Avatar-Model Interaction in Virtual Worlds Improves Distributed Team Collaboration through Issue Discovery

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ABSTRACT

In this study, we observed distributed construction engineering management teams as they discovered issues in building models while collaborating in a 3D virtual world. This paper contributes to visualization and building information modeling (BIM) literature by exploring how the affordances of the media-rich 3D environment of a virtual world support mutual discovery of construction coordination issues among team members. In Winter/Spring 2013, graduate and undergraduate students from four globally distributed universities met in three teams once a week for eleven weeks. Numerous communication affordances were available to the teams both within and external to the virtual world, including voice, text chat, screen-sharing, and exploring avatar-scaled models imported into the virtual world. When exploring the imported model, individuals controlled their own viewpoint by "walking" through the building as an avatar using the arrow keys on a keyboard and, as a result, all members of the team were able to view the model, together, regardless of BIM experience. We found the rate of issue discovery to be significantly higher in the avatar-scaled models compared to other methods of viewing the model, such as passively viewing the model on a 2D shared screen, indicating that bringing team members and building models into the same interactional space is more effective for quickly discovering coordination issues.

INTRODUCTION – COLLABORATION IN VIRTUAL WORLDS

Due to communication technology improvements, a growing number of firms in the architecture, engineering, and construction (AEC) industry are able to tap into a large educated workforce outside of local regions for complex design and construction work in globally distributed virtual teams. These teams are composed of members located at a distance from each other who collaborate to accomplish organizational tasks (Kirkman et al. 2002; Nayak and Taylor 2009). They are characterized as being mediated by technology, though the specific medium can range from e-mail to a fully immersive 3D environment (Chinowsky and Rojas 2003; Schroeder 2006) . Teams that collaborate in real time experience advantages of synchronous distributed collaboration such as "efficiency of project execution, removal of physical boundaries, the integration and optimization of competencies, and the ability to form new partnerships" (Chinowsky and Rojas 2003, p. 98).

When grappling with complex multi-disciplinary problems, AEC teams are effective when team members collaborate and synthesize knowledge across disciplinary domains (Carrillo and Chinowsky 2006; Whyte et al. 2008). With the rise of globalization and virtual work environments in AEC settings, it is increasingly important to understand how to support efficient systems of collaboration, information transfer, and joint problem solving in virtual teams. Many types of complex design and construction problems require shared analysis and planning that even collocated teams struggle to do efficiently and effectively (Dossick and Neff 2011), making the challenge facing virtual teams even greater.

BACKGROUND

Virtual worlds are defined as "persistent, avatar-based social spaces that provide players or participants with the ability to engage in long-term, coordinated conjoined action" (Thomas and Brown 2009, p. 37). An avatar is a digital representation of the user who, with this avatar, navigates the virtual world. By definition, interactions in the virtual world take place in real time and an action is expected to be met with reaction almost immediately (Bartle 2004). While many collaborative technologies have video, voice and chat capabilities, what is unique to virtual worlds is that a 3D environment is navigated by avatars that provide an additional layer of nonverbal communication in the form of gestures and avatar position and gaze (Yee et al. 2007; Anderson et al. 2011; Iorio et al. 2011).

Communication and Copresence in Virtual Worlds. People are social beings that rely on body language and other non-verbal cues to communicate (Kock 2004), and studies have shown that social conventions tend to carry over from the physical world into the virtual world (Bailenson et al. 2005; Yee et al. 2007). In a previous study, participants reported feeling emotions such as embarrassment and anger, and tried to avoid passing through other avatars, sometimes apologizing when they did so (Slater et al. 2000). This indicates that a sense of "copresence" exists in virtual worlds. Building on the definition of "presence" in an electronically-mediated environment as *the sense of being there* (Steuer, 1992), copresence is defined as *the sense of being there with others* (Schroeder 2006).

Visualization and Collaboration in AEC teams. For collocated AEC teams, much work has been done around how shared visualizations, such as Building Information Modeling (BIM), support distributed knowledge exchange through interaction, collaboration and communication (Orlikowski 2000; Liston 2007; Taylor 2007; Whyte et al. 2008). Tacit knowledge exchange is vital. For the practitioner who creates them, visualizations and models both serve as a way to communicate knowledge and as a means of knowing, making the division of tacit and explicit knowledge almost inseparable (Whyte et al. 2008). Those who receive a drawing or a model reinterpret it through their own domain lens, their role on the project, and their disciplinary expertise (Dossick and Neff 2010). Consequently, models and documents are sites for conversation where meaning is made in part through talk (Neff et al. 2010). Dossick and Neff define messy talk as "unplanned, unforeseen and unanticipated" talk supporting brainstorming and mutual discovery (2011, p. 85). Visualization leads to "unexpected discoveries" through designers' rapid-fire process of sketching, analysis, and synthesis (Suwa 2000, p. 240).

In this paper we explore visualizations in distributed team settings and how the affordances of virtual worlds populated by both models and avatars shape this discovery. We present findings from a study of globally distributed virtual teams who worked on design and planning tasks using Building Information Modeling (BIM) in an online 3D virtual world. The participants conducted all meetings online where they interacted with other team members as avatars.

RESEARCH METHODOLOGY

During the winter and spring of 2013, students from four globally distributed universities met in teams to complete an interdisciplinary design and planning task for a building project with each university's subteam being responsible for one component of the project. The teams each had 9 students: 3 from the Indian Institute of Technology-Madras (IITM) in Chennai, India (3D modeling in Autodesk Revit); 3 from the University of Twente (UT) in Enschede, Netherlands (Cost Estimating in BIMserver); 2 from Virginia Tech (VT) in Blacksburg, Virginia, U.S. (Baseline Schedule in Simvision); and 1 from the University of Washington (UW) in Seattle, Washington, U. S. (4D Modeling in Autodesk Navisworks). The teams met once a week for eleven weeks.

Figure 1. Students exploring the avatar-scaled building model.

Figure 2. Small model in the team room; Team Wall in the background.

The CyberGRID 3D virtual world. The teams met in an online virtual world called the CyberGRID (Cyber-enabled Global Research Infrastructure for Design), developed by Virginia Tech to support research of geographically distributed team work in the AEC industry (Figures 1 and 2). To navigate the CyberGRID, a participant creates an avatar, which is a digital representation of a human, and navigates the space using the arrow keys on a keyboard. Communication affordances within the CyberGRID include voice, text chat, Team Walls for desktop sharing, overhead thought bubbles, C-mail (electronic mail within CyberGRID) and a file repository (Iorio et al. 2011). 3D building models can be imported into the space where they may be explored by participants as avatars. Avatar location and position are also effective means for communication (Anderson et al. 2011). In addition, participants had access to external communication tools such as instant messaging, Google Docs, a file repository (Dropbox) and e-mail.

Data Collection and Analysis. Data collection included ethnographic observation in the virtual world, audio and video recordings of meetings, transcripts from the online chats, Google Docs, and submitted assignments. Because our research focused on issue discovery, the week 3 meetings were chosen for analysis. Week 3 was the first time the teams viewed model revisions provided by the IIT-Madras students. The IITM students were new to the Revit modeling software so it was expected there would be errors in the model to be discovered by their teammates. The meetings were transcribed using ELAN, an annotation tool developed at the Max Planck Institute for Psycholinguistics. ELAN allows multiple media—in our case video and audio—to be imported, transcribed and annotated. The ELAN transcriptions were annotated for speaker, typist (person typing chat) and discoveries. The discoveries were coded for discovery trigger (e.g. avatar-scaled model or Team Wall), discovery type (e.g. error or confirmation), and cue type (e.g. avatar position or verbal description). Each discovery has a video time stamp that is used to identify the discovery. The discoveries were bracketed from first mention of the discovery to agreement by at least one other member. The time duration and number of words for each discovery were noted.

FINDINGS

Communication Tools Used. The teams had several communication tools available to them both within and external to the virtual world. Table 1 lists the tools each team chose to use in week 3. One factor that complicated the study was that the IITM students were unable to access the CyberGRID virtual world. In order to communicate with their teammates synchronously, each team used instant messaging (IM) through Google Talk which required one team member to invite all other team members to the IM conversation at the beginning of the meeting.

Table 1. Communication tools used in week 3 meetings

	Voice	IM/Text chat	Google Doc with chat	Shared screen	Pens on shared screen	Gesture bubbles	Avatar location and position	Dropbox	E-mail
Team A	✓	✓	✓	✓	✓	✓	✓	✓	
Team B	✓	✓		✓	✓		✓		✓
Team C	✓	✓		✓		✓	✓	✓	

Team A chose to communicate primarily by voice within the virtual world as they explored the avatar-scaled model (Figure 1) to review updates provided by IITM. Only six IM exchanges were recorded while they explored the model. In one of the exchanges, IITM asked what they thought about the about the model and VT responded by saying they were "going through it now." As they explored, they took notes using a synchronously shared document via Google Docs to which the IITM group had access. While walking through the imported Revit model (which took a total of 25 minutes) Team A found 22 issues -- nearly one per minute.

Team B was simultaneously engaged with voice in the virtual world and with IM to communicate with IITM. Typically, one student in the virtual world would bring something to the others' attention using voice, discuss it briefly, and then share it via IM with the IITM students. Team B only spent seven minutes in the avatar-scaled model, but during those seven minutes discovered five issues with the model -- nearly one per minute. Even though they had significantly fewer discoveries than Team A, their discovery rate in the model was nearly the same.

Team C chose a different way to communicate with their teammates than Teams A and B. Roughly 20 minutes into the meeting, after the group IM had been established, one member stated, "I think we should do everything in Google Chat and we can just talk with our headsets with each other but what's the point of just getting with everyone in the CyberGRID then? Maybe to check the model or something." They proceeded to conduct the majority of their subsequent communication through IM unless something warranted using voice, which happened few times. They entered the avatar-scaled building model 36 minutes into the meeting and spent the remainder of the meeting in the model for a total of 75 minutes in the model. Team C found five issues that were triggered by the avatar-scaled model – a rate of 0.07 discoveries per minute, which is roughly 1/10 the discovery rate of the other two teams.

Discovery Triggers. The discovery trigger is defined as the delivery medium for model information. In other words, what was the team viewing when a discovery was made? There were four primary ways to view the Revit building model:

(1) The avatar-scaled model in the yard outside the virtual team room. See Figure 1.
(2) The small-scale model located in the virtual team room. See Figure 2.
(3) Having Revit open on one's own computer and viewing it directly in the Revit software. UW, UT, and IITM had access to Revit on lab computers; VT did not.
(4) Viewing the model on a shared-screen, i.e. one person has the model open on their desktop and shares their desktop on the Team Wall in the virtual team room where their teammates are also able to view it. See Figure 2.

For all three CyberGRID teams, the vast majority of the discoveries were triggered while walking through the avatar-scaled model (79%, 83% and 83% for Teams A, B, and C respectively). The students were informed that avatar-scaled models were available in the space for exploration, but were not required to use them. They had the freedom to communicate with any tool available to them (see Table 1) and to structure the meeting how they chose. Teams A and B chose to communicate primarily using voice while in the avatar-scaled model (85% and 73% voice for Teams A and B respectively, based on word count), while Team C chose to communicate using both voice and IM while in the model. Based on a word count, 49% of the words exchanged by Team C were via voice, with the other 51% being IM.

DISCUSSION AND CONCLUSION

All three teams successfully used multiple channels to communicate with each other, including voice, text chat, and shared screens within the virtual world as well as IM, a file repository, and e-mail outside the virtual world. Because they used all of the tools successfully, this indicates that the channels used to communicate specific items were chosen purposively.

In the third week of the study, the teams were tasked with reviewing the Revit model to ensure revisions made to the model by the IITM students were in accordance with what the team had discussed in the previous week. Team A chose to systematically explore the avatar-scaled model and then return to the virtual team room where they shared the Revit model on the Team Wall to brainstorm solutions to the issues they discovered (indicating that Team A was capable of using shared screens to view the model but chose to walk through the model to review the updates). Team B only explored the model after one team member noticed something odd in the small-scale model located in the team room and proceeded to the avatar-scaled model to "go check," followed by his teammates. It happened that entering the avatar-scaled model to check that one item wound up triggering five more discoveries for Team B as they walked through the model – discoveries that they may not have found had they not entered the model. Team C also entered the avatar-scaled model, but because the majority of their communication was via IM, they spent very little time "in" their avatars while in the model. Their attention was focused on the IMs with their team. Even though Team C's rate of discovery was low while in the model, the percentage of discoveries in the model, 83%, was still quite high.

Given the four different ways that the teams had to view the Revit model, the viewing method that triggered the most discoveries was exploration of the avatar-scaled model. While in the model, the members of Teams A and B would bring discoveries to the attention of others as they walked through the model together, each member having a unique viewpoint and viewing different items as they walked, e.g. one student said, "the columns are shown on the outside which is no good" followed shortly by a team member in the same area saying, "yeah and the handrails are not aligned."

When considering how a model is viewed when walking through the model versus viewing it on a shared screen, the teams are copresent with each other and with the model in both scenarios, but there are two primary differences between the way the model is viewed in each case:

(1) Independent navigation vs. single viewpoint. Using an avatar to navigate the model allows the user to control one's own viewpoint. In the screen-sharing scenario, one person controls what is shared on the screen and everybody must view the same thing. Independent navigation allows more issues to be discovered when a team is exploring the model because more items are being viewed at any given time.

(2) Avatar centric vs. object centric viewpoint. Viewing a model using avatars more closely resembles how people explore buildings in the real world. The viewpoint when a user is walking through a building model as an avatar is egocentric (the viewpoint originates through or near the avatar and the objects in the building or model move around the avatar as the user navigates. The user can also see other avatars (teammates) in view, and can see what they are viewing when they discover an issue, which is natural when exploring a building with others.

Our findings indicate that, if discovery of issues is critical, the best way to trigger discovery of those issues is to bring the model and the team into the same interactional space where navigation is independently controlled such that they may more effectively engage with each other and with the building model.

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