DETERMINING THE EFFECTS OF IMMERSIVE ENVIRONMENTS ON DECISION MAKING IN THE AEC INDUSTRY

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ABSTRACT

Research into the use of immersive projection displays (IPDs) and immersive environments has shown promise for improving design and construction planning within the Architecture, Engineering, and Construction (AEC) Industry. IPDs allow a project team to be immersed into a virtual prototype of a building project. The review of the prototype in this display environment allows the project team to easily navigate the prototype at full scale with a display system that provides depth perception and a large field of view.

This paper presents a case study which analyzes the value of using an immersive projection display system along with a 4D CAD model for performing a construction process review meeting. During the meeting, data was collected to evaluate the type of communication that occurred within the IPD. The research team was specifically aiming to determine if the display system along with the virtual prototype would shift the focus of the team discussions toward higher level problem solving discussions. Upon analysis of the data, the discussions which occurred within the IPD during the case study contained greater percentages of explanative and predictive conversation than in a typical project meeting. The meeting also yielded valuable construction solutions that were later implemented on the project to save time and money. This case study will guide future efforts to understand the potential value of using IPDs to provide a productive decision making environment.

KEY WORDS

Decision Making, Immersive Projection Displays, Virtual Reality, Construction, 4D CAD

BACKGROUND

"Modern technologies can aid the resolution of many problems by providing information channels (media or representation) that would support the use of virtual models as the medium for communication, interaction and integration."- Gopinath 2004

The visualization of design and construction information can be very beneficial to a construction project team. The goal of this research was to evaluate the impact of the use of immersive display media for construction visualization of 3D and 4D CAD models,

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with an aim to measure the potential improvements in quality of a construction plan review meeting. The underlying hypothesis was that the use of immersive display media, which allows a project team to be more immersed within a virtual prototype of a project, would improve the quality of communication between team members and, therefore, yield improved decisions from the team.

IMMERSIVE DISPLAY SYSTEMS AND THE ICON LAB

Previous studies in which researchers evaluated the potential value of immersive display systems have illustrated improvements in the communication process and decisions made by the team when using large format or immersive virtual environments (Liston, 2000; Garcia, et al. 2003; Yeraptathruni, 2004; Gopinath, 2004). The value illustrated by these IPDs included the ability for better communication between the team members, improved visualization of the design and construction process, and an improved sense of scale.

For this case study, the immersive display system that was used is the Immersive Construction (ICon) Lab (CIC Research Group, 2006). The Immersive Construction (ICon) Lab is comprised of a three screen passive stereoscopic display system. With the use of polarized glasses, horizontally and vertically polarized filters, six high lumen output digital projectors, and a high end computer system, the ICon lab produces an environment that simulates real world spaces at full scale. The three, six foot high by eight foot wide screens are set at 135 degrees from each other to provide a panoramic virtual reality environment. Figure 1 shows a schematic diagram of Penn State's ICon Lab.

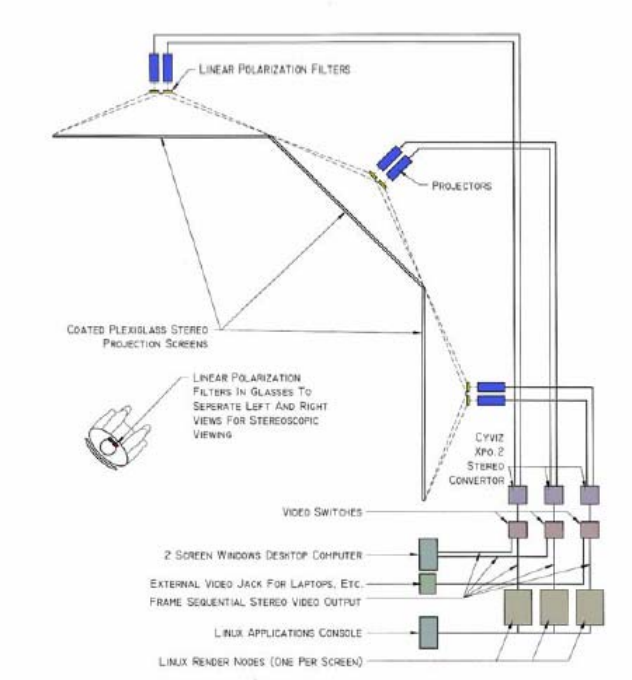

Figure 1: Schematic of the ICon Lab

The three screen system lends itself to versatility as multiple items can be displayed at one time. For a design review, all three screens are used to display one construction

project so that each audience member typically gets the feeling of immersion. In other scenarios, such as schedule reviews, the display system can be used as a multimedia display with two screens showing the 3D model and the third screen displaying the schedule logic.

PROJECT MEETINGS USING IMMERSIVE PROJECTION DISPLAY SYSTEMS

Besides students in architecture, engineering, and construction, construction project teams have seen benefits to using these spaces. Previous research has found that the use of large scale visualization systems in meetings help display a variety of information simultaneously. This reduces a project manager's reliance on multiple paper documents, which may be hard for all participants to follow. According to (Liston, 2000; Garcia, et al. 2003) and their initial case studies where large scale visualization systems were used in project meetings, they believe that project teams perform more meaningful tasks. This visual interaction with project information helps to support decision making tasks (Liston, 2000).

THE VILLAGE AT SHIRLINGTON PROJECT BACKGROUND

A project was undertaken to evaluate the value of using IPDs for the detailed review and analysis of the construction schedule for a building construction project. The project is The Village at Shirlington project currently under construction in Shirlington, VA, USA. The project was initially delayed due to contaminated soils and unexpected groundwater issues during the excavation phase. Therefore, the developer and contractor decided to participate in a schedule review meeting within the ICon Lab with the goal to identify methods to recover schedule time.

The Village at Shirlington is a condominium composed of 16,400 square meters (176,570 square-feet). This condo will house 159 units on eleven levels, 176 parking spaces on five levels, in a suburb of Washington, DC. The construction of this building started in September 2004 and is scheduled for completion by the end of June 2006.

RESEARCH METHODOLOGY

This project is an exploratory case study into the value of IPDs in construction plan reviews. The methodology developed includes the collection of both quantitative and qualitative data related to the case study.

1. *Define case study research procedure:* A research procedure was defined that allowed for the collection of quantitative data associated with the quality of construction review meetings. The procedure is summarized below.
2. *Develop Models:* A 4D CAD model with two different views illustrating the construction sequence for the project were developed and a team including members from the developer and contractor were placed in the ICon Lab to review the schedule and seek opportunities for schedule improvements.
3. *Perform project review:* The project review for the case study project was conducted in the ICon Lab. Data related to the communication types was collected during the

meeting along with observations regarding the general progress and decisions made during the meeting.
4. *Post meeting interviews:* Following the meeting, detailed interviews were performed with key personnel from the developer and contractor organizations. The goal of these interviews was to determine the participant perspective of the construction review performed in the ICon Lab.
5. *Data synthesis and Conclusions*: The data was analyzed and compared to data previously obtained from project meetings. The impact of the display system on the identification of the innovative solutions identified in the ICon Lab was analyzed to the extent possible. Conclusions and recommendations for further study were defined.

INITIAL PROJECT TEAM PERCEPTIONS

Prior to the project meeting in the Immersive Construction Lab, team members had little or no experience with immersive display systems and 4D CAD modeling. According to project team members, the current way of reviewing the schedule for the contractor on the project involved posting a large size printed version of the CPM on the wall and using a string line to check progress and review upcoming activities. By using the string line, the contractor could tell when different contractors had to have their activities under progress or complete. While this method is effective for a quick check to see which activities are on schedule and which are behind schedule, it has limitations when aiming to identify creative opportunities to resequence or reschedule the project.

In the schedule review meeting held in the ICon Lab, the team used a 4D CAD model to review the job progress and future schedule activities. The schedule review meeting served two main purposes. The first was to verify the baseline schedule logic. The second was to see if the team could identify new opportunities for schedule acceleration or rephasing of the project to recover initial lost time with minimal or no added cost. Prior to investigating the schedule logic, a 4D CAD model was developed. The model was developed from the 2D drawings. The model took approximately 100 hours of modeling time to create. The model does not include all elements on the project, but instead focused on the elements that the developer and contractor identified as the activities which could yield the greatest potential benefit from resequencing. This included the structural system, façade, and interior elements for one typical floor.

Two primary views of the model were developed. The first view of the model (Figure 4) detailed the excavation, cast-in-place structural system, and brick façade. It also included objects to graphically represent the formwork and reshores for the cast-in-place concrete work. A second view of the model (Figure 5) detailed the flow of the interior trade contractors for a typical floor. This model was developed to evaluate the typical floor sequence which is repeated eight times in the upper floors of the building.

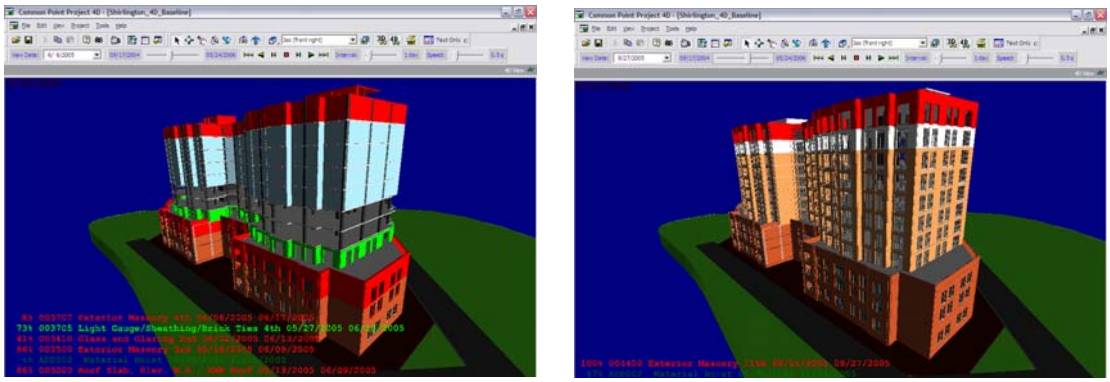

Figure 4: Excavation, Structure, and Façade Model

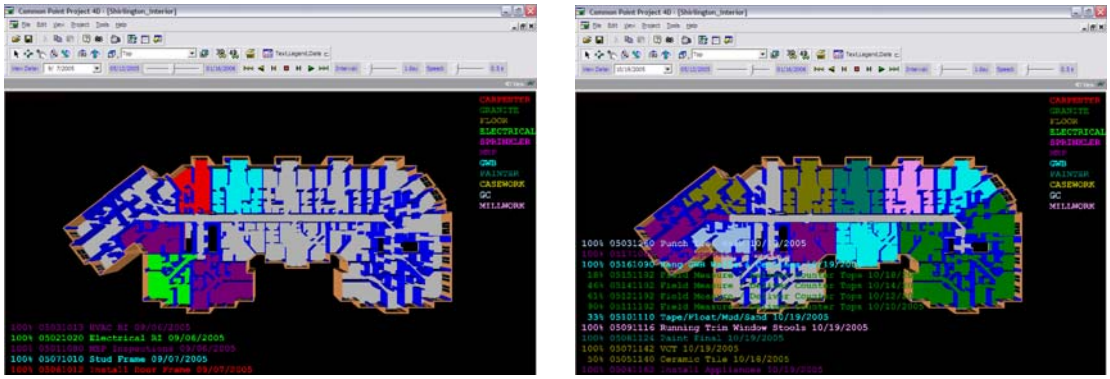

Figure 5: Interior Trade Sequence Model

Prior to attending the meeting at Penn State, The Village at Shirlington was behind schedule by 45 working days, most of it due to groundwater and contaminated soils delays. Despite the delays, the developer still needed to turnover the units to the future condominium owner's at the contractual date. The interest carrying cost for the developer would be approximately $300,000 per month beyond the proposed final completion date, along with any other damages that the developer and contractor would incur.

In a project debrief following the immersive schedule review, project team members stated advantages of the 4D model over the current schedule review process. Some of these advantages included:

1) Understanding more of the details involved with some activities. For example by seeing the masonry activity on the immersive screen the project team could determine staging requirements as well as where and when the follow on activities could occur.
2) They could see how far along the project would be on a certain date in the future. A quote from the meeting was, "Wow, we really need to be that far along on August 1".
3) The 4D model helped the team better visualize the schedule. A quote from the meeting was, "Things popped out that didn't on paper".

The immersive model allowed the project team to evaluate and look at different alternatives which were stated to spark more conversation where each person in the room could play off of each other's comments.

One useful idea proposed and adopted as a result of the schedule review meeting was a second anchor point for the exterior masonry scaffolding. During the review meeting, a member of the contractor noticed that the start exterior façade activities waited until the structure was topped out. This constraint was embedded in the schedule to allow the masonry contractor to anchor the hanging scaffolding for their work from the top floor, therefore, only installing one set of anchors. The contractor proposed that this activity could start earlier (once the reshores were removed from the 6th floor) if an additional set of anchors was installed on the sixth floor. This acceleration would cost approximately US $10,000, but would contribute to getting the project back on schedule. It was estimated by The Village at Shirlington project team that the acceleration was partially responsible for the recovery of 14 schedule days. The acceleration due to double-hanging the scaffolding would allow the interior spaces to be ready earlier for framing and unit fit out. Further gains could not be quantified at this time, as the project is currently in the interior framing and drywall phase.

OBSERVATIONS FROM THE MEETING IN THE ICON LAB

To test their schedule logic and progress to date, the contractor determined how many days they were behind schedule and cycled the 4D model back the same amount of days. The contractor and owner were pleased when they determined that the progress displayed on the screen was approximately the status of the project during the week of the visit.

To test the decision making process during this immersive project meeting a conversation type analysis was performed. The team was successful in the identification of solutions to help the project recover valuable schedule time.

CONVERSATION TYPE ANALYSIS

With reduced amounts of paper documents to contend with and more visual methods of displaying project information, project meetings in the IPD will be different than traditional project meetings. One way to see and assess these differences is to analyze the type of conversation that occurs at traditional project meetings and compare it to the type of conversation that occurs in immersive project meetings. To categorize conversations that occur in project meetings four types of communication were measured. Described by Liston (2000) and Garcia et al (2003) the first four categories include: descriptive, explanative, evaluative, and predictive communications. Additional categories, decision making, problem solving, and other discussions were proposed by Gopinath (2004) and used to parse out decision making and problem solving from other types of conversation (Liston, 2000; Garcia, et al 2003; Gopinath, 2004). By segmenting a meeting by conversation type, effectiveness can be judged. Table 1 gives an overview of each type of conversation and key words and examples of the use of these terms.

Table 1: Conversation Types & Categories

Conversation Type	Actions or Key Words	Examples
1. Descriptive	What, When, Where, Who	Showing drawings and discussing cost estimates
2. Explanative	Why, why not	Discussing an idea or proposal
3. Evaluative	Weighing advantages/ disadvantages	Assessment of alternatives to a problem
4. Predictive	Predicting consequences or estimating the value of the unknown	Cost estimation of an activity during a meeting
5. Decision Making	Selecting one alternative out of many	Discussions related to selecting an alternative
6. Problem Solving	Discussion and input from all team members	Resolving problems or challenges
7. Other Discussions	Communication on topics unrelated to the project	Moments of silence

Descriptive conversation is considered the lowest order form of conversation, whereas predictive conversation is the highest order. It is inferred that evaluative and predictive conversation lead to decisions and problem solving as they are more related to weighing the value of potential alternatives. Descriptive and explanative conversations are more focused around one-way communication of the details of an idea or concept. These conversation types are more tangible and relate more to explicit knowledge. Whereas evaluative and predictive conversations are more focused on opinions and can lead to instances of tacit knowledge being shared with the group.

Though this characterization alone may not be an indication of an effective meeting, it helps define what types of conversation should be utilized for an ideal project meeting. Being able to define and map conversation types to schedule review, design review, and weekly progress meetings will help determine what types of conversation should occur in an IPD. The modifications needed to achieve these idealized results are an important future step of this study.

RESULTS

TYPES OF COMMUNICATION IN THE ICON LAB

A conversation type analysis was used to quantify and analyze communication types during this project meeting. The conversation was coded every 30 seconds based on the categories of conversation types described by Liston (2000) and Gopinath (2004). Upon completion of the meeting, percentages for each conversation type were developed.

The aim of this study beyond eliciting new ideas was to determine how conversations in an immersive environment differ from a traditional project meeting. The figures below show the amount of time spent in typical non-immersive project meetings (SALA) (Figure 4) and the immersive project meeting held for the Shirlington Village Project team (Figure 5).

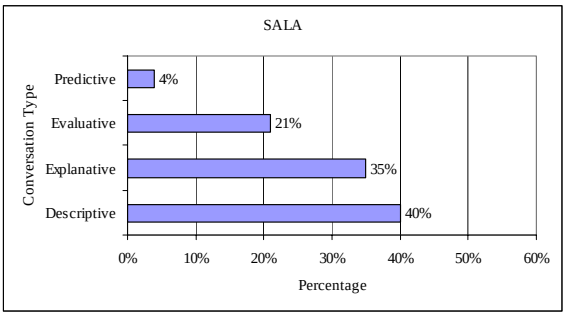

Figure 4: Traditional Project Meetings

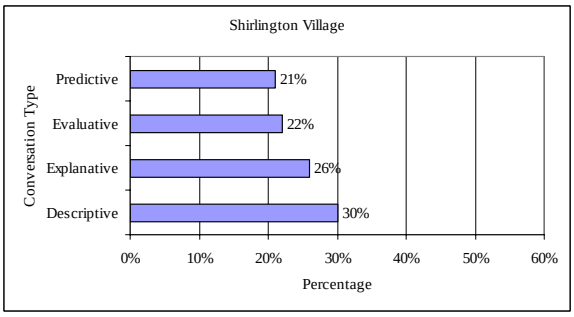

Figure 5: Immersive Project Meetings

In the Shirlington Village study we see that there is a greater portion of time spent on predictive and evaluative conversation than in the traditional project meetings. This may illustrate that there was more time used in the immersive space to debate ideas and scenarios that were suggested than in the traditional project meetings. A greater proportion of conversation focused on discussing problems or solutions and predicting possible consequences. We also see a decrease in the amount of descriptive conversation. Another important item to note in analyzing the conversation is that before the team members referenced other team members to look at the model they were engaged in explanative conversation (57%) and after looking at the model they tended to engage in descriptive conversation (61%).

INTERVIEW RESULTS

In addition to the quantitative data collected during the project review meeting, several meeting participants were interviewed following the meeting. These included the project manager for the contractor and the VP of Operations for the developer. They both noted benefits using immersive virtual environments. One member of the project team stated that "the lab validated our schedule and helped us see opportunities for (schedule) recovery". They also felt that the model aided in the evaluation of multiple alternatives. Another project team member stated, "The group played off of each other's comments and could look at different alternatives". In regards to reviewing the model in 4D, even members of the project team who were skeptical at first of spending time away from the job site, felt that the IPD helped. According to one participant, "The biggest thing was validating the schedule". Project team members could physically see what areas of the jobsite would be occupied at what time, and evaluate the progress needed.

CONCLUSION

This paper has illustrated the potential value of using a 4D model, projected in an immersive display system for schedule review. For The Village at Shirlington project, the project team was able to identify several ideas though greater instances of evaluative and predictive conversations that contributed to recovering approximately fourteen working schedule days.

Upon analysis of the data, the discussions which occurred within the ICon Lab during the case study contained greater percentages of predictive and evaluative conversation than in a typical project meeting. Changing the conversation types in project meetings is

an initial step in achieving more productive project meetings. This case study will guide future efforts to understand the potential value in the use of immersive virtual environments as a decision making environment.

It is important to note that the precise benefit of the immersive display system and the 4D model are difficult to measure. The positive results that were achieved could have been a result of 1) the 4D model, 2) the media display, 3) the secluded meeting location, 4) the added time reviewing the schedule and model, or 5) a chance event, but it seems clear that type of discussion which occurred during this design review differed from previous meetings. This improved communication should result in more consistent identification of innovative solutions and more effective meetings.

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