

# Implementation of 4D CAD and Immersive Virtual Environments in Construction Planning

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## **Abstract**

*VirtuBuild, a group of students at Purdue University, developed a project for initial use by Purdue University faculty and students concentrating in all fields relating to construction. The assets and processes for development of a Virtual Construction Lab were produced that will provide an interactive learning environment for visualization, simulation, and education. The lab is unlike traditional learning methods used by the University – building labs, classroom settings, etc. – in that the Virtual Construction Lab is highly configurable for client or preferred needs. VirtuBuild worked with Clark Cory, a professor in Computer Graphics Technology teaching Construction Graphics. They also worked with Steve Dunlop and graduate student Jack Moreland in the Envision Center in order to understand processes and software relating to the development of the virtual construction lab. VirtuBuild's goal was to create effective assets for use in soliciting support for a Virtual Construction Lab at Purdue.*

## **INTRODUCTION AND BACKGROUND**

Completion of Purdue University's Computer Graphics Technology programs requires its senior design students to actively participate in industry related topics to research emerging technologies and develop a product that utilizes the knowledge and abilities that they have learned throughout their college education. The architectural, engineering, and construction industries have continued to strive towards merging today's technologies with the foundations that have supported them for many years (Messner, et al., 2003). The use of virtual reality to combine traditional construction planning and scheduling with complex computer designed models is currently in development to help reshape the industry (Messner, et al., 2003). The immersive components of virtual reality create a dynamic environment that allows a high level of interactivity as well as an entirely new way to visualize data (Bricken, 1991). A project was proposed to the students in the Computer Graphics Technology department to actively research and develop assets and processes for a Virtual Construction Lab that would showcase the effective benefits of using virtual reality in the AEC industry. This project, supported by the research done by professors

and professionals who researched virtual reality as it relates to construction at Stanford University, Penn State, and Washington University, became one of the first virtual reality environments utilizing four-dimensional components at Purdue University (Steven Dunlop, personal communication, November 2006) [figure 1].

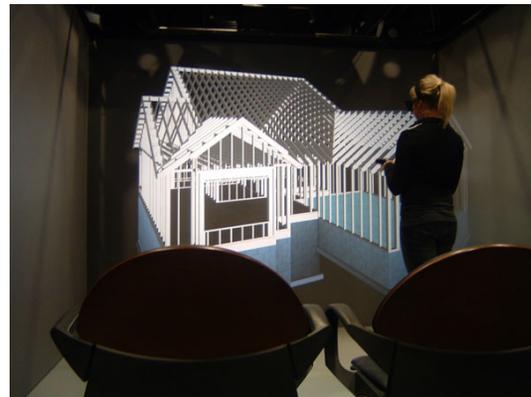


Figure 1. Envision Center's virtual reality FLEX

Virtual reality in construction has been implemented in other universities, such as Washington University and Penn State University. Industry has also found virtual reality to be an asset to the construction process (Messner, 2003). Dr. John Messner has been an integral part of the implementation of the

Immersive Construction (Icon) Lab at Penn State University. He, too, believed students needed a better way to understand and interpret construction processes (Messner, 2003). Experiments done within the Icon Lab suggest students can gain quality experience learning and critiquing different construction scenarios in a virtual environment (Messner, 2003). Studies also showed students were very engaged in an immersive virtual environment (Messner, 2003).

Professor Cory and other College of Technology faculty believe this will be an important tool in construction education, and could also be a great opportunity for the University to be on the leading edge of technology within the building and construction fields.

### **PROBLEM STATEMENT**

Currently the construction industry uses traditional two-dimensional design drawings, cost estimates, and schedules to analyze and plan construction projects. Planning and review of these design drawings are performed by individuals mentally visualizing spaces which can allow room for error if an individual does not have the ability to accurately visualize space. Having varying abilities in visualization can result in the development of unreliable and inaccurate construction plans (Yerrapathruni, 2003).

Based on this research, Sai Yerrapathruni, a former graduate student at Penn State and current project engineer at Turner Construction, contends that the construction industry needs a better way to visualize construction plans to reduce error (Yerrapathruni, 2003). Advancements in technology have allowed new visualization techniques to be developed. Several new applications dealing with 3D and 4D CAD are beginning to help construction planners to visualize and review construction plans and schedules (Yerrapathruni, 2003).

### **RESEARCH QUESTION**

Does the creation of effective visual assets improve Purdue University's potential to ob-

tain financial support for a Virtual Construction Lab?

- Effectiveness of assets can be measured by successful industry response to funding requests for the Virtual Construction Lab at Purdue.

### **HYPOTHESIS**

It is believed that the creation of visual assets will improve Purdue University's potential to obtain financial support for a Virtual Construction Lab.

### **METHODOLOGY**

The purpose of this project is to supply Purdue University faculty with visual assets for use in soliciting support for a Virtual Construction Lab. The visual assets include a "prototype" of what the Virtual Construction Lab could be in the future. This includes an interactive wall section and a 4D model house for use in an immersive virtual reality environment. These will be used to solicit support from outside AEC firms and other organizations to help create a Virtual Construction Lab at Purdue University.

The project began with research into the use of virtual reality and 4D modeling in the construction industry. Research was also done into the equipment currently available for use at the Envision Center. After reaching a saturation point in the research, actual creation and implementation of models began in the Envision Center's virtual reality FLEX.

Models for use in the project were created and converted into a format suitable for the FLEX. They were successfully uploaded and navigated through in the FLEX. The interactive wall section will include components such as collision detection and utilizing informative text about certain parts of the structure.

An online survey was created to assess whether or not a Virtual Construction Lab would be a useful tool in the construction industry. Surveys were sent out to individuals in the architectural, engineering, and construction industries. The survey was sent through email and asked the individuals to follow a link to an online survey. Approximately three hundred surveys were sent out to companies across the entire United States. The individuals being surveyed were first asked to read a brief description about the project, but a link was also supplied that directed them to the project website where they could read more information. The questions in the survey first asked them about who they were and what they did at their company. The second part of the survey asked the individuals how they felt about implementing virtual reality as a tool for the design phase of a project, areas in training, and lastly areas in education. Finally, they were surveyed on whether or not they believed that their company would potentially fund a Virtual Construction Lab at Purdue University. In total forty-one individuals responded to the survey.

## **TECHNOLOGY**

Virtual reality is primarily defined as an “interactive visual simulation environment that immerses the user in a responsive virtual world (Sutherland, 1965).” In the early 90s virtual reality caught the attention of the public in science-fiction and high level governmental projects (Allison, Hodges, 2000). Since then it has become increasingly more accepted as an instrument that allows individuals to respond to “global market opportunities” and “competitive demands” within industries and research groups (Cruz-Neira, 2005). Today virtual reality is being used for numerous reasons including designing, analyzing, testing, and evaluating both products and processes. “The key aspect of Virtual Environments is that the line between data, computations, and the user is blurred (Cruz-Neira, 2005).” Currently virtual reality still hasn’t reached its full potential, and its development as an emerging technology continues today (Messner, et al., 2003).

There are several core technologies involved with Virtual Reality. The key element is the visual display system. The most common display system is known as the “CAVE”. The Cave Automatic Virtual Environment (CAVE) was created in 1992 and unveiled to the public at the ACM SIGGRAPH convention that same year (Leetaru, 2000). It was created in the Electronic Visualization Laboratory at the University of Illinois in Chicago by Thomas DeFanti and Dan Sandin with the help of graduate candidate Carolina Cruz-Neira and other individuals (Leetaru, 2000). The CAVE consists of three vertical walls with rear-projected stereo displays (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992). A fourth rear-projected stereo display that projects onto the floor is also common among most CAVE systems. One of the major benefits of the CAVE system is that it allows for multiple individuals to be in the environment manipulating and exploring the virtual space (Cruz-Neira, 2005). A system similar to the one found in the Electronic Visualization Laboratory can be found in Purdue’s Envision Center, and multiple projects have been created for both research and development from various areas of study at the University. Users of this type of environment use stereoscopic glasses to view the images in 3D. The glasses produce the image in 3D because the image on the screen is displayed from two different views. Each lens in the stereoscopic glasses only picks up one of the images and the two lenses flicker on and off back and forth at such a high rate that the viewer only sees one image. Because the combined two images are processed through the brain as just one image, depth is perceived; thus creating the 3D image (Leetaru, 2000).

Another type of system commonly found is using a head-mounted display (HMD). This type of system is considered to be the pioneer system of Virtual Reality, dating all the way back to 1968 (Owen, 2005). The constraint on this system is that it is limited to just one user. Head-mounted displays are commonly found with Augmented Reality which combines the real-world with virtual objects.

Both Augmented and Virtual Environments also commonly have interactive devices that allow an individual to navigate through the environment (Owen, 2005). These interactive devices also sometimes can be programmed to allow the individual with the device to manipulate objects in the Virtual Environment. Tracking devices are sometimes also used to center the perspective of the environment on the user (Owen, 2005). Using a tracking device creates problems when more than one viewer is in the Virtual Environment, since individuals other than the one wearing the tracking device will see the image in a distorted view.

Aside from the many potentials surrounding virtual reality such as its ability to be tailored to individuals, allowing a natural interaction with information, and a complete shared experience with other individuals, some challenges exist with cost and usability (Bricken, 1991). Originally, virtual reality systems were very costly and only affordable for large universities and governmental programs such as the military (Cliburn, 2004). Today cost issues have been somewhat resolved through less expensive computers and smaller setups. Additionally, some travel virtual environments have recently been created that allow individuals to take the system with them wherever they go (Messner, et al., 2003). Usability issues are still present with each virtual reality system often having its own set of unique software and hardware (Cruz-Neira, 2005). This becomes an increasing concern when research and development projects can only be viewed on the setup that it was constructed on. Currently many individuals and companies are trying to rectify this by developing universal software and hardware that would allow for a more networked experience across universities, companies, and governmental programs (Cruz-Neira, 2005).

#### **4D MODEL IMPLEMENTATION**

The models created by the group for this project were produced in Vertex BD Pro. The house consisted of a full basement foundation, framing system, completed drywall and

interior doors and trim, the HVAC system, plumbing, and exterior doors, windows, roofing, and finishing. Once the initial model was built, it was

imported into 3D Studio Max as a .3ds file. Layer groups were created and components were renamed for easier management of the file. A basic schedule was prepared using Primavera Project Planner (P3) which consisted of 39 scheduled activities [figure 2] and was then exported as an ASCII text file.

CommonPoint 4D was used next to link the 3D model elements with the corresponding schedule components creating a true 4D model. The model was next exported as a .VRML file and imported back into 3D Studio Max for texturing, lighting and preparation for use in a virtual reality setting.

Each phase of the project was exported as an OpenSceneGraph (OSG) file for use in the FLEX; this format allowed the file to be used in VR Juggler. The final stage of implementation was programming VR Juggler using C++ to allow each OSG file to be cycled through and viewed in the FLEX. By using the wand as a navigation device, users were able to view the different phases of the construction process.

#### **TRADITIONAL CONSTRUCTION DOCUMENTATION**

Architects and engineers typically review two-dimensional design drawings along with cost estimates and time schedules. These drawings are made in standard AEC software like AutoCAD or Microstation. These drawings are then distributed to other parties involved in the construction process. They review these drawings and return comments or additions to the plans. From these two-dimensional drawings, others involved in the construction process prepare sketches and drawings for their particular building system. These could be made for material organization, machine placement, and infrastructure. Many times extra costs arise out of this process because of design faults not originally recognized in the two-dimensional drawings. Studies are being done that are starting to

show that the use of two-dimensional design drawings limits one's ability to comprehend possible structural or scheduling complications (Messner et al., 2003).

#### 4D CAD IN CONSTRUCTION PLANNING

Because of inconsistencies caused by traditional documentation methods, 3D and 4D CAD models are being implemented in the planning process to aide in visualization of some complex projects. 4D modeling includes a 3-dimensional CAD model with schedule time as the 4<sup>th</sup> dimension. This is achieved by linking a Critical Path Method (CPM) schedule to a 3-dimensional CAD model (Yerrapathruni, Messner, Baratta, Horman, 2003) which allows the user to actually visualize the project throughout each step of the construction process.

The 3D CAD model can be developed using standard AEC industry software such as AutoCAD and CATIA (3D Product Lifecycle Management software). Depending on the size of the project, different CAD packages are more appropriate than others. Architects of the Walt Disney Concert Hall in Los Angeles, CA utilized CATIA for the creation of their 3D model (Haymaker, 2001). Building elements can be divided into models representing different building systems which can be anything from interior carpeting and finishes, different structural components, etc (Haymaker, 2001). Each of these models can be incorporated into one main view.

Scheduling can be done in any construction management software such as MSProject, Navisworks with Timeliner, and Primavera [figure 2]. Once the construction schedule is made, it can be linked to the 3D CAD model. Studies have shown 4D CAD to be a proficient tool in communicating and visualizing construction processes (Yerrapathruni et al., 2003).



Figure 2. Primavera Scheduling Software

#### LITERATURE REVIEW

Traditionally in the construction industry, two-dimensional design drawings are made and reviewed by individuals involved in the building process. They compare these two-dimensional drawings to cost estimates and schedules in order to make important decisions about the building design and construction process. Once construction on a project has begun, problems that arise on-site translate into costly changes and lost time. This has been a long-accepted flaw in the construction industry, and new technologies are attempting to correct this flaw by allowing those involved in the construction process better ways to visualize structural components of a building (Messner et al., 2003).

Three-dimensional representations of a building are being used as a tool for visualization in many projects. Walk-throughs provide a viewer with more detailed information as compared to standard two-dimensional drawings. However, these alone typically can not provide enough detailed information to actually be used as a tool for builders. With the introduction of 4D models, those involved in the construction process can begin to visualize the construction process in a more detailed way without ever having to be at a construction site. However, implementing a 4D model into an immersive virtual reality system could allow the viewers to recognize and

make changes dynamically (Sampaio, Henriques, Studer, 2005). Doing this upfront before construction begins reduces the need for costly change orders and drawing revisions (Yerrapathruni, 2003).

The use of 4D CAD has been successfully implemented into virtual reality environments in various construction projects. Studies have shown the use of 4D CAD in virtual environments can benefit project planning in the areas of schedule analysis, schedule generation, and collaboration and communication (Yerrapathruni, 2003).

### **Penn State University's ICon Lab**

Penn State University is one of the leading universities researching the use of 4D CAD models and virtual reality in construction education and planning. The Immersive Construction Lab (ICon) is located within the Architecture Engineering and Architecture Departments. This immersive display allows 2D and 3D models to be displayed in stereo at full scale. Ongoing research is being done to show the benefits of using 4D models and immersive virtual reality displays in the architecture, engineering, and construction industries.

Dr. John Messner is the head of the Computer Integrated Construction Research Program. One of his experiments was designed to assess the ability of students to read and interpret typical construction planning documents and measure the value of incorporating the use of 4D CAD models in a virtual reality environment (Messner, et al., 2003). The objective of the experiment was to see if students could identify scheduling errors better by using the standard CPM schedule or through the analysis of a 4D model. The results showed that prior to developing the 4D model, 52% of students were able to identify a specific concrete scheduling conflict, and only 28% identified a specific window conflict by reviewing the CPM schedule. After developing the 4D model, 84% of the students identified the concrete conflict, and 92% identified the window conflict. The results of this experi-

ment show students were better able to understand and comprehend construction scheduling using a 4D model.

### **Stanford University's Center for Integrated Facility Engineering**

Another leader in the use of 4D CAD and virtual reality is the Center for Integrated Facility Engineering (CIFE) at Stanford University. Similar to Penn State's ICon lab, CIFE is "striving to be the world's premier academic research center for Virtual Design and Construction of Architecture - Engineering - Construction (AEC) industry projects." (<http://www.stanford.edu/group/CIFE/Mission/index.html>). Stanford University's Center for Integrated Facility Engineering has been involved with many AEC industry projects implementing the use of 4D models and virtual reality at the job site. Two of their major projects include the construction of the Walt Disney Concert Hall in Los Angeles, CA, and Hall 600 at Helsinki University of Technology in Finland.

### **Walt Disney Concert Hall**

The use of 4D models and virtual reality in the planning process was implemented in the design and construction of The Walt Disney Concert Hall in Los Angeles, CA. Stanford University's Center for Integrated Facility Engineering (CIFE) funded the project, and has been researching 4D modeling and visualization of scope and schedule information in construction planning for several years (Haymaker & Fischer, 2001). They wanted to do research on the use of 4D models on a complex project. M.A. Mortenson Company, the general contractor of the project, provided the necessary assets to construct the 4D model. John Haymaker, of CIFE, worked on site to produce the 4D models used in the project.

The 3D models used in the project were constructed with CATIA. CATIA was used because of its ability to utilize NURBS-based curves and surfaces (Haymaker & Fischer, 2001). Designers believed this to be impor-

tant because this would maintain a high level of mathematical accuracy. CATIA was also able to handle the complexity of the models. Models of specific building elements were made, as well as sub-models containing smaller building systems. The layering of these models was helpful in isolated certain aspects of the building process if need be. Scheduling was done using Primavera P3 software (Haymaker & Fischer, 2001). Building elements were then linked to a scheduling activity. A variety of other software packages were used to convert each aspect of the 4D model into the appropriate format.

At the completion of work on the Walt Disney Concert Hall, four objectives were identified explaining the benefits and successes of the implementation of 4D models. These objectives were:

1. Schedule Creation
2. Schedule Analysis
3. Communication
4. Team Building

The use of 4D models aided schedule creation by allowing all parties involved in the project to properly “visualize overall project access at critical junctures of the project” (Haymaker & Fischer, 2001). The 4D model also aided planners and contractors in schedule analysis. The model allowed for the discovery of several conflicts in the schedule. These conflicts were not discovered by analyzing the CPM-based Gantt chart (Haymaker & Fischer, 2001). These conflicts were able to be discovered and resolved during the planning process. Early detection of scheduling conflicts could potentially save time and money once actual construction begins. Communication between contractors, designers and the general contractor was greatly affected by the use of the 4D CAD model and the use of a Virtual Reality Cave [figure 3]. The general contractor held training sessions in the Cave including as many as 40 people. Models were able to be discussed and reviewed with all parties involved present (Haymaker & Fischer, 2001).



Figure 3. Training session held in the Virtual Reality Cave

Team building was the final objective that was aided with the use of 4D CAD models. According to John Haymaker and Martin Fischer of CIFE,

“After a 4D review session ended, it was not unusual to have people from different subcontractors remain in the room for an hour or more beyond the scheduled meeting time to discuss issues and solutions to problems or questions identified during the meeting.”

As with any new technology, there were challenges in using the 4D CAD models. Lack of data, level of detail, and scheduling inconsistencies occurred during the project. However, even with these challenges, the use of the 4D model was successful in the project by improving communication between stakeholders (Haymaker & Fischer, 2001).

### **Helsinki University of Technology Lecture Hall**

Stanford University’s CIFE was also involved with construction of a 600 seat auditorium located on the Helsinki University of Technology’s campus in Finland. The use of 4D CAD models and virtual reality were implemented in a variety of ways to improve the building and planning process.

The Computer Science Department at the Helsinki University of Technology houses an Experimental Virtual Environment (EVE).

The room consists of 3 rear-projectors, 1 top projector and several computers. The immersive model was based off of an ArchiCAD product model and LIGHTSCAPE ray-traced scenes (Fischer & Kam, 2002). The project team was able to get feedback about potential conflicts in construction, cost, and performance on site by using the EVE. This process traditionally takes time, but with the use of these visualization tools, this gave the project team input much earlier than possible before (Fischer & Kam, 2002).

Lighting and spatial visualizations were also used to provide better comprehension of the project. The lighting model allowed end-users to visualize lighting schemes in the auditorium. The lighting model also showed lighting distribution curves, energy requirements, ratings, sources, and installation information for the designers to compare different lighting options (Fischer & Kam, 2002). Architects were able to continually update their designs to show stakeholders changes in the project. They used their models to provide exterior perspectives, interior views, and blended virtual designs with the existing site. These visualization tools helped owners and end-users better understand the construction process. One of the owners noted “that in traditional design briefings, there were often end-users who could not read 2D plans. In the HUT-600 project, the insightful questions and comments from the end-users were evidence of their good understanding of the design.” (Fischer & Kam, 2002). The major benefit of using 4D models in an immersive virtual reality environment is that design conflicts and possible alternatives can be discussed and analyzed early in the construction process, therefore allowing the architects and designers more flexibility to make modifications and satisfy client needs (Fischer & Kam, 2002). Other useful models were built including a flow model depicting particle paths [figure 4], cross sections and isosurfaces near ventilation illustrating velocity of airflow in the Hall (Savioja, Mantere, Olli, Ayravainen, Grohn, Iso-Aho, 2002).

The 4D models used in the project allowed a visual linking of the construction project with the schedule. This allowed models to be “cross checked” with the schedule. If there were left over objects within the model, this meant it was missing in the construction schedule (Fischer & Kam, 2002). Within this particular project, planners linked video showing the 4D model’s construction process with a webcam showing the actual progress at the construction site.

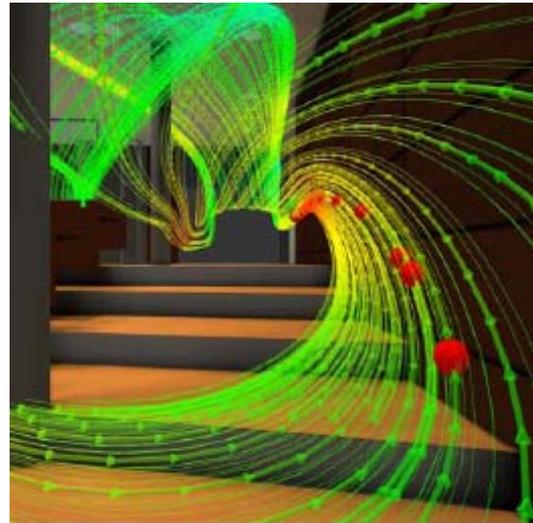


Figure 4. Model depicting particle paths in Hall 600.

## CHALLENGES

As with any emerging technology, the AEC industry is facing challenges in widespread implementation of virtual reality systems. One of the biggest challenges facing the construction industry is cost. Large virtual reality systems, like the one in the Envision Center at Purdue, provide high resolution images with sophisticated tracking systems. This, of course, provides the highest quality visualization, but typically costs over \$1 million. These types of systems also require trained personnel to set up and run them. Another drawback of a CAVE-like system is the limited space within the facility which doesn’t allow for a large number of people to be involved in a reviewing process. There is a need for more research to be done into more

low-cost facilities. Another challenge is the limited amount of software available that can be easily used by students and industry professionals. Currently, models must go through a series of conversions before they are ready for viewing in a stereoscopic virtual reality environment. Even with these challenges, 4D models and the use of virtual reality have proven themselves to be valuable visualization tools in many industry and academic projects (Messner, et al., 2003).

### TEST POPULATION AND SAMPLING METHODOLOGY

The sample population for the survey targeted industry professionals in the Architecture, Engineering, and Construction industries. Companies were contacted and asked to voluntarily complete an online survey. Accompanying this survey were several graphical assets created by the VirtuBuild team showing the use of virtual reality in an AEC workflow.

The survey included questions pertaining to the type of company each participant was involved with [figure 5], the number of years they have been in the industry [figure 6], the number of clientele they consult with each year [figure 7]. These questions helped us look at what types of companies would be interested in incorporating virtual reality into their company's workflow. The survey then questioned what types of visualization the company uses during the design/build stage of a project and concluded with questions asking whether the individual believes virtual reality could possibly be a useful tool in construction visualization and training.

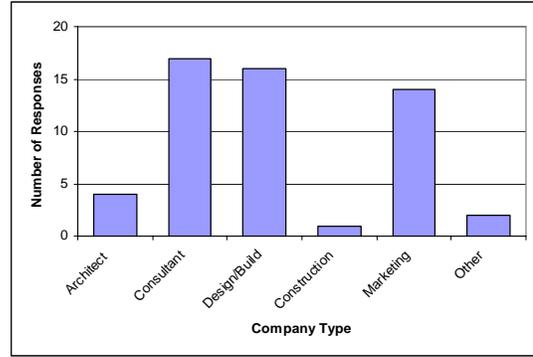


Figure 5. Type of Company

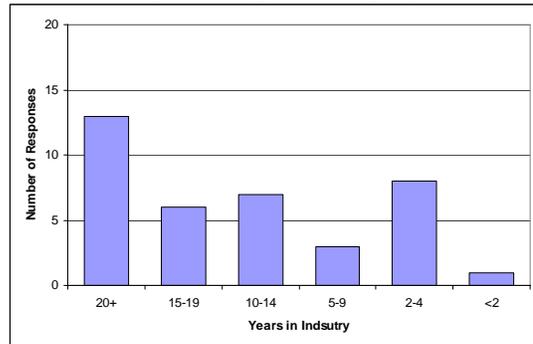


Figure 6. Number of years in industry

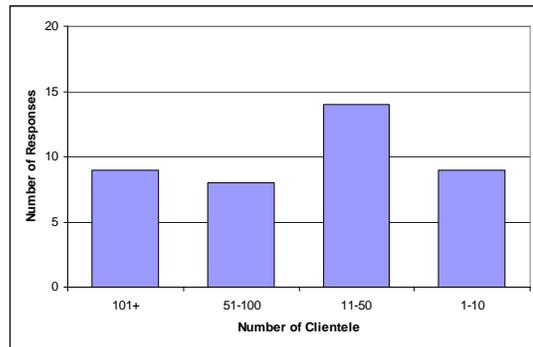


Figure 7. Number of Clientele

The survey targeted those in the construction, architecture, and engineering fields because these are potentially the types of companies that could benefit from the use of virtual reality.

Survey respondents were able to choose multiple answers when asked what type of company they worked for. The majority of respondents worked for consulting and design/build companies. When asked if the respondent's company would potentially fund a virtual construction lab at Purdue, 7% said they would potentially fund a virtual con-

struction lab at Purdue, 22% said no, and 71% said they were not sure [figure 8].

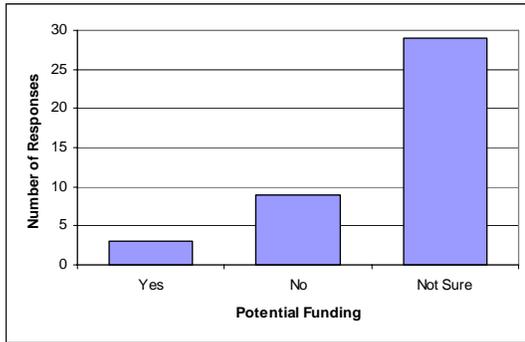


Figure 8. Potential to fund a Virtual Construction Lab at Purdue

Of those who answered ‘Yes’ [figure 9], all three believed that virtual reality would be an effective tool during the design/build phases of their projects. They also strongly favored its adoption for use as both a training tool for new techniques and practices as well as a way to educate employees on safety.

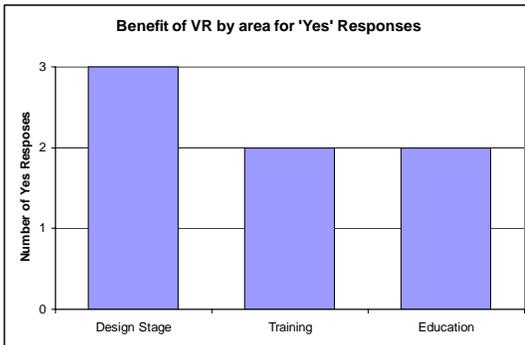


Figure 9. Yes responses

Of those who answered ‘No’ [figure 10], while they commented that they don’t believe that their company would directly fund a Virtual Construction Lab at Purdue University, they all did believe that virtual reality could help their companies during both the design/build phases of a project as well as the training of new techniques and practices. Some individuals who responded to the survey also sent back comments about virtual reality and how they see it relating directly to the construction industry. One anonymous individual who responded ‘No’ to potentially funding a Virtual Construction Lab at Purdue

stated that, “We have experienced the benefits of 3D and 4D modeling in planning and scheduling construction projects. It is an extremely valuable tool.” Another individual that answered ‘No’ said, “I am a graduate student from Texas A&M and have worked on 3D and 4D modeling to use as a teaching tool. I am of the opinion that 4D is very useful if kept updated with the changes happening on a construction site on day to day basis. 4D visualization is an excellent tool to avoid MEP clashes ahead of time. It’s overall an excellent tool and the future of construction.”

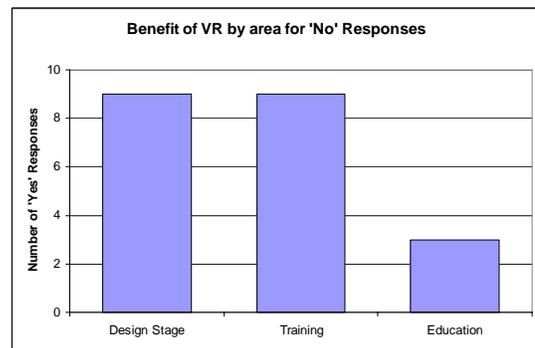


Figure 10. No responses

Of those who answered ‘Not Sure’ [figure 11], like those that answer ‘No’, they all still believed that virtual reality could be an effective tool for use in both the design/build phases and training of new techniques. Several reasons for individuals answering ‘Not Sure’ could be attributed to the possibility that they weren’t in the adequate position to answer that specific question. This might have been due to the fact that surveys were sent out to any individual listed on the company’s website or the company’s contact information. The individuals surveyed included presidents and vice presidents, project managers, and public relations individuals. This was done to ensure the largest possible response to the survey.

Another possible reason for the ‘Not Sure’ answers would be that the surveyed individuals weren’t given enough information at the time to make such a decision. The surveys were sent out during the midpoint of the project’s completion to ensure that enough re-

sponses would be acquired. This limited the amount of information that was able to be given to the individuals receiving the survey. Many individuals answering 'Not Sure' also took the time to comment on their opinions of virtual reality as it relates to the AEC industry. Some of these individuals commented that they are already actively using virtual reality for marketing purposes, and others commented that their company is currently researching the potential benefits of using virtual reality in several areas of their company. One individual stated that, "We believe the key to successful projects in the future lies in close partnership and collaboration between architect, contractor and owner. As such, [A Virtual Construction Lab] will bring the team closer and enable a quicker delivery of cost and design information."

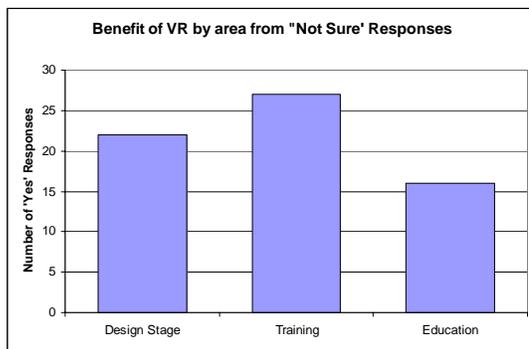


Figure 11. Not sure responses

From the data obtained from the survey, the results concluded that the AEC industry does have a strong interest in using virtual reality for various aspects in their company. While many stated that they would not directly help fund a Virtual Construction Lab at Purdue University, they did show an active interest in its potential benefits. As more information becomes available to the industry, the prospective for using virtual reality as a design,

planning, scheduling, training, and education tool will increase dramatically. The research involved in this project suggests that the creation of visual assets did in fact improve Purdue University's potential to obtain financial support for a virtual construction lab in that individuals in the industry have taken an active interest in our research and development of the Virtual Construction Lab.

## FUTURE RESEARCH

The use of 4D models and immersive virtual environments in the construction industry is an emerging technology. There are many possible benefits to aid construction design and planning. Virtual models could be used to depict anything in the real world such as materials management, design phase coordination, demolition, site surveying, and the incorporation with augmented reality (Messner, et al., 2003).

Models being put into the virtual reality environment could contain data crucial in the construction planning process, allowing a user to possibly touch a wall or component resulting in text appearing displaying all materials used in the wall (Faulkner, 2006). The model could contain all information pertaining to construction materials used. These models are being referred to as Building Information Modeling (Faulkner, 2006). The use of virtual reality could also be incorporated into construction training.

After researching and developing the assets and processes for a Virtual Construction Lab, and through the responses received through the survey and presentation, it can be concluded that the project created helped gain industry interest in potentially funding a Virtual Construction Lab at Purdue University.

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