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THE IMPACT OF AVATARS, SOCIAL NORMS AND COPRESENCE ON THE COLLABORATION EFFECTIVENESS OF AEC VIRTUAL TEAMS

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EDITOR: Amor R.

Anne Anderson, Assistant Professor
School of Design and Construction, Washington State University, Pullman, WA, USA
email: anne.anderson@sdc.wsu.edu

Carrie Sturts Dossick, Professor
Department of Construction Management, University of Washington
email: cdossick@uw.edu

Josh Iorio, Assistant Professor of Practice
Myers-Lawson School of Construction, Virginia Tech
email: iorio@vt.edu

John E. Taylor, Professor
School of Civil and Environmental Engineering, Georgia Tech
email: jet@gatech.edu

SUMMARY: *A growing number of architecture, engineering, and construction (AEC) firms are outsourcing complex design and construction work to international vendors. Due to the significant geographic distances that can separate project team members in global design networks, much of this work is executed in virtual teams, defined as teams composed of geographically separated members who collaborate to accomplish organizational tasks mediated by technology. The challenges of working in geographically distributed networks have prompted the development of alternative, virtual workspaces. Questions remain on how these virtual workspaces support or hinder collaborative work. People are social beings that rely on body language and other non-verbal cues to communicate. What happens to team formation and collaborative effectiveness when non-verbal cues are mediated through avatar actions? In this paper, qualitative ethnographic data collected over four years from studies conducted in a 3D virtual world are used to examine collaboration effectiveness of global virtual engineering project teams. We found that avatar movement and position was effective at communicating nonverbal information, even when done so unintentionally. Avatar actions that map to established social norms in the physical world results in more efficient communication. Collaboration was also enhanced when gesture bubbles were used for backchannel communication and when text chat was used to avoid interrupting voice communication. We found collaboration was hindered when the learning curve was too steep for participants to adapt to tool use or avatar actions in the environment. These findings have important implications for the future of collaboration in virtual environments, particularly in the AEC industry where 3D models can be imported into the virtual environment and explored synchronously by a project team.*

KEYWORDS: *BIM coordination, collaboration technologies, distributed teams, social norms, virtual worlds*

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1. INTRODUCTION

Due to communication technology improvements, a growing number of engineering firms are able to tap into a large educated workforce in different countries for complex engineering design and construction work. Because of the geographic distance that separates them, much of the work is executed in globally distributed virtual teams (Meyer et al., 2015). Virtual 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). Chinowsky and Rojas (2003) further refine the definition of virtual teams to include teams that collaborate in real time, citing the importance 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" (p. 98).

Literature on BIM collaboration in distributed teams largely focuses on who owns the data and where they will be stored (Eastman, 2011, Smith and Tardif, 2009). There is less focus on how the model may be explored and discussed as a team in a way that maximizes the 3D element of both the space and the model. Literature regarding avatars largely focuses on avatar identity and how avatar appearance affects behavior in the physical world and vice versa (Blascovich and Bailenson, 2011, Taylor, 2002, Yee and Bailenson, 2007). But little is known about how avatars can be used to communicate nonverbally through their position and gaze direction in relation to items in a building model that has been imported into the virtual environment. As BIM tools become more commonplace in the industry—in 2012, 71% of architects, engineers, contractors and owners reported engagement with BIM on their projects (Bernstein et al., 2012)—it is beneficial to understand how using a media-rich environment like a 3D virtual world has the potential to support team communication around 3D models. In this article, we present findings from a four-year ethnographic study of globally distributed virtual teams working on complex design and planning tasks using building information modeling (BIM) software. Because the participants were globally distributed, they conducted all meetings in an online 3D virtual world where they created an avatar and interacted with other team members as avatars. We examined avatar actions and interactions to determine the impact of avatars and copresence on collaboration effectiveness. By examining these factors, we aimed to have a more thorough understanding of how distributed AEC teams can more effectively collaborate, particularly in the context of BIM coordination.

2. THE COLLABORATIVE VIRTUAL ENVIRONMENT

Virtual teams have been 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). In a shared virtual environment, people are able to interact in the same computer-generated space (Schroeder, 2006). Different media are appropriate for different types of organizational tasks (Goodhue and Thompson, 1995). For example, teleconferencing works well for business meetings that are typically restricted to verbal communication (Sherman, 2003). Researchers have studied the use of 3D spaces for collaboration in areas such as microelectronics (Richardson and Adamo-Villani, 2010), surveying (Adamo-Villani and Dib, 2014) and architecture, engineering and construction (AEC) (Fruchter, 1999, Fruchter 2001). In the AEC industry, 3D environments are ideal for communicating spatial information that is critical in the design and construction of buildings and other planned environments (Eastman, 2011, Dossick and Neff, 2011). In a 3D collaborative environment, 3D building models or other objects may be imported into the space, which can then be shared with and explored, synchronously, by members of a geographically distributed team.

2.1 Virtual worlds for collaboration

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). A persistent environment is one that still exists after the user logs off. Changes may occur in the virtual world while the user is offline because other users still have access to the space (Castronova, 2005). An avatar is a digital representation of the user that is used to navigate the virtual world. The fidelity and form of the avatar depends on the virtual world being employed and can range from a human figure to an animal or mechanical device to a simple shape (Bailenson et al., 2005). By definition, interactions in the virtual world take place in real time and an action is expected to be met with reaction or feedback almost immediately (Bartle, 2004). Because virtual worlds are 3D environments, they add context to content for a richer experience (Padmanabhan, 2008). 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, avatar position and gaze (Bailenson et al., 2005, Yee et al., 2007).

The most salient area where virtual worlds have found success is in the realm of video games. Collaboration takes place on a regular basis in massively multiplayer online role-playing games (MMORPGs) such as World of Warcraft, Eve Online, and Halo where players collaborate to combat an enemy. "Game engines provide a real-time, interactive visualization" and as video game technology advances, scenes depicting the built environment in these worlds appear more realistic (Yan et al., 2011, p. 447).

One obstacle to the use of game technology in the AEC industry is lack of interoperability. Format conversions are required to import a BIM into one of the popular game engines, which frequently result in data loss. Second Life is particularly challenging because its unit of measurement, called Linden Meters, does not translate directly to real world Imperial or Metric measurements. A second obstacle is the perception of virtual worlds as being too game-like and frivolous for professional settings (Bateman et al., 2012, Dodgson et al., 2013). In 2015, computer and video game sales in the U.S. totaled $16.5 billion, and 54% of the most frequent gamers play multiplayer games (ESA, 2016). Numbers indicate that the real world is replete with people who collaborate in 3D virtual worlds for "play." With more gamers entering the workforce each year and the use of 3D technologies on the rise in the AEC industry such as BIM, CAD/CAM, and LiDAR, the industry appears poised to embrace collaboration in a 3D virtual world if it can be shown to enhance collaboration effectiveness.

Several earlier studies have explored the impact of collaborating in a 3D virtual world specifically developed for design and delivery of AEC projects in distributed teams. Findings from one study indicated that building information models (BIMs) imported into the virtual environment served as digital boundary objects which mediated negotiations between stakeholders with differing cultural and knowledge backgrounds, i.e. imported BIMs inhabit multiple linguistic worlds through visualization (Alin et al., 2013). Conflicts and cultural misunderstandings in distributed teams were minimized when team members referred to shared visualizations early and often (Iorio and Taylor, 2015). Shared visualizations in the avatar-model space led to mutual discovery of design issues that were more varied than issues discovered when using screen-sharing only (Anderson et al., 2014). Use of affordances in the virtual world including voice, imported models, and shared screens with pens allowed distributed teams to synthesize new knowledge (Dossick, 2014, Dossick et al., 2014, Dossick and Neff, 2011). Examining the use of collaborative tools in the virtual world found that simplifying the tools and the interface decreases the learning curve and allows teams to focus on work tasks rather than the technology (Iorio et al., 2011).

2.2 Interactional norms in the virtual collaborative environment

AEC collaboration in a virtual world presents new and interesting challenges because communication regarding complex engineering tasks is mediated through an avatar. Communicating through an avatar using affordances in the virtual world necessitates a new set of interactional norms that many people have not had to negotiate previously. For our study participants who had never appeared in the form of an avatar prior to the study, learning how to move and engage with each other digitally (such as walking and sitting through the use of a keyboard or mouse, talking enabled by pressing and holding a button, and manipulating their camera viewpoint to see other members) presented an additional challenge above and beyond the design and planning tasks they were asked to perform.

"The human perceptual system has been tuned through the process of evolution for the perception of real-world environments" (Steuer, 1992, p. 10). People are social beings that rely on body language and other non-verbal cues to communicate (Kock, 2004), and the avatars of our participants are not capable of rendering conscious or unconscious forms of nonverbal communication through typical channels. However, studies have shown that social conventions tend to carry over from the physical world into the virtual world. One study found that "social interactions in online virtual environments, such as Second Life, are governed by the same social norms as social interactions in the physical world" (Yee et al., 2007, p. 119). To determine this, they used proxemics, a set of measurable distances between people—also known as interpersonal distance—developed by anthropologist Edward Hall (1969), and applied this measurement to avatars in the virtual space. They also noted avatar gaze because eye gaze can be used to "equalize" interpersonal distance when we are forced to be close to somebody. For example, to reduce the undesired intimacy in an elevator we can avert our gaze to the front of the car.

In an earlier study, it was determined that even with low-fidelity boxy-shaped avatars, social conventions from the physical world carried over into the virtual world. 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). Additionally, studies have found that people seek out "face-to-face" interaction with other avatars even when an audio channel does not require this (Bowers et al., 1996, Iorio et al., 2011).

2.3 Presence and copresence

Presence is defined as "the sense of being in an environment" and telepresence as "the experience of presence in an environment by means of a communication medium" (Steuer, 1992, p. 6). Telepresence is a term originally used by Marvin Minsky in 1980 in reference to remote manipulation of physical objects and was subsequently shortened to "presence" by editor Thomas Sheridan in the 1992 launch of the MIT Press journal Presence: Teleoperators and Virtual Environments. More than a decade after Steuer's paper, Schroeder (2006), building on the definition of presence as *being there*, defines the term copresence as *being there together*. An important aspect of the concept of copresence is interaction (Schroeder, 2006). Interactivity is one of several components of presence is defined by Steuer (1992) to be the extent to which one can modify the form and content of the mediated environment in real time. As it pertains to *copresence*, interactivity is defined as the ability to communicate with others in real time (Schroeder, 2006). A spectrum that places various forms of media along dimensions of presence (the sense of being in an environment) and copresence (the sense of being in an environment *with others*) is shown in Figure 1. The IMAX, in which one feels immersed in an environment but not with others, is on one extreme and a fully immersive 3D environment such as a Cave Automated Virtual Environment (CAVE) provides both dimensions of being in an environment and interaction with others. The desktop-based shared virtual environment also provides both dimensions of being there and interaction with others, but to a lesser extent.

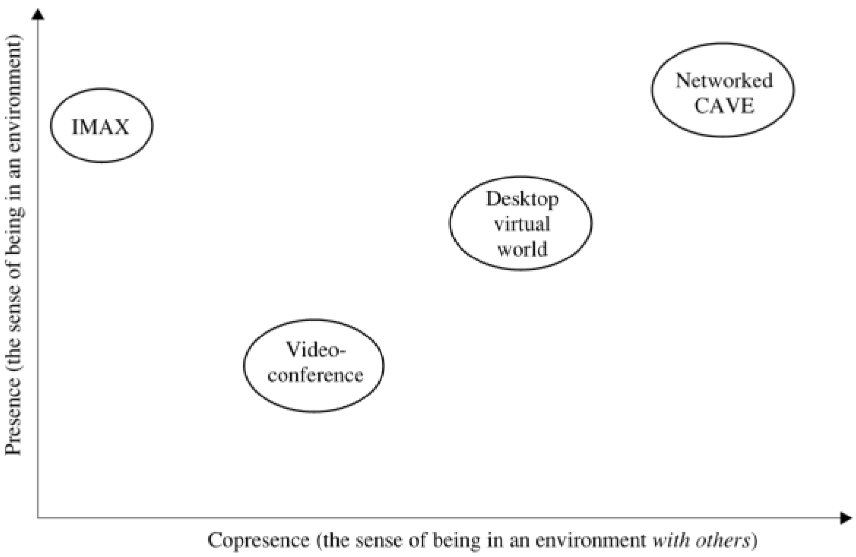

FIG 1. Various technologies plotted on a presence/copresence scale (adapted from Schroeder, 2006)

A virtual world is a digital environment distributed across the Internet and real-time activities among participants create a sense of copresence that is a necessary part of the world (Thomas and Brown, 2009). Mutual awareness must be present for interaction with others to take place in a mediated environment. Biocca et al. (2003) draw on Erving Goffman's work to define mutual awareness in a mediated environment as occurring when "the user is aware of the mediated other and the other is aware of the user" (p. 463). As discussed earlier, social conventions carry over from the physical world to the virtual world, and cultures and meanings emerge from interactions among the participants, which indicate that people do experience an awareness of others' presence in these environments (Yee et al., 2007, Thomas and Brown, 2009). Participants who are in a shared environment, but not immediately available to interact with others are not considered copresent (Zhao, 2003). Derived from Goffman's definition of physical copresence, participants who are copresent in a virtual environment must be aware of the other's actions in the environment, and that the other is also aware of the user (Goffman, 1963). Copresence is a critical element in helping establish how others perceive an object by allowing one to view what others are viewing in the virtual world (Wang and Wang, 2011).

In a previous study where three participants who hadn't met face-to-face solved puzzles together as avatars in a virtual world – one with a fully-immersive head mounted display and the other two using desktop virtual worlds – the fully immersed participant tended to emerge as leader (Slater et al., 2000). This indicates that immersion has a greater impact on ability to use tools and/or process information, which may translate to increased collaboration effectiveness in a virtual environment. Immersion is one factor that increases copresence. The extent of experience with the medium is another. Those who have become habituated to interacting with other avatars will experience a higher degree of copresence (Schroeder, 2006). A lower perceptual illusion of mediation will also increase copresence (Lombard and Ditton, 1997). Much of the literature states that copresence has positive effects on team collaboration such as increased motivation (Shen and Khalifa, 2008), engagement (Wang and Wang, 2011), trust (Bente et al., 2008, Wang and Wang, 2011), interaction (Richardson and Swan, 2003), and ability to maintain situation awareness (Gergle et al., 2013, Gutwin and Greenberg, 2002). In this paper, we consider that participants may also experience copresence with documents and 3D models in the virtual environment, i.e. in the 3D virtual environment, they may experience being there (presence), being there with others (copresence) and being there with mutable objects (copresence with documents and models).

2.4 Avatars and the development of mutual understanding

In a virtual world, an avatar symbolizes the person controlling the movements of the avatar. Avatar actions may also be symbolic if they replicate a real world social norm. The presence of the avatars helps users understand who is in the meeting and where their attention is focused based on avatar position. Regardless of where a person's attention is focused in the physical world, an avatar that is gazing at another will have the appearance of focused attention (Bailenson et al., 2005). Key to effective communication is development of shared understanding. During the information processing phase of a communication exchange, one must not only discern the meaning of the information transmitted to them, they must also understand how others interpret the information (Dennis et al., 2008).

3D virtual worlds are ideal for collaborating with 3D spatial information such as BIMs. However, most collaboration tools currently used in the AEC industry, such as GoToMeeting or WebEx, typically use shared screens, voice and chat to communicate, which is better suited for sharing 2D information. The design of the 3D virtual collaboration spaces used in our study evolved to allow team members to interact with each other and with imported 3D building models. This allowed us to ask research questions related to interaction in these spaces: Does the use of avatars and other tools in the 3D space provide a sense of "being there with others" that other non-spatial media do not provide? In what ways do virtual worlds support or hinder collaboration? In this paper we seek to examine these questions in the context of a 3D virtual collaborative workspace.

3. RESEARCH SETTING & METHOD

This study employed ethnographic observation of student teams from several globally distributed universities over a period of four years beginning in 2010. Each year, student teams ranging from 3 to 14 members were formed and met once a week for ten weeks in an online 3D virtual world (see Table 1). The study employed purposeful sampling when selecting participants (Patton, 2002), recruiting students from architecture, engineering, or construction management departments in order to simulate a complex project context these students would experience in professional practice.

TABLE 1. 2010 – 2013 Team composition and design tasks

	Number of students on each team				
University	2010	2011	2012	2013	**Design Task**
Indian Institute of Technology-Madras (IITM), Chennai, India	2 - 3	0	0	3	3D Model
Columbia University (CU), New York City, NY, U.S.	4	2	0	0	Baseline Schedule
Virginia Tech (VT), Blacksburg, VA, U.S.	0	0	2	2	Baseline Schedule
University of Washington (UW), Seattle, WA, U.S.	2	1-2	3	1	4D Model
University of Twente (UT), Enschede, Netherlands	2 - 3	0	0	3	Cost Estimate
Aalto University (AU), Helsinki, Finland	0 - 2	0	0	0	Facilitation
TOTAL STUDENTS ON EACH TEAM	10 - 14	3 - 4	5	9	
TOTAL NUMBER OF TEAMS	7	8	4	6	

The subteams from each university represented specialists from one domain who worked both independently and interdependently on an assigned design and planning task that resulted in a shared outcome for the team. The purpose was to necessitate collaboration among the team members to complete the overall task. Each participant was asked to create an avatar and meet with their global teammates in a designated space within the virtual environment. Projects in the CyberGRID have continued, but the research focus changed enough in 2014 that data from projects beyond 2013 were excluded from this analysis.

3.1 The CyberGRID 3D virtual environment

The CyberGRID (Cyber-enabled Global Research Infrastructure for Design) is a 3D virtual environment developed to support design work in global virtual networks (Taylor et al., in press). An early version of the CyberGRID, deployed in the 2010 study, was built within Second Life in which meeting spaces were created for each team comprising a conference room and adjacent plot of land called a sandbox where students could build virtual objects. Several synchronous communication tools either already existed within Second Life or were added as part of the CyberGRID, including: voice, text chat, team screen for desktop sharing and overhead gesture bubbles (Figure 2). The overhead gesture bubbles in the 2010 version contained only colors, no words, and were activated using a heads-up display. Pressing a button labeled “I want to speak” displayed a white bubble over the avatar’s head, pressing “Agree” displayed green, pressing “Neutral” displayed yellow, and pressing “Disagree” displayed red.

Situating the CyberGRID within Second Life proved to be problematic for two primary reasons. First, Second Life was a mature technology with myriad functionalities that resulted in a steep learning curve for students new to virtual worlds and difficulty using some of the collaboration tools (Iorio et al., 2011). Second, building models were not brought into the Second Life environment due to interoperability issues (units mismatch and loss of data), cost (users were charged for each import), and the complexity of the import process for typical users (Iorio et al., 2011).

FIG 2. Overhead gesture bubbles, one of several communication affordances in the CyberGRID (2010 version).

In the following year, 2011, the CyberGRID environment was removed from Second Life and recreated using the Unity game development platform. The design was simplified to include only tools needed for collaborative activities among design and planning networks. The same synchronous communication tools were used—voice, text chat, a Team Wall for screen-sharing, and overhead gesture bubbles for nonverbal communication—but in the Unity version, only one or two clicks were required to activate each tool. The use of pens was added to the Team Wall functionality allowing any team member to sketch on the Team Wall with one of four colors, regardless of who was sharing their desktop. Avatar appearance was greatly simplified such that there were only a few to choose from. The benefit was less confusion when creating the avatar (the Second Life avatars were highly customizable, but also difficult to create and maintain—more than one avatar lost their hair part way through the study). The drawback of less customizable avatars was that many participants looked the same and did not identify with their avatars, thus reducing the sense of presence and copresence. Another addition to the 2011 and 2012 versions was the ability to import building models into the space so researchers could observe how the models were used during collaboration. The building models were created by a non-participant graduate student using Autodesk Maya. The imported building models were monochromatic and contained little detail, but were sufficient for the 2011 and 2012 task of using the models to take inventory of building elements.

Building on lessons learned in previous years and focusing on some of the research questions regarding nonverbal communication and copresence with BIMs, the CyberGRID 2013 version was redesigned with some additional elements, e.g.: avatars gained more customizable features; a team room was added with four screens that could be used simultaneously by participants (the conference room with a single screen also remained); avatar-sized building models were imported with color and texture for a more realistic appearance; and smaller scale models were placed in the center of the team room for quick reference. The addition of the team room and more detailed building models encouraged participants to use their avatars to navigate the space. Because we had students from four universities participating in 2013 (see Table 1), we were able to create a complex assignment that encouraged students to use the avatar-sized model for more than just quantifying building elements. The teams in 2013 were tasked with adding three bays to an existing BIM, with all team members agreeing on the location of the additions and the IITM subteam creating the updated model. A summary of the 3D virtual environment functionalities from 2010 through 2013 may be found in Table 2.

TABLE 2. CyberGRID Functionalities

Year	Platform	Imported 3D Model	Avatars	Voice	Text Chat	Gesture Bubbles	Screen Sharing	Amenities
2010	Second Life	No	Very customizable	Yes, though difficult to activate	Yes	Yes, four colors	Yes, though difficult to activate	Conference room with table and one Team Wall
2011	Unity	Yes, monochromatic	Simplified, few options	Yes	Yes	Yes, four colors	Yes, simple to activate, with pens	Conference room with table and one Team Wall
2012	Unity	Yes, monochromatic	Simplified, few options	Yes	Yes	Yes, four colors	Yes, simple to activate, with pens	Conference room with table and one Team Wall
2013	Unity	Yes, with color and materials applied to surfaces	Still simple, but with several options for hairstyle and color of hair, skin, clothing, and shoes	Yes	Yes	Yes, four colors with text (e.g. “Yes” in the green bubble)	Yes, simple to activate, with pens	Team room with no table and four Team Walls

3.2 Data collection and analysis

Meetings in the virtual environment were audio and video recorded for analysis. In addition, one or more researchers each year created avatars and attended the meetings as participant-observers in the virtual environment, taking detailed notes of meeting activities in real time. Participant observation is a critical element of ethnography, allowing researchers to observe emergent phenomena and contextualize observations to develop meaningful interpretations (Boellstorff et al., 2012, Geertz, 1973). An ethnographic notes template was developed prior to the study to ensure that researchers were collecting relevant data. This paper discusses analysis and results from 2010 through 2013. Researchers reviewed the ethnographic notes to identify videos rich with interactions pertaining to the research. Video and audio files from the targeted meetings were imported into ELAN, an open-source annotation software package developed at the Max Planck Institute for Psycholinguists, The Language Archive, Nijmegen, The Netherlands (Brugman et al., 2004). In ELAN, annotations and, where applicable, transcriptions were mapped to the video/audio timeline. In ELAN, audible interactions are indicated by waveforms in the graphical interface (Figure 3).

Annotations in ELAN included speaker (voice) or typist (chat) identification, topic, and copresence. The annotations and transcriptions from ELAN were exported to .csv format then into Excel where data were analyzed for instances of interaction, particularly avatar interactions involving communication affordances in the environment and interactions with other avatars. To indicate copresence, we noted avatar/avatar interactions in the virtual world. In addition to interactions one would expect in traditional 2D communication, i.e. voice and text chat, we also noted instances of nonverbal communication such as gesture bubbles that appeared over the avatar and communication that involved position or movement of the avatar – in other words, non-verbal actions that are unique to 3D virtual worlds. We also noted whether the nonverbal communication was acknowledged by others – if so indicating copresence and, if not, indicating a lack of copresence. Each instance of communication was evaluated for effect on collaboration. For example, a nonverbal event that was ignored by others repeatedly would be considered ineffective, whereas a nonverbal event that elicited a response would be indicative of communicative efficacy. Each year, a second researcher coded, at a minimum, 10% of the data coded by the primary researcher. If agreement between coders was less than 80%, the coding schema was revisited and refined. The data were specifically coded for copresence beginning in 2011, and the 2010 data were subsequently revisited for instances of copresence.

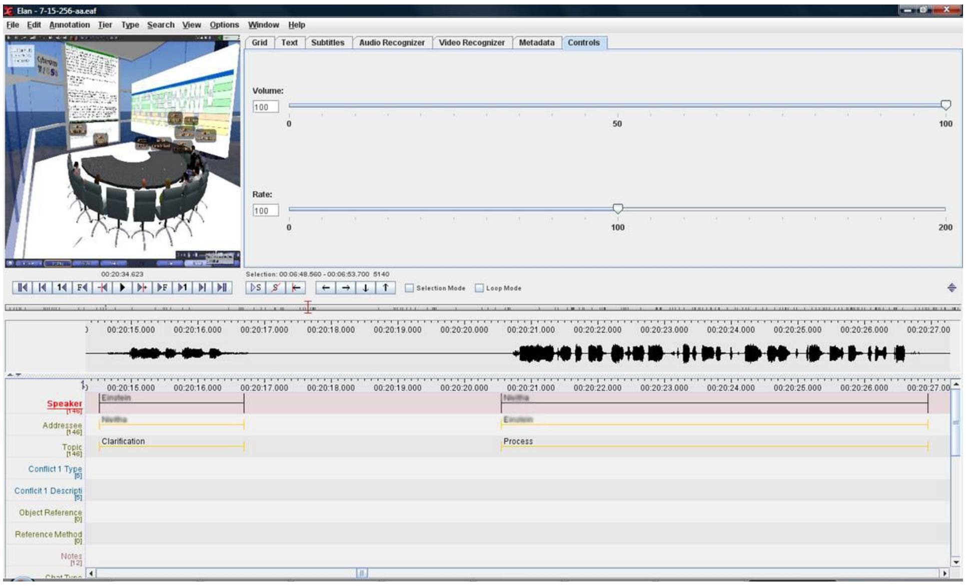

FIG 3. ELAN interface

4. FINDINGS AND DISCUSSION

4.1 Transfer and creation of social norms

In this study, we observed how participants used their avatars to communicate nonverbally. We observed both the transfer of norms from the physical world and the creation of new interactional norms in the virtual world. We noted reactions from others—e.g. was an avatar action acknowledged by others and did it have the intended effect? We observed the effect on collaboration effectiveness, asking if it supported or hindered collaboration. We were particularly interested in how the non-verbal avatar features supported communication when exploring BIMs that were imported into the space. First, we found that avatar position was significant in creating copresense and leveraged the transfer of social norms into the virtual world interactions. Second, gesture bubbles provided back-channel agreement or disagreement. Third, text chat provided an efficient way to share information without disrupting the conversational flow.

Avatar position: A striking observation was the effectiveness of avatar position in communicating intention. Not only is the avatar a symbol of the human user, but the position of the avatar has symbolic significance as well. In 2010, when one member of a team wanted to lead his team's first meeting, he positioned his avatar at the "head" of the table and proceeded to give direction to the other team members regarding how to use the CyberGRID technology (Figure 4). The position of one's avatar can provide direct real world mapping, and standing at the head of a table is a convention that is interpreted in the physical world as taking control of the floor. In this instance, the action supported collaboration as this team member emerged as the leader in this particular meeting and proceeded to give instructions to others regarding how to use the meeting space and what needed to be accomplished before the next meeting (Table 3, No. 1).

In another example conforming to physical world norms, avatars entering the virtual conference room were expected to sit in the virtual chairs provided around the virtual table. In a virtual world there is no need for an avatar to sit since there is no gravity and therefore no need to "rest." An avatar can stand on a table, sit on the floor or float in the air without becoming fatigued. In 2010, there were two instances where participants were unable to determine how to seat their avatars in the meeting room chairs (which required a right click on a chair then a selection from a menu to sit) and in both instances the facilitators asked the standing avatar to sit down. As the first avatar entered the conference room and remains standing, the facilitator said, "Would you like to sit down?" Two minutes later another avatar entered the space and remained standing. The facilitator said, "Question: would you like to sit down?" The avatar remained standing. A second facilitator asked, "Do you know how to sit down? Yeah, great [when the avatar finally sat in a chair]." Avatars not seated during a meeting were viewed as distracting or disruptive to the collaboration process (Table 3, No. 2).

FIG 4. CyberGRID (2010 version) - one member takes charge of the meeting.

In 2013, teams were encouraged by the design of the virtual space and design of the assignment to explore the models. One team explored the model by staying together as a group, with the exception of one team member who ventured out on her own. Communication among the group that stayed together was very effective. They were able to use deictic references such as "here" and "this" in reference to something directly in front of their avatar. When the others were in the same space, the reference was immediately understood. In one example, the team was exploring the additions to the building model developed by the IITM subteam. One of the participants said, "…and they have this window filled with brick here. … Do we even need that interior wall? Do we need these partitions?" To the others in the room, it was clear which interior wall he was referring to because he was standing right in front of it, the avatar gaze directed at the window filled with brick (Figure 6). By establishing that they stay close as they explore the model, they picked up on items that others were discovering in the model and were able to verify a discovery or have a discussion around whether an item should stay or go (Table 3, No. 3). The team member who explored the model alone could be heard, but because she was in a different area of the model and not immediately available to her teammates (i.e. not copresent), her use of deictic references were not picked up resulting in her discoveries not being acknowledged by others (Table 3, No. 4).

Gesture Bubbles: Not all norms transferred over as expected. The white gesture bubble was intended to facilitate turn-taking when speaking. Its purpose was analogous to a raised hand in a face-to-face meeting. A majority of the white gesture bubble usage in the early meetings appeared to be the result of a misunderstanding of intended button use. In the 2010 version, the "I want to speak" button was confused with Second Life's "talk" button that activates the voice. The "talk" button was small and located in an inconspicuous place. Participants pressed the "I want to speak" button when they literally wanted to speak. In other words, rather than using it to represent a raised hand, they used it with the expectation that it would activate their voice. After a while, participants found the "talk" button and were able to use it properly (Table 3, No. 5). Nevertheless, the white bubble never reverted to its intended use. We did not observe any instance of the white bubble being used properly by the participants in the 2010 study. Without use of the turn-taking function, members of larger groups (10-14 members) would often speak out of turn resulting in multiple conversations, hindering collaboration effectiveness. This was not an issue in smaller (e.g. four member) teams. In 2011, the collaborator tool was abandoned for single-click buttons at the top of the user interface. The five gesture bubbles (F1 – "I want to speak," F2 – "Agree," F3 – "Disagree," F4 – "I have a question," and F5 – "I am away") are shown at the top of Figure 5. Though the gesture bubbles were not used often in 2011 and 2012, they were less confusing than the 2010 version and were used as intended. Gesture bubbles were most often used in the meeting room.

FIG 5. CyberGRID (2013 version) – one member comments on brick-filled window and wonders if these interior walls are needed.

In addition to observing social norms transferred from the physical world, we observed new interactional norms develop in the space. For instance, in the 2011 and 2012 study, the teams comprised four members, rendering the voting tool unnecessary since such a small group can easily voice their votes. But the green gesture bubble was often observed in quick bursts to signal agreement with something a teammate would say, replicating backchannel communication such as a nod or a smile. This was a quick and effective way to maintain camaraderie and trust among the team, enhancing collaboration effectiveness (Table 3, No. 6). A unique appropriation of tool use occurred after a participant's avatar became invisible. His voice was still emanating from where his avatar had been before disappearing and he could still use gesture bubbles. Rebooting did not fix the problem, so he toggled his white gesture bubble and announced that he would keep it on at all times so he and the others would know where his invisible avatar was located whether in the meeting room or exploring the imported 3D model. This also is indicative of a preference for copresence in this environment.

Text Chat: Each year, both voice and text chat were available to participants. Voice was primarily used to discuss the task at hand. Text chat was used slightly differently, depending on the year. In 2010, it was mostly used for two reasons: (1) To ask if others can hear them—recall, there was confusion about the "I want to speak" vs. "talk" tools in this year—and (2) to have side conversations. The need for side conversations through text chat may be due to the large number of participants on each team (10-14), and it being difficult to have multiple simultaneous voice exchanges. Again, recall the white gesture bubble was largely ignored when used in 2010. In subsequent years, chat was used primarily to provide information that is better understood in text form such as an e-mail address or Web link or to communicate without interrupting the primary conversation, such as typing "brb" if someone needed to step out for a moment (Table 3, No. 7). Text chat was used regardless of avatar location, i.e. it was used while in the meeting room and while exploring the imported 3D model.

4.2 Copresence

Numerous instances were observed where distributed team members experienced copresence through interactions with team members in the mediated space and the effects they had on collaboration were noted. In the 2011 version of the CyberGRID, the avatars were simplified in response to complications participants experienced with Second Life avatars in 2010. As a result, very few avatar appearance options were available in the new 2011 version and many of the avatars looked alike. In a meeting where one avatar accidentally sat in the same chair as another avatar, the action went unnoticed by the students for quite some time. One remarked that she hadn't been able to tell because their avatars were identical. Because this occurrence largely went unnoticed, it was not viewed as disruptive. However, not relating to one's avatar (or, in this case, avatars appearing identical) reduces the sense of presence in a medium, which is a necessary precursor to copresence. Another participant remarked offline that she had accidentally chosen an avatar that looked older. She never really felt she was present in the meetings because her avatar looked like somebody else and she was not able to identify with it. If collaboration improves with an increased sense of copresence, in cases where participants are unable to identify with their avatar and, therefore, do not feel present in these meetings may be viewed as hindering collaboration (Table 3, No. 8).

Another issue was difficulty manipulating avatar movement. The ability or inability to maintain an "appropriate" interpersonal distance or the ability or inability to control one's viewpoint (i.e. camera angle) so other avatars may be seen, among other things, affected the feeling of *being there together*. In all four versions of the CyberGRID, participants had the ability to adjust the camera view to either first person or third person. In the 2010 Second Life version, the camera view could "detach" from the avatar and enter other spaces. In subsequent Unity versions of the CyberGRID (2011-2013) the camera view was aligned with avatar position which allowed researchers to more easily determine what participants were viewing during any given interaction. The default view in the Unity versions was third person and participants could use the mouse scroll wheel to zoom out for a bird's eye view of the environment or zoom in for a first person view. Using the mouse, participants were also able to raise or lower the viewpoint without moving the avatar to allow one to view areas such as interstitial space between floors that would be difficult for an avatar to access. In one example during week 7 of the 2010 study, after being addressed by another team member, a participant was trying to determine who had addressed him: "I'm still learning here … I'm kind of uncoordinated … is that you in the A with the exclamation point T-shirt?" The team member responds with, "Yeah, that's me, the guy sitting next to you." The technical difficulties experienced by some of the team members detracted from the sense of copresence (Table 3, No. 9). A higher sense of copresence also requires experience with the medium and Second Life has a steep learning curve.

To simultaneously take advantage of avatar position/movement and Team Walls, a new team room was created in the 2013 version with four Team Walls and no central table at which avatars would be expected to sit. The four screens allowed students from all four universities to share their work and students could walk from screen to screen to see what the others were working on. This worked as intended: once we removed the conference table and chairs from the team room, the participants were much more mobile in how they used the space. The students would often have at least two screens and sometimes three or four displaying something pertaining to the project, e.g. the meeting agenda on one screen and Revit model on another. When needed, one student would direct others' attention to the screen "where [so-and-so] is standing," yet another example of use of avatar position to communicate and support collaboration (Table 3, No. 10). Additionally, the small-scale models in the team room and the large-scale models in the yard outside the team room were updated between meetings (as they were revised by students each week), which provided the participants with a reason to explore the models each week.

The design of the virtual space can also affect copresence. Tool activation in subsequent versions was also simplified in response to difficulties using tools in the 2010 version. For example, use of the Team Wall in 2010 required several steps and was either abandoned after failed attempts or never used by the majority of participants. When this happened the lack of real-time screen sharing reduced connection presence and the meetings became little more than a teleconference (Table 3, No. 11). In the 2011 version, it was possible to zoom into the Team Wall so the content could be viewed more clearly. Unfortunately, when zoomed in, the Team Wall filled the participant's monitor and they could no longer see their teammates' avatars in the space. They were asked to occasionally zoom out to see if others had questions indicated by their gesture bubbles. Some did, but most either did not remember to do so or they deemed it unnecessary when they could voice their questions rather than use gesture bubbles. As a result, most of their meeting time was spent zoomed into the shared screen. Aside from walking to the conference room to meet their teammates for the meeting, the presence of an avatar was superfluous. The command for an avatar to stand up from a sitting position is to press the space bar. But because one often hits the space bar when typing, the participants would often fly out of their chairs and wind up standing on the table. Because they were all zoomed in to the Team Wall, these instances of standing on tables would rarely be noticed by anyone. This resulted in at least one person standing on the table for much of the meeting. Because everyone was zoomed in to the Team Wall, this was not viewed as disruptive, but the level of copresence is clearly lower in this scenario (Table 3, No. 12).

TABLE 3. Observations and collaboration effect

No.	Observation	Construct Observed	Collaboration Effect	Data Source
1	AVATAR POSITION: Avatar [UW41] positioned at head of table in the meeting room. See Figure 4.	Social norm	SUPPORTED COLLABORATION. Head of table indicates control of the floor	Year: 2010 Team 4/Project Week 1 ELAN file: 4-6-74 ELAN file time stamp: 02:02.3
2	AVATAR POSITION: Avatars not seated in the meeting room during the meeting. Example - AU62: "Question: would you like to sit down?" [to CCU61 who is standing] AU61: "Do you know how to sit down? [CU61 sits] Yeah, great."	Social norm	HINDERED COLLABORATION. Not understanding how to manipulate one's avatar was distracting	Year: 2010 Team 6/Project Week 1 ELAN file: 6-6-156 ELAN file time stamp: 01:24.8 and 03:15.6
3	AVATAR POSITION: Using deictic references with others present while walking through the imported 3D model or in the meeting room with four Team Walls. Example – UW11: "And they have this window filled with brick here." VT11: "Well, that window's not actually supposed to be there … If you come in back by the staircase you can see it from the side. It's an interior wall."	Social norm	SUPPORTED COLLABORATION. Deictic references typically used in the physical space were also used in the virtual environment; avatar position is used to indicate where "here" is, supporting collaboration	Year: 2013 Team 1/Project Week 3 ELAN file: 1_cybergrid_tue_w3_revit ELAN file time stamp: 19:45.7
4	AVATAR POSITION: Using avatar position to communicate when others are not present Example – VT12 discovers an issue with a slab while exploring the model ahead of others. Nearly 6 minutes later, the rest of the group "discovers" the issue indicating it was not originally acknowledged by the group.	Social norm	HINDERED COLLABORATION. When other avatars are not within view of the communicating avatar, use of avatar position does not support collaboration.	Year: 2013 Team 1/Project Week 3 ELAN file: 1_cybergrid_tue_w3_revit ELAN file time stamp: 17:12.0 and 22:56.1
5	GESTURE BUBBLE: Misuse of white "I want to speak" bubble during meetings in the meeting room. Example - IITM61, IITM62, and IITM63 have pressed the "I want to speak" button and activated the white gesture bubble. In the text chat they have typed: "I can hear you…" "He does not have voice" and "Trying to work voice"	Social norm	HINDERED COLLABORATION. Not understanding tool use was distracting	Year: 2010 Team 6/Project Week 1 ELAN file: 6-6-156 ELAN file time stamp: 06:47.9
6	GESTURE BUBBLE: Green gesture bubble used as backchannel communication Example – During a 'client' meeting, the client jokes with a participant who responds with a green bubble.	Social norm	SUPPORTED COLLABORATION. Gesture bubbles were a quick and effective way to maintain camaraderie and support collaboration	Year: 2011-2012 Team 4/Project Week 2 (2012) Ethnographic sheet file: 4_blue_tue_w2_client
7	TEXT CHAT: Using chat to communicate without interrupting the conversation. Used during meetings and while exploring the imported 3D model. Example – VT31: "files will be uploaded" (The conversation topic had moved on, but VT31 wanted others to know that updated files would be available)	Social norm	SUPPORTED COLLABORATION. Voice and text chat used properly (and simultaneously) can enhance collaboration	Year: 2010-2013 Team 3/Project Week 3 (2013) ELAN file: 3_cybergrid_wed_w3_revit ELAN file time stamp: 11:56.1
8	AVATAR APPEARANCE: Avatars less customizable. Example – A participant accidentally chose an avatar that looked older	Copresence	HINDERED COLLABORATION. Participants don't identify with avatars that do not resemble them	Year: 2012 Team 4 ELAN file time stamp: N/A (Offline comment)
9	AVATAR MOVEMENT: Difficulty controlling avatar movements and viewpoints. Example – UW52: "I'm kind of uncoordinated ... is that you in the A with the exclamation point T-shirt?" AU51: "Yeah, that's me, the guy sitting next to you."	Copresence	HINDERED COLLABORATION. The inability to control one's avatar in order to see other avatars or objects in the space (e.g. models or documents) hinders collaboration.	Year: 2010 Team 5/Project Week 7 Elan File: 5-12-210 ELAN file time stamp: 03:44.2

No.	Observation	Construct Observed	Collaboration Effect	Data Source
10	AVATAR POSITION: Using avatar position as a Team Wall location reference in the meeting room.	Copresence	SUPPORTED COLLABORATION. Avatar position is used to indicate where others should direct their attention	Year: 2013 Team 1/Project Week 5 Ethnographic sheet file: 1_cybergrid_tue_w5_simv
11	TEAM WALL: Team Wall difficult to use. Example – UW52: "No one knows how to get a live desktop broadcast?" UW51: "There's a button … saying Start Sharing." UW52: "I don't have any button that says Start Sharing."	Copresence	HINDERED COLLABORATION. If a tool is not used because it is too difficult for participants to operate (and time is used trying to operate the tool without success), collaboration is hindered.	Year: 2010 Team 5/Project Week 7 Elan File: 5-12-210 ELAN file time stamp: 40:02.7
12	TEAM WALL: Team Wall filled screen making avatars superfluous. Example – UW12's avatar was standing on the table, unacknowledged, for half of the meeting.	Copresence	HINDERED COLLABORATION. The inability to see items that support collaboration, such as other avatars' position and gesture bubbles, hinders collaboration.	Year: 2011 Team 1/Project Week 3 Ethnographic sheet file: 1_yellow_3-7_simv_dom

5. CONCLUSIONS

The CyberGRID virtual world design has adapted over the years in response to collaboration needs. Tools that worked as intended were kept, tools that were adapted in use were also adapted into subsequent iterations, and tools that were difficult to use were simplified. In the first three versions of the CyberGRID, a conference room with table and chairs was built to replicate a meeting space in the physical environment. This way, established social norms could be used (i.e. enter the room and sit in a chair) allowing the team members to focus more on the task and less on the technology. But limiting the virtual space to a replica of a real world space discouraged participants from taking advantage of the 3D space. We observed the teams in 2010 sit in conference room chairs and not move because they had no reason to. In 2011 and 2012, we placed building models in the area outside the conference room, but other than taking inventory, they had little reason to leave the conference room chair. In 2011 and 2012, we also added functionality to the Team Wall that allowed them to zoom in for a better view. Because there was no reason to look at other avatars, they would zoom in to the Team Wall and stay there, rendering the avatars almost pointless. In the 2013 version, spaces were created that could be fully used by an avatar. This illustrates that virtual worlds are fluid and can be adapted to the needs of the user. In this paper, we utilized the CyberGRID to investigate several elements of virtual worlds that may impact collaboration effectiveness: the impact of avatars, social norms, and copresence.

The most encouraging finding relating to avatars is that avatar position was impactful as a communication tool. Most of the time, the students positioned their avatars in the chairs (sitting), but in the early version when the avatars were not in the chairs (whether it was intentional or not) they never failed to elicit a response. The team member who wanted to take charge of the meeting was able to collaborate more effectively when he positioned his avatar at the head of the table. By doing so, he made sure all of his teammates could see him because he was standing immediately in their field of view. Once avatars were "released" from the conference room in later CyberGRID designs, avatar position was used to communicate with others in the building model to more effectively indicate to collaborators the design issue at stake. These examples illustrate how the communication richness of virtual worlds (avatar position in these examples) can either support or hinder collaboration. Our observations fell into two broad categories: social norms and copresence.

We examined how social norms from non-virtual settings transferred to virtual world settings, as well as new social norms that emerged in virtual world settings. Lack of technology training can disrupt social norms that typically occur in the physical world resulting in a less effective meeting. But habituation to the space allows users to communicate with team members in a manner that is very effective using avatar position and gaze direction, demonstrated when avatars toured the building models together. The alternative to communicating around a BIM among distributed team members is screen sharing and pointing. Given that team members used deictic references as they explored the model without having to explicitly state "when I say the window in front of me, I mean the window in front of my avatar" indicates that using the (avatar) body to communicate is an interactional norm that transferred easily from the physical environment and resulted in more effective collaboration in the virtual environment. The position of one's own avatar and that of others helps synchronize cognition—that is, knowing and understanding what others are perceiving—which is accomplished by sharing the same context during communication (Kan et al., 2011).

Finally, we also examined copresence in a virtual AEC work setting and found that ensuring avatar movement and tools in the virtual space are simple to learn and manipulate will help reduce perception of a mediated environment (Iorio et al., 2011) and, in turn, increase copresence. To experience copresence, the team must be able to see each other's avatars to experience connected presence. In the cases where participants explored the imported models on their own, they were heard but not seen by others and therefore not acknowledged. When team members hear each other but do not see each other, there is no "connected presence" and the meeting essentially becomes a teleconference which places the meeting lower on the copresence scale (Figure 1). The design of the team room in 2013, with four Team Walls and no central table, changed the way avatars were able to move about the space and more realistic model imports resulted in more interactions between avatars than past iterations. Based on the increased avatar interactions, the level of copresence in 2013 had increased from previous years. Our findings confirm that immediacy of team member availability is a critical factor for supporting collaboration in distributed teams.

The fluidity of space in the 2013 version allowed teams to discuss the imported models from within the model, from outside the model, and from within the meeting room. Even when in the meeting room, they would reference the imported model. This is why we chose to measure reference to the different representations rather than where they were located when they were doing the referencing. The space was designed such that the model could be referenced from multiple points of view within the 3D space, e.g. some team members could be inside the conference room referencing the 2D projection while others could be in the 3D model referencing the same thing. The copresence was in part established through the different representations of the model. We found there was value in being in the same shared space with an ability for some team members to view the model from a 2D perspective, others to view a scaled down imported model, and others to view the imported model from the inside out. The CyberGRID allows for multiple perspectives to be shared in the same space. One team member could project something to one of the screens, another team member could project something else on one of the other screens, and then both could walk together to the imported model in the yard to see it from yet a different perspective. These actions would be more complicated to coordinate if team members had to toggle between a 3D space and a 2D screen sharing application. In the CyberGRID, the avatars played a role in the coordination by signaling where the distributed team members were focusing their attention.

Because we chose to focus on specific elements of coordination with BIMs, this research was limited in its scope of data collection and analysis. Opportunities for future exploration include studying the impact of avatar gestures and emotions. Avatar gestures were available in the 2010 Second Life version but generally not used. In Second Life, activation of gestures added complexity to avatar movement, so the non-use of gestures aligns with findings from an earlier paper (Iorio et al., 2011) that simple affordances in the 3D space were more likely to be adopted. Limited gestures (nodding and hand raising) were added to the CyberGRID in 2014. Adding more gestures to provide additional non-verbal communication, as well as emotions which could be perceived by others, would be an opportunity for future development in the CyberGRID and, when developed, will accommodate further research on how avatar gestures and emotions impact interactions in the space.

6. IMPLICATIONS

BIM storage has been moving to the Cloud where multiple members can view a model simultaneously, e.g. Autodesk BIM 360 and Graphisoft BIMx. What is unique to viewing models with multiple members in a virtual world is the presence of avatars that allow members to communicate more efficiently through the visualization of the model and nonverbal cues of the avatar which allows mutual understanding to be reached with less effort since one can see what others see (Blumer, 1969, Dennis et al., 2008, Kock, 2004). The goal is to have more effective coordination meetings and fewer miscommunications resulting from the more effective and streamlined communication. The sense of distributed team members being in the environment together, the ability to import 3D models, and relatively little equipment and easy entry makes virtual worlds ideal for globally distributed teams collaborating on complex engineering design and construction planning.

Unlike social sites, the focus of BIM coordination meetings is the model, not the people in the meeting, therefore the affordances in the AEC collaboration environment can be simpler than those in an environment like Second Life. Some observations over the years of creating the CyberGRID environment have important implications for AEC collaboration. This includes the need to: (1) Create spaces in the virtual environment that take advantage of the ability to navigate with an avatar that is unfettered by physics (the addition of the team room and more detailed

BIMs changed the dynamics of the meetings from teleconference-like to an embodied walking tour); (2) simplify avatar creation but maintain enough customization so the user is able to identify with the avatar and establish higher levels of presence and copresence; and (3) keep tool activation simple—one or two steps if possible. Tools will not be used if they are too complicated (Iorio et al., 2011) and participants will find work-arounds thus minimizing the advantages and efficiencies of working in a virtual world. Considering the success of virtual worlds in gaming and the recent resurgence of virtual reality and augmented reality in many sectors, including AEC (for uses such as client engagement, design and construction coordination, and constructability reviews), there is an increasing need to understand how these emerging technologies can be leveraged in our industry. This study contributes to understanding how 3D virtual worlds may be used effectively for collaboration with imported BIMs in the AEC industry.

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REFERENCES

Adamo-Villani N. and Dib H. (2014). Online virtual learning environments: a review of two projects. *International Journal of Systems and Service-Oriented Engineering, 4*(1), 1-20.

Alin P., Iorio J., and Taylor J. E. (2013). Digital boundary objects as negotiation facilitators: spanning boundaries in virtual engineering project networks. *Project Management Journal*, *44*(3), 48-63.

Anderson A., Dossick C. S., Azari R., Taylor J. E., Hartmann T., and Mahalingham A. (2014). Exploring BIMs as avatars: using 3D virtual worlds to improve collaboration with models. *Proceedings of Construction Research Congress 2014: Construction in a Global Network*, 179-188.

Bailenson J. N., Swinth K., Hoyt C., Persky S., Dimov A. and Blascovich J. (2005). The independent and interactive effects of embodied-agent appearance and behavior on self-report, cognitive, and behavioral markers of copresence in immersive virtual environments. *Presence: Teleoperators & Virtual Environments*, *14*(4), 379-393.

Bartle R. A. (2004). Designing virtual worlds. Indianapolis, Ind., USA, New Riders Pub.

Bateman P. J., Pike J. C., Berente N. and Hansen S. (2012). Time for a post-mortem?: business professionals' perspectives on the disillusionment of virtual worlds. *Journal of Virtual Worlds Research*, *5*(3), 1-15.

Bente G., Rüggenberg S., Krämer N. C., and Eschenburg F. (2008). Avatar-mediated networking: increasing social presence and interpersonal trust in net-based collaborations. *Human Communication Research*, *34*(2), 287-318.

Bernstein H.M., Jones S.A., Russo M.A., Laquidara-Carr D., Taylor W., Ramos J., Healy M., Lorenz A., Fujishima H., Fitch E. and Buckley B., (2012). The business value of BIM in North America. *SmartMarket Report*. Bedford, MA, USA, McGraw Hill Construction.

Biocca F., Harms C., and Burgoon J. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators and Virtual Environments*, *12*(5), 456-480.

Blascovich J., and Bailenson J. (2011). Infinite reality: avatars, eternal life, new worlds, and the dawn of the virtual revolution. New York, New York, USA, William Morrow.

Blumer H. (1969). Symbolic interactionism; perspective and method. Englewood Cliffs, N.J., USA, Prentice-Hall.

Boellstorff T., Nardi B., Pearce C., Taylor T.L. (2012). *Ethnography and virtual worlds: A handbook of method*. Princeton, NJ, USA, Princeton University Press.

Bowers J., Pycock J. and O'Brien J. (1996). Talk and embodiment in collaborative virtual environments. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM*, 58-65.

Brugman H., Russel A., and Nijmegen X. (2004). Annotating multi-media/multi-modal resources with ELAN. *Proceedings of LREC 2006, Fifth International Conference on Language Resources and Evaluation*.

Castronova E. (2005). Synthetic worlds : the business and culture of online games. Chicago, IL, USA, University of Chicago Press.

Chinowsky P. S. and Rojas E. M. (2003). Virtual teams: guide to successful implementation. *Journal of Management in Engineering. 19*(3), 98-106.

Dennis A. R., Fuller R. M. and Valacich J. S. (2008). Media, tasks, and communication processes: a theory of media synchronicity. *Management Information Systems Quarterly*, *32*(3), 575-600.

Dodgson M., Gann D. M. and Phillips N. (2013). Organizational learning and the technology of foolishness: the case of virtual worlds at IBM." *Organization science*, *24*(5), 1358-1376.

Dossick C. S., and Neff G. (2011). Messy talk and clean technology: communication, problem-solving and collaboration using building information modelling. *The Engineering Project Organization Journal*, *1*(2), 83-93.

Dossick C.S. (2014) Messy work in virtual worlds: exploring discovery and synthesis in virtual teams. Cooperative Design, Visualization, and Engineering. *Lecture Notes in Computer Science*, Vol. 8683, 134-142.

Dossick C. S., Anderson A., Azari R., Iorio J., Neff G., and Taylor J. E. (2014). Messy talk in virtual teams: achieving knowledge synthesis through shared visualizations. *Journal of Management in Engineering*, *31*(1), A4014003.

Eastman C. M. (2011). BIM handbook a guide to building information modeling for owners, managers, designers, engineers and contractors. Hoboken, NJ, USA, Wiley.

ESA (Entertainment Software Association) (2016), Essential Facts about the Computer and Video Game Industry. Retrieved from http://essentialfacts.theesa.com/Essential-Facts-2016.pdf.

Fruchter R. (1999). Architecture/engineering/construction teamwork: a collaborative design and learning space, *Journal of Computing in Civil Engineering*, *13*(4), 261-270.

Fruchter R. (2001). Dimensions of teamwork education, *International Journal of Engineering Education*, 17(4/5), 426-430.

Geertz C. (1973). Thick Description: Towards an Interpretative Theory of Culture. In *The Interpretation of Cultures*. New York, NY, USA, Basic Books, 3-32.

Gergle D., Kraut R. E. and Fussell S. R. (2013). Using visual information for grounding and awareness in collaborative tasks." *Human-Computer Interaction*, *28*(1), 1-39.

Goffman E. (1963). Behavior in public places. New York, New York, USA, The Free Press.

Goodhue D. L. and Thompson, R. L. (1995). Task-technology fit and individual performance. *Management Information Systems Quarterly*, *19*(2), 213-236.

Gutwin C. and Greenberg S. (2002). A descriptive framework of workspace awareness for real-time groupware. *Computer Supported Cooperative Work: The Journal of Collaborative Computing*, *11*(3), 411-446.

Hall E. T. (1969). The hidden dimension. Garden City, NY, USA, Doubleday.

Iorio J., Peschiera G., Taylor J. and Korpela L. (2011). Factors impacting usage patterns of collaborative tools designed to support global virtual design project networks. *Journal of Information Technology in Consruction (ITcon), 16*(14), 209-230.

Iorio J., and Taylor J. E. (2015). Precursors to engaged leaders in virtual project teams. *International Journal of Project Management*, *33*(2), 395-405.

Kan J. W., Tsai J. J.-H. and Wang X. (2011). “Scales” affecting design communication in collaborative virtual environments. Collaborative Design in Virtual Environments, Dordrecht, The Netherlands, Springer Netherlands, 77-87.

Kirkman B. L., Rosen B., Gibson C. B., Tesluk P. E. and McPherson S. O. (2002). Five challenges to virtual team success: lessons from Sabre, Inc. *The Academy of Management Executive, 16*(3), 67-79.

Kock N. (2004). The psychobiological model: towards a new theory of computer-mediated communication based on Darwinian evolution. *Organization Science*, *15*(3), 327-348.

Lombard M. and Ditton T. (1997). At the heart of it all: the concept of presence. *Journal of Computer-Mediated Communication, 3*(2), 0-0.

Meyer S. R., Pierce C. S., Kou Y., Leonardi P. M., Nardi B. A., and Bailey D. E. (2015). Offshoring digital work, but not physical output: differential access to task objects and coordination in globally distributed automotive engineering and graphic design work. *Proceedings of 2015 48th Hawaii International Conference on System Sciences (HICSS),* 1758-1767.

Nayak N. V. and Taylor J. E. (2009). Offshore outsourcing in global design networks. *Journal of Management in Engineering, 25*(4), 177-184.

Padmanabhan P. (2008). Exploring human factors in virtual worlds. *Technical Communication*, *55*(3), 270-276.

Patton M. Q. (2002). Qualitative research and evaluation methods. Thousand Oaks, CA, USA, Sage Publications.

Richardson J., and Swan K. (2003). Examining social presence in online courses in relation to students' perceived learning and satisfaction. *Journal of Asynchronous Learning Networks, 7*(1), 68– 88.

Richardson J., and Adamo-Villani N. (2010). A virtual embedded microcontroller laboratory for undergraduate education: development and evaluation. *ASEE Engineering Design Graphics Journal*, *74*(3), 1-12.

Schroeder R. (2006). Being there together and the future of connected presence. *Presence: Teleoperators and Virtual Environments, 15*(4), 438-454.

Shen K.N., and Khalifa M. (2008). Exploring multidimensional conceptualization of social presence in the context of online communities. *International Journal of Human–Computer Interaction*, *24*(7), 722-748.

Sherman W. R. (2003). Understanding virtual reality : interface, application, and design. San Francisco, CA, USA, Morgan Kaufmann.

Slater M., Sadagic A., Usoh M. and Schroeder R. (2000). Small-group behavior in a virtual and real environment: a comparative study. *Presence: Teleoperators and Virtual Environments, 9*(1), 37-51.

Smith D. K., and Tardif M. (2009). Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. Hoboken, NJ, USA, John Wiley & Sons.

Steuer J. (1992). Defining virtual reality: dimensions determining telepresence. *Journal of Communication*, *42*(4), 73-93.

Taylor J.E., Alin P., Anderson A., Comu S., Dossick C.S., Hartmann T., Mahalingam A., Mohammadi N. (in press). CyberGRID: a virtual workspace for architecture, engineering and construction. Virtual Workspaces in AEC, American Society of Civil Engineers (ASCE) Technical Council on Computing and Information Technology (TCCIT).

Taylor T. L. (2002). Living digitally: embodiment in virtual worlds. *The Social Life of Avatars,* London, UK, Springer London.

Thomas D. and Brown J. S. (2009). Why virtual worlds can matter. *International Journal of Learning and Media*, *1*(1), 37-49.

Wang X. and Wang R. (2011). Co-presence in mixed reality-mediated collaborative design space. In *Collaborative Design in Virtual Environments*, Dordrecht, The Netherlands, Springer Netherlends, 51-64.

Yan W., Culp C. and Graf R. (2011). Integrating BIM and gaming for real-time interactive architectural visualization. *Automation in Construction*, *20*(4), 446-458.

Yee N. and Bailenson J. (2007). The Proteus effect: the effect of transformed self-representation on behavior. *Human Communication Research*, *33*(3), 271-290.

Yee N., Bailenson J., Urbanek M., Chang F. and Merget D. (2007). The unbearable likeness of being digital: the persistence of nonverbal social norms in online virtual environments. *CyberPsychology & Behavior*, *10*(1), 115-121.

Zhao S. (2003). Toward a taxonomy of copresence. *Presence: Teleoperators and Virtual Environments*, *12*(5), 445-455.