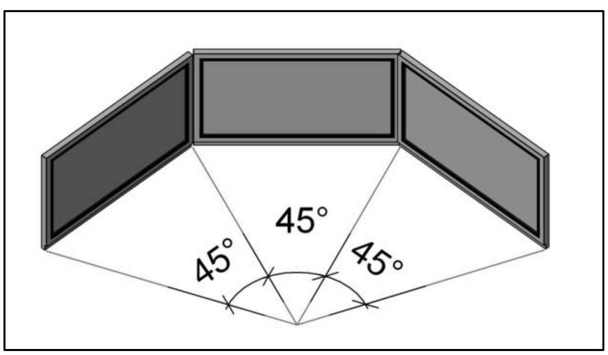

Figure 3-1: The Field Of View (FOV) of the BIM CAVE Screens

This section is devoted to the description of the BIM CAVE prototype, which was built in room 445 in the Department of Construction Science at Texas A&M University. The BIM CAVE prototype will be explained in four sections, the hardware components, the software programs, the mechanism, and the interface.

3.1. Hardware Components of the BIM CAVE Prototype

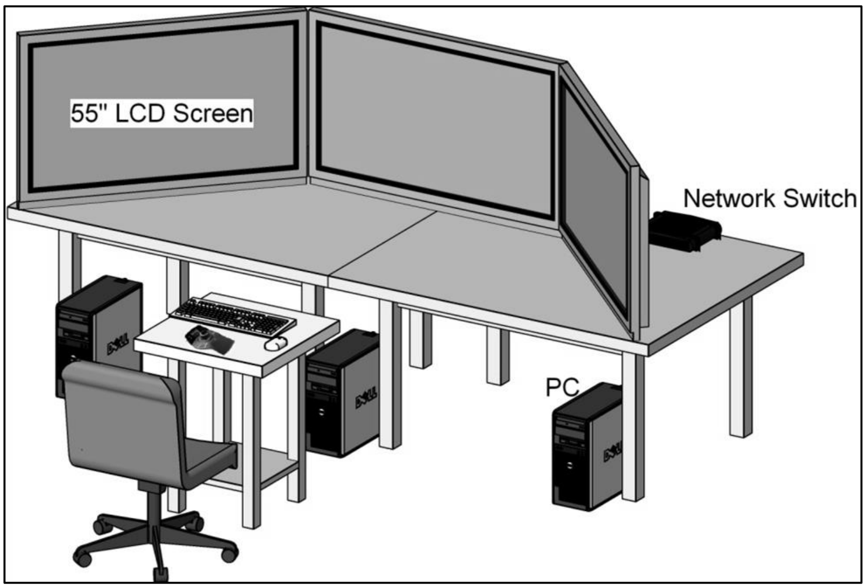

Figure 3-2: Hardware Components of the BIM CAVE Prototype

The BIM CAVE prototype consists of only commodity-off-the-shelf products which include (see Figure 3-2):

- Three desktop computers that contain high performance processors and powerful graphic cards with support of OpenGL. The support of OpenGL is recommended because most of the commercially available BIM applications use OpenGL to generate the 3D graphical images.

- Three 55" LCD TV screens. Each screen is connected to a computer.
- A Network Switch to create a computer network and assign an IP address to each computer.
- Input devices which include: a Keyboard, an Optical Mouse, and a Special Mouse.

3.2. Software Programs of the BIM CAVE Prototype

To create an immersive visualization environment from a commercially available BIM application, three software programs are used, Autodesk Navisworks, MaxiVista, and BIM CAVE.

3.2.1. Autodesk Navisworks Manage 2011

Navisworks Manage is a commercially available BIM Application. It has been selected to be used to in the BIM CAVE Prototype for many reasons. Navisworks Manage is customizable through a powerful application-programming interface (API). It is affordable. Autodesk offers a one-year free license for college students. Navisworks is widely used software that enables professionals from the AEC industry to combine their work into a single synchronized BIM. It allows the project team to achieve real-time visualization, 3D coordination, and 4D construction simulations.

3.2.1.1. Technical Description of Navisworks

A complete Navisworks model is accessed via a State object. A State corresponds to a document in Windows terminology. The State contains (Autodesk Incorporation 2007):

- A Partition forming the root of the model scene graph
- The Current View
- The Current Plan View
- The Current Section View
- The Current Animation
- The Current Selection
- A collection of SavedViews
- A collection of Scene Lights
- A collection of Selection Sets
- Various other Scene Properties
- A collection of Plugins

Out of the all the components above, the Current View component is the only one that is utilized in this study. The Current View component contains a ViewPoint and a collection of Section Planes. The ViewPoint defines a camera position and properties which control how the ViewPoint is displayed and modified. The ViewPoint contains the following:

- Camera: a 3D mathematical model that defines what you are looking at including Position, Orientation, Projection, and Field of View (F.O.V.)

- WorldUp vector: The preferred up direction when walking.
- FocalDistance: Distance from camera to center of attention when examining or orbiting.
- LinearSpeed: Defines speed of movement forwards and backwards.
- AngularSpeed: Defines speed of movement when rotating.
- Paradigm: Defines navigation mode (Walk, Orbit, Examine, etc.)
- Lighting: Off, Headlight or Scene Lights.
- Display Style: Full, Shaded, Wireframe or Hidden Line.

3.2.1.2. Navisworks API

Navisworks API can be used to customize and extend the Navisworks functionality. There are two interfaces for Navisworks API, Component Object Model (COM) interface and Dot NET interface. Originally COM API was the only interface available with Navisworks. Recently Dot NET API was added to Navisworks Manage 2011. Dot NET API offers several advantages over COM API. Some of these advantages are (Autodesk Incorporation 2010):

- Programmatic access to Navisworks models is opened up to more programming environments.
- Integrating with other Windows® based applications, such as Microsoft Excel and Word, is made dramatically easier by using an application's native .NET API.

- The .NET Framework is designed for both 32-bit and 64-bit operating systems. Visual Basic was only designed for 32-bit operating systems.
- Allows access to advanced programming interfaces with a lower learning curve than those for more traditional programming languages such as C++.

However, the transition to the Dot NET API is still in its early stages and Dot NET API interface is still not fully developed. Compared to COM API, Dot NET API has limited access to Navisworks functionalities. For this research, the COM API is used because it facilitates an access to Camera attributes while Dot NET does not. Navisworks COM API requires Visual Basic 6.0 to fully utilize its capabilities it. Navisworks COM API supports three areas:

- Navisworks ActiveX controls: allows for the Navisworks style of navigation of files to be embedded within web pages.
- Navisworks Automation: allows users to programmatically start up and manipulate Navisworks using Visual Basic, VBA or VBScript.
- Navisworks Plugins: allows users to extend the standard graphical user interface (GUI) functionality using Visual Basic.

3.2.1.3. Controlling Camera using COM API

To control the camera position and orientation in the BIM CAVE Prototype, Navisworks Automation is utilized. The library of the Navisworks Automation classes is stored in “roamer.tlb” file that is installed with Navisworks Manage. The class document of Navisworks Automation allows users to start the Navisworks application and access

Navisworks internal state. The library of Navisworks internal state classes is stored in "IcodieD.dll" file that is installed with Navisworks Manage. A list of all Navisworks API classes is provided in the APPENDIX A. The class that controls the camera form the internal state classes is InwNvCamera. Table 3-1 shows the properties and the functions of the InwNvCamera class.

Table 3-1: Members of the Camera Class (InwNvCamera)

Class Member	Type	Description
AlignUp	Input Function	Aligns the camera up orientation
PointAt	Input Function	Points the camera at a specified position
GetUpVector	Output Function	Vector representing the up direction
GetViewDir	Output Function	Vector representing the view direction
Position	Property	The 3D position of the camera
Rotation	Property	The 3D rotation of the camera
Projection	Property	The projection type of the camera
AspectRatio	Property	Aspect ratio of the camera
HeightField	Property	Height field (Radians)

3.2.2. MaxiVista

MaxiVista is a Virtual Network Computing (VNC) application that is used to control several computers on the network using the input devices of one computer. In other words, MaxiVista transfers the keyboard and the mouse events from one computer to another computer through the networks. Therefore, the mouse movements can be observed on the computer that it is connected to and on the screens of the other computers from the network. MaxiVista allows the user to utilize one mouse and one keyboard to use Navisworks on the three computers of the BIM CAVE Prototype without the need to change the mouse and the keyboard every time the control is moved from one computer to another.

3.2.3. BIM CAVE Software

The BIM CAVE software was developed using Visual Basic 6.0 to accomplish an immersive view in the BIM CAVE Prototype. Within the BIM CAVE software, there are three main algorithms that work together to achieve the immersion, Server-Client algorithm, Navisworks COM API algorithm, and 3D Mathematical Rotation algorithm.

3.2.3.1. Server-Client Algorithm

The purpose of the Server-Client algorithm is to facilitate the sending and receiving of data among the BIM CAVE computers. A Winsock Control is used to govern the data exchange between Server and Clients applications on the BIM CAVE computers. The transmission of the data goes only one way from the server to the clients. The server sends the current camera attributes and the clients receive them so they can follow what is shown on the server. Since the transmission speed is very critical to achieve the real time synchronization between the server and the clients, the User Datagram Protocol (UDP) was selected as the protocol that controls data exchange between BIM CAVE computers. Because of the Server-Client mechanism, the BIM CAVE application will have two independent exactable files (EXE). The first is the Server that works as the central point that sends data to clients, and the second is the Client that works as the host that receives data that was sent from the server.

3.2.3.2. Navisworks COM API Algorithm

The functionality of Navisworks API algorithm differs between the Server BIM CAVE application and the Client BIM CAVE application. On the server, Navisworks API algorithm gathers the camera attributes of the current view. Whereas on the client, it changes the current view by assigning new camera attributes. The camera attributes includes the 3D position and orientation of the camera. The camera 3D position is a member of InwNvCamera class, as shown in Table 3-1, and it represents the InwLPos3f class which includes properties and functions as shown in Table 3-2.

Table 3-2: Members of the Camera Position Class (InwLPos3f)

Class Member	Type	Description
SetValue	Input Function	Sets the camera position
Equals	Input/Output Function	Equality check method
Data1	Property	The X-coordinate of the camera position
Data2	Property	The Y-coordinate of the camera position
Data3	Property	The Z-coordinate of the camera position

The camera 3D rotation is a member of InwNvCamera class, as shown in Table 3-1, and it represents the InwLRotation3f class which includes properties and functions as shown in Table 3-3.

Table 3-3: Members of the Camera Rotation Class (InwLRotation3f)

Class Member	Type	Description
SetValue	Input Function	Sets the camera rotation axis and angle
GetAxis	Output Function	Gets the camera rotation axis
Angle	Output Property	Gets the camera rotation angle

In the Server BIM CAVE application, Navisworks API algorithm collects the camera position using the properties Data1, Data2, and Data3 of the InwLPos3f class. Next, Navisworks API algorithm gathers the camera rotation axis using GetAxis function and the camera rotation angle using Angle property of the InwLRotation3f class. Whereas in the Client BIM CAVE application, Navisworks API algorithm assigns the camera position using the properties Data1, Data2, and Data3 of the InwLPos3f class. Then, it sets the camera rotation axis and angle using SetValue the InwLRotation3f class.

3.2.3.3. 3D Mathematical Rotation algorithm

The 3D mathematical rotation algorithm works only on the Server BIM CAVE application. It utilizes the camera rotation attributes from the Server to generate the camera rotation attributes for the Client applications. The 3D mathematical rotation algorithm uses the same mathematical representation of camera rotation that is used by Navisworks. The way Navisworks represents the camera rotation is not documented by Autodesk. However, it was concluded from the way the camera rotation class (InwLRotation3f) is structured that the rotation representation used by Navisworks is the Axis Angle Method.

Axis Angle Rotation Method is based on the idea that a rotation can be represented by a unit vector and an angle. The unit vector indicates the direction of the rotation axis, and the angle describes the magnitude of the rotation about the axis. The direction of the rotation is governed by the right-had rule. The Axis Angle Rotation method implies that any rotation of a camera in a three dimensional space is equivalent to a rotation of the camera direction vector about some axis. Mathematically, the Axis Angle method can be applied by using a rotation matrix. Therefore, the rotation of a vector {V} indicates the multiplication of {V} by the rotation matrix [R] which will result in a new vector {V′}.

$$\{V'\} = [R] \times \{V\} \Leftrightarrow \begin{Bmatrix} v'_x \\ v'_y \\ v'_z \end{Bmatrix} = [R] \times \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} \tag{3.1}$$

If the unit vector that represents the rotation axis is $\{x\ y\ z\}^T$ and the rotation angle is θ, then the equation 3.1 would look as the following(Wikipedia contributors):

$$\begin{Bmatrix} v'_x \\ v'_y \\ v'_z \end{Bmatrix} = \begin{bmatrix} x^2+(1\text{-}x^2)\cos\theta & x.y.(1\text{-}\cos\theta)\text{-}z.\sin\theta & x.z.(1\text{-}\cos\theta)+y.\sin\theta \\ x.y.(1\text{-}\cos\theta)+z.\sin\theta & y^2+(1\text{-}y^2)\cos\theta & y.z.(1\text{-}\cos\theta)\text{-}x.\sin\theta \\ x.z.(1\text{-}\cos\theta)\text{-}y.\sin\theta & y.z.(1\text{-}\cos\theta)+x.\sin\theta & z^2+(1\text{-}z^2)\cos\theta \end{bmatrix} * \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} \tag{3.2}$$

In Navisworks, each view of the camera could be identified by a View Direction Vector and an Up Vector. Both the View Direction Vector and the Up Vector are unit vectors in Navisworks. To rotate the camera to a specific view with a specific View Direction Vector and a specific Up Vector, the camera should be rotated around a specific Rotation Axis with a specific Angle. Notice that a specific Up Vector is necessary when rotating the camera because otherwise the camera could go up side down. The Navisworks API documentations and support website do not clarify whether the rotation of Direction Vector and Up Vector start from the previous Direction Vector and Up Vector or from fixed Reference View Direction Vector and Reference Up Vector. However, the investigation led to the conclusion that the Axis Angle Rotation of the camera in Navisworks uses a fixed Reference View Direction Vector and a fixed Reference Up Vector. After several trials, it was found that the reference orientation of the camera is looking downward with the Up Vector pointing forward. In other words, the Reference View Direction Vector is $\{0\ \ 0\ \ -1\}^T$ and the Reference Up Vector is $\{0\ \ 1\ \ 0\}^T$. Therefore, to generate a camera view with a View Direction Vector $\{A\ B\ C\}^T$ and an Up Vector $\{D\ E\ F\}^T$, both the Reference View Direction Vector $\{0\ \ 0\ \ -1\}^T$ and the Reference Up Vector $\{0\ \ 1\ \ 0\}^T$ should be rotated about a rotation unit vector $\{x\ y\ z\}^T$ by a rotation angle θ. The rotation of the Reference View Direction Vector and Reference Up Vector could be expressed mathematically using the following:

$$\begin{Bmatrix} A \\ B \\ C \end{Bmatrix} = \begin{bmatrix} x^2+(1-x^2)\cos\theta & x.y.(1-\cos\theta)-z.\sin\theta & x.z.(1-\cos\theta)+y.\sin\theta \\ x.y.(1-\cos\theta)+z.\sin\theta & y^2+(1-y^2)\cos\theta & y.z.(1-\cos\theta)-x.\sin\theta \\ x.z.(1-\cos\theta)-y.\sin\theta & y.z.(1-\cos\theta)+x.\sin\theta & z^2+(1-z^2)\cos\theta \end{bmatrix} * \begin{Bmatrix} 0 \\ 0 \\ -1 \end{Bmatrix} \tag{3.3}$$

$$\begin{Bmatrix} D \\ E \\ F \end{Bmatrix} = \begin{bmatrix} x^2+(1-x^2)\cos\theta & x.y.(1-\cos\theta)-z.\sin\theta & x.z.(1-\cos\theta)+y.\sin\theta \\ x.y.(1-\cos\theta)+z.\sin\theta & y^2+(1-y^2)\cos\theta & y.z.(1-\cos\theta)-x.\sin\theta \\ x.z.(1-\cos\theta)-y.\sin\theta & y.z.(1-\cos\theta)+x.\sin\theta & z^2+(1-z^2)\cos\theta \end{bmatrix} * \begin{Bmatrix} 0 \\ 1 \\ 0 \end{Bmatrix} \tag{3.4}$$

The equations 3.3 and 3.4 can be broken down to the following equations:

$$-x.z.(1-cos\theta) - y.sin\theta = A \tag{3.5}$$

$$-y.z.(1-cos\theta) + x.sin\theta = B \tag{3.6}$$

$$-z^2 - (1 - z^2)cos\theta = C \tag{3.7}$$

$$x.y.(1 - cos\theta) - z.sin\theta = D \tag{3.8}$$

$$y^2 + (1 - y^2)cos\theta = E \tag{3.9}$$

$$y.z.(1 - cos\theta) + x.sin\theta = F \tag{3.10}$$

Since the above equations illustrate a rotation of a camera and to simplify the solution of the equations, the researcher assumed that the Up Vector of the any camera view is always directed upward. Then, the Up Vector will always be $\{0 \;\; 0 \;\; 1\}^T$ and the six rotation equations become:

$$-x.z.(1-\cos\theta) - y.\sin\theta = A \tag{3.11}$$

$$-y.z.(1-\cos\theta) + x.\sin\theta = B \tag{3.12}$$

$$z^2 - (1-z^2)\cos\theta = C \tag{3.13}$$

$$x.y.(1-\cos\theta) - z.\sin\theta = 0 \tag{3.14}$$

$$y^2 - (1-y^2)\cos\theta = 0 \tag{3.15}$$

$$y.z.(1-\cos\theta) + x.\sin\theta = 1 \tag{3.16}$$

From equation (3.15),

$$y^2 = \frac{-\cos\theta}{1-\cos\theta} \Rightarrow \boxed{y = \sqrt{\frac{-\cos\theta}{1-\cos\theta}}} \tag{3.17}$$

Since the View Direction Vector and the Up Vector are perpendicular, then the dot product of the vectors equals zero.

$$A.D + B.E + C.F = 0 \Leftrightarrow A.0 + B.0 + C.1 = 0 \Rightarrow \boxed{C = 0} \tag{3.18}$$

From equations (3.18) and (3.13),

$$\Rightarrow \boxed{z = y = \sqrt{\frac{-\cos\theta}{1-\cos\theta}}} \tag{3.19}$$

Since rotation vector $\{x\ y\ z\}^T$ is a unit vector,

$$x^2 + y^2 + z^2 = 1 \Rightarrow x^2 = 1 + \frac{2\cos\theta}{1-\cos\theta} \Rightarrow \boxed{x = \sqrt{\frac{1+\cos\theta}{1-\cos\theta}}} \tag{3.20}$$

From equation (3.16),

$$y.z.(1-\cos\theta) = 1 - x.\sin\theta \tag{3.21}$$

From equations (3.21) and (3.12),

$$-(1 - x.\sin\theta) + x.\sin\theta = B \Rightarrow \boxed{2x.\sin\theta = B+1} \tag{3.22}$$

From equations (3.20) and (3.22),

$$2\left(\sqrt{\frac{1+\cos\theta}{1-\cos\theta}}\right).\sin\theta = B+1 \Rightarrow \ 4\left(\frac{1+\cos\theta}{1-\cos\theta}\right).\sin^2\theta = (B+1)^2 \Rightarrow$$

$$4\left(\frac{1+\cos\theta}{1-\cos\theta}\right).(1-\cos^2\theta) = (B+1)^2 \Rightarrow \ 4\left(\frac{1+\cos\theta}{1-\cos\theta}\right).(1-\cos\theta)(1+\cos\theta) = (B+1)^2 \Rightarrow$$

$$\boxed{(1+\cos\theta)^2 = \left(\frac{B+1}{2}\right)^2} \tag{3.23}$$

Equation (3.23) has two solutions the first solution is:

$$(1+\cos\theta) = -\left(\frac{B+1}{2}\right) \Rightarrow \cos\theta = -\left(\frac{B+1}{2}\right) - 1 \Rightarrow \boxed{\cos\theta = \frac{-B-3}{2}}$$

B is a component of a unit vector. Therefore, *B* ranges between -1 and 1 which makes this solution invalid because cosθ has to range between -1 and 1. The second solution of the equation (3.23) is:

$$(1+\cos\theta)=\left(\frac{B+1}{2}\right)\Rightarrow \cos\theta=\left(\frac{B+1}{2}\right)-1\Rightarrow \boxed{\cos\theta=\frac{B-1}{2}} \qquad (3.24)$$

Equation (3.24) is a valid solution of the equation (3.23). If *B* ranges from -1 to 1 then cosθ ranges from -1 to 0 which means that θ ranges from 90˚ to 270˚. As a result, to generate a camera view with a View Direction Vector $\{A\ B\ 0\}^T$ and an Up Vector $\{0\ 0\ 1\}^T$, equation (3.24) can be used to calculate the rotation angle θ and equations (3.19) and (3.20) can be used to calculate the rotation axis components (x y z). The View Direction Vector is located in a horizontal plane XY because the Up Vector is upward. A is the X-coordinate component and B is the Y-coordinate component of the View Direction Vector. Since the View Direction Vector is a unit vector, then:

$$\sqrt{A^2+B^2}=1\Leftrightarrow\sqrt{\cos\alpha^2+\sin\alpha^2}=1$$

Therefore, *B* in the equation (3.24) can be substituted by sinα.

$$\boxed{\cos\theta=\frac{\sin\alpha-1}{2}} \qquad (3.25)$$

α is the angle between the View Direction Vector and the X-coordinate. α is very important for the entire BIM CAVE concept. By changing α, the camera will rotate about the Z-coordinate and will reflect an adjacent camera view.

The 3D mathematical rotation algorithm obtains the Y-coordinate (*B*) of the current camera view. Next, the 3D mathematical rotation algorithm calculates the value of α for the current camera view. Then, it adds the camera angle that is entered by the user to α to calculate the new value of α. Afterward; , the 3D mathematical rotation algorithm calculates θ, x, y, z using equations (3.25), (3.19) and (3.20). After that, the values of θ, x, y, z will be used by the Navisworks COM API algorithm on the client applications to reflect the rotated camera view.

3.3. BIM CAVE Mechanism

The BIM CAVE software is the core program of the BIM CAVE Prototype. It controls all the hardware and the rest of the software programs to generate an immersive visualization environment. The way the BIM CAVE software creates an immersive visualization environment is by producing a continued and synchronized view on all the LCD screens of the BIM CAVE Prototype. The BIM CAVE Prototype has three LCD screen and each one of them is connected to a separate computer. The view presented on one screen should reflect the view of the rotated camera and not the view of the adjacent screen. If the adjacent view is used, only 180 degree immersion will be achievable and the full immersion can never be achieved. While, if the rotated camera view is used, the 360 degree full immersive environment is achievable by adding more screens. This BIM CAVE Prototype covers 135 degree Field of View (FOV), each one of the three LCD screens shows a 45 degree FOV.

To achieve the continued and synchronized view on the three screens, one computer runs as a server and the other two computers run as clients. The BIM CAVE Software is triggered whenever the Navisworks camera view on the server changes. A change in Navisworks camera view could happen if the user navigated through a model. The first algorithm that works is the Navisworks API algorithm on the server. It collects the position and orientation attributes of the new camera view. Then, the 3D Mathematical Rotation algorithm uses the collected orientation attributes to create rotated camera attributes for the clients' screens. After that, the Server-Client algorithm transfers the position and rotated camera attributes to the clients. Then, the Server-Client algorithms on the clients receive the position and rotated camera attributes. Afterward, the Navisworks API algorithms on the clients apply the received position and rotated camera attributes on the clients' Navisworks. Figure 3-3 shows a flow chart that describes the way BIM CAVE software works.

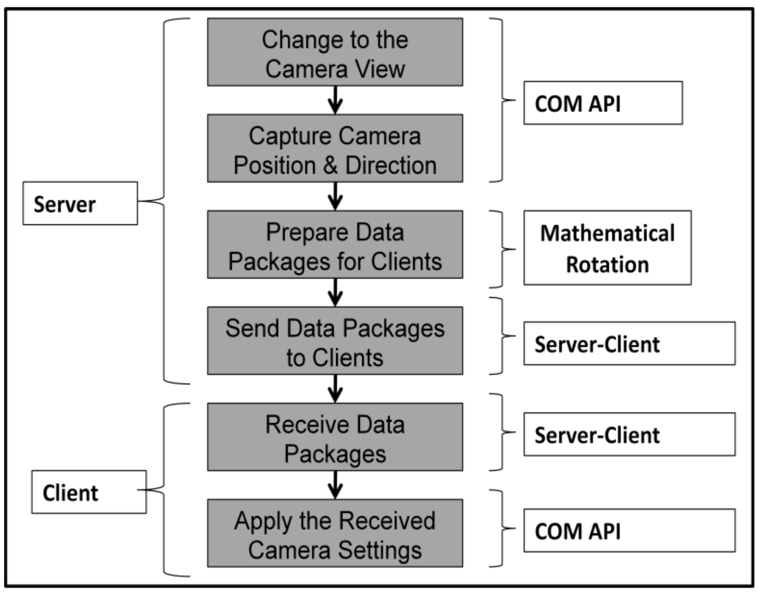

Figure 3-3: Flow Chart of the BIM CAVE Mechanism

3.4. BIM CAVE Software Interface

The BIM CAVE Software comes in two forms, a primary and a secondary. The primary should be installed on the server, while the secondary should be installed on all the clients. Both the primary and the secondary have a button to start Navisworks. The BIM CAVE system will not work if Navisworks is started from outside BIM CAVE

Software. The primary program allows the user to input the IP address and the camera angle for the clients and to select the port number to which the client will be connected. Figure 3-4 shows a screenshot of the BIM CAVE Primary interface.

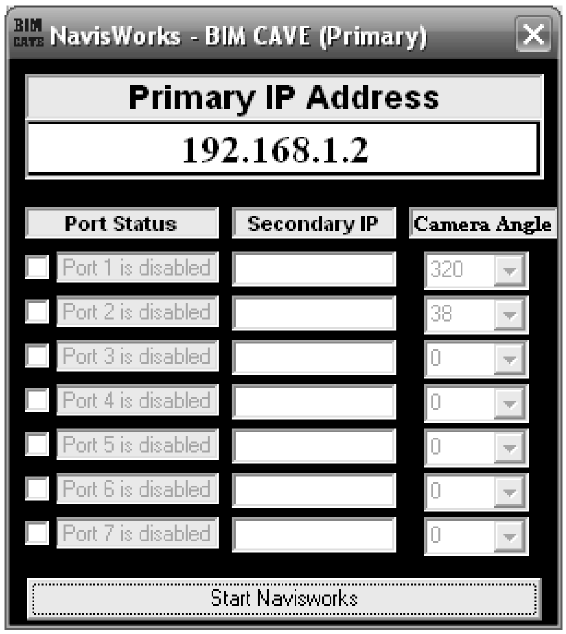

Figure 3-4: Screenshot of the BIM CAVE Primary Interface

The secondary program shows the IP Address of the Client that should be entered into the primary program. It also has a drop box that allows selecting the port number that will facilitate the connection between the primary and the secondary. In addition, the secondary program has a button to establish the connection between the primary and the secondary. However, the secondary program will not work unless the secondary's IP address is entered into the primary program. Also, the connection between the secondary and primary will not work unless the port number is the same on the primary and the secondary. Figure 3-5 shows a screenshot of the BIM CAVE Secondary interface.

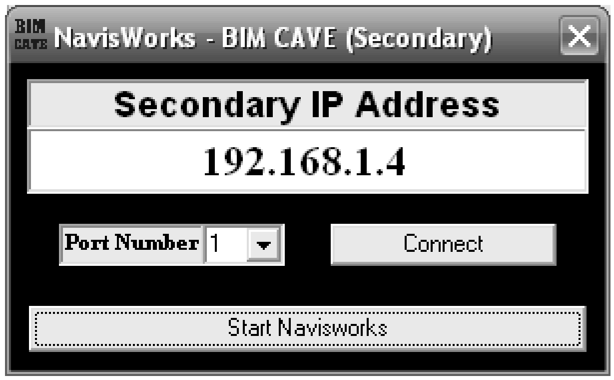

Figure 3-5: Screenshot of the BIM CAVE Secondary Interface

3.5. Summary

To verify if it is possible to create a BIM CAVE form a commercial BIM application, a BIM CAVE prototype was built in room 445 in the Department of Construction Science at Texas A&M University. The BIM CAVE prototype consists of three computers, three 55” LCD screens, and a network switch. Autodesk Navisworks was installed on each one of the computers and a BIM CAVE software program was developed to control and coordinate Navisworks camera view on every screen. BIM CAVE software controls the camera view is by placing Navisworks camera at the same location in all the computers and aiming it to a slightly different angle in each one. The BIM CAVE software program has two platforms Server or Primary and Client or

Secondary. The Server captures the location of the camera and sends commands to the clients through the network while the Client follows the Server commands.

The next section describes the research methodology that was followed in this research.

4. RESEARCH METHODOLOGY

This section describes the research techniques used throughout this study. Due to the nature of this study, a social science research method has been utilized and an explanation of the selection is provided.

4.1. Methodology Introduction

This research seeks to evaluate the BIM CAVE prototype and see if it can be considered an immersive visualization environment. Therefore, qualitative research was conducted to evaluate the validity of the BIM CAVE prototype as an immersive visualization environment. The research technique that was used was a Phenomenological Study. A Phenomenological Study is a study that attempts to understand people's perceptions, perspectives, and understandings of a particular situation (Leedy and Ormrod 2000). The purpose of the phenomenological approach is to study the experience of the research participants from their perspectives. The phenomenological approach is based on the knowledge and subjectivity of research participants.

The intention of the study was to explore and develop a phenomenological understanding of how research participants perceived the BIM CAVE system. However, this research focused on identifying attributes that supports the claim that the BIM CAVE is an immersive visualization environment. The research strategy that was developed was to facilitate a collaborative informal discussion between a research participant and the investigator about the use of BIM CAVE system as a visualization system. The purpose of the extended discussion was not to prove that the BIM CAVE system an immersive visualization environment. Rather, it was to provide opportunities whereby the research participant could communicate his or her thinking about the BIM CAVE as a visualization system. It was hypothesized that undertaking the collaborative informal discussion over an extended period of time would enhance the chance of gaining access to how research participants viewed the BIM CAVE system.

4.2. Research Design

The purpose of the research design was to allow access to research participants' knowledge and experience about Building Information Modeling and immersive visualization environment but more importantly to understand how the research participants viewed the BIM CAVE system. As a Phenomenological Study, this research depended on in-depth interviews with carefully selected sample of participants. A typical sample size in a Phenomenological Study is from 5 to 25 individuals (Creswell 1998). For this research, six individuals were interviewed.

Four factors are needed for the success of the research design. First, research participants must be Subject Matter Experts (SMEs) who are specialized in Building Information Modeling and immersive visualization environment. Second, it is hypothesized that there will be constrains that could hinder SMEs from experiencing the BIM CAVE system. Constrains include technical constrains such as a non-responsive software, and ambient constrains such as noise. These constrains were identified, effectively addressed and if possible removed in order to enable the participants to communicate their attitude about the BIM CAVE system. Third, the BIM model that is visualized on the BIM CAVE system during the interview has to be relevant to what the participant has experienced before. Fourth, the researcher in his interaction with the SME during the study should be collaborative and cooperative.

Therefore, the discussion needed to be non-aggressive, collaborative, and flexible to allow the participants to express their view of the BIM CAVE system. The interviews were audio recorded to facilitate the informality of the interview and the flow of the participant feedback. Also, research participants, who are industry professionals with direct experience in BIM and advanced visualization systems, had to meet certain criteria to be chosen. Research participants needed to possess some or all of the traits listed in Table 4.1 to be considered SMEs.

Table 4-1: Traits That Make Research Participants SMEs

Trait	Experience Description
Modeling	Creating BIM models using commercial BIM application such as Revit, Bentley, etc.
Coordination	Coordinating BIM Models created by different BIM platforms
Clash Detection	Managing clashes between different trades' models
Plugins & Families	Developing Plugins and parametric families for BIM applications
4D Modeling	Developing construction simulation models
Immersive VE	Using Immersive visualization environment such as CAVE
Semi-immersive VE	Using Multiple Screens visualization environment
Desktop VE	Using Desktop visualization environment

4.3. Data Collection

To collect data and gain knowledge from the SMEs, interviews were selected as a research instrument. The type of interviews that was conducted was semi-structured interviews. The reason why the semi-structured type was selected is because it allows the researcher to explore and probe deeper into the interviewee knowledge. Semi-structured interviews allow the researcher to change questions depending on the direction of the interview. Unlike in structured interviews, in semi-structured interviews researcher does not need to adhere to a detailed interview guide. The interviews were designed to gain the understanding of the SMEs thinking about the BIM CAVE system. The interviews procedures needed to be flexible to enable the SMEs to communicate their perspectives easily. Table 4.2 shows a list of questions that were asked in the interviews. However, additional questions were asked during the interviews based on the interviewees' answers.

Table 4-2: List of Questions That Were Asked in the Interviews

Questions
1. How would you describe BIM CAVE if someone asked you about it?
2. How do you think it could be improved?
3. How would compare the use of Navisworks between BIM CAVE and regular PC monitors?
4. Where do you think the BIM CAVE could be used and why?
5. What are the advantages and the disadvantages of BIM CAVE from your experience?

The interviews were audio recorded then transcribed to avoid memory loss and to facilitate the informality of the interview. The transcribed interviews are included in APPENDIX C. Data collection involved three phases:

1) The Pre-System Introduction Phase:

The purpose of this initial phase of data collection was to allow SMEs to introduce themselves and talk about their experience utilizing Building Information Modeling in an advanced visualization environments. This phase allowed accessing the SMEs more general views about BIM technology and advanced visualization systems.

2) The System Introduction Phase:

This phase was an opportunity for the researcher to introduce the BIM CAVE system and to expose the research participants to the BIM CAVE concept. The introduction started by navigating through a BIM model using Navisworks on each one of three computers of the BIM CAVE Prototype. Then, the researcher would activate the BIM CAVE software functionalities which would create a continued synchronized view on the three screens. What was important about this phase was not the way the researcher navigated through the model before and after activating BIM CAVE software but rather the SMEs reactions and inquires about the BIM CAVE system. This phase was a catalyst for the SMEs discussion with the researcher.

3) The Post System Introduction Phase:

This phase involves a collaborative and flexible discussion which was conducted immediately after the BIM CAVE system is introduced. In this phase the SMEs were invited to comment on what had occurred when the BIM CAVE software was activated.

As this was the last phase of the interview, it lasted longer but more importantly it sought to understand how the research participants viewed the BIM CAVE system. In this phase, the researcher attempted to access the SMEs' knowledge and experience about immersive visualization environments to motivate them to express how they viewed the BIM CAVE system. Also, this phase sought to access what the SMEs thought about the BIM CAVE benefits and limitations.

4.4. Validity and Reliability

The collection of data using semi-structured interviews can be accurate and reliable because the researcher is certain of the source of the data (the interviewees). Also, the informal communication and interaction quality between the researcher and participants in semi-structured interviews may decrease the amount of misunderstanding and misinterpretation by the researcher. Semi-structured interviews allow the researcher to explore for more explanations and verifications from participants. Findings from semi-structured interviews can be made more valid and reliable by comparing them with findings revealed by the other methods, for example, structured interviews, employed in the same research (Kvale 1996).

4.5. Data Analysis

The data analysis will follow the typical data analysis of a phenomenological study. The central task during data analysis is to identify common themes in people descriptions of their experiences. After transcribing the interviews, the researcher takes the following steps (Leedy and Ormrod 2000):

1) Identify statements that relate to the topic.

This step was accomplished by identifying statements that describe how the SMEs viewed the BIM CAVE system. Any phrase or statement that the SME described some features of the BIM CAVE system was located and marked. This step allowed identifying the general perspective of SMEs about the BIM CAVE system.

2) Group statements into "meaning units" or themes.

This step was accomplished by searching for key words in the identified statements. Key words that were searched for were words that could be used to describe an immersive visualization system such as immersive environment, large screens, field of view, and virtual reality. The main goal of this step was to identify whether the SMEs used some of the immersive visualization features to describe the BIM CAVE system.

3) Seek divergent perspectives.

This step was implemented by scanning the transcripts to identify how SMEs described the benefits and the limitation of the BIM CAVE.

4) Construct a composite.

In this step, the identified attributes from the previous steps were used to develop an overall description of how the SMEs viewed the BIM CAVE system. Then, the researcher checked the overall description to see if it could be concluded that BIM CAVE is a valid immersive visualization environment.

4.6. Summary

To evaluate the BIM CAVE as an immersive visualization environment, industry professionals with experience in BIM and advanced visualization were invited to participate in the research. A qualitative study was conducted using a phenomenological approach to explore how research participants view BIM CAVE system from their perspectives. The research was designed to allow research participants to communicate their opinions about the BIM CAVE in non-aggressive, collaborative, and informal discussion. Semi-structured interviews type was selected as an instrument to collect data because it allows the researcher to explore and probe deeper into the interviewee knowledge. The analysis of the collected data will allow identifying the general perspective of the research participants about the BIM CAVE system and documenting their opinions regarding its benefits and limitations.

The next section will layout the research findings and will present how research participants viewed the BIM CAVE system.

5. RESEARCH RESULTS

This section presents the findings of this research by following the research methodology. The main goal of this section is to present and analyze how the SMEs viewed the BIM CAVE system. The outcome of this research will form the foundation to draw conclusions and make recommendations. The analysis of the findings will provide the information needed to meet the research objectives by proving that it is possible to develop BIM CAVE using a commercially available BIM application and by evaluating BIM CAVE as an immersive visualization environment.

As part of the preparation for the interviews, the same Navisworks model was copied to all three computers to be visualized by the BIM CAVE prototype. The model was for a building called Emerging Technologies Building which was under construction at Texas A&M University. The Emerging Technologies Building is a 212000 square feet that includes classrooms, offices, research labs, computer labs, and three-story atrium designed for events, gatherings and display of innovative research.

By following the first phase of data collection as mentioned in Section 4, SMEs were asked to introduce themselves and talk about their experience utilizing Building Information Modeling in an advanced visualization environments. The number of SMEs who were invited to participate in this research was six. Research Participants were all industry professionals with experience in BIM technology and knowledge in advanced visualization techniques. The six participants were one Architect, two BIM Manager, and three Project Managers. In order to protect the identity of the research participants, their names were kept confidential and each participant was assigned a number. The participants who carried number 1, 3, and 6 were project managers. Participant number 2 was an Architect. Participants number 4 and 5 were BIM Managers. Table 5-1 shows some of the areas of experience that each SME has in the field of BIM and advanced visualization. Explanations of the areas of experience are presented in Table 4-1.

Table 5-1: SMEs Expertise

SME	Current Position	Expertise						
		Modeling	Coordination	Clash Detection	Plugins & Families	4D Modeling	Immersive or Semi-immersive Visualization	Desktop VE
1	Project Manager	---	Yes	Yes	---	Yes	Yes	Yes
2	Architect	Yes	Yes	---	Yes	---	Yes	Yes
3	Project Manager	---	Yes	Yes	---	Yes	Yes	Yes
4	BIM Manager	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	BIM Manager	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Project Manager	---	Yes	Yes	---	Yes	Yes	Yes

In the second phase of data collection, System Introduction Phase, the researcher introduced SMEs to the BIM CAVE system. First, the researcher showed how Navisworks works separately on each computer and how to set up BIM CAVE software. Figure 5-1 shows a photo of setting up the BIM CAVE software.

Figure 5-1: Setting up BIM CAVE Software

Next, the researcher activated BIM CAVE software which transformed the three separate views on the three screens to a single continued view on all the three screens. Figures 5-2 and 5-3 show an inside the model view before and after the activation of BIM CAVE software.

Figure 5-2: Before Activating BIM CAVE (Inside the Model)

Figure 5-3: After Activating BIM CAVE (Inside the Model)

Figures 5-4 and 5-5 show an outside the model view before and after the activation of BIM CAVE software.

Figure 5-4: Before Activating BIM CAVE (Outside the Model)

Figure 5-5: After Activating BIM CAVE (Outside the Model)

After the System Introduction Phase, interviews turned into collaborative flexible discussions during which the researcher asked the interviewees the questions listed in Table 4-2. However, additional questions were asked throughout the interviews based on the interviewees' answers. A transcription of all the interviews is included in APPENDIX C.

To analyze the collected data, the data analysis steps, mentioned in Section 4, were followed to analyze the SMEs perspectives about the BIM CAVE system. Therefore, the data analysis focused on three areas according to the data analysis steps. First, areas in which SMEs related BIM CAVE system to immersive visualization systems. Second, areas in which SMEs described the benefits of BIM CAVE system. Third, areas in which SMEs described the limitations of BIM CAVE system.

5.1. BIM CAVE as an Immersive Visualization System

Following the first two steps of data analysis allowed the researcher to identify statements that SMEs used to relate BIM CAVE to immersive visualization systems and to group these statements by the features they describe. The analysis of the SMEs' views of the BIM CAVE system led to the fact that all the six participants used immersive visualization features to describe the BIM CAVE system. Five of the participants described the BIM CAVE as an immersive or a step toward full immersion. Two participants pointed to the wide Field of View (FOV) as one of the BIM CAVE features. And one participant described his experience in the BIM CAVE as virtual reality experience. Table 5-2 summarizes how SME related BIM CAVE system to immersive visualization systems.

Table 5-2: SMEs Description of BIM CAVE System

SME	Immersive Visualization Features		
	Immersive	Wide FOV	Virtual Reality
1	Yes	---	---
2	---	---	Yes
3	Yes	---	---
4	Yes	Yes	---
5	Yes	Yes	---
6	Yes	---	---

Participant 1 described the BIM CAVE as immersive by saying "*if you're looking at a model for the first time, a 3D model in this immersive environment will give you a better idea of what you're looking at".* Participant 2 noted that adding more screens to the BIM CAVE prototype will make the BIM CAVE a virtual reality system when stated "*I see where you're going with the 14 screens. That goal I can see being pretty amazing, virtually being in the space*". Participant 3 thought that the BIM CAVE is a step toward full immersion by saying "*This, what you have here is a big step into an* *immersion. The point is, if you can immerse somebody, in an environment like this and they can get a grasp on what it is and what it's going to look like*". Participant 4 viewed BIM CAVE as a system that allows for a wider field of view and immersion by stating "*The way you have your cameras set up it's very nice that you have this because in one Navisworks view you can't really stretch that panoramic view that far. I could see the way you have it set up so that you're linking camera views and I saw that you had point to this machine and your angle of cameras. I could see where, potentially, you could turn a room into a fully immersive studio with this capability*". Participant 5 also pointed to the wide field of view and the immersion that BIM CAVE allows for by saying "*as far as the concept. I love the concept, I think it's a great concept, being able to sit here in your little workspace and being able to visualize, it's almost like sitting in your room and turning your head and seeing everything that's there. And it's certainly a step further than looking at it on one screen and then having to turn around because you don't really know, but like I said, being able to see the peripheral, if you will, probably like a 200 degree angle of vision is very powerful. The field of vision is a lot more limited just with it being stretched, you might only see half of this part and you'd still have to rotate it that way. Stretching it is great, but what you've done is to be able to change the different camera angles. So you've gone from a 70 degree peripheral to a 200 degree peripheral. So you're able to see that much more. It's important for duct work and long runs of pipe*". Participant 6 perceived the BIM CAVE system as an immersive system by saying "*it's an immersive BIM experience where you're getting a better perspective of the model*".

5.2. Benefits of BIM CAVE System

Following the third step of data analysis allowed the researcher to identify statements that SMEs used to describe the advantages of BIM CAVE system. The analysis of the SMEs' perspectives about the BIM CAVE system showed that all the participants used parts of the interviews to describe the anticipated benefits of utilizing the BIM CAVE system in the industry. The BIM CAVE advantages that the research participants shared with the researcher during the interviews can be summed up to that the BIM CAVE system could improve the following tasks:

- The communication of the BIM information among project participants, including geometries, materials, light … etc.
- The presentation of the design intent to the owner
- The identification of clashes to help subcontractors
- The facility management
- The construction efficiency

Participant 1 stated "*Depending on the way this model was extracted, there's still some information in there. You see the glass on the windows, I think; it recognizes that it's glass. I think this, presentation-wise, would be great to set this up in a conference room in a main building and show them what's being built. It works great, it's really great. It's better than the one screen we use. It gives you more awareness of where you are. If you're looking at it for the first time, a 3D model in an immersive environment will give you a better idea of what you're looking at, but if it's on the field,* *if you're just looking at a clash or conflict, but I think it's much more powerful as a presentation tool and maybe for facility management*".

Participant 2 stated "*There are certainly two situations where I think it would be beneficial. One is for the owner to better visualize what the building is actually like, but then working out conflicts in the field with subcontractors is a use that's totally different. There are a lot of times when we do clash detection and we're moving around, trying to figure out, what's going on there and if it was more of a virtual environment. This system helps really in gaining more knowledge of the building*".

Participant 3 said "*To me this system leads to less cost, future competitiveness, to less waste, both material, human, time, the whole thing. So, to me, it allows itself, or allows for a more efficient process. Also, the more you can engage or draw somebody into the geometry that you're looking at the more they'll be able to understand, and at least in their mind, they'll be able to put things together*".

Participant 4 stated "*I think this system could help in several different avenues. You have whatever you do between an architect and an owner, being able to portray that design and intent to the owner*".

Participant 5 said " *In lieu of having to build very expensive mock-ups that not only take up a lot of time, but a lot of money to do, and space, you're able to do it in a virtual atmosphere for a lot less cost and a lot less time. What used to take weeks to configure now takes hours. It's very minor in terms of cost, being able to visualize this. If you rendered it out, it's going to take a little bit more and you have to invest money in the software and hardware to be able to do it, but it's changing the industry worldwide.*

95% of people in the world are visual learners. Once they see it one time they understand it. Being able to visualize something; the knowledge you gain from being able to visualize it before you have to go build it is tremendous".

Participant 6 stated "*This is definitely useful. The more you see of the model at one time, it helps you get a better grasp*".

5.3. Limitations of the BIM CAVE System

Following the third step of data analysis allowed the researcher to identify statements that SMEs used to describe the limitations of BIM CAVE system. The analysis of the interviews' transcripts showed that the research participants recognized limitations in the BIM CAVE system. The limitations that the SMEs pointed to can be summed up to the following issues:

- The vertical limitation of the camera rotation which prevents tilting the camera up and down
- The practicality of using the BIM CAVE system on a job site
- The slow processing speed of Navisworks API which sometimes cause a delay in the synchronized view on the three LCD screens

Participant 1 stated "*The only issue that I could think with that is that if I have a clash and I'm in the room and it's above me, what do I do? Also, on the jobsite though, it may not be, I don't think the word is 'practical.' Having that many screens and that much technology on a job site depends on the job site. There's some risk to it. Is it practical?*"

Participant 2 said "*If you can't adjust that angle look-up, that's really an issue*".

Participant 4 stated "*Honestly, we haven't seen anything that does this same thing where you have several different ideas tied to one control. I know there's this lag issue because of the API. I could see though, potentially, if Navisworks could catch up to what you're doing*".

Participant 5 said "*As far as the concept and I'm not saying there's an issue with what you've prepared, what you've prepared is great, the concept is great, you're just hindered a little bit by the equipment you currently have in terms of processing speed in terms of how quickly it refreshes*".

Participant 6 stated "*I think that's a big thing because a lot of what we do, you have to look at multiple angles to figure out the best solution, if that makes sense. Sometimes to get the best view of something, you have to be below it looking up or looking down*".

5.4. Summary

To analyze how the SMEs perceived the BIM CAVE system, the steps of data collection and data analysis, presented in Section 4, were followed. The data collection throughout the interviews went from pre-system introduction phase to system introduction phase to the post system introduction phase. The interviews took a form of non-aggressive, collaborative, and informal discussion. The analysis of the collected data followed the four steps of data analysis from Section 4. The data analysis identified three ways the interviewees viewed the BIM CAVE system. First, areas in which SMEs related BIM CAVE system to immersive visualization systems. Second, areas in which

SMEs described the benefits of BIM CAVE system. Third, areas in which SMEs described the limitations of BIM CAVE system.

The next section provides a summary of this research. Then it lists some of the limitations of this study and the recommendations for future research.

6. CONCLUSIONS

This section provides a summary of this research that briefly explains the research problem, motivations, and findings. Then, the limitations of this study and recommendations for future research are presented.

6.1. Research Summary

This study is an attempt to prove that it possible to transform a commercial BIM application into an immersive visualization environment and overcome a problem presented by the available immersive visualization systems. The problem is that in order to visualize an information rich BIM model from a commercially available BIM application in an immersive visualization environment, the model needs to be converted to formats such as VRML or X3D that can be used in the immersive visualization system. The conversion is a time consuming process and would cause a loss of information in the model. To overcome this problem, this research proposed a new approach (concept) called BIM CAVE. The concept behind the BIM CAVE is to establish an immersive visualization environment by having a commercial BIM application installed on multiple computers and utilizing Application Programming Interface (API) to control and coordinate the camera view in every computer by placing the camera at the same location in all the computers and aiming it to a slightly different angle in each one. Navisworks was chosen to test the BIM CAVE concept because it is widely used among industry professionals; It allows the project team to achieve real-time visualization, 3D coordination, and 4D construction simulations; and it is customizable through a powerful application-programming interface (API). The BIM CAVE approach was applied by developing a software program that utilizes Navisworks' API to control Navisworks' camera angle and generate an immersive visualization environment. A prototype of the BIM CAVE was built in the Department of Construction Science at Texas A&M University. The objectives of this research are to prove that it is possible to develop a BIM CAVE using a commercial BIM application and to evaluate the BIM CAVE as an immersive visualization environment.

To evaluate the BIM CAVE as an immersive visualization environment, a phenomenological study was conducted by interviewing subject matter experts (SMEs) from the industry. The intention of the study was to explore and develop a phenomenological understanding of how research participants perceived the BIM CAVE system. The study focused on identifying keywords in which SMEs described features from BIM CAVE related to features from immersive visualization systems. Features from immersive visualization systems could include immersion, wide field of view, large displays, virtual reality, and stereoscopic. The analysis of the participants' view of the BIM CAVE system led to the fact that all the six participants used immersive visualization environment features to describe the BIM CAVE system. Five of the participants described the BIM CAVE as an immersive or a step toward full immersion. Two participants pointed to the wide field of view as one of the BIM CAVE features. One participant described his experience in the BIM CAVE as virtual reality experience.

As a conclusion, with some limitations the SMEs' evaluations of the BIM CAVE prototype provide evidence that it is possible to transform a commercial BIM application to an immersive visualization system. However, this research does not provide enough evidence to make generalizations about the BIM CAVE system. In order to make the generalization that any commercial BIM application can be transformed to a fully immersive visualization system, several screens must be installed at the walls and the ceiling to achieve the full immersion and the BIM CAVE concept must be tested on several other commercial BIM applications.

6.2. Limitations

This study faced two types of limitations, limitations related research methodology and limitations related software programs.

6.2.1. Research methodology limitations

The research methodology limitations include that the typical sample size range for a Phenomenological Study is between 5 and 25. The sample size that was used in this research was six. The fact that sample size of this study resides in the lower side of the range could limit the confidence level of the research outcome. Also, even though the researcher tried to obtain an unbiased sample of the SMEs population, there was only limited number of SMEs who were willing to come to Texas A&M campus to participate in the research during the limited time of the study. These limitations increase the possibility of biased sample which could affect the reliability of the research outcome.

6.2.2. Software related limitations

Several issues need to be solved before a fully immersive visualization environment can be developed using the API of Autodesk Navisworks. Some of these issues were addressed by the research participants. These issues could limit the practicality and the usability of the BIM CAVE system.

The first issue is the slow synchronization speed between the views presented on the BIM CAVE screens. This problem is directly related to the speed in which Navisworks processes API commands to change the camera views. This problem has been address to the Navisworks engineering team through Autodesk Developer Network (ADN).

The second issue is the vertical limitation of the camera rotation which prevents tilting the camera up and down. This issue can be solved in two ways. The first way is by adding screens to the BIM CAVE ceiling and floor so there will be no need to tilt the camera. The second way is by changing the 3D Mathematical Rotation algorithm of the BIM CAVE software. However, releasing the vertical limitation of the camera in the mathematical rotation algorithm could create a set of equations that might be challenging to solve.

Finally, the BIM CAVE prototype operates only with three screens. If several other screens were to be used in the system, some other limitations might arise.

6.3. Future Research

1. Research can be carried out to add more functions to the current BIM CAVE prototype. For example, a function that allows the user to visualize the data embedded in the BIM model during the navigation.
2. Further research can be accomplished to validate the BIM CAVE concept in general by utilizing API from BIM applications other than Navisworks.
3. Research can be carried out to test the effectiveness of BIM CAVE in communicating the BIM information including the geometry, construction sequence and clashes.
4. Further research can be performed by adding the stereoscopic element to the BIM CAVE system and testing effectiveness of BIM technology when the stereoscopic view is activated.

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APPENDIX A

NAVISWORKS COM API CLASSES

Class Member	Description
_InwControlEvents	Interface represents events for Navisworks ActiveX control
_InwOpStateEvents	Interface represents Navisworks state events
_InwScriptParserEvents	Script parser events interface
Document	Represents an instance of NavisWorks
Inavisdoc	Primary dispatch interface for NavisWorks automation interface
InwBase	Base interface for most Navisworks objects
InwClashPlugin	Navisworks COM Clash plugins must implement this interface
InwClashPlugin_Site	Interface represents a place holder for a Clash plugin
InwClashTestsColl	Interface represents a collection of clash tests
InwClippingPlaneColl	Interface represents a collection of clipping planes
InwClippingPlaneColl2	Clipping Planes Collection Extension Interface
InwCollBase	Base interface for all collections
InwCommentsColl	Interface represents a collection of user comments
InwControl	Navisworks ActiveX Control
InwControl2	Navisworks ActiveX Control
InwControl3	Navisworks ActiveX Control
InwControl4	Control extension interface
InwControl5	Control extension interface
InwExportPlugin	Navisworks COM Export plugins must implement this interface
InwExportPlugin_Site	Interface represents a place holder for an Export plugin
InwGlobalProperties	Interface represents Navisworks global properties
InwGlobalProperties2	GlobalProperties extension interface
InwGUIAttribute	Interface represents a GUI attributes, this is a named list of properties, takes overrides into account
InwGUIAttribute2	GUI attributes extension interface
InwGUIAttributesColl	Interface represents a collection of GUI attributes
InwGUIPropertyNode	Interface represents a node as a list of GUI attributes, taking into account overrides
InwGUIPropertyNode2	GUI property node extension interface
InwLBaseVec3f	Base interface representing a vector of 3 doubles

Class Member	Description
InwLBox3f	Interface represents a 3d box
InwLightsColl	Interface represents a collection of lights
InwLPlane3f	Interface represents a 3d plane
InwLPlane3f2	3d plane extension interface
InwLPos3f	Interface represents a 3d position
InwLPos3fColl	Interface represents a collection of positions
InwLRotation3f	Interface represents a 3d rotation
InwLRotation3f2	Interface represents a 3d rotation
InwLTransform3f	Interface represents a 3d transform
InwLTransform3f2	Extra transform interface
InwLTransform3f3	Interface represents a 3d transform
InwLUnitVec3f	Interface represents a 3d unit vector
InwLVec3f	Interface represents a 3d vector
InwNodeAttributesColl	Interface represents a nodes attributes as a attributes
InwNodeFragsColl	Interface represents a collection of fragments in a node
InwNodeNodesColl	Interface represents a nodes children as a collection of nodes
InwNvCamera	Interface represents a camera
InwNvViewer	Interface representing a viewer
InwNvViewPoint	Interface represents a viewpoint
InwNvViewPoint2	Viewpoint extension interface
InwOaAttribute	Interface represents an attribute of a node
InwOaBinaryAttribute	Binary Attribute interface
InwOaClipPlane	Interface represents a plane that clips rendering
InwOaCommonLight	Base interface for lights
InwOaDistantLight	Interface represents a distant light
InwOaFragment	Interface represents a fragment
InwOaFragment2	Extra fragment interface
InwOaFragment3	Fragment extension interface
InwOaGeometry	Interface represents a node that represents geometry
InwOaGroup	Interface represents a node that contains child nodes
InwOaMaterial	Interface represents an attribute that represents a material
InwOaNameAttribute	Interface represents an attribute that consists of a name string
InwOaNat64Attribute	Interface represents an attribute that consists of a 64 bit integer

Class Member	Description
InwOaNode	Base interface represents a node in the model
InwOaPartition	Interface represents a node that represents a file
InwOaPartition2	Extra partition interface
InwOaPartition3	Partition extension interface
InwOaPath	Interface represents a path through the model data from the root partition to specific node
InwOaPath2	Extra path interface, helper methods
InwOaPath3	Path extension interface
InwOaPointLight	Interface represents a point light
InwOaProperty	Interface represents a named Variant property
InwOaPropertyAttribute	Interface represents an attribute consisting of a collection of named properties
InwOaPropertyColl	Interface represents a collection of properties
InwOaPropertyVec	Interface represents a standalone collection of properties
InwOaPublishAttribute	Interface representing a published attribute
InwOaSceneBase	Base interface for scene objects
InwOaSpotLight	Interface represents a spot light
InwOaTextAttribute	Interface represents an attribute that consists of a text string
InwOaTransform	Interface represents a transform
InwOaURLAttribute	Interface represents an attribute that consists of a collection of URL's
InwOclClashTest	Interface represents a Clash Detective test
InwOclClashTest2	Clash Test extension interface
InwOclTestResult	Interface represents an individual clash test result
InwOpAnimView	Interface represents a named animation
InwOpAnonView	Interface represents an un-named view
InwOpClashElement	Interface represents 'Clash Detective'
InwOpComment	Interface represents a user comment
InwOpComment2	User comment extension interface
InwOpComment3	User comment extension interface
InwOpCutView	Interface represents a cut view
InwOpFind	Interface represents a find object, used to search the model for a particular find specification
InwOpFindCondition	Interface represents a find condition
InwOpFindConditionsColl	Interface represents a collection of find conditions
InwOpFindSpec	Interface represents a find specification, used for to detemine model searching

Class Member	Description
InwOpFolderView	Interface represents a folder containing other saved views
InwOpGroupView	Base interface represents a group of other saved views
InwOpInternalPlugin	Member of Navisworks API
InwOpProgress	Interface represents progress of an operation
InwOpSavedView	Base interface for all saved view types
InwOpSelection	Interface represents a selection in the model
InwOpSelection2	Interface represents a lightweight Int32 vector
InwOpSelectionSet	Interface represents a named selection that can be saved
InwOpSelectionSet2	Extra selection set interface
InwOpSelectionTreeInterface	Interface that implements a a selection tree
InwOpState	Interface represents the internal state of Navisworks
InwOpState10	State extension interface
InwOpState2	Extra state interface
InwOpState3	Extra state interface
InwOpState4	State extension interface
InwOpState5	State extension interface
InwOpState6	State extension interface
InwOpState7	State extension interface
InwOpState8	State extension interface
InwOpState9	State extension interface
InwOpUserFindSpec	Interface that implements a user find specs
InwOpUserFindSpecsColl	Interface that implements a collection of user find specs
InwOpUserSelectionTreePlugin	Interface that implements a user selection tree plugin
InwOpUserSelectionTreeSpec	Interface that implements a user selection tree spec
InwOpView	Interface represents a named view
InwOpView2	View extension interface
InwOw2DTextureSpaceShader	Interface represents a Presenter 2D texture space shader
InwOw3DTextureSpaceShader	Interface represents a Presenter 3D texture space shader
InwOwBackgroundShader	Interface represents a Presenter background shader
InwOwColorShader	Interface represents a Presenter color shader
InwOwDisplacementShader	Interface represents a Presenter displacement shader

Class Member	Description
InwOwMaterial	Interface represents a Presenter material
InwOwMaterialMapping	Interface represents a mapping between a Presenter material and geometry
InwOwMaterialMappingsColl	Interface represents a collection of material mappings
InwOwPresenterElement	Interface represents Presenter
InwOwReflectanceShader	Interface represents a Presenter reflectance shader
InwOwShader	Base interface for all Presenter shaders
InwOwShaderArgument	Interface represents a shader argument
InwOwShaderArgumentsColl	Interface represents a collection of shader arguments
InwOwTransparencyShader	Interface represents a Presenter transparency shader
InwOwUserMaterialsColl	Interface represents a collection of user materials
InwPathNodesColl	Interface represents a path as a collection of nodes
InwPlugin	All Navisworks COM plugins must implement this interface
InwPlugin_Site	Interface represents a place holder for a plugin
InwPluginLicense	Plugin licensing interface
InwPluginsColl	Interface represents a collection of COM callable plugins
InwPresenterPlugin	Navisworks COM Presenter plugins must implement this interface
InwPresenterPlugin_Site	Interface represents a place holder for a plugin
InwPropertyPlugin	Navisworks COM Property plugins must implement this interface
InwPropertyPlugin2	Interface representing a property plugin (2)
InwPropertyPlugin2_Site	Interface representing a property plugin site (2)
InwPropertyPlugin_Site	Interface represents a place holder for a plugin
InwSavedViewsColl	Interface represents a collection of saved views
InwScriptParser	Interface allows access to registered script engines
InwSeekSelection	Call-back interface for searching through Navisworks model
InwSelectionPathsColl	Interface represents a selection as a collection of paths
InwSelectionSetColl	Interface represents a collection of selection sets
InwSelectionSetExColl	Hierarchical collection of selection sets, may contain InwSelectionSetFolder and InwOpSelection interfaces
InwSelectionSetFolder	Selection Sets Access
InwSelectionTreePlugin	Interface representing a selection tree plugin

Class Member	Description
InwSelectionTreePlugin_Site	Interface representing a selection tree plugin site
InwSimplePrimitivesCB	Geometry simple primatives callback
InwSimpleVertex	Simple Vertex interface
InwSmartTagsOpts	Interface representing smart tag options
InwTestResultsColl	Interface represents a collection of individual clash tests results
InwUInt32Vector	Interface represents a lightweight Int32 vector
InwUResource	Interface representing a string resource object
InwUResource2	InwUResource extension interface
InwURL	Interface represents a named URL
InwURL2	Extra URL interface
InwURLCategoriesColl	Interface represents a collection of URL categorys
InwURLCategory	Interface represents a collection of URL categorys
InwURLColl	Interface represents a collection of URL's
InwURLOverride	Interface represents a URL override
InwUtilityObject	Interface representing a utility object
NavisworksCtrlAPI8::nwControl	Implements the Navisworks ActiveX control
nwControl	Navisworks ActiveX Control
nwControlProp	Property page for Navisworks ActiveX control
nwOpState	Interface represents the internal state of Navisworks
NavisworksAPI8::nwOpState	Implementation of InwOpState10, created internally
NavisworksCtrlAPI8::nwOpState	Implementation of InwOpState5, created internally
NavisworksAPI8::nwScriptParser	Utility that makes it easy to implement user scripting
nwScriptParser	Interface allows access to registered script engines
NavisworksCtrlAPI8::nwScriptParser	Utility that makes it easy to implement user scripting
NavisworksCtrlAPI8::nwUtilityObject	Implements the Navisworks general utility object
NavisworksAPI8::nwUtilityObject	Implements the Navisworks general utility object
nwUtilityObject	Member of Navisworks API
nwVerIndependentControl	Version Independent Helper Components
nwVerIndependentScriptParser	Version Independent Helper Components
nwVerIndependentState	Version Independent Helper Components

APPENDIX B

SOURCE CODE

The Source Code of the 3D Mathematical Rotation Algorithm:

```
Private Sub m_state_OnCurrentViewChanged()
Dim i, PortCount As Integer
Dim Pos_X, Pos_Y, Pos_Z, Cos_Rot_Angle, Rot_Angle, Rot_X, Rot_Y, Rot_Z,
Sign_Test, Current_Rot_Angle, Current_Angle, New_Angle, View_Dir As
Double
Dim Data_Package, Data_Package1, time1 As String
time1 = TimeToMillisecond()
'Dim sFileText As String
'Dim iFileNo As Integer
If Abs(m_state.CurrentView.ViewPoint.Camera.GetViewDir.data3) > 0.0001
Then
    Current_Rot_Angle =
m_state.CurrentView.ViewPoint.Camera.Rotation.angle * 180 /
3.14159265358979
    If m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data2 > 0
Then
        Sign_Test = 1
    Else
        Sign_Test = -1
    End If
    View_Dir = 2 * Cos(Current_Rot_Angle * 3.14159265358979 / 180) + 1
    If 1 - Abs(View_Dir) < 0.00001 Then
        If View_Dir > 0 Then Current_Angle = 90
        If View_Dir < 0 Then Current_Angle = 270
    Else
        If Current_Rot_Angle <= 180 Then
            Current_Angle = 180 - Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        ElseIf Current_Rot_Angle > 180 And Current_Rot_Angle <= 240
Then
            Current_Angle = 360 + Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        Else
            Current_Angle = Atn(View_Dir / Sqr(-View_Dir * View_Dir +
1)) * 180 / 3.14159265358979
        End If
    End If
    Cos_Rot_Angle = (Sin((Current_Angle * 3.14159265358979 / 180)) - 1)
/ 2
    If 1 - Abs(Cos_Rot_Angle) < 0.00001 Then
        Rot_Angle = 3.14159265358979
    Else
        If Current_Angle >= 90 And Current_Angle < 270 Then
            Rot_Angle = (Atn(-Cos_Rot_Angle / Sqr(-Cos_Rot_Angle *
Cos_Rot_Angle + 1)) + 2 * Atn(1))
        Else
```

```
            Rot_Angle = 2 * 3.14159265358979 - (Atn(-Cos_Rot_Angle /
Sqr(-Cos_Rot_Angle * Cos_Rot_Angle + 1)) + 2 * Atn(1))
        End If
    End If
        If Current_Angle >= 90 And Current_Angle < 270 Then
            Rot_X = ((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^ (1 /
2)
        Else
            Rot_X = -((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^ (1 /
2)
        End If
            Rot_Y = Sign_Test * ((-Cos_Rot_Angle) / (1 -
Cos_Rot_Angle)) ^ (1 / 2)
            Rot_Z = Rot_Y
        If Current_Rot_Angle = 0 And
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data1 = 0 And
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data2 = 0 And
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data3 = 1 Then
            'cmdStart.Enabled = True
            Exit Sub
        Else
            On Error Resume Next
            Rotate_Axis.SetValue Rot_X, Rot_Y, Rot_Z
            m_state.CurrentView.ViewPoint.Camera.Rotation.SetValue
Rotate_Axis, Rot_Angle
        End If
End If
    Pos_X = Format(m_state.CurrentView.ViewPoint.Camera.Position.data1,
"#0.00000")
    Pos_Y = Format(m_state.CurrentView.ViewPoint.Camera.Position.data2,
"#0.00000")
    Pos_Z = Format(m_state.CurrentView.ViewPoint.Camera.Position.data3,
"#0.00000")
    Current_Rot_Angle =
m_state.CurrentView.ViewPoint.Camera.Rotation.angle * 180 /
3.14159265358979
    If m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data2 > 0
Then
        Sign_Test = 1
    Else
        Sign_Test = -1
    End If
    'Text1.Text = m_state.CurrentView.ViewPoint.Camera.HeightField *
180 / 3.14159265358979
    'Text2.Text = m_state.CurrentView.ViewPoint.Camera.AspectRatio
    'Text3.Text = 2 *
Atn(Tan(m_state.CurrentView.ViewPoint.Camera.HeightField / 2) *
m_state.CurrentView.ViewPoint.Camera.AspectRatio) * 180 /
3.14159265358979
    View_Dir = 2 * Cos(Current_Rot_Angle * 3.14159265358979 / 180) + 1
    If 1 - Abs(View_Dir) < 0.00001 Then
        If View_Dir > 0 Then Current_Angle = 90
        If View_Dir < 0 Then Current_Angle = 270
```

```
    Else
        If Current_Rot_Angle <= 180 Then
            Current_Angle = 180 - Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        ElseIf Current_Rot_Angle > 180 And Current_Rot_Angle <= 240
Then
            Current_Angle = 360 + Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        Else
            Current_Angle = Atn(View_Dir / Sqr(-View_Dir * View_Dir +
1)) * 180 / 3.14159265358979
        End If
    End If
    For i = 0 To 6
    If chkPort(i).Value = 1 Then PortCount = PortCount + 1
    Next
    For i = 1 To PortCount
        Winsock(i - 1).RemoteHost = Trim$(txtIP(i - 1).Text)
        Winsock(i - 1).RemotePort = CLng(i + 186)
        New_Angle = Current_Angle + Val(cmbAngle(i - 1).Text)
        If Sign_Test = -1 Then New_Angle = Current_Angle + (360 -
Val(cmbAngle(i - 1).Text))
        If New_Angle > 360 Then New_Angle = New_Angle - 360
        Cos_Rot_Angle = (Sin((New_Angle * 3.14159265358979 / 180)) - 1)
/ 2
        If 1 - Abs(Cos_Rot_Angle) < 0.00001 Then
            Rot_Angle = 3.14159265358979
        Else
            If New_Angle >= 90 And New_Angle < 270 Then
                Rot_Angle = (Atn(-Cos_Rot_Angle / Sqr(-Cos_Rot_Angle *
Cos_Rot_Angle + 1)) + 2 * Atn(1))
            Else
                Rot_Angle = 2 * 3.14159265358979 - (Atn(-Cos_Rot_Angle
/ Sqr(-Cos_Rot_Angle * Cos_Rot_Angle + 1)) + 2 * Atn(1))
            End If
        End If
            If New_Angle >= 90 And New_Angle < 270 Then
                Rot_X = ((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^
(1 / 2)
            Else
                Rot_X = -((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^
(1 / 2)
            End If
                Rot_Y = Sign_Test * ((-Cos_Rot_Angle) / (1 -
Cos_Rot_Angle)) ^ (1 / 2)
                Rot_Z = Rot_Y
        Data_Package = Pos_X & "|" & Pos_Y & "|" & Pos_Z & "|" &
Format(Rot_X, "#0.00000") & "|" & Format(Rot_Y, "#0.00000") & "|" &
Format(Rot_Z, "#0.00000") & "|" & Format(Rot_Angle, "#0.00000") & "|" '
& time1 & "|" & TimeToMillisecond()
        Winsock(i - 1).SendData Data_Package

          'iFileNo = FreeFile
```

```
          '  Data_Package1 =
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data1 & "|" &
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data2 & "|" &
m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data3 & "|" &
Current_Rot_Angle & "|" & Rot_X & "|" & Rot_Y & "|" & Rot_Z & "|" &
Rot_Angle * 180 / 3.14159265358979 & "|" & Current_Angle & "|" &
New_Angle & "|" & View_Dir & "|" &
m_state.CurrentView.ViewPoint.Camera.GetViewDir.data2 & "|" &
m_state.CurrentView.ViewPoint.Camera.GetViewDir.data1 & "|" &
Cos_Rot_Angle
          'Open "C:\Documents and Settings\BIM CAVE1\Desktop\Test1.txt"
For Append As #iFileNo
          'Print #iFileNo, Data_Package1
          'Close #iFileNo
    Next
End Sub

Private Sub cmbAngle_Click(Index As Integer)
Dim i As Integer
Dim Pos_X, Pos_Y, Pos_Z, Cos_Rot_Angle, Rot_Angle, Rot_X, Rot_Y, Rot_Z,
Sign_Test, Current_Rot_Angle, Current_Angle, New_Angle, View_Dir As
Double
Dim Data_Package As String
i = Index
    Pos_X = Format(m_state.CurrentView.ViewPoint.Camera.Position.data1,
"#0.00000")
    Pos_Y = Format(m_state.CurrentView.ViewPoint.Camera.Position.data2,
"#0.00000")
    Pos_Z = Format(m_state.CurrentView.ViewPoint.Camera.Position.data3,
"#0.00000")
    Current_Rot_Angle =
m_state.CurrentView.ViewPoint.Camera.Rotation.angle * 180 /
3.14159265358979
    If m_state.CurrentView.ViewPoint.Camera.Rotation.GetAxis.data2 > 0
Then
        Sign_Test = 1
    Else
        Sign_Test = -1
    End If
    View_Dir = 2 * Cos(Current_Rot_Angle * 3.14159265358979 / 180) + 1
    If 1 - Abs(View_Dir) < 0.00001 Then
        If View_Dir >= 1 Then Current_Angle = 90
        If View_Dir < 1 Then Current_Angle = 270
    Else
        If Current_Rot_Angle <= 180 Then
            Current_Angle = 180 - Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        ElseIf Current_Rot_Angle > 180 And Current_Rot_Angle <= 240
Then
            Current_Angle = 360 + Atn(View_Dir / Sqr(-View_Dir *
View_Dir + 1)) * 180 / 3.14159265358979
        Else
```

```
            Current_Angle = Atn(View_Dir / Sqr(-View_Dir * View_Dir +
1)) * 180 / 3.14159265358979
        End If
    End If

    Winsock(i).RemoteHost = Trim$(txtIP(i).Text)
    Winsock(i).RemotePort = CLng(i + 187)
    New_Angle = Current_Angle + Val(cmbAngle(i).Text)
    If Sign_Test = -1 Then New_Angle = Current_Angle + (360 -
Val(cmbAngle(i).Text))
    If New_Angle > 360 Then New_Angle = New_Angle - 360
    Cos_Rot_Angle = (Sin((New_Angle * 3.14159265358979 / 180)) - 1) / 2
    If 1 - Abs(Cos_Rot_Angle) < 0.00001 Then
        Rot_Angle = 3.14159265358979
    Else
        If New_Angle >= 90 And New_Angle < 270 Then
            Rot_Angle = (Atn(-Cos_Rot_Angle / Sqr(-Cos_Rot_Angle *
Cos_Rot_Angle + 1)) + 2 * Atn(1))
        Else
            Rot_Angle = 2 * 3.14159265358979 - (Atn(-Cos_Rot_Angle /
Sqr(-Cos_Rot_Angle * Cos_Rot_Angle + 1)) + 2 * Atn(1))
        End If
    End If
        If New_Angle >= 90 And New_Angle < 270 Then
            Rot_X = ((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^ (1 /
2)
        Else
            Rot_X = -((1 + Cos_Rot_Angle) / (1 - Cos_Rot_Angle)) ^ (1 /
2)
        End If
            Rot_Y = Sign_Test * ((-Cos_Rot_Angle) / (1 -
Cos_Rot_Angle)) ^ (1 / 2)
            Rot_Z = Rot_Y
    Data_Package = Pos_X & "|" & Pos_Y & "|" & Pos_Z & "|" &
Format(Rot_X, "#0.00000") & "|" & Format(Rot_Y, "#0.00000") & "|" &
Format(Rot_Z, "#0.00000") & "|" & Format(Rot_Angle, "#0.00000") & "|"
    Winsock(i).SendData Data_Package
End Sub
```

APPENDIX C

INTERVIEW TRANSCRIPTS

Interview #1

Interviewer: This is version 1 and we are working on version 2 which is going to have 14 screens displayed in two layers from the floor to the ceiling, to get you guys surrounded almost like 270 degrees whenever you are in the BIM CAVE. So this system is developed and fabricated to prove the concept, that we invented and see how it goes. And it is working, so we are about to move on to a second phase which will have more screens and I'm looking at multiple options. The first option is use a 14, 55" screens, that's the easiest thing we can do. But I don't like the edge of the screens, it's ugly. So I'm looking for edgeless displays which will be a little more expensive. I'm contacting Samsung electronics to establish a video wall. Video wall is their own product that has multiple screens up to 25 screens with almost edgeless displays. It's kind of similar things that you see at the airport, multiple screens. So I'm thinking of kind of getting the multiple screen systems at the BIM CAVE.

Interviewee1: I can't remember what I saw, I think at one of the movie theatres nearby where they have a couple of screens. I think they have a really small edge.

Interviewer: That's they system that I'm talking about. I worked on programming the BIM CAVE software that control Navisworks on several computers.

Interviewee1: So you run, in this case three computers, and you control it with one mouse.

Interviewer: You control the three computers with one mouse, one keyboard you can control the three computers and you can control Navisworks on the three computers.

Interviewee1: Ok, so you actually just, it's kind of like a Windows functionality where you can use one mouse on the same screen. You locate one synchronized location of the mouse on all three computers…

Interviewer: Not really, you use the mouse on one computer and the other computer will follow

Interviewee1: Ok, but when you move the mouse on this computer, the mouse actually moves on two other computers too.

Interviewer: The model will move, but the mouse will still on the computer you are controlling. For this system, we're having the mouse on the server. Like what was said, we're trying to prove the concept, that you can really control. Like, if the system works on three screens, then the idea will work on 8 screens or whatever amount of screens you want.

Interviewee1: So why not use one computer and multiple screens.

Interviewer: Because if you want to visualize, like if you want to have immersive system, how can you do it with one computer. If you want to be surrounded by the model, that's the main motivation instead of stretching the model, that's the main motivation. The concept of immersion is to be surrounded.

Interviewee2: So when you have 14 screens, you'll need 14 computers.

Interviewer: Yes, or 7 computers, each computer with 2 screens.

Interviewer: I would like to ask you how you like the BIM CAVE system from the professional point of view and basically, I will ask you the difference between when you view the model on one screen versus three screens and we like to see how much more information you think can get on three screens versus one screen. Also, at the same time, we like to ask you, what will have to be proved. Obviously, there's some limitation that this application has.

Interviewer: First, I would like to learn about what kind of experience you have with virtual reality systems and BIM in general.

Interviewee1: This is my first project I've used BIM. I've done a little bit of AutoCAD, 2D and a little bit of 3D too. My background is, I did Civil Engineering as my undergrad and Construction Management as my masters. But this is my first project where I use Navisworks. I also have a little bit of training in DProfiler, it's a 3D software but it's a focus on estimating. It's just building a wall and the cost information that's on that wall in the 3d model.

Interviewer: Now, on the project you're working on, what kind of advanced visualization are you working on. Are you using one screen, two screens…

Interviewee1: When we were doing this one, we were using two screens and I think 20" screens. He was just using one to visualize the space and I think one as tool bars. For our team meetings, we had a projector, so we projected it onto the screen and we were looking at the projector on the wall.

Interviewer: How about you Keith?

Interviewee2: On the architecture side, we work on Revit, so we use it on a daily basis. Then, we export that Revit model for the guys in the field to use in Navisworks. So we don't really use Navisworks ourselves but then we participate in the discussions when we go to the job sight and using clash detection and if there's a conflict, we'll all look at the screen together.

Interviewer: So you use the same visualization method?

Interviewee2: In the field, but when we're designing in the office it's just a computer screen.

Interviewer: I'll start with the application and how it works. Basically we have the server and two clients. I'll start Navisworks from inside my application. See there is a little time lag between the screens because these two computers are looking at what the main computer is working on. So you will see a little lag. Sometimes the system is more complicated than when you using one computer with three screens. We had to have three screens talking to each other. The reason we are having three screens talking to each other is because we want this system expanded with more screens in the future. I'm using this because this is much slower. If we use this everything is going to be moving pretty slow. We are still working on it. We kind of blocked the angle of the camera. The camera can't move to change the pitch of the angle. So even if you try to look up, it is because, let's say you are surrounded by all the screens, 360 degrees and if you look up your neck, by changing the angle of the camera, the front part of the screen will be ok, but what about the screens behind you, it's going to be looking at the floor. Because of that future situation that we thought about, we blocked the angle of the camera.

Interviewee1: The only issue that I could think with that is that if I have a clash and I'm in the room and it's above me, what do I do?

Interviewer: Another idea is to put the screen attached to the ceiling so that when you move, when you walk through the building, you don't have to change the angle of the camera and the pitch of the camera, instead, you just take a look up to the ceiling to take a look at what's above you. So that's another idea.

Interviewee1: Now are these three screens on a flat surface and you're tilting the surface a little bit?

Interviewer: No it's located like this angular shape, because we positioned these three cameras at the same location looking at a little bit different angles. Naturally, if you project this to three screens allocated in a flat area, then the view is going to look a little awkward. Naturally, whenever you have cameras, you are looking at different angles at one location; natural view is coming when you get the screen surrounding you 360 degrees.

Interviewee1: What's your primary goal besides having this virtual room?

Interviewer: We try to accomplish this. It's not working at the moment. Whenever you see this building information model, the main reason of using the building information modeling CAVE system is not only to see the building in an immersive environment, but also you want to retrieve some information in the building information model. So the tendency is you want to touch want of the components of the model and then extract some of the information embedded in the model. So if you can touch the model like this and then the menu pops up. And then if you select one of these, you can take a look at information embedded in the component. That function is still undeveloped. Basically, whenever you like to distinguish this BIM CAVE system from the regular CAVE system, which is just about showing you the graphics in an immersive environment. Information is something you are supposed to collect from BIM. So that's another thing we are trying to do as a next step. But you get the idea as to how we will be able to extract some of the information from the model in the near future. We are working on one screen. But if we want to use more stuff, we would like to use a touch screen.

Interviewee1: Depending on the way this model was extracted, there's still some information in there. You see the glass on the windows, I think; it recognizes that it's glass.

Interviewer: A lot of information is embedded in Navisworks. If I go like this, it's still working synchronizedly. You can see the property. So if I touch this one, it gives me any information embedded in this. Unfortunately, when we enlarge the screen, it disappears. So we don't have a chance to see what it is. One additional thing we need to do is to be able to pop up the same screen with this F11 function.

Interviewee2: Who do you imagine extracting this information from the model, is that the owner or the builder?

Interviewer: Basically the GC is the first one who wants to extract some kind of information when the construction process is going on. And secondly when the construction process is over, when the owner is taking over this model, then they are going to be using this BIM model for facilities management, if this model has all the information they want for maintaining the facility, which is another issue going on at the moment. Not all BIM has information that owners need to run their facility. We are talking about what other information we are supposed to embed in this model for facilities management after the construction is over.

Interviewee1: The way we've talked about it is that, we basically add a link. Let's just say we have a pump and I want the information about the pump. We just add a link to the pump and that link will take you whatever PDF, let's just say the O&M manual.

Interviewer: That's one of the easiest ways to do it.

Interviewee1: Instead of having Navisworks have the information.

Interviewer: Navisworks has a function to embed those URL to each and every component.

Interviewee2: So with the contractors, the eventual goal is to replace documents? Or is it in addition to construction documents to better understand.

Interviewer: They like to use this BIM as a hub to get into information that they need to use to maintain their facility or to do whatever they need to do.

Interviewee1: And you see this CAVE concept as the way the owner will use this as opposed to one screen.

Interviewer: If they have funding available, why not. The more screens will give you a more realistic feeling that you are in the facility. Especially, this system is going to help your subs understand what they are supposed to do at a certain timeframe within the construction process. If we embed the timeline in this model and you show those timelines with the immerse system to all the subs in the coordination meeting then you can easily get them to understand what they are supposed to do at a certain timeframe at a certain location. This is a system you can use to run the construction process. It's going to give you a chance to build a building in cyberspace. Then you get a chance to know the potential conflicts or challenges you will have to handle in advance in cyberspace. And then make a correction, in advance, proactively. And then, for the real project, you don't have that issue anymore because you got them fixed in advance, so you are not going to have to handle those same issues anymore on the job sight.

Interviewee1: Having multiple screens is an interesting idea. When we are having these meetings, usually we are having 10 plus people, so whatever you do with this concept, it needs to be more than one user, something that everyone can be in.

Interviewer: There's two ways. Having multiple users to take a look at the same thing at the coordination meeting is critically important. That's the reason why people are a little reluctant to use head-mounted display. Whenever I use head-mounted display, I see certain things, but it doesn't guarantee you'll see the same thing I see. But if we have this immersive system going on. If you have multiple people in this immersive system in the same room, then everybody's looking at the same stuff and then you pinpoint here and there as if you are on the job site and you can bring up all the issues you want to talk to the subs about. That's the beauty of having this kind of system. Now the way you see the system and how, in the future, it could be advanced, do you think it would help you in the type of work you do.

Interviewee1: Yes, having more real estate, you're going to have a better idea of what you're looking at – it's definitely a plus. On the jobsite though, it may not be, I don't think the word is 'practical.' Having that many screens and that much technology on a job site depends on the job site. There's some risk to it. It's the practicality; someone needs to be aware of it.

Interviewee2: There are certainly two situations where I think it would… One is for the owner to better visualize what the building is actually like, but then working out conflicts in the field with subcontractors is a use that's totally different. Going back to what was said, when we do that clash detection, the ability to stand in a space and look around is really critical. If you can't adjust that angle look-up, that's really an issue.

Interviewee1: This could be a great presentation tool for an owner. You're proposing something and you want him to look at, it would be great. I think this, presentation-wise would be great to set this up in a conference room in a main building and show them what's being built.

Interviewer: This is going to be a pretty good promotional tool. But we like to see a chance of taking this to the field, that the people in the coordination meeting can use the system to get a better understanding of the project so that the project manager can have everyone on the same page.

Interviewee2: I see where you're going with the 14 screens. That goal I can see being pretty amazing, virtually being in the space. What do you think about one conventional screen versus these three screens, are you getting anything more? There are a lot of times when we do clash detection and we're moving around, trying to figure out, what's going on there and if it was more of a virtual environment, we could understand it better. But I'm not sure going from one conventional screen to this CAVE right here, if we're getting there.

Interviewee1: I don't know, maybe it's just me as a preference. The flat screen, I know where I'm navigating. When I have three screens at a different angle, it's kind of, for me, it's may be a little bit confusing. It's probably just a little getting used to.

Interviewee2: When I'm navigating around a model and trying to walk through it, one thing that's constantly running through my head is, "where am I?" And I don't know if there's a way you could have a key map, like a plan, so that when I'm scrolling through there, you're also where in the plan or section you are.

Interviewee1: There is a way; Navisworks has that function, where you can see the plan with the little arrow. It's definitely interesting. There is plus and minuses. I can definitely see my surroundings, but how much is it valuable here versus just one screen.

Interviewer: The benefit using this system. Think about using one screen and try to look around. If you have one screen you have to do this to look around. With this system, you don't have to do that. Instead you just look around. Instead of using the computer to move around, you just look around. It's very intuitive, not only for the BIM coordinator, but also those using the BIM model. One of the challenges I know BIM coordinators have at a meeting, is they have a hard time getting into a certain spot so that they can keep getting attention from those attending a meeting. Whenever you don't bring into a certain space within 5 seconds or so, you will see people flipping through their drawings to figure out where they are. So if you can bring people into a certain location very rapidly. If you save this position or location, You just bring the camera into that location almost immediately. Then you don't have to look around, because you get people surrounded by the screen already. So all of the sudden people will have a chance to look around that space. All you have to do is bring that camera into a certain spot that you are talking about and then the coordinator doesn't have to move around all the time. As opposed to just using one screen, if we had this sort of involvement then you don't have to move around to take a look at everything going on in this clash, so that's one beauty of using multiple screens.

Interviewee1: I could see using having maybe three or a couple, but usually if you're navigating to one spot, you may catch something on the back.

Interviewer: it's a totally different approach to looking at BIM. One screen is just one camera and everyone's looking at the one camera to try to understand the space. This system expands the view to almost 160 degrees. The BIM coordinator's job is going to be much easier to have people understand what's in the space. All you have to do is bring the camera into one space. You don't have to look around just to bring the camera into one space. And then people will have a chance to look around.

Interviewee2: Let's say the final, it was at TAMU, 14 screens, working perfectly. Us as Beck, we could make an appointment and bring our model, bring the owner.

Interviewer: Or we can install all these screens in a trailer and then take the trailer to your job sight.

Interviewee2: You can just imagine having a client and saying OK, now we're going to look at the class room and you're in the class room. And then saying now we're going to look at the lobby and then you're in the lobby. I remember in grad school we would make cardboard models and would joke saying if only we could make models 1:1 so we could crawl in it, but this is like getting as close as you can.

Interviewer: Do you think we should put the screen on the ceiling as well, if we can?

Interviewee2: Yeah, because for clash detection, that's where all the conflicts occur is in the ceiling.

Interviewee1: Unless you want to raise the eye level up, but then you wouldn't have to have them on the ceiling, but still you need a way to look up.

Interviewer: We want to take a look at that. This BIM CAVE is going to give us a chance to put people in the space.

Interviewee2: You're 14 screens, are they all like that or is it like a dome sphere?

Interviewer: We would like to have some type of sphere-type of screen if it's technically possible. But as you see, no LCD projector is released with this type of shape. So we have to deal with these technical limitations at the moment. So I guess one option is to have, instead of a rounded screen, a cubic type of screens, in front, side and bottom. That way we can handle everything that you guys want to have. I would say for the ceiling, you might use a projector instead of hanging a screen. Projector is not the option because it's going to be cumbersome technology to handle. LCD projector is much easier for us to handle than any other projecting system.

Interviewee2: If the 14 screens were all this area, if you could look up and move up to look, that would probably do the trick.

Interviewee1: Is there away to have a viewport, I know AutoCAD does that.

Interviewee2: Wait viewport, what do you mean?

Interviewee1: If I'm looking at the plan, I have multiple sheets, I can do that here.

Interviewee2: You can do that in Revit.

Interviewer: Even in Navisworks.

Interviewee1: When you navigate it doesn't follow you.

Interviewer: That's a good idea; it has something to do with the idea of putting a key map on the screen if we can designate one screen showing different information, like the drawing or any schedule or anything like that. For example, let's say we are in a room and people ask, ok, what's the schedule of all the material belonging to this room and then we have one screen showing all the schedule, that would be awesome.

Interviewee2: That would be nice. Sometimes you are navigating around and you get stuck in a wall and you have no idea where you are. If you have a key, you would know which direction to move.

Interviewer: The information is another issue we will have to handle. We will see the space using the BIM CAVE, another thing people will ask is information attached to this space. The ultimate goal is when you click anywhere on this screen it will tell you this thickness or dimension is whatever.

Interviewee2: So we the architects have to be much more precise with our modeling.

Interviewer: That will be the issue in the near future. Because I will have some owners in Texas talking about what information we are asking architects and GC's to put into the BIM for maintaining the facility after the construction is over. That information may not have anything to do with what you do in the design phase or in the construction phase. It might be additional work to provide this information, whether you want to do it for free or get paid for it…

Interviewee1: It's like an enhanced turn-over.

Interviewer: Enhanced as built model.

Interviewee1: On the field side, we look for clashes more, that's pretty much what we do in the field. The architects, they dimension this and basically build a 3D models and put 2D drawings together so they can distribute it out in the field. It would be great to have, construction people are really good at looking at 2Ds, looking at the plans and saying this is what it is. 3D is a step up but it's the arrangement you have to make it easier for them to understand what it is. It works great, it's really great. It's better than the one screen we use. It gives you more awareness of where you are.

Interviewer: Another idea, these applications have the ability to do what's called stereoscopic, where you can really see 3D and recognize the depth too and see the object moving toward you. Do you think this type of functionality would help.

Interviewee1: It's something awesome and cool, but how different it is from what we use right now…

Interviewee2: It could be a way to wow a client.

Interviewee1: For a presentation tool it's awesome. For the field, I don't know how appropriate it would be from a 2D.

Interviewee2: Yeah, are really gaining more knowledge of the building.

Interviewer: Now if you have, let's say pipe, do you think 3D is much easier than 2D?

Interviewee1: If it's a clash, the link will take you there and then you zoom in and out to give people an idea of where they are. If you're looking at it for the first time, a 3D model in an immersive environment will give you a better idea of what you're looking at, but if it's on the field, if you're just looking at a clash or conflict, but I think it's much more powerful as a presentation tool and maybe for facility management.

Interviewee2: If it's a complicated clash with a bend and maybe it could be pretty helpful in coming up with a solution.

Interviewee1: And the way we do that is we just go around the object many times

Interviewee2: So this would speed that up.

Interviewer: How about managing space, do you think this kind of system could help?

Interviewee1: You would have to model whatever you would want to be shifting around into that and move it on the 3D model to understand. Usually that's coordination by the superintendent which has a more pragmatic view on this. You may need to put someone in between to explain to that person. You would need a little bit of a buffer between technology and practicality.

Interview #2

Interviewer: I would like to talk about, you mentioned a little go about, the immersion, you said, what do you think the benefit of the immersion model.

Interviewee3: The benefit, from my perspective, revolves around, taking somebody who does not understand what's happening as far as a building being built. The analogy I was using earlier, um, we do a lot of hospital work, typically you have Ors, on the hospital jobs we're doing now, we build full scale mock-ups of an OR room and we bring the chief surgeon in and we arrange things and allow him to interact with that and say, "no, I want my surgical light over there, I want this here, so we do all that so we get it right before we actually start building. What this technology allows for is trending that way with the advancement of technology hardware to interact to do that type of mock-up. So someone truly understands that this is what it's going to look like when it gets built as opposed to just looking at a set of drawings. A doctor is really good, chief surgeons are very good at surgery, conceptualizing in 3D by looking at a 2D plane, probably not so good. A lot of the work I've done in high-tech laboratories, the investigators are absolutely bank up with it comes to performing their science, but when it comes to using a copy machine, hanging a picture on the wall, not so good. So, they joke about the fact that they're not allowed to do it. So, I'm not making fun of them too bad, because they make fun of themselves, but the point is, if you can immerse somebody, in an environment like this and they can get a grasp on what it is and what it's going to look like, that leads to better decisions up front, which means, you have a better chance at building it once, not having to change things or move things around. To me that leads to less cost, future competitiveness, to less waste, both material, human, time, the whole thing. So, to me, it allows itself, or allows for a more efficient process.

Interviewer: I would like to ask about your experience with building information model technology and with virtual reality system when you started working on building information modeling software or the technology in general.

Interviewee3: Um, true building information modeling software, I started working with 2003-4, um, I've been using AutoCAD and have been using AutoCAD to try to do the things we're trying to do today in AutoCAD since '87, um when I started using AutoCAD. Also, in a former job, when I was self-employed, I utilized some other software packages from around '94, AP design which was a parametric database but it was geared more towards residential. Well before Revit time, Revit, we always wondered when they were going to do something like an AP design for the commercial side. Then Revit came out and we started using it. As far as virtual reality, I'm probably better studied in it than having actual experience with it, um, I read a lot about it based on what I'm trying to accomplish in my job, but actual implementation, I'm not there yet.

Interviewer: Since you have theoretical experience with it, what are you trying to accomplish with it, immersion, stereoscopic. What kind of dimensions of the system you are trying to accomplish.

Interviewee3: The end goal of what I'm trying to accomplish is being able to put someone in a room where they have little to do to interact, and be able to interact within a room or a building, 360 degrees, east west, up and down. That's where I'd like to be. I've looked at the use of holograms. Realistically, a lot of what we're looking at today, somebody…

Interviewer: A hologram today, is pretty new technology. If you want to take a look at the car, as an object, from outside the object.

Interviewee3: It's an outside object.

Interviewer: Right, but if you want to take a look at certain things within the building, then obviously holograms are something that have some limitations because you cannot get into the building to take a look at what's in there.

Interviewee3: Not entirely true.

Interviewer: Is that right?

Interviewee3: You can. Uh, there's a company in Austin , MIT grads, they came up with a process of printing holograms on a special film. Instead of pencils, you have a single source of light that brings a hologram up, but what they also figured out. If I have a square of this film with a hologram on it, I'm on this side, my viewpoint's coming this way, if you're to my left, you're at a different viewpoint and he's at his viewpoint looking this way. Well they can print the holograms so looking from your direction, you see a building with a roof, from my direction, it's sectioned, so I see it with the roof pulled off. And from your viewpoint, you can see it with the wall pulled off. So, and what they're doing is very interesting. They're primary focus has been military. They support stuff in Afghanistan and Iraq. Typically, they take satellite pictures of a valley that someone's going to drive through and the soldiers look at that before they go through, figure out what they're issues. What they're struggling with right now is finding a commercial application for that technology. The other thing they're working on is a dynamic hologram that is interactive. Which is a totally different deal but it's small. I want the big one that I can step inside.

Interviewer: Right, that's what I mean about the hologram. If we can get into the hologram, then all of the sudden it's working in the construction industry. If it is small, then I can see it as a good application in the car industry.

Interviewee3: We've been experimenting a little bit. I need to pick up my experimentation a little bit, but utilizing it in construction. Taking coordination drawings for instance, if I have, if you are a pipefitter and we have pipe running overhead, I can position a point of view, in space, looking up. So if I held that up and shined a flashlight on it, I would see the pipe, the lights, whatever, turn it, section it, so I can go up the levels of MEP. Is it that, will a pipefitter who's been in business 30 years actually do something like that, maybe, maybe not, I don't know. What I've found with the things I've been working on on-job sites, it tends to be the older superintendents and the holder hands that tend to like this technology more than the younger, which is totally different.

Interviewer: Is that right?

Interviewee3: Oh yeah.

Interviewer: That's a little bit different experience that I had. When I was working with other construction company in 2004 and I was working to test on the build for the first time. One of the superintendent that we dealt with, kind of refused to take advantage of this technology. It took almost 3 months for us to get his attention to this model at the coordination meeting.

Interviewee3: Well, that's short-sighted, but, within a week, first time I showed him, he was like, that's crazy, I don't need that – typical answer. But then, I started walking him through the model, going underneath it and allowing him to see it from different angles that he typically wouldn't be able to see and next week he's like, do we have a new model yet. I have an issue with how I'm going to form this area up and I want to get underneath and look at this crawl space and see how the mechanical interacts. And I'm like, I'll call you as soon as I get one. I went and got one and I had him driving around, oh yeah, this is a little different than what I thought, but yeah this is good. So he developed his whole plan of attack in five minutes of spinning around in the model. And to me, that's a very efficient way of doing it. Instead of forming it up and getting half way through it and saying, um, this isn't going to work. I need to rip this down and start over. My experience at least, within my company is the older generation is starting to embrace this technology a lot more. Partially because, they realize that it's coming and they figure all the younger guys know all this stuff and they want to make sure they're staying competitive with the younger guys.

Interviewer: Now the other question that I guess I need to ask you, on behalf of him is between one screen and multiple screens, do you see any benefit in terms of browsing the model.

Interviewee3: With multiple screens there's a definite benefit because when you're fixing your point of view on the center screen and you're moving around the model, the side screens engage your peripheral vision. At least to me, it's somewhat more realistic. If I was walking on this roof that we're looking at right now and seeing everything move to my side. The only thing that would make that more is if I was closer so that these came out so that more of my peripheral vision was engaged, if that makes sense.

Interviewer: The vision that we have, is there is no kind of control screen whatsoever in the BIM CAVE anymore, and everything kind of a control display to somebody is. Let's say we have 5 people in the BIM CAVE and I see this one more important, but there will be other people who think the object is kind of more important for him to take a look so it's a multiple reaction for multiple people have a different interest in the object. I guess it's a little bit different. It's a more advanced way of looking at the function of the building image modeling CAVE. Do you think the size of the screen factors, like, do you think we should go with several screens next to each other, or this size is enough. Or bigger size. Do you think we should cover the whole room with this size or what.

Interviewee3: What I think is, ya'll need to figure out a way to cover all the walls, the ceiling and the floor and then somebody can walk in.

Interviewer: That's exactly what we talked about. And I thought about how I want to do it. At the beginning I thought about using a sphere, but with the rectangular LCD projector, it is not possible for us to replicate any sphere with a screen thing, unless you are using a projector.

Interviewee3: Unless you use a projector. But then you have the issue with, typically projectors focus on a flat surface, so when you're going to a sphere, you have to have focus correction because it's focused here, it's not, it's not, it's not and it's focused here.

Interviewer: Sphere with a little flat screen, so it's not a full sphere, it's a kind of edged.

Interviewee3: Like Epcot.

Interviewer: Yeah, Epcot, exactly. But at the same time, when I saw the technical difficulty to fabricate that one using rectangular LCD screen, I thought about, why don't we put that screen into a square box, with a screen up and down, back and forth, obviously in the corner of the screen, we may have some skewed vision of the model in the corner. Obviously that would be a draw-back of that, sort of a cubic CAVE system, but at the same time, we will have a chance to put the screen up and down and if we put kind of a glass floor on top of the screen on the bottom we can even walk on to the model. It will give people a pretty awesome feeling and the realistic feeling. So there will be pros and cons between going with the sphere system and the cubic CAVE system. And I guess from a project management point of view, we want to go with a cubic system instead of a sphere.

Interviewee3: Well even if you have a sphere and you're at that corner right there and you've got ceiling and two walls, it depends on how you use it. If someone's going to come up and stare in that corner, will it bug them; they might say something about it. But the point is, you're trying to give them the ability to physically move their head around be immersed in the model. I was joking with him earlier, because I was working on my BIM CAVE, and Samsung had some thin bezel monitors and I was looking at them, trying to do a video wall, and kicking around in angles. And this one specific monitor came with software that allowed you to synchronize 250 monitors. So I went to my boss and said, yeah, I need 250 of these monitors and they only cost like $6000 a piece and I want to put them on the ceiling, the floor and the walls and put an acrylic over the floor and he looked at me like I was absolutely crazy, which, I knew he would and that's why I did it. But, the point is, I just thought it would be. This, what you have here is a big step into an immersion. But the more you can engage or draw somebody into the geometry that you're looking at the more they'll be able to understand, and at least in their mind, they'll be able to put two and two together.

Interviewer: This interview session has been giving us a good idea. It's always good to get the multiple comments from the industry. And I've been thinking on this BIM CAVE myself and I was willing toward the sphere type of the BIM CAVE until I had the chance to talk to you guys today. Now I guess I'm changing my mind to a cubic style BIM CAVE, to put the screen up and down with the glass floor so we can actually get on the BIM CAVE.

Interviewee3: The thing that I haven't figured out about doing that, is how you stretch. And I'm still looking. You're working on multiple computers and different camera angles. When I was looking at it, I was looking at stretching the image and it works up and out, but when you do a cube and you're taking up and bringing it down like this…

Interviewer: You cannot have you're camera to take a look at the back.

Interviewee3: No you can't.

Interviewer: So that's the kind of difference. We kind of thought about, if I use one computer, and multiple screens, I can have the screen moving a lot faster than what you saw. But there is also a limitation right there, you can get the screen stretched to a certain angle, but you have to handle the skewed angle, the skewed view of the model first and then if you want to do more immersive stuff, you have to deal with some limitation there. Now are you checking the stereoscopic too, I mean the feeling of the depth where. Because Navisworks itself, if you buy certain graphic cards, you can enable this feature and you can really feel the depth.

Interviewee3: I have the graphics card and the projectors I'm getting are 3D ready.

Interviewer: The graphics card we purchased cannot do that. I mean its expensive computer, right there.

Interviewee3: I have an ATI firepro V8800 which can push four monitors at a time or four projectors.

Interviewer: How much you paid for that?

Interviewee3: $1300

Interviewer: That's what I'm talking about. That's $700.

Interviewee3: It's got 2 gigs of RAM, and it can be, you can buy two and crosslink them.

Interviewer: What computer did you buy

Interviewee3: Dell precision T5500

Interviewer: That's not the workstation, right.

Interviewee3: Mhmm. Zenon processors.

Interviewer: I don't know. I mean this one is workstation level, but it's not giving us what we want.

INTERVIEWER: It's not about what's the workstation or not, it's the graphic card itself and the features.

Interviewee3: It's got a desktop board, so, when you do have laptop, you're limited by mobile boards, so this has a desktop board so I have a faster processor, I have I7980 Extreme, 12 coolers and this has been the only thing that. It prefers to be plugged in because it sucks down battery.

Interviewer: You've been using this computer longs enough so that you have to get the new battery to run a little longer.

Interviewee3: I don't have it. I was doing some animation that I had for another project. About the same as a Dell Precision M6500.

Interviewer: How much is that?

Interviewee3: Fully..

Interviewer: The one I have for the PC, I paid $5000 for the one piece of…

Interviewee3: Dell Precision M6500, fully loaded out

Interviewer: It's XPS

Interviewee3: That was Dell's gaming computer before they bought out Alienware. The Dell Precision M6500 is a lot faster than the XPS. It's around $4200 to $4500.

Interviewer: I have this computer for longer than three years now, but I paid $5000 back then. I'm still happy with that.

Interviewee3: Well that's good. You need to be happy. Sager's out of California and they have been in the gaming computer business solely for 30 some-odd years and this is their professional..so as soon as I get my BIM CAVE set up, I'll be getting Halo or something just to see how well it works.

Interviewer: Now, an immersive virtual reality system like this one, how could it help you as a general contractor, whether to deal with subcontractors or to deal with the owner, I mean, if you want to see.

Interviewee3: There's a lot of different things. Marketing, obviously it has a huge marketing component. You can bring in an owner, a potential client. Right now, because it's not as common as it will be. There's a huge marketing component. As far as visualization, kind of what I'm doing with the set-up I chose, I'm moving towards taking it, because the projectors I got are 3D capable, but they're not the most expensive projectors. So my intent is to prove it out and on some of our larger jobs I'm looking at taking this toned down version and deploying it to the field. So we have a big conference room trailer, we can set this up in the conference room trailer. Typically the way we set up a job when we're engaged in 3D coordination, we have a computer there. The subcontractors are always welcome to come and look at the model, because we feel if they're going to take the time to look at it, we need to make it available because it's going to allow them to do a better job. The more they understand what they're doing, the better quality we are going to get, the more efficiency we'll get out of production, so anytime you can come up with a way for someone to understand something quicker, easier and more fully – it's better.

Interviewer: How much is the trailer? I mean the big trailer. We were thinking about it.

Interviewee3: How much does a trailer cost?

Interviewer: Yeah, do you have any idea about. I'm thinking of putting this system into a trailer so we can take the system to any job site per request from the construction company.

Interviewee3: Well, what I would do, is I would go buy a Conex.

Interviewer: A Conex?

Interviewee3: A C-can. You know the shipping. We call them Conex boxes. They pick them up, they put them on the ship.

Interviewer: Yeah, and get the student's to fabricate it.

Interviewee3: You get two twenty foot Conex boxes, you cut out one side on both of them so you can put them together. You start getting some volume. Because one of them is not too deep.

Interviewer: You're talking about container boxes.

Interviewee3: Yeah, we just call them Conex boxes. But if you get that, then you can, there are people in town that will come pick them up. Typically they have iso-connections on them. You just pick them up, they don't even need a trailer. You pick them up and take them wherever you want. I thought you were talking about my conference room trailer at the MSC. That's 16 x 40 and that's not easy to take around with you.

Interviewer: I kind of need some space, wide and big to put the CAVE system and then bring to the job site. And then help you guys to entertain your client with the BIM CAVE system.

Interviewee3: Then you can start marketing services and bringing in revenue to afford more BIM CAVES and other stuff too. To answer your question. There's a multitude of different things that you can utilize it for. Some of them I won't even know until I start doing it. Just like anything, once you engage in a process, you start seeing different ways you can apply this.

Interviewer: When I purchased, there is another one that has 21 inch monitor from Dell and the keyboard was even detachable from the main computer and it was still a portable computer. The issue was whether we can bring the computer to the airplane because it was too big for the cabinet of the airplane and people were talking about whether we can carry the computer on to the plane or not and it's got 21 inch monitor and it's still a laptop computer. I went to the field trip in one of my classes to your immersion technology and I noticed you have a technician who is…

Interviewee3: the QA QC guy and what we do, depending on the job, we like to let our QA/QC personnel run the coordination process with all the subcontractors. Because, it's a natural fit. They're sitting there hammering on them about quality, they get everybody in, they visualize, they coordinate, and that's the basis of what's going up. As far as judging the quality of workmanship, is it in the right place, that's the genesis of that, and it just carries through naturally with Brandon going out in the field. He already knows what it's supposed to look like because he's gone through the process.

Interviewer: What you do normally, you hire some QA/QC and train them to use Navisworks and

Interviewee3: We take QA/QC people that we already have in the company, we don't just go out and hire them because we have a pretty beefed up…

Interviewer: Have you tried any application other than Navisworks?

Interviewee3: Um, Solibri. has something similar. If I wasn't going to use Navisworks I would use Solibri. I demoed the program, they have the checker. Evidently the two gentlemen, who created Navisworks, left after Autodesk bout them out and now they're with Solibri and it has a lot more capability than Navisworks does. It has clash detection and things like that but, it gets a lot into validity of models. So if you're an architect and you gave me a model, I could run a number of out of the box analysis of your model.

Interviewer: Light and stuff?

Interviewee3: You can do light, you can do ADA compliance based on the ADA information they have loaded in the program, which I think is 1994. But you can get into issues of how they drew a model. Interior walls and partitions…did they model them correctly. Do the walls connect like they're supposed to connect or do they go to the inside. Are the walls that are supposed to be full height to the deck, are they actually full height to the deck. You can generate reports. So from a construction management standpoint, I look at that as an incredibly ability in pre-construction to come out and say, hey, we can't use BIM technology to its fullest potential because you're not modeling the way you should be modeling.

Interviewer: Have you checked if they have programming ability like API?

Interviewee3: No I haven't gotten that far.

Interviewer: Because it's a key step that's good about Autodesk, that they allow their clients to play with their application and they provide customer support and technical people. I mean, that's why you see a lot of products that utilizes AutoCAD and those are separate companies that will give you tools. It's giving Autodesk a huge advantage over the other companies, that's the reason, that's how I developed this application using API of Navisworks.

Interviewee3: I think you should call Autodesk up and tell them that if they don't cough up some really, beefed up computers for your BIM CAVE, then you're going to Solibri. I think you should find someone who's eager to engage in the process. Autodesk is such a behemoth, if you look at market share, I think they have around 80%-85 %percent of the entire market in the world and there are a lot of good things about that, but there are also things that aren't good about that.

Interviewer: Yeah, we've been through their bureaucracy because I wanted access to their ADN, Autodesk developer network but it's pretty costly. But since we're researchers we got free access to it. Then you go through the huge, I showed them that they have deficiencies in their Navisworks, in the technical problem in the code of Navisworks. They said they agreed, well those problems need to be fixed by our programmers but you have to tell us how much benefits we get if we fix them, I mean, that's how they deal with. I tell you there's a problem, you tell me you're going to fix it, you don't tell me you have to tell me how much benefit I'm going to get if I fix it or I'm not going to fix it for you.

Interviewee3: That's, I was messing around with Autodesk labs, seeing what they're doing. I noticed someone had come up with a quick program for AutoCAD, it was a dimension checker. It would go through and check the dimensions that someone had physically overridden, which when we are all dealing solely CAD, architects and engineers would historically just type in the dimension, so the drawings were never drawn to the dimension. Used to tick me off, so I said, I went through and found a place to send an email to somebody, six months ago and last week I got a response, which said, did anybody every get back to you on this, I said, no and now they have me on the Revit beta sight. My big deal is all their software, at least in my segment of the market is geared towards architects and engineers, the reality of the world is architects and engineers don't have all the money, the contractors do. The contractors take risks, they make more money and they save money, so they typically have money to invest and if you look at who's actively engaged in BIM, contractors are the ones out there pushing the limits, it's not the architects, and it's not the engineers. So in my mind, I think Autodesk is missing out on a huge opportunity to gear their software more towards, or at least offer software that's geared more towards contracting with the exception of changing the same software package and changing the menus to things that contractors would want do as opposed to architects. Does that make sense?

Interviewer: The main objective of the whole interview is just to validate the system as a virtual reality system.

Interviewee3: you need to look at the Wii hack for head tracking and the Xbox Connex. The Connex, a bunch of people are looking at this, because it's a sensor, and you put it up if you're playing a game, it maps your body, so when you move, you're the controller. So a lot of people who are in robotics are like, hey, this is a sensor that costs $150; we need to figure out how we can use it for robotics or things like that. I said three days after it came out, somebody had hacked it and figured out how to plug it in the computer and map them on the computer. Depending on what Microsoft does about that, there are a lot of different ways to try to draw somebody in to the visualization. Kind of my concept, in studying some of that, was if there's a way to make the person the mouse, and map movements to specific mouse commands. Like if want to look left and I'm in Navisworks, I use the feet motion, I don't use the wheel, so if I turn my head to the left, it would be the equivalent of me pushing that button and moving my mouse to the left. So I could steer around with my head. So I could look up, camera up, camera down.

Interviewer: Ipad has a thing which is not released to the public but it's an application.

Interviewee3: Do you have that application on your Ipad?

Interviewer: Not really, they didn't give me, but they showed me how it is working. You hold up the Ipad, take a look at the 3D model, and if you want to take a look at this portion of the model, you simply move your Ipad around and it shows the model looking at that portion of the building and I was fascinated. I asked him if it was going to be available for the public and he said no. I asked for a copy and he said not yet, so it was very fascinating. I saw it a month ago.

Interview #3
Interviewer: The system here as you can see, three separate computers. This is one of the buildings on campus; it's called the merging technology building. The idea here is to create synchronized system from the screens. What's on the screen will follow and I'm controlling the Navisworks on those computers from here. Go up, down. Now, if you notice here, it's a little slow in communication and this problem after trying to investigate it for a while, turned out to be a problem in Navisworks itself. The problem here is the way Navisworks API works from inside the programming and they're actually working on fixing it. I submitted two problems and they have two change orders for their software to fix the problems. Hopefully the new version of Navisworks with solves these problems.

Interviewee4: Does it get worse when you get inside the building.

Interviewer: When you move more, because it creates a queue of commands. So if I go and fly through for a while, it creates this. It's by the navigation mode; if you're zooming in and out it's pretty fast. More than if you're flying through. I would like to ask you a couple of questions just to get feedback, in general, do you think this advanced visualization system could work as immersive virtual reality system?

Interviewee4: I think so, like you said, with the full 360 degrees, you'd have the capability to walk inside the room and see everything around you. The way you have your cameras set up it's very nice that you have this because in one Navisworks view you can't really stretch that panoramic view that far. As far as immersive, you can essentially have the capability to have everything set up for the bottom, the top and not just a three foot strip around you. You could essentially have 25 camera views around you or maybe more. I can definitely see the capability. Have you looked at running two copies of Navisworks on the same machine? Is there still significant lag time?

Interviewer: What do you mean two copies?

Interviewee4: Say you open up Navisworks once and you open it up a second time, say you have the first copy on this screen and the second one on the second time and you can be panning between those on the same machine. You couldn't open ten copies of it, but you could still do three or four. Then, again like you said though, it's a problem internally using the API.

Interviewer: I think it won't work though. Because it's the speed; I thought at the beginning it's the speed of the network, then I went to the millisecond of transferring the information on every step, then I figured, the Navisworks itself that's delaying the information when you're flying through because it's giving priority to the visualization. So if you get a computer with an advanced visualization card that processes information fast, it will function better. It's a problem. Basically I asked Navisworks engineers to raise the priority of transferring information because it could be beneficial for future use of the product. That was my argument because you have to argue that it will bring future income for Autodesk if they want to make the change.

Interviewee4: I could see the way you have it set up so that you're linking camera views and I saw that you had point to this machine and your angle of cameras. I could see where, potentially, you could turn a room into a fully immersive studio with this capability.

Interviewee5: I think you're hindered a little bit by monetary capital, I think if you had enough money in the bank account, you could get more powerful computers and that would solve a lot of your problems. And also, you're using; LCD TVs and I think the video cards are lacking a little bit in those. Like I said, it all goes back to money. You could spend $100,000 and you could have a Cadillac. As far as the concept and I'm not saying there's an issue with what you've prepared, what you've prepared is great, the concept is great, you're just hindered a little bit by the equipment you currently have in terms of processing speed in terms of how quickly it refreshes. I do see the benefit. I would almost even like to have a fourth one and it's like a true semi-circle Imax, where you're sitting in the center and it's just within your peripheral where you have four screens and you have your cameras set up on there but you have to have four separate machines that were real powerful and all working as one system. Or figure out a way to do it with one machine and four separate views. You're going to run into, you're going to have to have better video cards because right now, what you've got is two masters and one slave. So the slave has got to be behind, because of the inputs. So you'd almost have to build a computer, if you did it with one computer with three or four inputs and I'm sure you could do it, but like I said, it's going to cost you a lot more money, but as far as the concept. I love the concept, I think it's a great concept, being able to sit here in your little workspace and being able to visualize, it's almost like sitting in your room and turning your head and seeing everything that's there. And it's certainly a step further than looking at it on one screen and then having to turn around because you don't really know, but like I said, being able to see the peripheral, if you will, probably like a 200 degree angle of vision is very powerful. I love the concept, I think it's kind of what Tim said, you guys continue to amaze me with what you do with this technology.

Interviewer: What is your experience with BIM and immersive visualization and is your experience different than this and what could this technology offer?

Interviewee4: Honestly, we haven't seen anything that does this same thing where you have several different ideas tied to one control. I know there's this lag issue because of the API. I could see though, potentially, if Navisworks could catch up to what you're doing; you could turn this into a 100% immersive environment where you are literally inside of a room or inside the model.

Interviewer: Now, how about your experiences, what kind of immersive environment you were exposed to before, or any advanced visualization.

Interviewee4: Basically something similar to this, but nothing that's 100% immersive. We've seen a lot of articles about them, but we've never been into one. And you've seen where they have the goggles and the immersive that way.

Interviewer: Where the goggles go to another feature of the virtual reality system. Because the virtual reality system has several components, immersion is one of them. Immersion means that whenever you turn your head you will see the model, but the other step is stereoscopic. When you wear the goggles, it gives you the feel of the depth and Navisworks itself, because of the limitation of the graphic cards and the equipment, you need special screens, special graphic cards and special glasses to get this depth feeling, but whenever it works, you will see the model really coming to you and you will feel the depth. Navisworks in one of the menu's you can activate the stereoscopic.

Interviewee4: We've toyed with that, using stereoscopic in renderings, but it's no more advanced than any other things going on in the movie industry, using stereoscopic viewings in the animations and renderings, but as far as a live use of it, we haven't done that.

Interviewer: Now about your experience in BIM, what do you think this kind of system could help for the BIM technology?

Interviewee4: I think it could help in several different avenues. You have whatever you do between an architect and an owner, being able to portray that design and intent to the owner, obviously if they're walking in the building and moving through the rooms, they're going to understand the building a lot better. Whereas, if you have flat 2D renderings, you're not going to show them everything on those flat images the way you could show them on an immersive environment. And on the other side of that, whenever you're dealing with issues, Y coordination issues, whatever they may be, you can actually move inside the room. I think an older way of doing the same thing is you build a mock-up. I know in hospital settings when they have say a nurses station built, they have all the nurses come in and say, well we need this plug here so that it's more accessible for this and the switch needs to be here and the outlet needs to be here. So they'll build a full scale mock-up of that room, say an ICU room or unit, they'll build a full scale mock-up and draw on the wall where those outlets are going to be and with this, you could essentially go from one room to the next to the next without actually building anything.

Interviewee5: In lieu of having to build these very expensive mock-ups that not only take up a lot of time, but a lot of money to do, and space, you're able to do it in a virtual atmosphere for a lot less cost and a lot less time. What used to take weeks to configure now takes hours. It's very minor in terms of cost, being able to visualize this. If you rendered it out, it's going to take a little bit more and you have to invest money in the software and hardware to be able to do it, but it's changing the industry worldwide, but it's nothing new. We've been doing this since the 70's, the manufacturing industry has been doing this since the 70's, and it's just now becoming the latest buzz.

Interviewee4: Do you do much with 3DSMax?

Interviewer: No, I haven't.

Interviewee4: Talk about a realistic environment, they have something called Iray and it's a plug in. It's an instant rendering process and basically. The hardware technology is caught up and you can essentially walk around in the 3D environment and it's fully rendered in any point as you move.

Interviewee5: When you get into rendering, owners can visualize the space before you spend a lot of money on finishes that you may not even like.

Interviewer: So you may have customers wanting to see more realistic views.

Interviewee5: Well, Autodesk has that technology now and they showed it off at Autodesk University.

Interviewer: What I'm asking you are customers asking to see that.

Interviewee5: They love it when we show them something more than that, you take it and you actually render a space out and they can actually visualize what the VCT tile is going to look like, for instance in a school.

Interviewer: Do you talk about those issues at the coordination meeting or the design meeting.

Interviewee4: No, it's typically earlier on.

Interviewer: Are you guys getting involved in that process of talking about materials and interacting with the clients.

Interviewee5: Well what we'll do is we'll talk about it to the architect obviously and look at them and where they've got them drawn and talk about getting back within a budget. It's something you can just draw it in a model real quickly and render it out, render the space out and the owner can look at it and go, you know, that's not what I want, but that is what I want. And you can make the changes within a virtual atmosphere, without spending thousands of man hours and hundreds of thousands of dollars. It's not something you put something in and you have to wait for the finished project before they take a look at and say, well, I don't like it.

Interviewee4: One example would be, we actually helped out with some rendering on a school they were building and it was the same handrail configuration on some stairs. They put the panel in-fill on the glass or a wood panel in-fill. Well we did renderings on both, and the glass is obviously more expensive.

Interviewer: You guys did it? What about the architects?

Interviewee5: Well it was one of these jobs that were already designed. When you try to VE something out of a job, this was the wrong word, this was a fail CMR that they fired the original construction manager and then they gave it back to us. So then the architect comes back to us and says, we don't believe it's that high of a cost, can you help us out? So there are just extraneous things and there are some specialty items. And it's material selection. This is an elementary or middle school. Is it absolutely necessary to have glass handrails at a middle school, maybe in a shopping mall, yes, but in a middle school ; no. There's something else we can do to emulate that. So an architect might say; well how about a wood panel, so we'll quickly throw in a wood panel in the model and render it out. With the way the market is structured now, everyone wants the most scope for the least money.

Interviewee4: Our group is simply a group of problem solvers. If there's something that can be changed or needs to be done better, our group is going to work to help out whatever group to figure out what's going on. And a lot of the time, the architect may have the capability and they may not, but sometimes they just simply don't provide the service.

Interviewer: Now it was mentioned that this could help with the owner, now about coordinating with subcontractors. What do you think this kind of immersive system could help with subcontractors knowing that they are not always interested in advanced technology?

Interviewee5: Regardless of whether you are talking about owners, engineers, architects, subcontractors, the bottom line is better scope definition. They have no excuses because they see all the moving part, they see all the components that are there and they realize that their system is not the only system that goes in that building or structure. They have a lot of other systems they have to coordinate with. I think sometimes 95% of people in the world are visual learners. Once they see it one time they understand it. Being able to visualize something; the knowledge you gain from being able to visualize it before you have to go build it is tremendous.

Interviewee4: We do put set ups on job sites where you have coordination meetings in the trailer. I think you've seen some of them in place, but it's not immersive. Given that ability to look both directions or all directions changes a lot when you're trying to decide if you have room to move a pipe over two feet or not. It does provide an advantage there if you set that kind of situation up.

Interviewer: Did you figure out the difference between this system and the system you built?

Interviewee4: I understand that you have, with one Navisworks running and you stretch the program across three screens, it's not nearly the same ability to see a panoramic-type view.

Interviewee5: Your field of vision is a lot more limited just with it being stretched, you might only see half of this part and you'd still have to rotate it that way. Stretching it is great, but what you've done is to be able to change the different camera angles. So you've gone from a 70% peripheral to a 200% peripheral. So you're able to see that much more. It's important for duct work and long runs of pipe where you're not having to go and say, this goes here, but what happens after it goes through this fire separation wall, does it make a left-hand turn or does it continue to go straight? Does it go over a beam, does it go under a beam, and what does it do? That kind of thing, and being able to visualize more of it, bottom line; it's better scope clarification.

Interviewer: One of the limitations I have in the system is the ability to look up and down, with the idea first, it was more complicated. Second, when the model is not straight, it could be hard to understand it from my point of view. What's your take on this limitation on tilting?

Interviewee4: I can understand what you're saying and I don't know how you'd address that. I believe that moving forward, in our application, that up and down in necessary.

Interviewer: How about tilt up and down or putting screens on the ceiling and on the floor, which do you think is better?

Interviewee4: Obviously, for more of a fully immersive environment, putting things on the ceiling and the floor. Then when you are in a room and you want to look at the ceiling, you look up at the ceiling and same thing with the floor.

Interviewee5: I would agree with what Tim said. Sometimes you need that ability to tilt it a little to see between, you need to change the plane of view just enough to see how much room you have between a duct and a ceiling time. Sometimes you need that ability.

Interviewee4: Well if you have that ability to use your head as the tilt, when you're looking up or down, I think that compliments that.

Interviewer: How often do you see ceilings or anything in the ceilings when you're looking at BIM?

Interviewee4: That's what we do, mostly above ceilings. Most of our co-ordinations in the field are between the ceilings and the slab.

Interviewer: We're now using Navisworks to visualize; do you suggest any other applications?

Interviewee5: 3DS Max, if you actually get to that level where you're doing 3D renderings, if you're doing it through that application. Syncro is not a bad platform, the problem with Syncro is you're going to run into program issues with Syncro. It does not multi-thread across multiple processors. They're aware of the defect and they're working to correct it. You just have some lag time issues, the rate of refresh, will sometimes crash your machine.

Interview#4
Interviewer: I would like to know a little bit about your background and experience with building information modeling and virtual reality.

Interviewee6: Well, I was a project manager. My first BIM project was in February of 2009. We started a courthouse expansion. That was the first project. The architect had modeled it in Revit, that was really when we had started to push all of our VDC and BIM stuff, so they selected me and sent me to training in Navisworks and Revit and that kind of stuff. I basically ran the clash detection and coordination using the architectural/structural and we had our subcontractors modeling MEP systems and BIM and then when that project was done, I went for six months to work on new competency center and there we were really working on tool testing and kind of finding what programs work together and what's the best way to get the most useful information out of the model. As far we're concerned, that's what we're looking to get. What kind of information can we get, can we get quantities, do take-offs. Also, the clash detection – that's a big part of it and what systems. Over there, they use some different programs, they don't necessarily use Navisworks. I came back here in July and I've been on a Health Science Center project,and that job was all modeled in Revit, the MEP, everything except the fire protection system. We did clash detection on that and we did a little bit of quantities, quick estimating using the model.

Interviewer: About advanced visualization systems, do you use anything , like virtual reality system or multi-screen system.

Interviewee6: Yeah, we have some smart boards. I'm not in the VDC group, per say. There are people there that probably know more about this than I do. But we do have some different projects; they'll get innovation grants to try some new things. I know we haven't had anything like this set up, so far.

Interviewer: So normally, if you are working on Navisworks, how do you work on it?

Interviewee6: Either we get a high definition projector or we get a TV like this. So we all sit around the conference table and we display it on one screen.

Interviewer: What do you think using three screens, do you like the set-up like this? Do you think it could help?

Interviewee6: I think this is definitely useful. The more you see of the model at one time, it helps you get a better grasp. A lot of times when you do clash detection, you're trying to get into an area and evaluate a particular clash and what the best way to fix it is, it's kind of difficult. It takes a while to maneuver around and get your bearings. Where, if you have something like this and you're zoomed in on a component, you can see around it. When you're doing the clash detection, a lot of times, there will be other things in the way if you try to zoom back too far, then you can't see without hiding some elements that you need. This allows you to be up-close but still maintain perspective on what you're looking at.

Interviewer: So what do you think it is? The multiple screen, the size of the screen, the angle of the camera…

Interviewee6: I think it's the angle of the camera. I think it's being able to have an immersive experience with the model. Instead of just looking, even though it's a 3D model you're looking at it from one point of view. As you're surrounded by the model and you can look around the entire way, it's an expanded perspective that makes it really beneficial.

Interviewer: One of the limitations we have in this system is a limited angle. You cannot really tilt the model. The reason is a little complicated. It's complicated to rotate the model on the screens at the same time. Do you think this limitation can affect the visualization? Is it a feature you use all the time?

Interviewee6: I think that's a big thing because a lot of what we do, you have to look at multiple angles to figure out the best solution, if that makes sense. Sometimes to get the best view of something, you have to be below it looking up or looking down.

Interviewer: So do you think adding a screen or adding a feature of pitching the model or tilting the model would be better.

Interviewee6: That's difficult to say. If you're constantly looking up, I think it would be easier on everyone if you could just take these screens and move them up, if that makes sense. Can you take the top button and look down at the model?

Interviewer: No.

Interviewee6: See, that's critical and very important. That's where when you're clashes show up and you pull them up, that's how you identify where they are. Then you go in and look at them. That top view is the main view you're in, the plan view.

Interviewer: What's your opinion about features like stereoscopics, which allows you to wear glasses to feel the depth. It's more of a depth perception concept. Do you think activating such a feature could be beneficial, if you're selling to the owner.

Interviewee6: I think that's where more of your benefit is in the 'wow' factor. The actual implementation of it on the jobsite, having never used it, I can't really say. But I don't know how much benefit the 3D image would be. I don't really know, I can't really say. For the sales it would be very cool.

Interviewer: Just to finalize the interview, if someone asked you what Texas A&M was doing, describing the BIM CAVE system, how would you describe it.

Interviewee6: Succinctly, it's an immersive BIM experience where you're getting a better perspective of the model.

VITA

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