

VISUALIZATION, COMMUNICATION, AND COPRESENCE: USING BUILDING  
INFORMATION MODELS IN VIRTUAL WORLDS

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## **Abstract**

# VISUALIZATION, COMMUNICATION, AND COPRESENCE: USING BUILDING INFORMATION MODELS IN VIRTUAL WORLDS

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In the architecture, engineering and construction (AEC) industry, work in distributed teams is becoming more common, adoption of building information modeling (BIM) is increasing, and effective time management is essential to remain competitive. BIM is a powerful technology, but the current method of sharing and collaborating with BIM, typically on a shared screen where viewpoints are controlled by one person as others passively observe, limits interaction with the building information model which, in turn, may hinder cross-discipline communication and understanding of issues. In this dissertation, a 3D virtual world as a collaboration medium is examined as a potential way to engage a team with BIMs for more effective and efficient collaboration. Participants were asked to navigate the 3D models by creating an avatar and entering a virtual world into which their building models had been imported. The ability to explore the avatar-sized model in a 3D environment with members of the team also present in the virtual space allowed the team members to find and reach agreement about issues in the model at a much faster rate than those who were sharing their model on a shared screen with one person in control of the viewpoint, indicating that viewing 3D models in a 3D environment with members of the team increases productivity during the construction design and coordination process.

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# Chapter 1

## Introduction

In the architecture, engineering and construction (AEC) industry, work in distributed teams is becoming more common, adoption of building information modeling (BIM) is increasing, and effective time management is essential to remain competitive. BIM is a powerful technology, but the current method of sharing and collaborating with BIM, typically on a shared screen where viewpoints are controlled by one person as others passively observe, limits interaction with the building information model which, in turn, may hinder cross-discipline communication and understanding of issues. In this dissertation, a persistent 3D virtual world as a collaboration medium is examined as a potential way to engage a team with BIMs for more effective and efficient collaboration.

### *Table 1-1. Chapter 1 Contents*

#### **1.1 The Problem**

#### **1.2 BIM Terminology Defined**

1.2.1 Building Information Modeling (BIM) and Building Information Models (BIMs)

1.2.2 Autonomous Navigation vs. Single Viewpoint Navigation

#### **1.3 Overview of the Study**

#### **1.4 Summary of Chapters**

### **1.1 The Problem**

According to the BIM Handbook (Eastman, 2011), building information modeling is a better way to visualize, communication and share knowledge among disparate actors on an AEC

project than previous paper-based practices, in part because 3D models are “much closer to everyday reality” (p. 96). Coordination practices are steadily shifting from 2D paper-based coordination using printed plans to BIM-based coordination using 3D, 4D and 5D models during design, preconstruction and construction phases. Typically, during coordination activities with the project team, the models (BIMs) are shared and discussed with other members using passive methods where one person (“the navigator”) projects the model onto a shared screen and navigates through the model while others observe. The rest of the team only sees the navigator’s viewpoint. Other members of the team who wish to discuss an item in the model must direct the navigator to the location of the item using descriptive words or by taking control of the model, becoming the navigator while others observe. This is an inefficient way to work and may limit others’ understanding of issues or protract the process of reaching a shared understanding among the team. In an industry where misunderstandings and miscommunications can result in costly delays and BIM use is increasing, it is becoming more critical to find an effective way to have synchronous discussions about BIMs with the project team.

There has been a significant amount of research on the use of BIMs for visualization and increasing collaboration effectiveness in the construction industry (Alin et al., 2014; Boland et al., 2007; Eastman, 2011; Smith and Tardif, 2009). Recent research has emphasized advantages of collocation, such as the ability to engage in impromptu sidebar conversations, resulting in a trend in the industry to move to a “big room” concept where the design and coordination team physically collocates at the project site for the duration of the project or at regular intervals to be available for face-to-face coordination (Boland et al., 2007; Kemmer et al. 2011; Khanzode et al., 2007; Staub-French and Khanzode, 2007). However, even when the team is collocated, sharing and coordinating with BIMs is still passive for participants. Shared understanding is

reached when one understands another's. To understand the other's viewpoint, one must know what the other is seeing. This is the default in face-to-face coordination, but has been a challenge when sharing information digitally using traditional collaboration media (Daft et al., 1987). Because continually improving communication technologies allow AEC teams to reach out to talent across the globe, new methods for communicating with BIMs over distance (i.e. digitally) must be explored. For the study described in this dissertation, the media-rich environment of a virtual world is used – an environment where building models can be imported into the space and explored as avatars (human representations of the user). “Walking around” the model is a very different way to view the BIM, synchronously, with the project team. The presence of avatars in the virtual world adds a layer of communication (i.e. nonverbal communication using the avatar body) to the traditional screen-sharing collaboration tools. In addition, collaborating in a virtual world provides a platform for all team members to be involved and engaged by enabling all team members to control their own viewpoints.

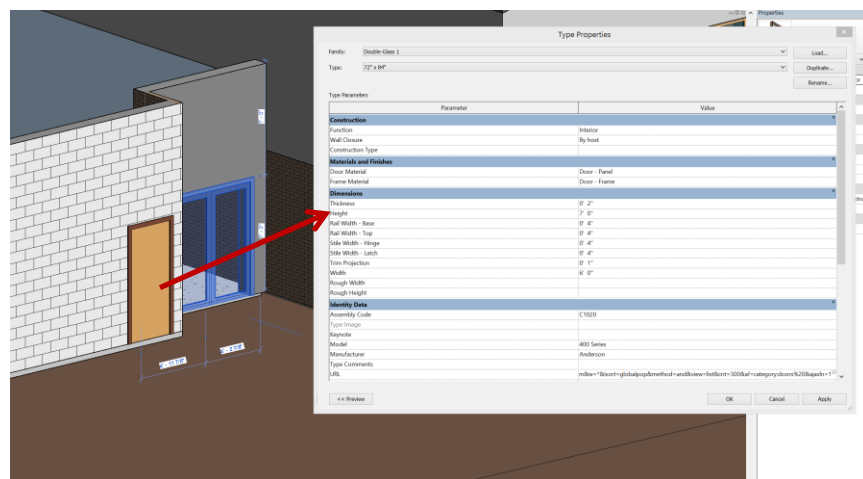
## **1.2 BIM Terminology Defined**

### **1.2.1 Building Information Modeling (BIM) and Building Information Models (BIMs)**

A building information model is a 3D scaled, parametric, object-oriented model of a building (Eastman, 2011). Prior to the appearance of parametric 3D modeling, drawings created with the use of computer-aided drafting (CAD) contained lines, surfaces, and hatches, much like a hand-drawn sketch. These elements contained no information other than line weight and color. The “new” type of modeling, parametric 3D modeling, had been in use for 15 years and was referred to in various ways by various software developers (such as “integrated project modeling”) when, in 2002, Jerry Laiserin suggested in The Laiserin Letter that the industry agree

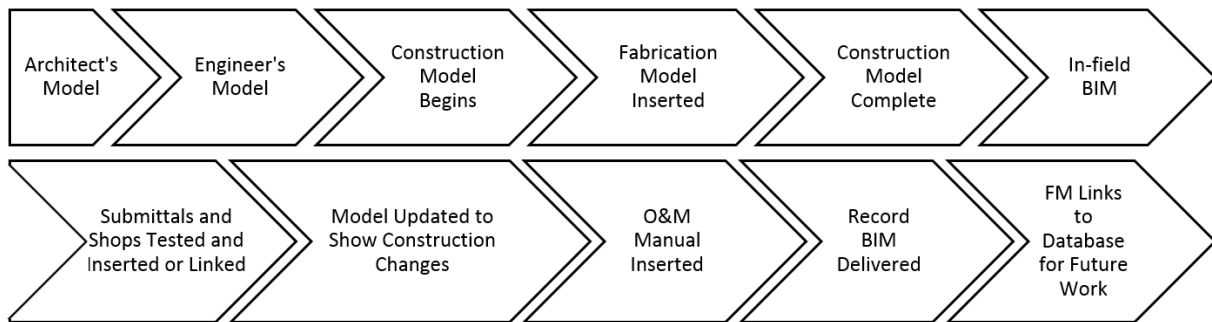
to replace the then-standard umbrella term “CAD” with Autodesk’s nomenclature, “Building Information Modeling” (Laiserin, 2002). Despite its appearance in the late 1980s, BIM was slow to be adopted in the North American construction industry but that has changed significantly in the last decade as reports of the benefits of BIM circulated among those in the industry, particularly owners. According to the 2012 SmartMarket Report, 71% of architects, engineers, contractors and owners are reporting engagement with BIM on their project, a 75% increase since 2007 (Bernstein and Jones, 2012).

BIM is the newest generation of computer aided drafting, but it is more than just a drafting tool. Unlike its CAD predecessor, BIMs comprise intelligent objects. For example, a door “knows” it belongs in a wall and can contain attributes such as size, composition, and manufacturer (see Figure 1-1). BIM is defined as “a modeling technology and associated set of processes to produce, communicate, and analyze *building models*” [emphasis in the original] (Eastman, 2011, p. 13). Because of the “I” in BIM (information), building information modeling is a transformational technology in the AEC industry that is changing how information is exchanged between stakeholders, in turn changing roles and communication practices in the industry (Eastman, 2011; Smith and Tardif, 2009).



**Figure 1-1.** Building Information Model (Autodesk Revit)

A BIM can be used throughout the lifecycle of a building, from design to construction to facility management (see Figure 1-2). Using BIM, the building can be virtually constructed in a computer prior to construction of the physical building which allows designers to get a feel for scale, allows builders to find potential construction issues, and allows owners to calculate long term operating costs.



**Figure 1-2.** BIM evolution in a project, adapted from (Hardin, 2009).

### 1.2.2 Autonomous Navigation vs. Single Viewpoint Navigation

*Single viewpoint navigation* is a term being introduced in this dissertation to describe the current method of sharing and collaborating with a BIM, i.e. when a team is viewing a model that is being manipulated by one person and all team members view the same scene. This is a passive way to view the model for all team members except the navigator. *Autonomous navigation* is the term being used to describe exploration of a BIM where each team member is able to control their own viewpoints. This engages all members of the team with the model and with each other. In a virtual world where each participant enters the space in the form of an avatar, each team member controls the placement of their own avatar. An example of autonomous navigation is shown in Figure 1-3. In the figure, three people are viewing the model

(through their own avatars) and each is positioned such that they have different viewpoints than the others.



Photo credit: Helen Juan

*Figure 1-3. An example of autonomous navigation. Participants here are controlling their own viewpoints.*

### 1.3 Overview of the Study

During the winter/spring of 2013, six geographically distributed student teams coordinated design and construction activities for an assigned building project over a period of ten weeks. Two different collaboration technologies were used which allowed comparison of coordination with models when viewing the model using autonomous navigation vs. single point navigation. Half of the teams met in a 3D virtual world where BIMs could be imported and explored by the team and the other half used collaboration software that allowed teams to share and discuss the building model by viewing it on a shared screen. The two collaboration platforms used in the study are described in more detail in Chapter 2.

Early discovery and quick resolution of coordination issues is critical to eliminate potentially costly (in both time and money) conflicts later in the project. The use of BIMs during

the coordination process helps issues be discovered earlier, but because the use of BIM is relatively new in the construction industry and is still often used in face-to-face coordination, the process of using BIMs effectively with team members who are distributed requires further development.

The goal of this exploratory study was to measure the efficiency (quantitatively) and effectiveness (qualitatively) of the discovery of issues in the building models that were imported into the virtual world and explored by the team to gain a better understanding of how the virtual world medium influences the discovery effort. Coordination efforts with BIMs in two different environments were studied and compared. One environment in which single viewpoint navigation was used emulates industry practices currently in use and the second environment in which autonomous navigation was used is being studied as an alternative way to work with BIMs.

The findings indicate that 3D environments provide quantitatively and qualitatively better outcomes than single viewpoint navigating for the discovery of coordination issues. Specifically, a wider variety of discoveries were made when autonomous navigation was employed whereas when single viewpoint navigation was used, discoveries were narrower in scope, tending to be limited to specific areas in the model.

#### **1.4 Summary of Chapters**

Chapter 2 describes current BIM coordination practices and defines virtual teams, explaining why they are becoming more common in the construction industry. Virtual worlds are defined and the affordances, particularly those that could be helpful during coordination practices, are outlined. Virtual worlds are popular in other sectors of our economy, but have yet

to gain a foothold in the construction industry. Possible hindrances to acceptance of virtual worlds are discussed. The advantage of using virtual worlds for collaboration is also discussed, such as the ability to reach a shared understanding earlier through the use of nonverbal cues provided by the avatar. Chapter 2 ends with a description and synthesis of four previous studies in the CyberGRID 3D virtual world.

Chapter 3 details the methodology used for this study, including the motivation for the research question, the setting, data collection methods, variables and unit of analysis, the analysis method and, finally, reliability and validity.

Chapter 4 describes the findings. The data were analyzed both quantitatively and qualitatively and this chapter displays several of the trends and patterns identified and displayed in graphs or tables. Three constructs were identified in the data and grouped into propositions, which are outlined in this chapter.

Chapter 5 outlines the goal of the study and the efficacy of the experimental design. Findings from the previous chapter are discussed in detail, including the three constructs that emerged from the data (visualization, communication, and copresence).

Chapter 6 provides limitations of the study as well as potential impact on the industry and possible directions for future studies.

## Chapter 2

### Background

This dissertation reports on a study conducted in 2013 where BIM collaboration among distributed team members took place using two different online platforms. One, a screen-sharing platform that represents current BIM coordination processes in the construction industry; the other, a desktop 3D virtual world that allows participants to enter and explore their building model as a team. The current study builds on four previous studies, beginning in 2010, in which student and industry professional interactions were recorded and analyzed in various online virtual environments. What emerged from the previous studies was an understanding that affordances available in the 3D virtual world are powerful and effective methods of communicating design and construction coordination issues. This chapter begins by describing why there is a need to study virtual teams in the construction industry who collaborate using BIM, discusses why virtual worlds are well-suited to collaboration with BIM, and provides a description, summary and synthesis of the previous research in virtual environments leading up to the 2013 study.

#### *Table 2-1. Chapter 2 Contents*

- 2.1 BIM Use in the Construction Industry**
  - 2.1.1 Collaboration with BIM
  - 2.1.2 Distributed Teams in the Construction Industry
  
- 2.2 The Use of Virtual Worlds for BIM Collaboration**
  - 2.2.1 Virtual Worlds Defined
  - 2.2.2 Virtual Worlds for Collaboration

2.2.3 Presence and Copresence

2.2.4 Avatars and the Development of Shared Understanding

### **2.3 Previous Studies in the CyberGRID Virtual World**

2.3.1 Summary of Studies Conducted in 2010-2012

2.3.2 Synthesis of 2010-2012 Studies

### **2.1 BIM Use in the Construction Industry**

As of 2014, parametric modeling had been in use for over 20 years, but only in recent years gained a foothold in the construction industry – an industry known for being slow to adopt new technologies (Harty, 2008). Among those in the AEC industry, contractors are seeing the highest return on investment for BIM use (Bernstein and Jones, 2012). The biggest benefit is using BIMs for construction coordination, particularly clash detection where 3D models from various disciplines are consolidated into a single 3D space in a program such as Autodesk Navisworks, which allows construction managers to compare models and find conflicts between different disciplines' modeled objects. An example of a conflict in the consolidated 3D model would be a plumbing pipe occupying the same space as a heating duct. The systems most often modeled and analyzed for coordination purposes are mechanical, electrical, plumbing and fire protection (MEPF), but other disciplines may also model their systems depending on contract requirements. Finding conflicts in the model and resolving them prior to construction is much less costly and time-consuming than discovering and resolving issues in the field while the building is under construction.

### **2.1.1 Collaboration with BIM**

On construction projects, activity is “displaced across numerous organizations and disciplines [which] requires high levels of information sharing between disparate actors” (Harty and Whyte, 2010, p. 468). Visual representations are key components in collaboration since they not only communicate what is known, but also makes more apparent, or explicit, what is unknown (Ewenstein and Whyte, 2007). The BIMs used in coordination meetings are used to communicate coordination issues to the various stakeholders on a construction project – i.e. the owner, designers, and subcontractors. “[O]nly visual models have the power to support description to and evaluation by a broad class of stakeholders” (Kunz and Fischer, 2009, p. 43). The construction manager in charge of consolidating the models, often called a BIM Manager or BIM Specialist (Eastman, 2011; Smith and Tardif, 2009), typically leads weekly coordination meetings attended by the project’s stakeholders. In these coordination meetings, the consolidated model is projected onto a screen and conflicts in need of resolution, as determined beforehand by the BIM Manager, are highlighted and discussed with the team. In this context, the BIM is a boundary object, defined as “objects that inhabit intersecting social worlds while at the same time satisfying the information requirements for each separate group” (Taylor, 2007, p. 993). The BIM allows the various disciplines to mediate cross-boundary knowledge without having to share a common language (Alin et al., 2014; Bechky, 2003; Carlile, 2004). In a study where participants viewed models in both 2D and 3D, building end users were able to identify 20% more building features when viewing the 3D models (Carvajal, 2005), indicating 3D models are more effective for visualizing building components than traditional 2D (often paper-based) plans.

Aspin (2007) argues both for and against the way BIM is currently used in coordination meetings by stating that interactive visualization is an important tool for allowing emerging

designs to be evaluated and discussed *but* that the form of visualization used during these meetings is a limited functionality, navigable, abstraction of the current model iteration with little facility for experimentation or evaluation. In an ideal coordination meeting, each participant would be able to interact with the model and share the task of navigation and manipulation (Aspin, 2007).

### **2.1.2 Distributed Teams in the Construction Industry**

Due to globalization and improvement in communication technologies, geographically distributed teams are becoming more common in the construction industry (Becerik-Gerber et al., 2012). Because of the geographic distance that separates them, much of the work is executed in virtual teams, defined as teams 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). Chinowsky and Rojas (2003) further refine the definition of virtual teams to include only teams that collaborate in real time, citing 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” (p. 98).

Virtual teams are well-suited to the construction industry when considering some of the characteristics of construction industry work practices. For example: “(a) non-co-location of individuals and teams collaborating on projects; (b) project-oriented nature of the industry with a tendency for actors to be involved in several projects at the same time; and (c) multi-disciplinary and mobile-working practices” (Rezgui 2007, p. 97). While there are some advantages to

collocation, such as creating closer relationships among the team and the ability to engage in sidebar conversations (Cachere, 2003), there are also disadvantages in that some find collocated work more distracting with constant interruptions which delays work or necessitates overtime to catch up (Lehtinen, 2013). However, the process of collaborating with BIMs in geographically distributed teams is challenging. Communication often happens via e-mail or other lean media. When participants are distributed and models are shared synchronously on a shared screen using collaboration software such as GoToMeeting or Skype, it is more challenging to engage in discovery and discussion through pointing or sketching as would happen with a collocated team (Dossick and Neff, 2011; Ewenstein and Whyte, 2007). Because the construction industry is heavily reliant on visual media for the communication of ideas, virtual teams are challenged with finding an effective way to communicate with BIMs over distance, mediated by technology.

There has been a significant amount of research on the effectiveness of BIMs for visualizing building design and increasing collaboration effectiveness in the construction industry (Boland et al., 2007; Smith and Tardif, 2009), but much of the BIM research tends to fall in one of two categories: face-to-face coordination meetings or asynchronous coordination using electronic networks to transfer files. The goal of this study was to explore the use of 3D virtual worlds for BIM coordination – specifically how affordances in the virtual world support the discovery of coordination issues – and to extend the findings regarding the need to match communication media to organizational task in order to improve collaboration performance (Fox, Leicht et al. 2010). This dissertation presents findings from an ethnographic study of globally distributed virtual teams working on complex design and planning tasks using Building Information Modeling (BIM) software. The participants conducted all meetings in an online 3D virtual world where they created an avatar and interacted with other team members as avatars.

## 2.2 The Use of Virtual Worlds for BIM Collaboration

When using collaboration technologies to coordinate work, 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). In distance collaboration with BIM, when models are shared synchronously with virtual team members, a screen-sharing technology such as Skype or GotoMeeting is typically used.

In the AEC industry, 3D environments are ideal for communicating spatial information that is critical in the design and execution of buildings and other planned environments. 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.

One primary difference between viewing a model on a shared screen and viewing the model as an avatar in a 3D virtual world is perspective. In a virtual world, the default view is “through the eyes” of the avatar where the user is central and view orbits around the viewer. Scrutinizing an object entails walking closer or zooming the camera toward the object as if looking through binoculars. The viewpoint is further characterized by *centrality* which is how far the viewpoint is removed from the nominal viewpoint. Is it better to see the world “through the eyes” of one’s avatar or over the shoulder of the shoulder of one’s avatar? This depends on what the user is trying to accomplish. Often in virtual worlds, the camera can be adjusted to the eye level perspective, over the shoulder, or even leave the vicinity of the avatar altogether. Each degree removed from the nominal viewpoint requires more mental transformations to be

performed in order to situate oneself in the environment (Dunston and Wang, 2005). Humans have a propensity to “construct” rather than “see,” since perception is affected by, for example, cognitive limitations, attention, and past experience; therefore, “creating successful visualizations is challenging in order to provide a framework for effective collaboration and communication” (Johnson, 2009, p. 96).

The user-centric perspective is a more “natural” way of viewing items since this is how we view the physical world. This is a completely different way of viewing the model than how it is typically viewed in the industry – that is, object-oriented rather than user-centric. “Any time we depart from the natural or intuitive way of manipulating or interacting with the world, we require the user to build new mental models, which creates additional overhead and distracts from the primary task” (Furness, 2001). It is possible to manipulate the camera away from the user’s avatar and simulate the object-oriented view of the BIM software, but that is not the default mode of viewing and probably would only be undertaken by someone more familiar with the software. Some commonly-used BIM software programs, such as Navisworks, have incorporated avatars, but it is not yet possible to interact with the model and with others on the project team in these programs.

### **2.2.1 Virtual Worlds Defined**

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). This differs from commonly used screen-sharing media,

such as GoToMeeting or Skype, because the screen-sharing environment is only exists during the meeting time.

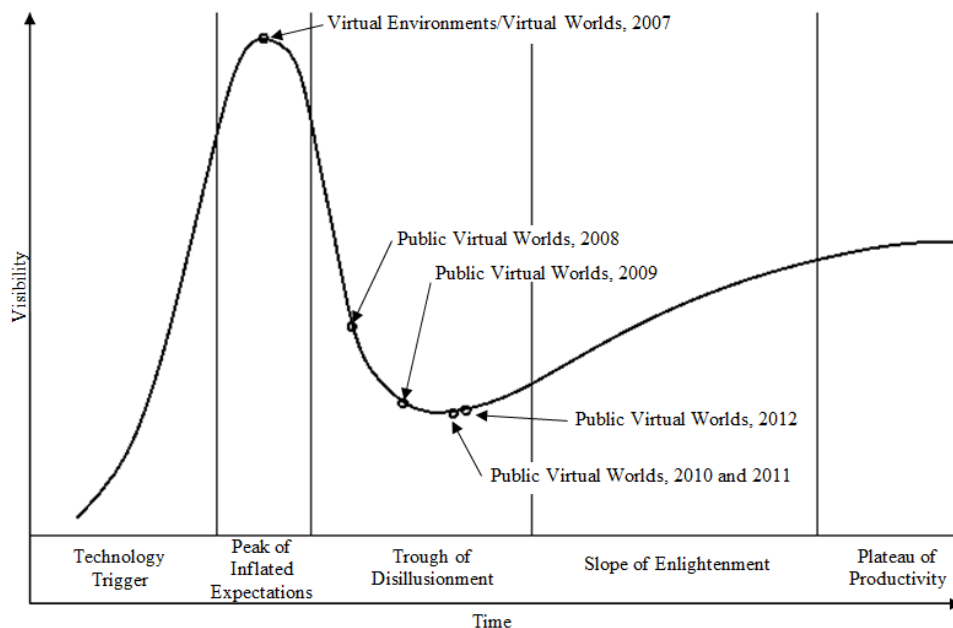
An avatar is a digital representation of the user that is used to navigate the virtual world. The fidelity and form of the avatar depends on the virtual world being employed and can range from a human figure to an animal or mechanical device to a simple shape (Bailenson et al., 2005). By definition, 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 and avatar position and gaze (Bailenson et al., 2005; Yee et al., 2007).

### **2.2.2 Virtual Worlds for Collaboration**

Several 3D virtual worlds have been designed specifically for professional collaboration such as ProtonMedia's ProtoSphere, Altadyn®, and SAIC's On-Line Interactive Virtual Environment (OLIVE). Second Life, launched in 2003, is a 3D virtual world that was originally developed to be a social site where people could reinvent themselves virtually (Rosedale, 2008). The year that Second Life was open-sourced, 2007, saw an increase in virtual world use for business and for collaboration, followed within the next two years by a decline, indicating that simply replicating the physical world in a virtual world is not compelling (Cyphert et al., 2013). The Gartner Group is a firm that researches trends in technology and publishes an annual report of current and anticipated trends. Technologies are plotted on a curve called the hype cycle

which was developed by Gartner in 1995 to represent the progression of technologies from introduction to assimilation (O’Leary, 2008). Figure 2-1 shows the position of virtual worlds on the hype cycle from 2007 to 2012 as determined by the Gartner Group. In 2007, virtual worlds were at the top of the curve (called the “peak of inflated expectations”) and by 2009, they had fallen to the bottom of the “trough of disillusionment,” where they remained as of July 2012.

Where virtual worlds *have* found success is in 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 the popular game engines which may



**Figure 2-1.** Position of virtual worlds on the Gartner hype cycle, 2007-2012.<sup>1</sup>

<sup>1</sup> Retrieved from <http://www.gartner.com> February 15, 2015.

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 2013, video game sales in the U.S. totaled \$15.4 billion<sup>2</sup> and as of November 2014, World of Warcraft had over ten million subscribers<sup>3</sup>. Numbers indicate that the physical 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.

### **2.2.3 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*. A decade after the publication of Steuer’s paper, Schroeder (2002a, 2002b, 2006), building on the definition of presence as *being there*, defined the term copresence as *being there together* where copresence is characterized by mutual awareness, connected presence, and engagement. Biocca (2003) draws on Erving Goffman’s work to define two

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<sup>2</sup> Retrieved from <http://www.joystiq.com/2014/02/12/npd-us-video-game-sales-reach-15-39-billion-in-2013/> March 14, 2015.

<sup>3</sup> Retrieved from <http://www.forbes.com/sites/erikkain/2014/11/19/world-of-warcraft-tops-10-million-subscribers-following-warlords-of-draenor-expansion/> March 7, 2015.

essential elements of copresence: *sensory awareness of the embodied other* which, in a virtual world, is an avatar or other representational device and *mutual awareness* where “the user is aware of the other and the other is aware of the user” (p. 463). Real-time activities among participants in a virtual world create a sense of copresence that, by definition, is a necessary component of the world (Thomas and Brown, 2009).

Collaboration in a virtual world presents new and interesting challenges because communication 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 participants in the study who had never appeared in the form of an avatar before, learning how to move and engage with each other digitally (such as walking and sitting through the use of a keyboard or mouse 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 participants’ avatars 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. A recent 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

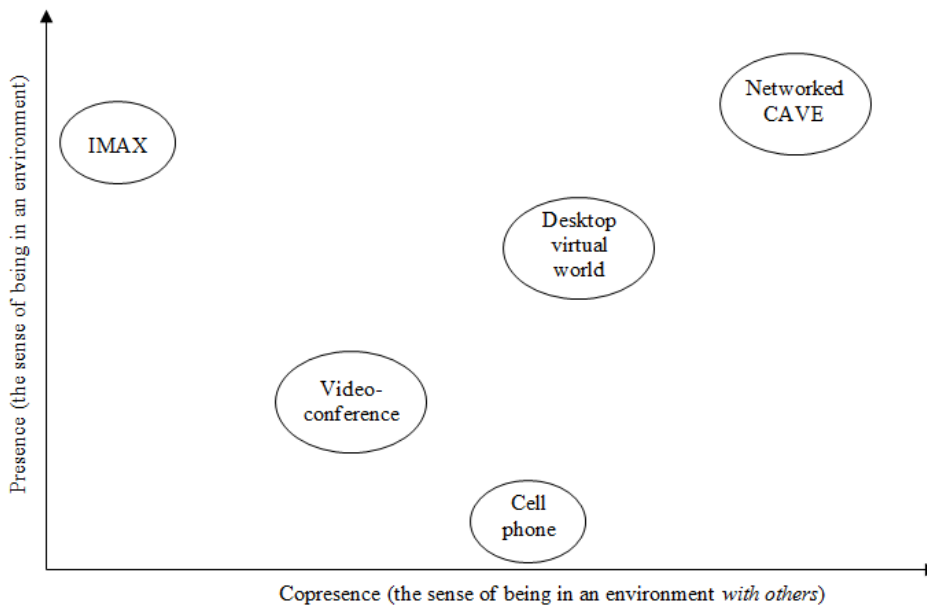
measurement to avatars in the virtual space. They also noted avatar gaze because eye gaze can be used to “equalize” interpersonal distance when people are forced to be close to others. For example, to reduce the undesired intimacy in an elevator we can avert our gaze to the front of the car.

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).

Communicating through an avatar with other avatars resembling a human form map more directly to communication practices in our physical environment than other communication media such as communication via e-mail. “Humans have evolved to favor [face-to-face] communication” and the more a communication medium maps to natural actions (e.g. collocation, facial cues, body language, and spoken words), the less cognitive effort is required to use it (Kock, 2004, p. 587; Dennis et al., 2008).

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). As described earlier, an important aspect of the concept of copresence is interaction (Schroeder, 2006). Copresence is a form of collocation that “is a set of spatio-temporal conditions in which instant two-way human interaction takes place” (Zhao, 2003, p. 446). Figure 2-2 shows 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*). 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, but to a lesser extent.



**Figure 2-2.** Various technologies plotted on a presence/copresence scale (adapted from Schroeder, 2006)

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. This indicates that immersion has a greater impact on ability to use tools and/or process information, which may translate to increased collaboration effectiveness (Slater et al., 2000). 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 than those who haven't (Schroeder, 2006). A lower perceptual illusion of mediation will also increase copresence (Lombard and Ditton, 1997). Studies have shown that realism in the avatar or the environment is not required to achieve a feeling of copresence (Bailenson et al., 2005; Kapp, 2012).

Much of the literature states that copresence has positive effects on team collaboration such as engagement, increased trust, and the ability to maintain situation awareness (Gergle et al., 2013; Gutwin and Greenberg, 2002; Wang and Wang, 2011).

#### **2.2.4 Avatars and the Development of Shared Understanding**

Literature regarding avatars largely focuses on avatar identity and how avatar appearance affects behavior in the physical world and how behavior in the physical world affects behavior in the virtual world (Bailenson et al., 2005; Yee et al., 2007). However, literature 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 space is nascent. An economy of words due to the shared visualization is anticipated as is a more accurate shared understanding among members of a team when compared to distance collaboration using a screen-sharing platform.

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 physical 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). Development of shared understanding is critical for effective

collaboration (Gibson and Cohen, 2003). 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).

Symbolic interactionism (SI) is used as a framework for this study. SI states that, rather than meaning only being inherent in an object or the object only being defined by how a person perceives it, meaning is a social product derived from how one perceives how others see an object (Blumer, 1969; Lindlof and Taylor, 2011). In this respect, copresence may be a critical element to help establish how others perceive an object by allowing one to view what others are viewing in the virtual world (Wang and Wang, 2011). The process of communication involves encoding and decoding messages, and some media require more encoding and decoding than others (Kock, 2004). The less effort required for this process, the less time it takes to reach a shared understanding (and thus coordinate). Experience with a medium decreases effort, but most construction projects are still “one-off” products with unique elements and those elements must be communicated to the stakeholders in the form of models or drawings. Each element of the model or drawing is a symbol (two lines for a wall, for example) that must be encoded by the drafter and decoded by all who view it. The less abstract the code (e.g. a 3D visualization of a wall versus two lines on a piece of paper), the less cognitive effort required to decode and, in turn, the less time required to encode/decode, the smaller the impact on coordination efforts.

In this study, participants were observed as they used their avatars to communicate nonverbally. The effect on others was noted – e.g. was avatar action acknowledged by others and did it have the intended effect? Of particular interest was if avatar position would streamline communication regarding issues when exploring BIMs that were imported into the 3D environment.

## **2.3 Previous Studies in the CyberGRID Virtual World**

This dissertation reports on the methodology and findings from a 2013 study in two virtual environments that follows three years of previous studies in a virtual world called the CyberGRID. With each successive year, the CyberGRID environment evolved as the research themes emerged. The following sections describe the development of the CyberGRID virtual world and the focus of the studies each year.

### **2.3.1 Summary of Studies Conducted in 2010-2012**

#### *2010 Pilot study with student participants*

In the winter/spring of 2010, a study with 87 graduate and undergraduate students from five globally distributed universities, including the University of Washington, was launched in an online virtual world called the CyberGRID (Cyber-enabled Global Research Infrastructure for Design Networks) built within Second Life.<sup>4</sup>

Students were asked to create an avatar and met in teams of 10 to 14, once a week for ten weeks. Each team was asked to complete a complex design task for a building project scenario with each university being responsible for one component of the task such that collaboration between universities would be necessary. The 3D environment was designed such that each team had its own small island on which were located a conference room and a sandbox. (In Second Life, a sandbox is an area where users may build objects using building elements called primitives, or “prims,” that may be resized, textured, and connected with other prims to create larger objects.) The conference room was equipped with team walls (Figure 2-3) on which the students could share their desktops. The 2010 study focused on virtual team issues such as tool

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<sup>4</sup> The CyberGRID is detailed further in the methodology chapter.

use (Iorio et al., 2011), communication (Anderson et al., 2010), facilitation (Iorio et al., 2012), and transactive memory systems (Comu et al., 2013).



*Figure 2-3. The CyberGRID conference room in Second Life, 2010*

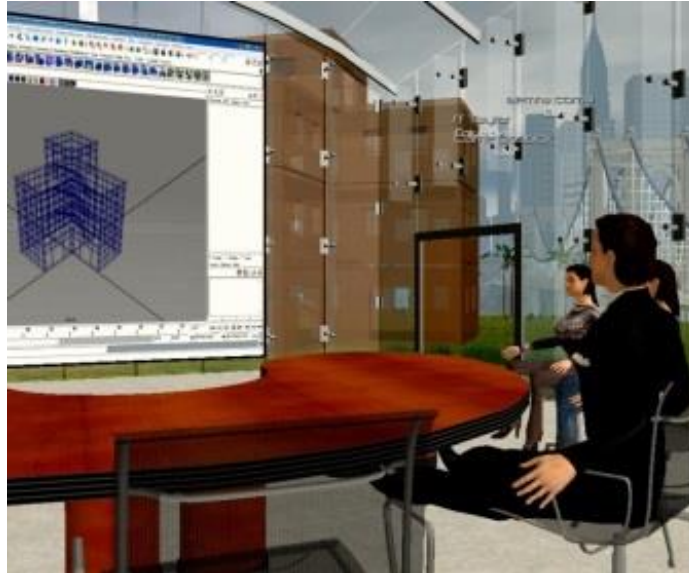
In the 2010 pilot study, the building models were not imported into the virtual world, so the majority of in-world communication took place in the virtual conference room. The environment provided numerous communication affordances including voice, chat, and thought bubbles (Iorio et al., 2011). One observation from this study was that avatar position was effective at communicating with others, whether purposive or not (Anderson et al., 2010). An example of communicating via avatar position is shown in Figure 2-4, where one student took charge of the meeting by standing (i.e. positioning his avatar) at the “head” of the table. It was this behavior that prompted the question in subsequent studies about how avatar location and position may be used to communicate when collaborating with building models in the same interactional space as others.



**Figure 2-4.** Using avatar position to communicate “I am in charge of this meeting.”

#### *2011-2012 studies with student participants*

Because of the steep learning curve of the Second Life virtual environment, the CyberGRID was moved out of Second Life in 2011 and into a virtual environment built on the Unity game development platform. The intent was to allow the students to focus more fully on the project and less so on trying to learn the technology. Two universities participated in the 2011 and 2012 studies: University of Washington and Columbia University in 2011 and University of Washington and Virginia Tech in 2012. The new virtual environment platform allowed the research team to import building models into the space. The models used were very simple 12-bay models developed in Autodesk Maya. Only walls, floors, stairs and roofs were modeled. Figure 2-5 is a screenshot of the researchers in one team’s conference room and the building model can be seen in the background, located just outside the conference room.



*Figure 2-5. The CyberGRID conference room in Unity, 2011*

The students used the imported 3D models primarily to count items (such as walls) which helped them determine labor and time needed to construct the building. Even though utility and use of models in 2011 and 2012 was limited, there were exchanges that justified further pursuit in the study of BIM coordination in virtual worlds – for example, as one team was taking inventory of doors by walking through the models with their avatars, they stopped in front of a large door and discussed how this particular door would be classified: as a man door, as an overhead door, or as something else.

Alin et al. (2013) analyzed the 2011-2012 dataset and found the imported building models acted as boundary objects that facilitated knowledge transfer among participants. The 2011 and 2012 data was also analyzed for the presence of messy talk (Dossick and Neff, 2011), defined as “unplanned, unforeseen and unanticipated” talk supporting brainstorming and mutual discovery (p. 85). The concept of messy talk originated through observation of collocated teams using shared visualization tools such as drawings, spreadsheets, construction schedules, and 3D and 4D models. The question now became whether digital visualization tools in a virtual

environment could also support messy talk. The definition of messy talk was refined to facilitate observation and analysis of messy talk interactions in the virtual world. The operationalized definition of messy talk comprises four elements: mutual discovery, critical engagement, knowledge exchange, and resolution (Dossick et al., 2014). The presence of all four elements are necessary to achieve knowledge synthesis through messy talk. Analysis of the 2011 and 2012 data indicated that, indeed, messy talk can be achieved in virtual environments (Dossick et al., 2014).

### *2012 Pilot study with industry professionals*

In the summer of 2012, a virtual worlds study with industry professionals was launched. Skanska, an international construction firm, had been seeking a way for their Virtual Design and Construction (VDC) Managers to collaborate with Project Engineers located at multiple construction sites without having to be physically present at each site. Through an internal grant program, Skanska was able to participate in a study of three different virtual world technologies to coordinate with BIM in virtual worlds. As part of their exploration, they asked the University of Washington to help install and train the teams on the new virtual world software and invited researchers to observe the team as they worked in the virtual worlds. Contrary to the previous studies where relatively inexperienced participants were using virtual worlds to collaborate, this study provided an opportunity to observe experienced professionals in the construction industry who routinely use BIM as part of their work and were willing to do so in virtual worlds.

The participants used three different collaboration technologies: Sococo, a screen-sharing software (explained in more detail in Section 3.1), the CyberGRID, a virtual world (also explained in more detail in Section 3.1), and Second Life, an online open-source virtual world

(described earlier in Section 2.2.2). Field experiments were conducted from July to August 2012 in Sococo, followed by an in-world CyberGRID usability test in December 2012. In the final stage, a Second Life model was developed and demonstrated during the Construction Industry Research Conference (CIRC) Expo in April 2013. The preference would have been to conduct field experiments using all three technologies, but BIM coordination was winding down on the project as construction neared completion just a few weeks into the study, so alternative methods were used to test the technologies. Data collection included individual interviews, team interviews after each technology cycle, weekly surveys, and ethnographic observation both in the virtual worlds and in the physical space.



**Figure 2-6.** The CyberGRID usability test, December 2012, showing the building model import (background) and CyberGRID conference room (foreground) where the industry study orientation was held.



*Figure 2-7. Building model exterior in the CyberGRID as displayed at CIRC, April 2013. The model was imported directly from Autodesk Navisworks.*



*Figure 2-8. Building model interior in the CyberGRID as displayed at CIRC, April 2013.*

The findings were encouraging. According to the interviews and surveys, the virtual worlds did provide a sense of “being there together” when members of the team were not physically collocated. When in the building model, participants felt like they were “really walking around the building.” They were able to use their avatars for nonverbal communication to indicate items being discussed. Some challenges were also encountered while running the field experiments with professionals on the project site, such as:

- Skanska’s firewall required working with IT to open ports before attempting to launch new technologies. Skanska’s IT is not local and our experiment was not a top priority for the IT group which caused delays in the study schedule.
- Limited bandwidth/connectivity at jobsite trailers hindered use of the collaboration technologies which required workarounds so the team could use them temporarily. They were unable to connect to their network (where they received e-mail, etc.) while simultaneously logged into the 3D virtual worlds.
- It was difficult for the project engineers to be in the virtual world and the physical world concurrently. Distractions and interruptions in the physical environment occurred too frequently for them to focus fully on the virtual environment.

Because the construction phase of their project ended just as the 3D virtual worlds portion of the study began, the research question was not directly addressed.

### **2.3.2 Synthesis of 2010-2012 Studies**

Observations of interactions over the span of four years confirmed the findings of numerous other studies in virtual worlds that concluded social conventions carry over from the physical world into the virtual world (Bailenson et al., 2005; Yee et al., 2007). The observation that most shaped the 2013 study was how effectively participants were able to communicate nonverbally with their avatars using avatar location and position – even when the communication was unintentional. When an avatar was standing rather than sitting in a chair in the large conference room where all others were sitting, the standing avatar was always met with a reaction from others such as “do you need help sitting down?” Knowing that avatar position was so useful as a communication tool, the next logical step was to import models into the space to

see how communication with avatars would be used in the model. The broad goal was to determine how geographically distributed AEC team members leverage the ability to explore BIMs as avatars present with other avatars in the virtual world. The previous studies resulted in a refinement of research questions for the 2013 study. For example, would autonomous navigation in the model with other members of the team increase the number of issues brought to the attention of others? Does the ability to locate and position the avatar in the building model support more efficient and effective communication because it provides cues to others (such as location and position/gaze direction) regarding which item in the model is being discussed?

It turns out that participants who collaborate as avatars with other avatars in an imported building model use deictic references (such as “this” and “here”) and leverage avatar location and position/gaze direction to reference to a specific item in the model (Hanks, 2009; Yee et al., 2007). Copresence supports cues because it confirms the item being discussed is in the model, e.g. when a participant says “this window” it is assumed to be the window that the avatar is facing in the virtual world, not one the participant is facing in the physical world.

In the screen-sharing scenario, it was anticipated that more words or descriptive phrases are needed to describe the item being discussed. To refer to a specific window, a participant might say “The window on the first level, west elevation, between grids B and C.” This may be followed by a clarifying question, “West elevation? Is that on the left side?” The expectation was that communication in the virtual world would be more efficient and effective than communication using the screen-sharing technology. The 2013 findings confirmed that communication was more efficient in the 3D virtual world than in the screen-sharing scenario.

It wasn't until the 2013 study that buildings imported into the space could be manipulated by students. That is, in 2013 students were exploring models in the virtual world that had been

created or manipulated by members of their team. When a participant's model was revised, the new iteration of the model was imported into the space to be re-explored by the team.

This study uses data from the 2013 study to build on messy talk findings from the 2011-2012 data, focusing on the essential first step in the messy talk exchange, mutual discovery. In a mutual discovery exchange, one participant would remark on something and another team member would acknowledge the remark, either agreeing or disagreeing. Acknowledgement of the discovery by another member was necessary to engage in a subsequent element of messy talk, critical exchange. Without acknowledgement, "mutual" discovery did not exist and knowledge synthesis through messy talk could not occur (Dossick et al., 2014). This dissertation explores more deeply the instances of mutual discovery through observation of interactions in the 2013 study and discusses its potential impact on the construction industry.

## **Chapter 3**

### **Methodology**

This dissertation describes a study conducted in Winter/Spring 2013 in which six globally distributed teams collaborated with BIMs using two different online platforms – half using one platform, half using the other. This chapter details the research design, data collection methods, and analysis approach.

#### *Table 3-1. Chapter 3 Contents*

#### **3.1 Research Design**

- 3.1.1 Research Question
- 3.1.2 Population and Sampling
- 3.1.3 Research Setting
  - 3.1.3.1 Physical Setting
  - 3.1.3.2 3D Virtual World
  - 3.1.3.3 Screen-sharing Platform
- 3.1.4 Design Task
- 3.1.5 Measurement and Variables

#### **3.2 Data Collection**

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- 3.2.2 Ethnographic Observation
- 3.2.3 Digital Artifacts

#### **3.3 Data Analysis**

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- 3.3.2 ELAN Annotation and Transcription
- 3.3.3 Quantitative and Qualitative Coding
- 3.3.4 Discovery Definition and Analysis

#### **3.4 Reliability and Validity**

### **3.1 Research Design**

This section describes the participants, research setting, and participant tasks designed to address the research question that had been shaped during the previous three years of study in the virtual environment.

#### **3.1.1 Research Question**

The research question was developed after observing participants using their avatars as a communication tool in previous studies. Because social conventions carry over from the physical world to the virtual world, the avatar was effectively used to express nonverbal cues. The specific question addressed by this study is: How is the efficiency and effectiveness of communication regarding discovery of coordination issues impacted when geographically distributed CEM team members collaborate by exploring avatar-scaled BIMs as avatars present with other avatars in a 3D virtual world compared to collaborating with screen-sharing software?

#### **3.1.2 Population and Sampling**

Participants in the study were graduate and undergraduate students from four globally distributed universities (Table 3-2). The study employed purposeful sampling when selecting participants (Patton, 2002), recruiting students from engineering and construction management departments in order to simulate a complex project context. Similar to the 2010 study described in Chapter 2, students 3D groups from each university represented specialists from one domain who worked both independently and interdependently with the student groups from other universities on an assigned design and planning task that resulted in a shared outcome for the team (Iorio et al., 2011). The purpose was to necessitate collaboration among the team members to complete the overall task.

**Table 3-2. Universities, student teams and responsibilities**

<b>University</b>	<b>Number of students on each team</b>	<b>Design Task</b>	<b>Software</b>
University of Washington (UW), Seattle, WA, U. S.	1	4D Modeling	Autodesk Navisworks
Virginia Tech (VT), Blacksburg, VA, U.S.	2	Baseline Schedule	SimVision
University of Twente (UT), Enschede, Netherlands	3	Cost Estimate	BIMserver
Indian Institute of Technology-Madras (IITM), Chennai, India	3	Addition of three rooms to 3D Model	Autodesk Revit
<b>TOTAL</b>	9		

### **3.1.3 Research Setting**

Participants were situated in the physical environment of a university lab using one of two collaboration platforms to communicate with their global teammates: a 3D virtual world or screen-sharing software. Each of these is described in the following sections.

#### **3.1.3.1 Physical Setting**

Participants met in labs located on the campuses of their respective universities to ensure they had access to functioning technology and help from teaching assistants if needed (Figure 3-1). They were each provided with a headset, a computer with internet access and second monitor. Both collaboration technologies used in this study had screen-sharing functionalities and the participants were asked to use one monitor to view the virtual environment and the other for their local work. This way, students could monitor activities of their team members in addition to performing their own work locally.



Photo credit: Carrie Sturts Dossick



Photo credit: Josh Iorio



Photo credit: Timo Hartmann

**Figure 3-1.** Lab space at UW, VT, and UT.

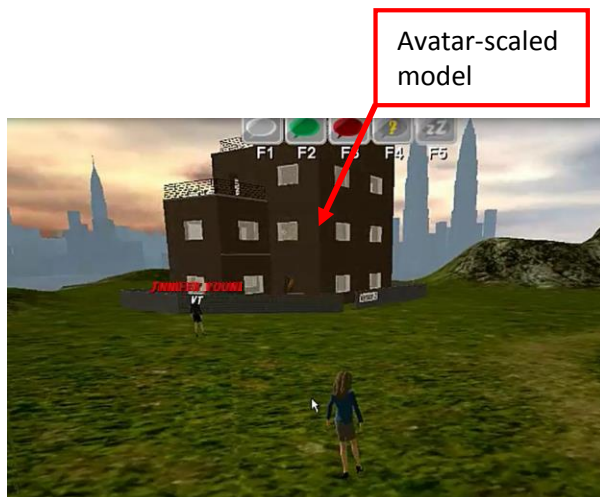
### **3.1.3.2 3D Virtual World**

Three of the six teams met in a 3D virtual world called the CyberGRID (Cyber-enabled Global Research Infrastructure for Design) which was developed to support design work in global virtual networks (Iorio et al., 2011). The CyberGRID was developed in 2010 and is currently being updated and maintained by researchers at Virginia Tech.

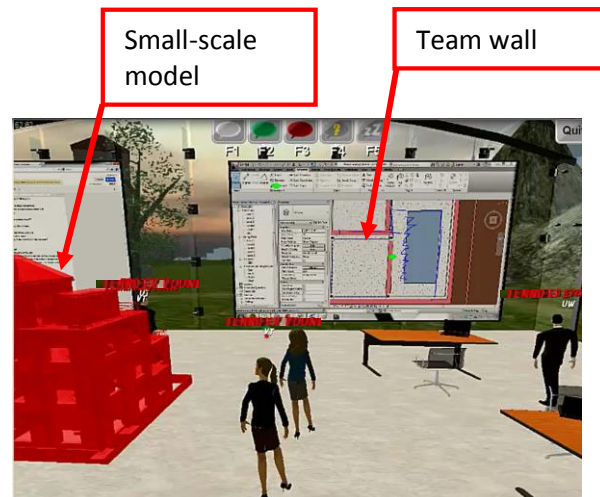
Building on lessons learned from previous studies in the 3D environments and focusing on research questions regarding nonverbal communication and copresence, the CyberGRID was redesigned for the 2013 study by researchers at Virginia Tech. Added elements included: more customizable avatars; addition of a team room with four screens that could be used simultaneously by participants; imported avatar-scaled models with color and texture for a more realistic appearance; and small-scale models placed in each team room for quick reference (Figures 3-2 and 3-3).

The addition of the team room and more detailed building models encouraged participants to use their avatars to explore and move about the space. The assignment was designed such that the students would be encouraged to use the avatar-sized model for more than just quantifying building elements as students had done in previous years. The teams were tasked

with adding three bays to an existing building model, with all team members having to agree on the location of the new bays and the IITM students revising the model. In the first week of the 2013 study, a complication was encountered when implementing the CyberGRID: the IITM team was unable to access the CyberGRID without crashing the system. To keep the IITM students involved in the study, the research design was changed to allow IITM to communicate with their teammates via online chat. This meant that UW, VT and UT had to communicate with their teammates using two different media simultaneously. Each team chose to work with this condition differently, which is explained further in the Chapter 4 findings.



**Figure 3-2.** Students walking through the Imported building model in the CyberGRID



**Figure 3-3.** Students using the team wall to brainstorm a new top floor layout

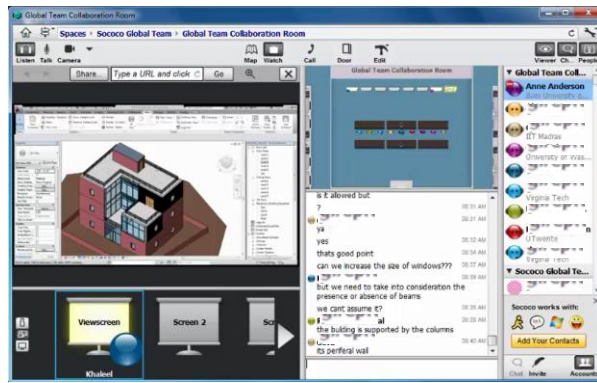
### **3.1.3.3 Screen-sharing Platform**

The remaining three of six teams met weekly using Sococo, a commercially available collaboration technology designed for distributed teams. Sococo (short for Social Communications Company) is a platform where each team member is represented by a solid circle referred to as an avatar. Avatars enter a space where a 2D floor plan represents offices, hallways, and conference rooms (Figure 3-4). Communication affordances used by the students

in this environment included voice, text chat and multiple team screens for desktop sharing (Figures 3-4 and 3-5). Additional features that are available in Sococo but not used by the students in this study are video conferencing and a Sococo phone where an outside phone line may be reached from within Sococo. Participants were encouraged to only use the voice, chat, and screen-sharing functionalities of Sococo to more closely represent a typical BIM coordination meeting. Students from all four universities in the study were able to access and use Sococo without any issues.



*Figure 3-4. Sococo layout*

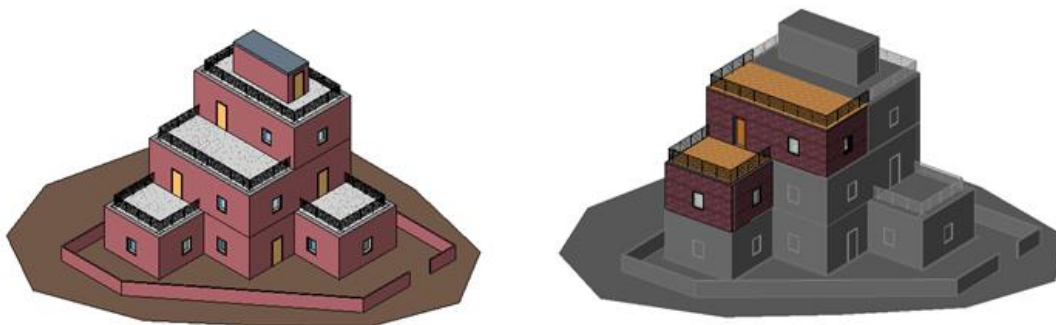


*Figure 3-5. Sococo's screen sharing functionality*

### 3.1.4 Design Task

The study was incorporated into courses offered at the four participating universities. Each of the six teams had nine members distributed as shown in Table 3-2. The teams met once each week for ten weeks and meeting times were scheduled to be 2.5 hours long. As part of the course, the students were provided with a 12-bay 3D building model and asked to model the three new bays using the BIM software, create a cost estimate for the new additions, a baseline schedule, and a 4D model. Each university was responsible for one of those tasks (Table 3-2). Each week's tasks are listed in Appendix D, Table D-1.

Students were asked to submit the revised building model with the three new bays in week 3 of the study. One team's before and after models are shown in Figure 3-6. After creating the cost estimate, schedule and 4D model in the following weeks, they were asked to review and optimize their models. The research team was able to import the original 12-bay 3D model into the 3D virtual world for participants to explore and use for collaboration if desired. The most recent version of the building model was imported each week until the design was finalized. In Sococo, participants were only able to view their models by projecting them onto a shared screen. Therefore, three teams were able to explore their models by “walking through” them and the remaining three teams were not.



*Figure 3-6. Left: Original building model provided to Team 5 at the beginning of the course. Right: Three additional bays modeled by Team 5 IITM students.*

### **3.1.5 Measurement and Variables**

An independent variable is one that is manipulated by the researchers. In this study, the independent variable was the medium used to collaborate with the BIM, i.e. the 3D virtual world versus the screen-sharing software. The teams using the screen-sharing software were used as the control group because the affordances represent those currently used by teams in the construction industry. The teams using the 3D virtual world were used as the treatment group to determine how collaboration in a 3D environment differs from typical collaboration.

A dependent variable is that which is measured in a study as it is affected by the independent variable(s). In this study, the items measured were the number of issues discovered; the time needed to communicate discovery of an issue; and the number of words needed to reach a shared understanding of the issue. The unit of analysis was discoveries which is defined later in this chapter in section 3.3.4.

## **3.2 Data Collection**

Data were collected through video and audio recordings, ethnographic observation, and collection of digital artifacts. Details of each are described below.

### **3.2.1 Video and Audio Recording**

Meetings in both collaboration platforms were recorded at the University of Washington using Camtasia Studios screen capture software. The video files were converted to .mp4 format then uploaded to secure servers at the University of Washington and Virginia Tech for analysis by researchers.

### **3.2.2 Ethnographic Observation**

Ethnography provides the opportunity to see how people interact in context. “Without contextual embedding, it is not possible to meaningfully interpret what we see” (Boellstorff et al., 2012, p. 16). This study employed a type of ethnography referred to as “microethnography.” Microethnography involves the study of a setting or an activity rather than an entire society and differs from traditional ethnography in that analysis is concentrated on “recorded specimens of interaction, usually without consulting participants’ judgments” (Fitch and Sanders, 2005, p.

381). This type of analysis gained popularity in the 1970s when researchers studied children in the classroom by recording their interactions and studying both verbal and nonverbal communicative events frame by frame. Because this study involves the analysis of both verbal and nonverbal communication, it was critical to review, frame by frame, the interactions among participants in the virtual space.

Researchers from the University of Washington and Virginia Tech created avatars and entered the virtual environments with the student participants, with at least one researcher present at every meeting. The researchers did not participate in the assigned tasks, but provided assistance to students when needed. Some scholars believe having a researcher present may “contaminate” the data, but Boellstorff et al. (2012) argue that maintaining a lengthy presence on site with those being observed “normalizes” the presence of a researcher.

The observation method differed slightly between the two collaboration technologies. Because of the time constraints due to the difference in time zones (from Pacific Standard/Daylight Time on one extreme to Indian Standard Time on the other – a 12.5 hour difference), one team using the 3D virtual world and one team using the screen-sharing software met simultaneously in the university labs. There was a researcher in each meeting, but only one researcher was available to actively take detailed ethnographic notes and this needed to happen in the 3D virtual world. Scenes captured by the Camtasia screen capture software were controlled manually and because activity in the 3D environment was so dynamic the researcher needed to be present and actively recording. If the students’ avatars in the virtual world walked from the conference room to the 3D building model in the yard, the researcher’s avatar followed to maintain recording of the activity.

Observation of teams using the screen-sharing platform took place after the meeting was over. Because the meeting platform was static, the screen capture was not as labor- or attention-intensive as the virtual world. The researcher only needed to ensure the correct shared screen was being recorded – several screens could be shared simultaneously and attention was drawn to the current screen when a team member would announce something like, “Everybody, please look at screen 2 where I am sharing the updated Revit model”.

Ethnographic notes were taken during each meeting using an Ethnographic Observation Sheet tool (Appendix A) developed prior to the study kick-off. At the top of the sheet is a table with checkboxes that allows use of communication tools in the environment to be quickly noted if used. Following the table is a list of items to be noted such as meeting topics and communication channels used. The average completed Ethnographic Observation Sheet for a single meeting was two pages long. The sheets were used during the analysis phase to determine which meeting would be of interest to analyze more deeply.

### **3.2.3 Digital Artifacts**

The 3D building models, cost models, construction schedules and Navisworks 4D models that were submitted as part of the students’ coursework were collected for analysis. Chat logs from the meetings and contents of their online file repositories containing progress work were collected. Teams who collaborated using Google Docs, an online application that allows multiple people to edit documents simultaneously, shared those documents with researchers as well. The 3D building models were used to compare issues discovered by each team to the number of issues that were discoverable in the model. For example, if one team only discovered two issues during their coordination meeting and another team discovered twelve issues during theirs, was it

because the first team only had two issues in their model? Analysis of the models indicated that all teams had roughly the same number and type of issues in their models. This is expected, considering the students who developed the models were in the same course and learning the same material about Revit modeling. Conversations in the chat logs and Google Docs were included in the analysis because not all discoveries were communicated through voice or avatar nonverbal communication. The determination of efficiency of communication necessitates comparing the various forms of communication in the discovery and agreement of an issue – those being voice, text, avatar position and location, gesture bubbles or a combination of some or all of the above.

### **3.3 Data Analysis**

#### **3.3.1 Sample Frame**

Because this dissertation focuses on communication around BIMs, it was important to choose a sample frame from the data that included significant model use for the purpose of finding issues in the model. Table D-2 in Appendix D shows the amount of time each team spent in the 3D environment exploring the imported building models, broken out by week over the course of the 10-week study. Most model exploration occurred during week 3 because it was the first time the UW, VT and UT students viewed additions to the building model as generated by the IITM students. This translated to increased opportunities for discovery of issues in week 3 compared to other weeks that were less focused on model exploration.

### 3.3.2 ELAN Annotation and Transcription

Video and audio data from the week 3 meetings were imported into ELAN<sup>5</sup> (Eudico Linguistic Annotator), a software program developed at the Max Plank Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Brugman and Russel 2004). ELAN allows multiple media – in this case video and audio – to be imported and annotated. In ELAN, annotations are mapped to the video/audio timeline and waveforms in the graphical interface indicate audible interactions. Figure 3-7 shows a video in the upper left-hand corner and the audio waveforms of the participants' voices in the center horizontal strip. A flat audio waveform indicates silence. This indicator speeds analysis considerably by not having to listen to long gaps of silence (Iorio et al., 2011). The buttons shown under the video display allow refined control of the video which provides more accurate annotation so each interaction can be analyzed frame by frame as required by the microethnographic method. Transcription of the audio entails a few simple steps in ELAN. First, audio waveforms are segmented by the researcher as shown in the bottom horizontal strip of Figure 3-7. Next, segments are annotated with the name of the team member who is speaking or typing. Finally, a transcription segment is created under the speaker and ELAN is switched to transcription mode where audio captured by the spanned segments is played using controls on the keyboard, obviating the need for specialized equipment. Figure 3-8 shows ELAN's transcription mode and Appendix B details the steps in ELAN that were used from beginning (importing raw data) to end (transcribing and annotating). All six meetings in week 3 were fully transcribed for analysis.

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<sup>5</sup> <http://tla.mpi.nl/tools/tla-tools/elan/>

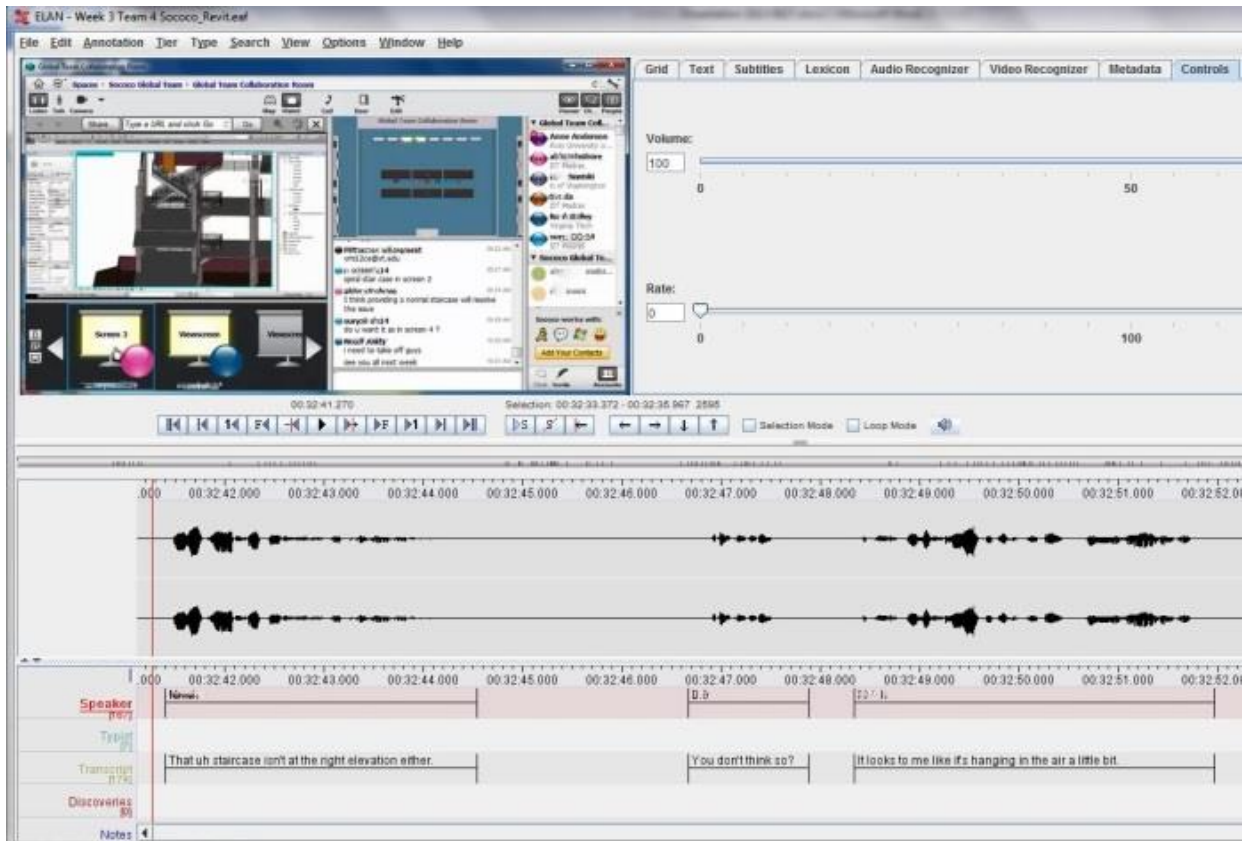


Figure 3-7. ELAN interface – annotation mode

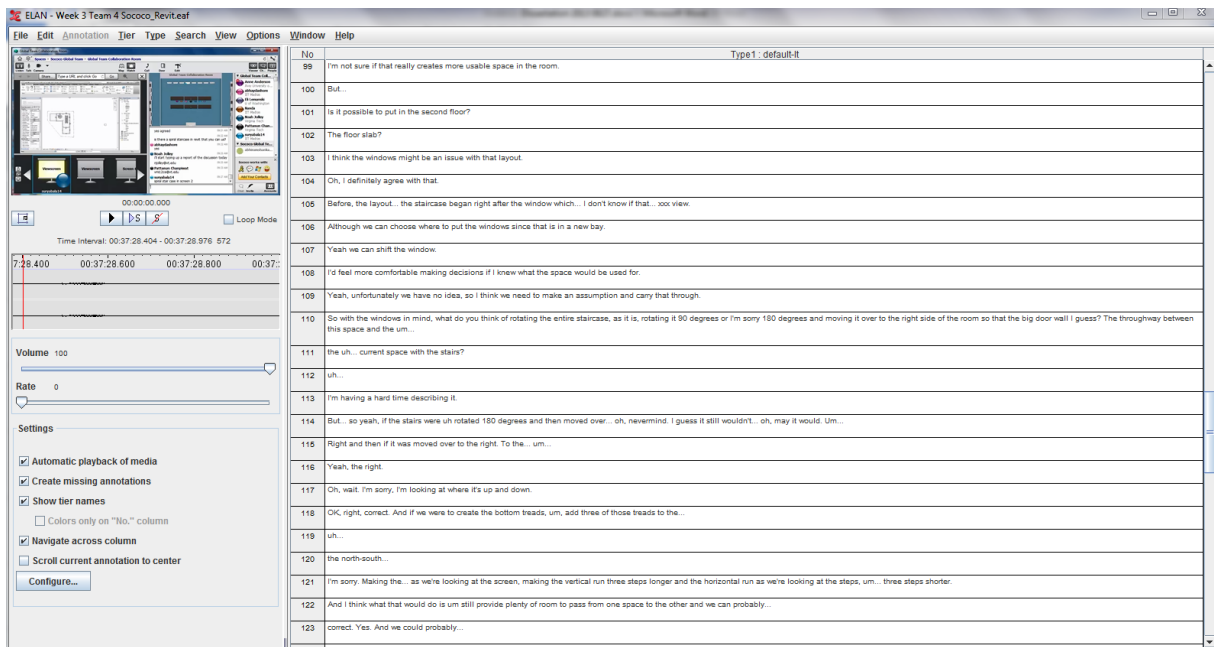


Figure 3-8. ELAN interface – transcription mode

### **3.3.3 Quantitative and Qualitative Coding**

Annotations and transcriptions from ELAN were exported in .csv format to Excel where data were quantified and coded. Text from the chat conversations were included in the annotations and analysis.

A mixed methods approach was used during the analysis phase. Some items, such as number of words needed to reach agreement about an issue, were counted while other items, such as what triggered discovery of an issue, were coded as themes and categories emerged.

A total of 37,564 words were exchanged in the week 3 meetings of all six teams which were transcribed and analyzed by a primary coder. Video from the meetings were used to contextualize the transcripts because avatar location and position as well as items shared by team members on a shared screen or team wall were critical components of the analysis.

In the initial round of analysis, a small portion of the data (30 minutes of Team 1 in the virtual world and 30 minutes of Team 2 in the screen-sharing environment) was coded for copresence, scale, cues and discovery as developed in the coding schema for the earlier 2012 industry study described earlier. After this initial round of coding, the schema was revisited and refined to narrow the scope of the analysis to discoveries. The scope was narrowed after determining that scale would be more critical for design whereas the focus of this study is construction coordination. The analysis in this dissertation is focused on instances of mutual discovery as described in section 2.3.1. Mutual discovery is an essential element of messy talk (Dossick et al., 2014) and an important part of the construction coordination process.

### **3.3.4 Discovery Definition and Analysis**

In this analysis, discovery is defined as finding something for the first time. If the discovery was acknowledged by a team member it was characterized as a mutual discovery.

Unacknowledged discoveries were disregarded in this analysis. The analysis focuses specifically on discovery of items that were added to the building model by the IITM students. Some examples include, “That staircase isn’t at the right elevation” and, “They added a balcony over here.” In meetings prior to week 3, students reviewed an existing building model given to each team at the beginning of the study and decided on a location for three new bays. The three new bays were then modeled by the IITM students on their own time and presented to the rest of the team in week 3. A participant could make a discovery in one of four ways: pointing out a new item (confirmation), finding an error in the model (error), finding a new item that is not an error but could or should be changed (suggestion) or pointing out an item that they are unclear whether or not it is new and asking others for verification (clarification). Examples of each are provided in the next chapter.

With the scope of analysis narrowed to acknowledged (mutual) discoveries, the next round of analysis identified discoveries made during the week 3 meetings and the verbal or nonverbal cues associated with those discoveries. Avatar locations and positions associated with discoveries were noted per the frame-by-frame analysis used in the ELAN phase. Noting avatar position and location in relation to discoveries added a layer to the analysis that is not typical in verbal analysis such as content analyses.

In a second pass, the entire week 3 meetings of Team 1 (virtual world) and Team 2 (screen-sharing software) were coded using the revised codes, then analyzed more thoroughly to determine patterns. After pattern codes were determined from this second round of analysis, the week 3 meetings of the remaining four teams were analyzed and pattern codes again revised. The annotation definitions were determined iteratively in a cycle of analysis and refinements as the

amount of data being analyzed expanded. The final iteration of annotation and coding schema (with operationalized definitions) is shown in Appendix C.

Each participant is identified with the initials of their schools followed by a numerical identifier per Table 3-3. Only participants of the week 3 meetings have been given identifiers for the purpose of this analysis. For example, Team 2 had six members present: one from the University of Washington (UW2), two from Virginia Tech (VT3 and VT4), two from the University of Twente (UT3 and UT4) and three from the Indian Institute of Technology-Madras (IITM4, IITM5, and IITM6). Note that because week 3 was a holiday for University of Twente per Table 3-3, fewer UT members were present in the meetings this week.

**Table 3-3.** *Participants present at each week 3 meeting, listed by their identifiers*

		Participants
3D Virtual World	Team 1	UW1, VT1, VT2, UT1, UT2, IITM1, IITM2, IITM3
	Team 3	UW3, VT5, VT6, IITM7, IITM8, IITM9
	Team 5	UW5, VT9, VT10, UT5, UT6, UT7, IITM13, IITM14, IITM15
Screen-sharing Platform	Team 2	UW2, VT3, VT4, UT3, UT4, IITM4, IITM5, IITM6
	Team 4	UW4, VT7, VT8, IITM10, IITM11, IITM12,
	Team 6	UW6, VT11, VT12, UT8, IITM16, IITM17, IITM18

Data were analyzed both quantitatively and qualitatively (Lindlof and Taylor, 2011). While quantitative analysis helps to identify patterns and trends, qualitative analysis helps to explain what they might mean (Boellstorff et al., 2012). The use of various data displays, shown in Chapter 4, were employed to identify patterns in the data (Miles and Huberman, 1994).

### 3.4 Reliability and Validity

Reliability concerns consistency of observations (Lindlof and Taylor, 2011). To be reliable, a process must be “reasonably stable over time and across researchers and methods” (Miles and Huberman, 1994). Reliability for this study was estimated using an inter-rater reliability test. A second rater independently coded interactions from Team 1 data using the videos and transcripts from week 3. Agreement between the original and second rater was 87%. In determining whether inter-rater reliability agreement is sufficient, there is no established rule but an absolute agreement of 75% is typically deemed minimum and 90% is considered high (Hartmann, 1977), therefore agreement between the two coders in this study is within acceptable values.

Validity concerns the truth value of findings and may be characterized by internal, external, or conceptual dimensions (Miles and Huberman, 1994; Lindlof and Taylor, 2011). “Validity is a property of knowledge, not methods. . . . To use an overly simplistic example, if someone claims to have nailed together two boards, we do not ask if their hammer is valid, but rather whether the two boards are now nailed together” (Shadish, 1995).

*Internal validity* requires careful construction and administration of the research instrument so it measures what it is intended to measure (Patton, 2002). To ensure internal validity, one should consider negative evidence and rival explanations to increase validity of one’s own claims. Potential threats to internal validity might involve, for example, changes to the research instrument or changes in the participants (Lindlof and Taylor, 2011). Internal validity for this study was increased by:

- Using an Ethnographic Observation Sheet (Appendix A) developed before data collection began that was designed to make note of instances of presence and copresence, communication tools used, etc.
- Video-recordings of the meetings allowed interactions to be reviewed as often as needed rather than relying on field notes from the original observation which would have been limited to what the researcher deemed was important at the time. This provided a much more comprehensive set of data to work with.

*External validity* permits findings to be generalizable, or transferable, to other contexts (Miles and Huberman, 1994; Lindlof and Taylor, 2011). Findings are transferable if outcomes described are generic enough to be apply to other settings and/or replication efforts could be conducted easily. A threat to external validity would be if the conditions of the experiment differ greatly from that which the researcher wishes to generalize (Lindlof and Taylor, 2011). One way to enhance validity is through triangulation, i.e. multiple methods of data collection. If the same findings are reached through multiple methods, the external validity is enhanced. In this study, several methods were used to collect data: video-recording, participant-observation notes taken with an observation sheet developed prior to the study, and collection of the before-and-after 3D models created by participants. The before-and-after models provided confirmation that models did have the same type and number of errors that were discovered by some teams and remained undiscovered by others.

*Conceptual validity* “involves measuring a phenomenon according to how a theory or construct has explained it” (Lindlof and Taylor, 2011, p. 273). “Findings gain power if they are

connected to theoretical networks beyond the immediate study” (Miles and Huberman, 1994, p. 279). Because proxemics in virtual worlds had been shown to exist in previous studies and was confirmed through observation in the earlier CyberGRID studies, one of the premises of the 2013 study was that social conventions carry over into the physical world. The indication was that the participants feel as though they are “really there” and therefore any actions taking place in the virtual world are just as real (to participants) as any actions in the physical world. Copresence is related to proxemics in that participants experience the feeling of being there in a virtual environment with others. Conceptual validity was further enhanced by using symbolic interactionism as detailed in Section 2.1.5 to describe and interpret the interactions as the team members reach a shared understanding about discoveries.

## Chapter 4

### Findings

This chapter presents findings of a research study designed to determine how team exploration of BIMs as avatars impacts BIM coordination. As described in the previous chapter, the week 3 meetings of a 10-week study were analyzed to determine how new building model items created by the IITM students were discovered and discussed by the whole team in a 3D virtual environment compared to teams using screen-sharing software. The activity around the discovery of issues in the model is detailed in this chapter. During the analysis phase, numerous data displays were created from the coded data in an effort to determine patterns and themes. The annotation and coding schema for each stage of analysis is listed in Appendix C.

*Table 4-1. Chapter 4 Contents*

- 4.1 Meeting Lengths and Number of Discoveries in Each Meeting**
- 4.2 Discovery Trigger**
- 4.3 Discovery Topic**
- 4.4 Discovery Category**
- 4.5 Voice vs. Chat Usage**
- 4.6 Length of Time and Number of Words to Reach Agreement**
- 4.7 Discovery Cues**
- 4.8 Timing of Discoveries and Discovery Rate**

#### **4.1 Meeting Lengths and Number of Discoveries in Each Meeting**

Six teams, each comprising nine students from four different universities, met once a week for ten weeks (Table 3-2) to complete a building design and construction planning project.

As described in Section 3.3.1, the week 3 meetings were used for analysis because this was the week that students were seeing the updated models for the first time. Their task during week 3 was to review the models to ensure the changes were as they discussed and agreed to in the previous meeting.

The meeting lengths in week 3 were roughly 1-to-2 hours in length with Team 4 having the shortest meeting time at 47 minutes and Team 5 having the longest at 1 hour 55 minutes. Team 1 had significantly more discoveries than the five other teams even though their meeting time was comparatively short. Team 1 also spent more time in their avatar-scaled model than the other two teams who worked in the 3D environment. Among all of the findings presented in this chapter, time spent in the model has the strongest correlation with number of discoveries.

**Table 4-2.** *Week 3 meeting lengths and discoveries*

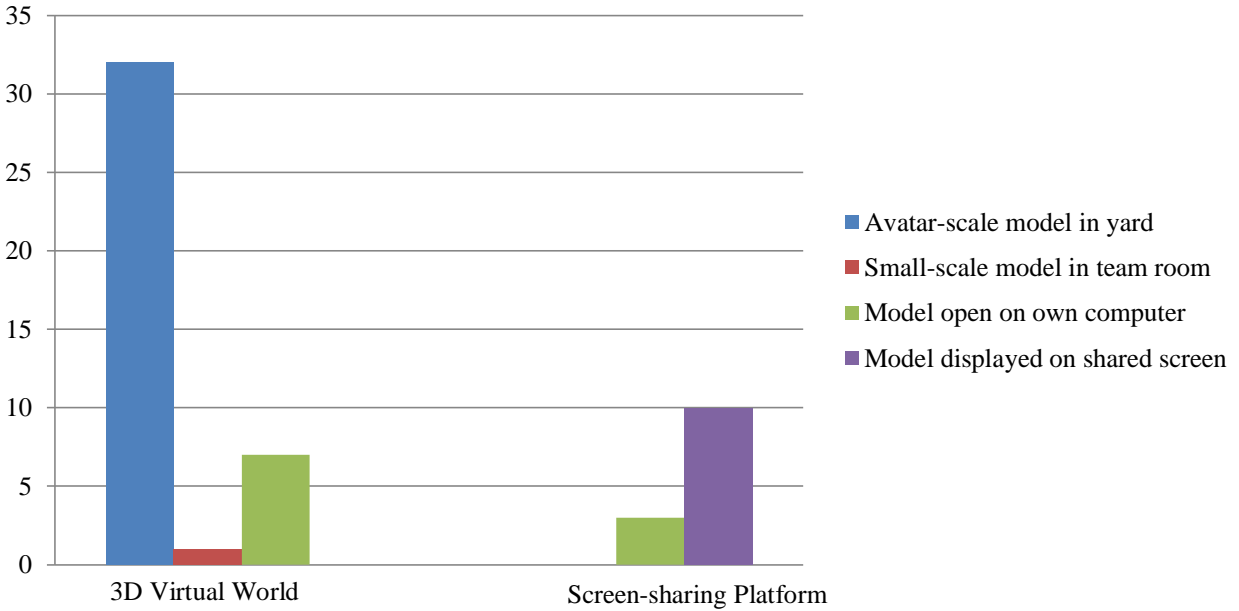
		Length of meeting (minutes)	Number of discoveries during the meeting
3D Virtual World	Team 1	84	28
	Team 3	106	6
	Team 5	115	6
Screen-sharing Platform	Team 2	92	6
	Team 4	47	5
	Team 6	107	1

#### 4.2 Discovery Trigger

The discovery trigger is defined as what the team members were viewing when the discovery was made. There were four ways for participants to view the building model in this study, and the trigger was coded as one of those four:

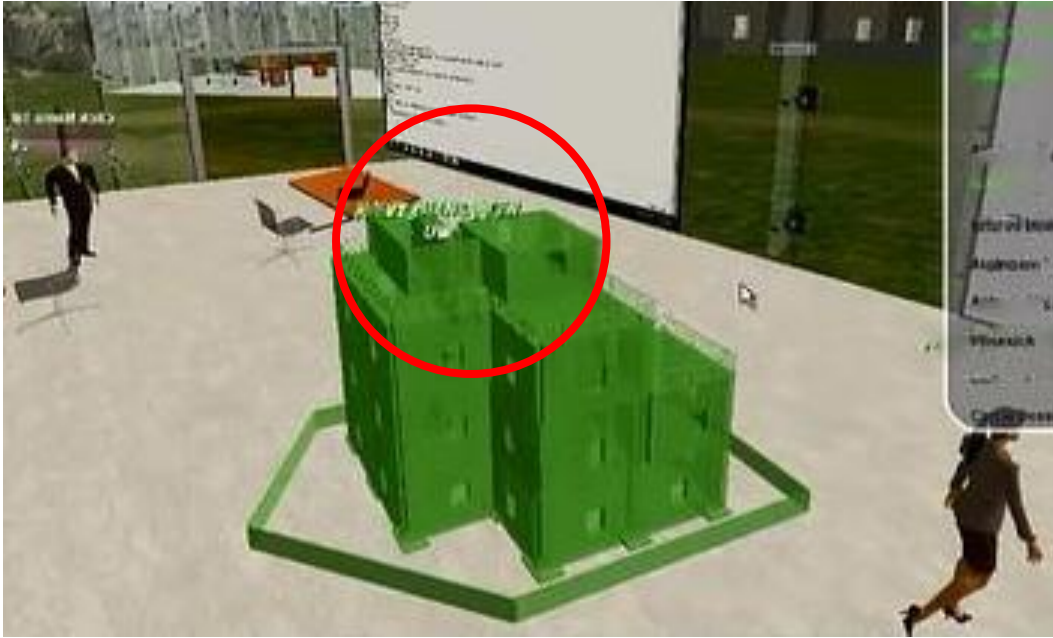
- (1) The avatar-scaled model in the yard outside the virtual team room – available in the 3D environment only. See Figure 3-2.
- (2) The small-scale model, roughly the same height as the avatar, in the virtual team room – available in the 3D environment only. See Figure 3-3.
- (3) Having the BIM software open on one’s own computer in the physical space, i.e. not screen-sharing. Available only at UW, UT, and IITM where the BIM software was installed on lab computers.
- (4) Viewing the model on a shared-screen, i.e. one team member has the model open on their desktop and is sharing their desktop with the rest of the team via screen-sharing software – available in both collaboration platforms. See Figures 3-3 (virtual world) and 3-5 (screen-sharing).

Figure 4-1 shows the triggers for all discoveries. For all three teams in the 3D environment, roughly 85% of the discoveries were made while walking through the avatar-scaled model. Participants had the freedom to structure the meeting as they chose and that included the freedom to decide which of the four different model viewing methods to use when exploring the model. Team 1, for example, structured their meeting by first exploring the avatar-scaled model located in the yard floor-by-floor as a group then returning to the virtual team room to discuss the issues they had seen in the model.



*Figure 4-1. Discovery triggers*

While the majority of items in the 3D virtual world were discovered in the avatar-scaled model, one discovery was triggered by the small-scale model in the team room. Team 3 had decided to conduct their meeting in the team room and not use the model in the yard, but then one participant saw something unusual in the small-scale model located in the team room – what appeared to be a narrow walkway (Figure 4-2). After seeing this he stated, “Hopefully a person can fit through that ... walkway. That’s the only thing. Let me go check, though.” He walked to the avatar-scaled model in the yard, followed by his teammates, where they decided the walkway was indeed too narrow. Once they entered the model, they found five more issues. Despite not originally intending to use the avatar-sized model, they spent seven minutes in the model and wound up discovering approximately one issue per minute.



*Figure 4-2. Discovery triggered by the small-scale model.  
One participant sees a walkway that looks too narrow.*

### **4.3 Discovery Topic**

Because it was the current viewpoint that triggered the discovery, it was expected that discoveries occurring in media that allowed dynamic and independent views would be more varied than those where the view is static and controlled by one person. This turned out to be the case as shown in Figure 4-3. On one extreme, Teams 1, 3, and 5 (all three virtual world teams) encountered a wide variety of coordination items. On the other extreme, Team 4 (a screen-sharing team) only had discoveries pertaining to a staircase in one of the new bays. This is because an IITM student was modeling that set of stairs on a shared screen while the others watched – i.e. the only shared visualization throughout the meeting was the staircase (see Figure 4-4).

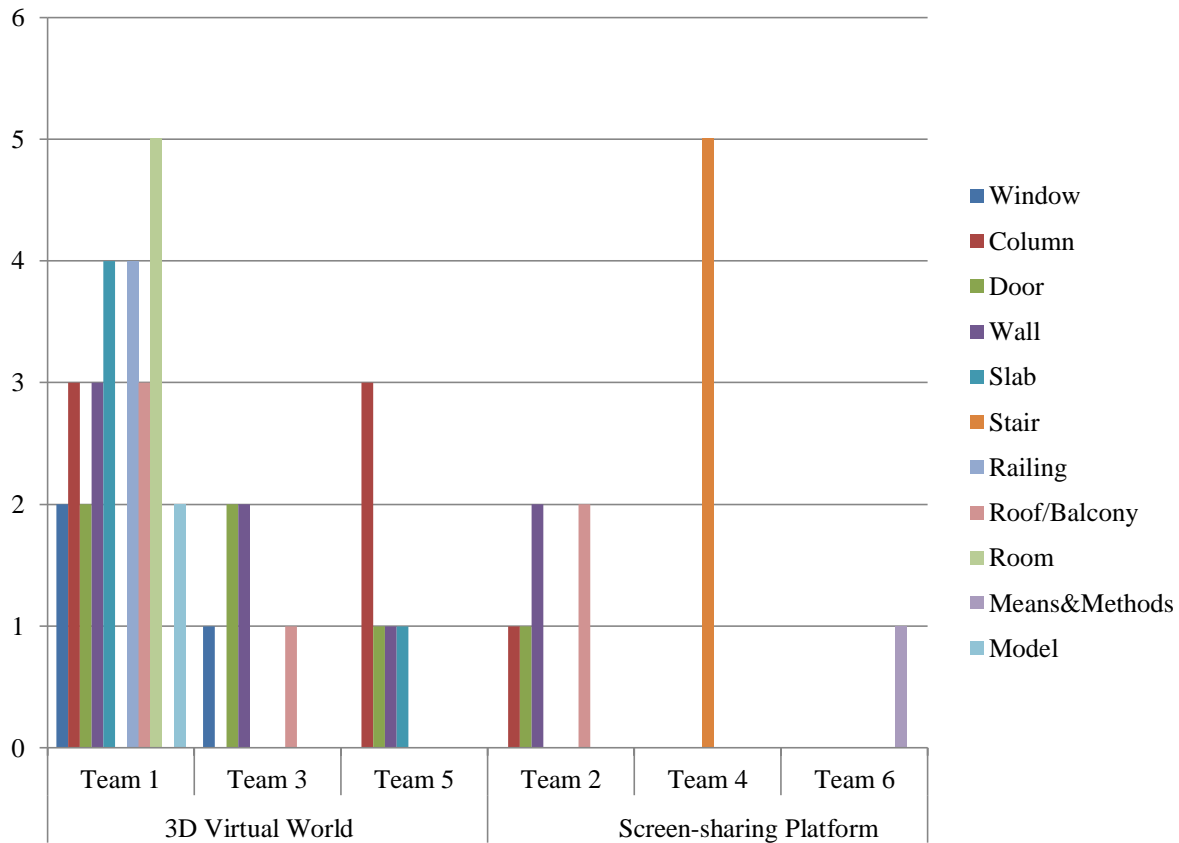


Figure 4-3. Discovery topics

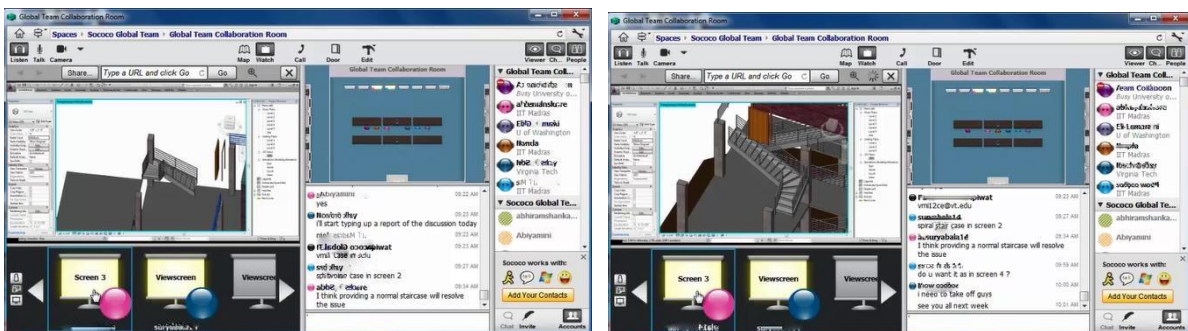


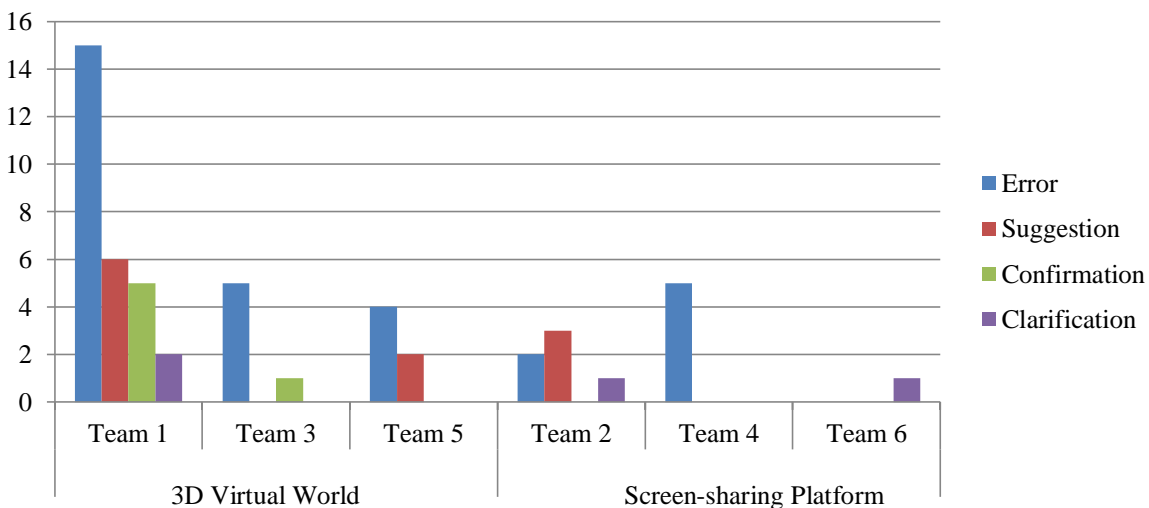
Figure 4-4. Team 4 observing as IITM models stairs to the new addition on the roof

#### 4.4 Discovery Category

Discoveries were categorized as an error, suggestion, confirmation, or clarification. The breakdown of discovery category for each team is shown in Figure 4-5. Some examples of discoveries and their categories are:

- “That staircase isn’t at the right elevation” [Error]
- “Do we really need that outside walkway because it doesn’t really go anywhere” [Suggestion]
- “They added a balcony over here” [Confirmation]
- After seeing new patios: “How many patios should we have?” [Clarification]

Most of the discoveries were errors followed by items that were suggestions for improvement. As an example, the statement above “Do we really that outside walkway...” is not an error in the model, but rather a suggestion for improvement in the design. Note that Team 6 did not find any errors or have suggestions. Rather the team observed as IITM modeled in real time and upon completion, when asked by IITM if the additions looked good, the responses were “Yeah, perfect,” “Good, good,” and “Looks pretty good.”



*Figure 4-5. Discovery Categories*

#### 4.5 Voice vs. Chat Usage

The teams had several communication tools available to them and Table 4-3 lists the tools they chose to use in week 3. One complicating factor in this study was that the IITM students were unable to access the 3D environment due to limitations in connectivity. Each of the three virtual world teams set up an online chat forum (requiring one team member to invite all other team members and participant observers) at the beginning of the meeting so all team members would have immediate communicational access to each other. Each of the 3D teams (Team 1, Team 3, and Team 5) approached the chat communication differently. The differences are illustrated in Figure 4-6 where the number of words used in voice communication are plotted adjacent to number of words used in text chat communication for the 3D teams. Based on the comparison of voice vs. chat used, the teams are characterized as using voice and chat in comparative levels that are high, medium or low. This is described in the following paragraphs.

**Table 4-3. Communication tools used in week 3 meetings**

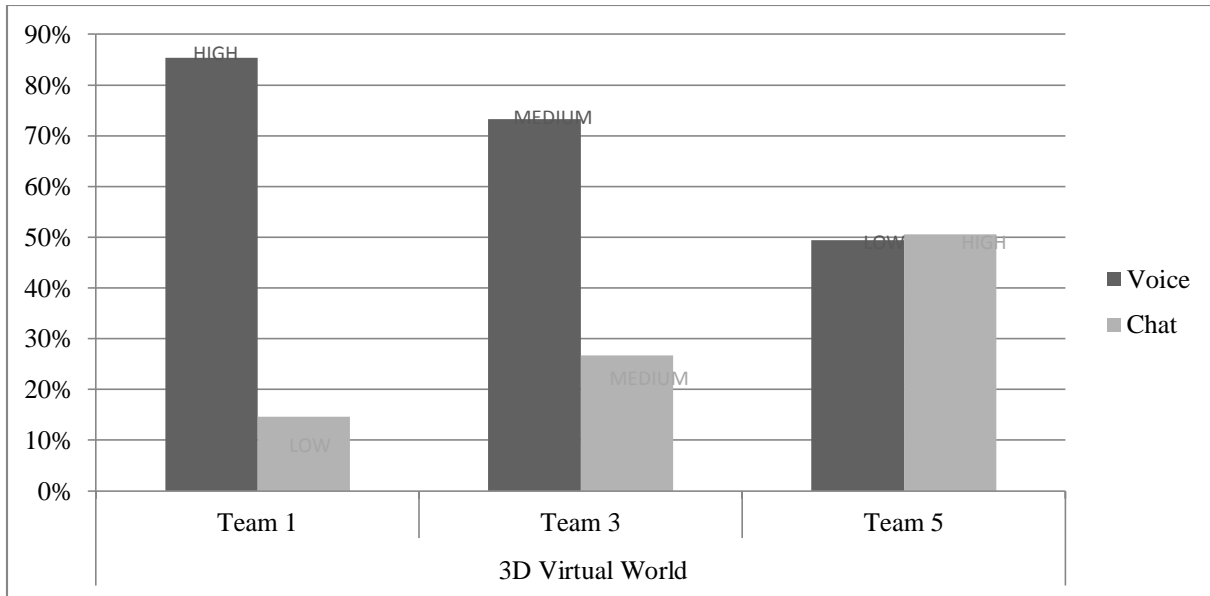
		Voice	Text chat	Google Doc with text chat capabilities	Shared screen	Pens on shared screen	Gesture bubbles	Avatar location and position	Dropbox	E-mail
3D Virtual World	Team 1	✓	✓	✓	✓	✓	✓	✓	✓	
	Team 3	✓	✓		✓	✓		✓		✓
	Team 5	✓	✓		✓		✓	✓	✓	
Screen-sharing Platform	Team 2	✓	✓		✓				✓	
	Team 4	✓	✓		✓					
	Team 6	✓	✓		✓				✓	

**Team 1: High voice; Low chat.** Team 1 chose to ignore the chat as they explored the model in the 3D environment using primarily voice to communicate with each other. Only six text chats were exchanged while they explored the model. IITM asked via chat what they thought about the model and a VT team member responded via chat, saying they were “going through it now.” As they explored, they took notes using a Google Doc to which the IITM group had access. Team 1’s exploration of the model was very efficient, and after walking through the model for 25 minutes, managed to discover 22 items -- nearly one per minute.

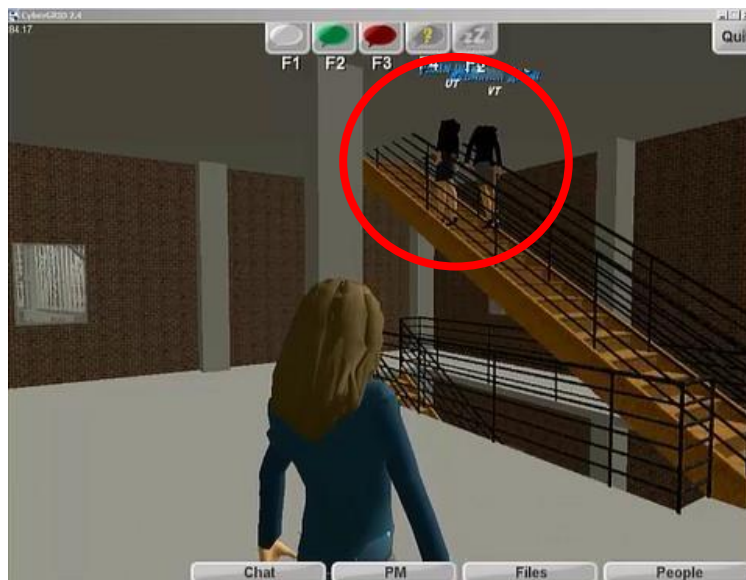
**Team 3: Medium voice; Medium chat.** Team 3 engaged with the IITM team using chat throughout the meeting but they were simultaneously engaged with each other in the virtual world. UT members were not present due to a holiday, but UW and VT members would typically have a short discussion in the virtual world then share their thoughts with the IITM students using chat. They only spent seven minutes in the model, but during those seven minutes recorded five discoveries -- nearly one per minute. Even though they had significantly fewer discoveries than Team 1, their discovery rate in the model was nearly the same and quite efficient.

**Team 5: Low voice; High Chat.** Team 5 chose to communicate with their teammates through chat. One team 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 conducted most of their subsequent communication through chat unless something warranted using voice, which happened few times. In addition, this team was only able to access one of the three new bays due

to a missing opening in the 3<sup>rd</sup> level slab (Figure 4-7). They entered the 3D model 36 minutes into the meeting and spent the remainder of the meeting in the 3D model for a total of 75 minutes in the model, but most of that time was not spent “in” their avatars. Rather, their avatars were standing in the model, unoccupied, as they communicated with each other via chat.



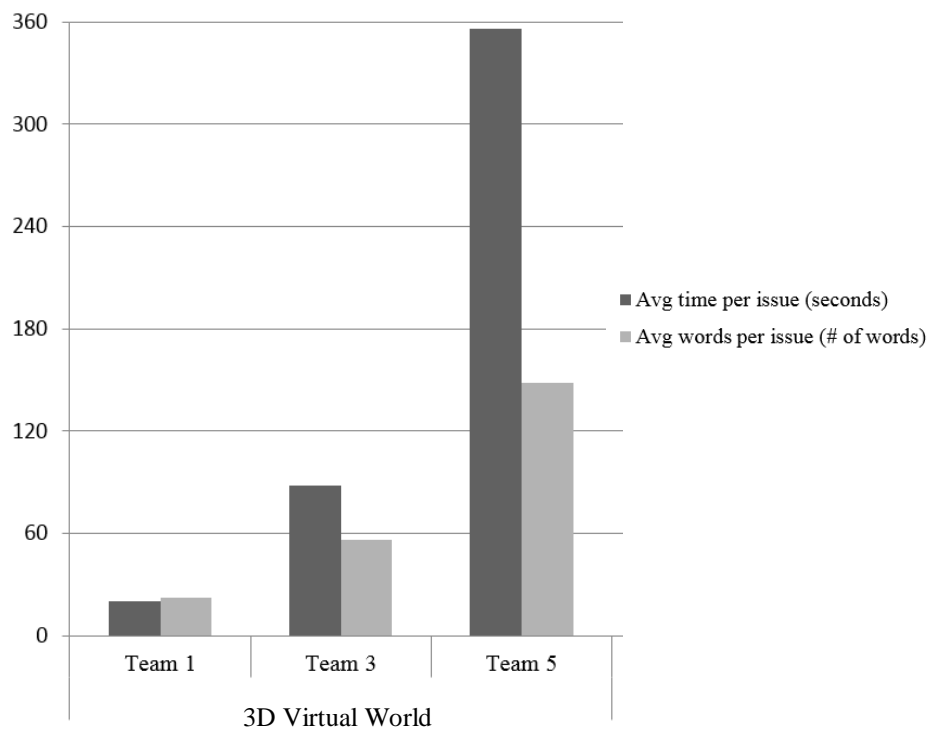
**Figure 4-6.** Verbal communication during meetings: Voice vs. Chat (based on word count)



**Figure 4-7.** Team 5 unable to access the model above the 2<sup>nd</sup> floor.

#### 4.6 Length of Time and Number of Words to Reach Agreement

Figure 4-8 shows the average length of time (in seconds) and number of words needed to bring an item to the attention of others and have it acknowledged as a discovery. Discoveries that were unacknowledged were not included in the averages. The trends in this figure appear similar to the chat use trend. That is, the more a team used chat, the less efficient they were at communicating discoveries. Team 5 had the highest chat usage followed by Team 3 and, as shown in this figure, Team 5 has the least efficient discovery communication followed by Team 3.



**Figure 4-8.** Average length of time and number of words needed to reach understanding about an issue.

## 4.7 Discovery Cues

The discovery cue is the method used to communicate discoveries to others. The discoveries were coded for locational, deictic only, and verbal descriptive cues. These three types of cues are defined as follows:

***Locational:*** a 3D cue that is based on location in the environment. When an avatar uses a locational cue, it might be a reference to where the avatar is standing or what the avatar is facing. There is a deictic component to a locational cue which is why the second category is “deictic only.”

***Deictic only:*** a referent is indicated by words such as “this” or “here,” often accompanied by pointing or other nonverbal cues (Hanks, 2009), and can be used in either the virtual world or screen-sharing scenario.

***Verbal descriptive:*** an item is described using references such as grid lines, cardinal directions or building levels.

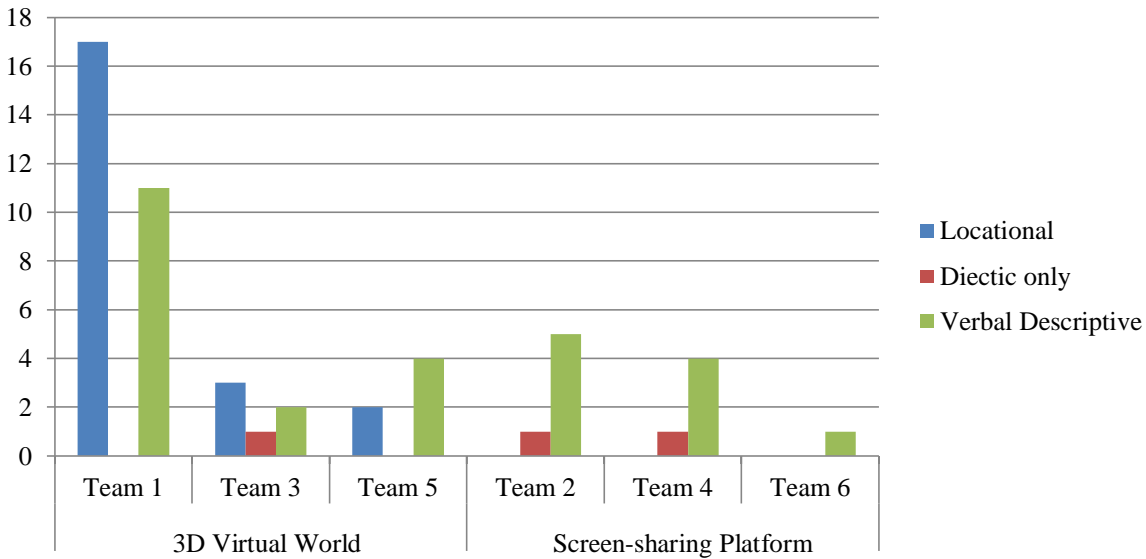
Examples of each are shown in Table 4-4. Figure 4-9 shows an example of a locational cue from Team 1 and Figure 4-10 shows the breakdown of discovery cues for each team. The majority of verbal descriptive cues occur when a member has the BIM software open on their own computer and is describing what they see in the model.

**Table 4-4. Discovery cue examples**

Cue	Definition	3D Virtual World example	Screen-sharing example
Locational	Based on location in the environment	“Some of the windows are correct but the one I’m standing at now doesn’t seem right.”	N/A
Deictic only	Referent indicated by words such as “this” or “here”	“Hopefully a person can fit through that ... walkway.” (UW3 was in the team room looking at the small model.)	“We should have columns here in the corners.” (UW2 highlighted the corners on his shared screen.)
Verbal Descriptive	Referent indicated by descriptive phrases	“The door going onto the third floor is not lined up correctly.”	“The floors on top that will form the new patios will need to be thicker to accommodate the terrace on top of the roof.”



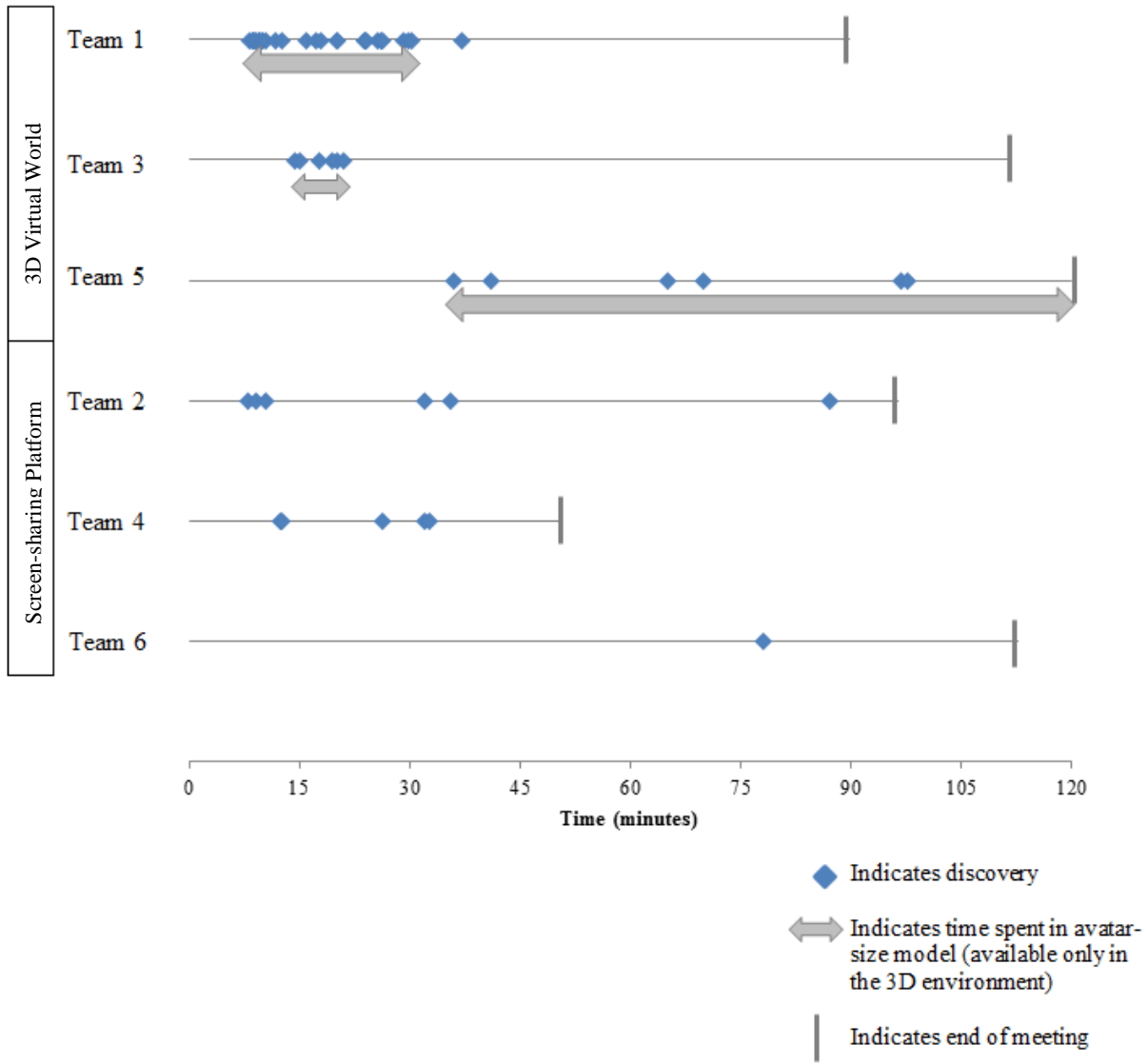
**Figure 4-9. Locational cue:** In frame one, UT1 states, “Some of the windows are correct, but the one I’m standing at now doesn’t seem right.” The following frames show his teammates moving to the window. They agree that the glazing is on the wrong side (Anderson et al., 2013).



*Figure 4-10. Discovery cues*

#### 4.8 Timing of Discoveries and Discovery Rate

Figure 4-11 shows the timing of discoveries throughout each meeting. For the teams in the 3D environment, there is a gray arrow in the figure indicating when and for how long teams were in the avatar-scaled model in the yard. Time spent in the model by Teams 1 and 3 was strikingly productive regarding discovery of new items compared to Team 5. Recall from Section 4.1.5 and Figure 4-6 that Teams 1 and 3 communicated primarily using voice while Team 5’s voice and chat communication, based on word count, were roughly equal. For Team 5, five out of their six discoveries were triggered by visualization in the avatar-scaled model, but only two were mentioned using voice in the 3D virtual world and the rest of the discoveries were communicated exclusively in chat. Team 5’s discovery pattern more closely resembles the screen-sharing teams (Teams 2, 4, and 6).



**Figure 4-11** Timing of discoveries

Table 4-5 shows how much time each team spent in the model and the discovery rate of the overall meeting (number of discoveries divided by meeting time) as well as discovery rate while in the avatar-scaled model (number of discoveries made in the model divided by time in the model). This reinforces the earlier observation that model exploration is effective for finding discoveries quickly in the 3D virtual world. It must be emphasized that all of Team 4’s discoveries pertained to *one* set of stairs whereas Team 1’s discoveries covered nine different

building elements throughout the building. Even though Team 1 and Team 4 have nearly the rate of discovery, the variety of discoveries is considerably diminished in Team 4. Team 1's discoveries were qualitatively superior.

**Table 4-5. Comparison of overall number and rate of discoveries**

		Length of meeting (minutes)	Time spent in 3D model (minutes)	Number of discoveries made in model	Discovery rate overall (#discoveries per minute)	Discovery rate <i>in model</i> (#discoveries per minute)
3D Virtual World	Team 1	84	25	22	0.33	0.88
	Team 3	106	7	5	0.06	0.71
	Team 5	115	75	5	0.04	0.07
Screen-sharing	Team 2	92	N/A	N/A	0.08	N/A
	Team 4	47	N/A	N/A	0.25	N/A
	Team 6	107	N/A	N/A	0.00	N/A

## Chapter 5

### Discussion

The findings from this study indicate that autonomous navigation in the 3D virtual world provided quantitatively and qualitatively better outcomes than single viewpoint navigation for the discovery of coordination issues in the 3D building model. Specifically, the use of single viewpoint navigation (screen-sharing) resulted in the discovery of issues that were narrower in scope, limited to certain areas of the model, and discoveries tended to be drawn out over a longer period of time. The use of autonomous navigation (in the 3D virtual world) resulted in discoveries that were more varied and happened at a faster rate when “walking through” the avatar-sized model. Therefore, collaboration media choice can impact productivity when working with building information models. The shared visualization, additional communication affordances in the 3D environment, and being present with others in the model (i.e. copresence) all appeared to contribute to more efficient and effective coordination with the model. Three constructs – visualization, communication and copresence – emerged from the data from which propositions were developed.

#### *Table 5-1. Chapter 5 Contents*

### **5.1 Constructs and Propositions**

- 5.1.1 Visualization
- 5.1.2 Communication
- 5.1.3 Copresence

### **5.2 Summary**

## 5.1 Constructs and Propositions

### 5.1.1 Visualization

Several concepts from the findings contribute to visualization as they relate to the unit of analysis, discoveries. Those concepts are: Discovery Trigger (Section 4.2), Discovery Topic (Section 4.3), and Discovery Category (Section 4.4).

Visualization was the primary trigger for discoveries. Participants only discovered items that were within their view. The avatar-sized 3D model in the virtual world triggered far more discoveries than all other methods available for viewing the model combined. The other methods available to participants for viewing the model were: small-scale model in the team room, model open on one's own computer, and model displayed on a shared screen.

Viewing the model in the virtual world also resulted in a greater *variety* of discoveries in more varied areas of the model. More elements in more locations such as windows, doors, and railings were discussed in the virtual world than in the meetings in which only screen-sharing software was used. When individuals controlled their own viewpoint, as they did in the 3D environment, the resulting views were dynamic and varied. When one “walks” in any 3D environment (virtual or real), the default view is one that is dynamic and varied if one is moving. With multiple viewpoints exposed while walking, more potential issues were within view of the participants. All of these various viewpoints enabled issues to be made known that may otherwise have remained undiscovered if not directly viewed. When issues were viewed and discovered with the team, the shared visualization provided context for discussion and communication affordances in the 3D virtual environment provide immediacy of feedback necessary for communicating the issue. Being able to independently navigate a model allows each participant to see critical items. Those trained in certain disciplines will focus on items

related to their own knowledge domain as they walk through the model and thus be able to identify more of those particular items, bringing them to the attention of others. If a single navigator were in control of the viewpoints, providing a more general walkthrough, this person would need a thorough knowledge of all disciplines involved otherwise items could be missed.

The increased variety indicates that the dynamic viewpoints experienced when using autonomous navigation will produce BIM coordination meetings with improved outcomes, whereas in the screen-sharing scenario, items in need of discovery might be missed. Using Team 4 (a screen-sharing team) as an example, they discovered four items in their model during the week 3 meeting that was analyzed for this study. Discovering four items is better than discovering zero, but when considering all four discoveries pertained to one stair case, the lack of discovery variety is emphasized. Their common viewpoint during the entire meeting was focused on the stairs while the remaining portions of the model had numerous issues and errors that remained undiscovered. The result was a coordination meeting with a low quality outcome.

An additional benefit that autonomous navigation in the 3D environment provides is engagement. In the screen-sharing teams in which one person was controlling navigation of the model, it was easy for other team members to tune out which may have resulted in missing critical issues. In a 3D virtual world, it becomes apparent who is not focused on a meeting when an avatar is immobile. With the exception of all objects being virtual, the scenario of “walking through” an avatar-sized model is quite similar to a walkthrough of an existing structure with the team. The advantage in this case is that the structure is still virtual and issues can be resolved in the coordination/pre-construction phase.

Finally, there was a greater variety of discovery *categories* in the 3D environments – i.e. errors, suggestions, confirmation or clarifications. With the screen-sharing software, where the

viewpoints tended to be stagnant, there were fewer viewpoints about which team members could make comments. With autonomous navigation where more eyes are viewing more areas of the model, a clarification question, for example, could lead to discovery of an error in the model. The early detection of errors is critical for teams who are reviewing models for coordination.

***Proposition 1.*** Dynamic viewpoints of the 3D model exposes participants to more viewpoints which allows a greater variety of model elements with issues to be seen and be discovered as well as a greater variety of discovery categories. This contributes to an increased quantity and quality of issues discovered earlier in the building information model.

### **5.1.2 Communication**

Several concepts from the findings contribute to communication as they relate to the unit of analysis, discoveries. Those concepts are: Voice vs. Chat Usage (Section 4.5), Length of Time and Number of Words to Reach Agreement (Section 4.6), and Discovery Cues (Section 4.7).

The use of available communication tools varied among the teams. Comparing the voiceto-chatchat usage among the three virtual world teams to the number of discoveries made by those teams indicates that teams who favored voice over chat were more efficient. This seems intuitive considering the act of typing takes more time than speaking, but voice and chat were measured in two ways: time and number of words. Even when time was not considered, only number of words, favoring chat over voice reduced team performance. In other words, choice of communication tool had a significant impact on team performance.

Virtual worlds provide multiple channels needed for effective communication. In this study, it was found that using voice in combination with the avatar-sized 3D model in the yard

(with avatar location and position) was the most effective way to locate and communicate discoveries. Using the model alone was not a predictor of effective communication because Team 5, who communicated more with chat than voice was the least effective team even though they did use the model to some degree.

Nonverbal communication can take many forms. When sharing screens, for example, a pointer may be used to reference a particular window. But the nonverbal communication of the avatar, where the window that an avatar is facing is the one being referenced, simulates communication that humans have been using for much longer than we've been using computers. Because social norms carry over from the physical world into the virtual world, as discussed in Chapter 2, there is a more immediate understanding of which window one is referencing when one is standing in front of it. Fewer words were needed to communicate issues due to less encoding and decoding required to reference an item when using both voice and position of the avatar. Participants were able to contextualize the discovery based on where they were standing in the model.

The highest performing team, Team 1, walked through the model systematically and used voice and avatar position to indicate discoveries. Staying in close proximity allowed others to see what was being referenced. As a counter-example, one team member ran ahead of the others to a higher floor and the discoveries made by that team member were unacknowledged by other team members. Shared understanding is not established if others cannot see what is being referenced (unless verbal descriptions were used). As a result, there was a redundancy of work in this team with many of the discoveries being made twice. The unacknowledged discoveries were not included in the discovery measurement or subsequent analysis. Reaching a shared understanding quickly is one factor needed to increase efficiency as it relates to communication. Using the logic

of symbolic interactionism (Blumer, 1969), an equation for shared understanding in the 3D environment would look something like this: *Object (model item) + person (who gives meaning to object) + second person who gives meaning to first person's position in relation to the model = shared understanding.*

The type of discovery cue used also appeared to impact team performance. Three types of cues used by the participants in this study to draw attention to model items were avatar location, deictic only, and verbal descriptive (described further in section 4.7). Nonverbal locational cues provided by the avatar in the 3D environment provided a greater efficiency in communication than the other cue types. That is, the location and positions of the avatar in the 3D model provided a cue for other team members regarding what was being discussed which reduced the verbiage needed to refer to that item. Increased locational cues were correlated to a reduced number of *words* needed to reach agreement and less *time* needed to reach agreement. An additional factor in this study was differences in terminology due to the multi-cultural backgrounds of the global team participants. There were several instances where terminology confusion in the 2D environment protracted the discussion. For example, there was a misunderstanding about which floor was the second floor (this occurred when one participant asked about a door on the second floor). In the U.S., the second floor is located above the ground floor, but elsewhere the second floor is located above the first floor which is, in turn, located above the ground floor. What we call the second floor in the U.S. is located one floor lower than in other countries. Perhaps if the team had been able to stand in the 3D model at that particular door, they would have reached an understanding sooner.

**Proposition 2a.** When the chat-to-voice ratio is high, more words and more time are required to find and agree about issues discovered in the model. This contributes to less efficient coordination with building information models.

**Proposition 2b.** Nonverbal cues provided by avatar location and position allows fewer words and less time to be spent finding and agreeing upon discoveries in the model. This contributes to more efficient coordination with building information models.

### 5.1.3 Copresence

One of the most salient findings was how the pattern of discovery differed in the virtual world differed from that in the screen-sharing teams as indicated by Figure 4-11. Also drawing from the two previous constructs, visualization and communication, teams that used the avatar-sized 3D models in the virtual world discovered and communicated issues at a higher rate than those teams that did not. In the screen-sharing scenario, the viewpoint was controlled by one person (the one sharing their own desktop) and fewer discoveries were made over a comparable time frame. If a goal is to quickly find issues in a 3D model, the apparent solution is to view the 3D model with the team in the virtual world (i.e. be copresent with the team in the model).

Among all of the findings presented in the last chapter, *time spent in the model with the team* has the strongest correlation with discovery efficiency. The participants were not asked to perform the task of finding items *quickly*, in fact they were given 2.5 hours to complete the task if needed. But as teams moved through the model together, there seemed to be a new issue

around every corner. Mutual discovery was facilitated by the presence of their team members in the model.

The following two examples are given to illustrate how effective the avatar-sized model was for discovering issues. Team 1 chose to systematically explore the model, and found 22 items during the 25 minutes they spent in the model. The high number of discoveries is not surprising considering how much time they spent in the model and how they explored the model room by room, floor by floor. Team 3, on the other hand, appeared to be content discussing the model in the team room. It was only when one member, viewing the small-scale model in the team room, observed a narrow hallway and wondered if a person could fit through it. He told the others he intended to investigate by walking out to the avatar-sized model in the yard to get a feel for the scale. His teammates followed and during the seven minutes they were in the model, found five more issues (in addition to the narrow hallway of concern). If the team member curious about the narrow hallway had, instead, opened the model on his own computer to check the dimension of the hallway width, it's questionable whether the team would have discovered the additional issues they encountered while walking through the model together.







***Proposition 3.*** Being copresent the team in the avatar-sized model (i.e. in the proximity of the issues/objects) while using voice results in a higher rate of issue discovery. This contributes to more efficient coordination with building information models.

## **5.2 Summary**

The findings indicate that efficient and effective discovery of issues in a model is a dynamic activity that requires copresence with the team in the model. Autonomous navigation

affords the multiple viewpoints and engagement needed to successfully find a varied set of issues quickly. The most successful communication method was voice combined with avatar nonverbal cues in the BIM, which resembles face-to-face communication more so than text communication such as e-mail. The constructs described in this chapter and the associated outcomes are shown in Table 5-2.

**Table 5-2. Constructs and Outcomes**

<b>Construct</b>	<b>Implementation</b>		<b>Outcome</b>
#1 Visualization (dynamic, static)	Dynamic viewpoints associated with autonomous navigation		Increased quality of discoveries
	Static viewpoints associated with single viewpoint navigation		Decreased quality of discoveries
#2 Communication (avatar nonverbal, voice, text chat)	Model + high voice usage + low chat usage		More efficient communication
	Model + low voice usage + high chat usage		Less efficient communication
#3 Copresence (with each other in the model)	Team in 3D model		Discovered issues at a rate of approximately one per minute
	Team sharing model on screen		Discovered issues at a rate of approximately one per ten minutes

As illustrated in Figure 1-2, building information modeling has multiple uses throughout the lifecycle of a building and there are many tasks associated with the use of BIM. One of those tasks is coordinating construction activities and locating/coordinating trades' items in the model. Because time is critical in any construction schedule, using a method of coordination that is efficient and effective is desirable. If the goal is to find a wide variety of coordination issues quickly when using BIM, coordination outcomes will be improved if the model is imported into

a virtual world and explored by the team as compared to the current method used in BIM coordination meetings of projecting the model onto a shared screen.

## Chapter 6

### Conclusion

The goal of this study was to compare efficiency and effectiveness of coordination efforts when participants reviewed building information models using two different collaboration platforms: one, a 3D virtual world into which the BIM could be imported and explored by the team and the other, a collaboration platform in which models were viewed by the team on shared screens. The screen-sharing platform represents current BIM coordination practices and the virtual world is being examined as a potential way to engage a project team for improved collaboration outcomes.

In the virtual world, each user has autonomous control of their viewpoint and is able to use voice communication with other team members. The question was how collaboration performance was affected when individuals were present *with* others (visually and aurally) *in* the 3D model. Findings indicate that the virtual world in which participants used autonomous navigation provided quantitatively and qualitatively better outcomes as opposed to the screen-sharing platform where the viewpoint was passive and controlled by one person. In the virtual world, a greater variety of issues were discovered at a higher rate.

#### *Table 6-1. Chapter 6 Contents*

- 6.1 Limitations**
- 6.2 Potential Impact on the Industry**
- 6.3 Future Studies**

Visualizations are critical for finding coordination items. The visualizations when walking through the model made explicit what was unknown. Participants found items that may have remained undiscovered if not for the multiple viewpoints afforded by autonomous navigation. The ability to communicate with voice and avatar location and position made the communication more natural. Less encoding and decoding was required to communicate messages about issue discoveries to teammates. Additionally, 3D environments are ideal for communicating spatial information. Copresence contributed to more efficient and effective communication because the teams felt they were there together, facilitating deictic references when using voice to communicate. Importing models into a virtual world to be explored with the team as avatars is *the best way* to view the model during coordination.

## **6.1 Limitations**

This study was conducted in university labs with architecture, engineering and construction management students as participants. The lab provided a quiet atmosphere where students could focus on the project task. There were few, if any, distractions while in the space. This allowed researchers to focus on the interactions among the team members assigned to the task. As a contrast, in the 2012 industry study, the participants were situated in the project trailer on an active construction site. Interruptions by people who were not participating in the study were constant. On the one hand, the lab atmosphere allowed researchers to precisely measure the dependent variables such as number of words needed to reach agreement. On the other hand, the research may be limited if the intent is to deploy virtual worlds on a project site if the site is not an appropriate place for this new technology. With the knowledge that the media (virtual worlds) has been appropriately matched to the task (finding coordination issues more efficiently and

effectively), a future step would be to determine how to tailor the technology and develop a BIM/virtual worlds workflow for project sites.

When students, rather than industry professionals, are participants in studies, the question is raised regarding how the inexperience of the students affected the study results. In this study, the IITM students were just beginning to learn the BIM software. In this particular case, their relative inexperience with the BIM software helped create issues and errors in the model that were available to be discovered by their teammates.

## **6.2 Potential Impact on the Industry**

Now that that majority of contractors are engaging with BIM, attention must be focused on how to get the maximum benefit from BIM. Maximum benefit occurs when the medium is matched to the task (Fox et al., 2010). The task is finding coordination issues and the medium with which to accomplish that task is a virtual world because the perspective of the model and interaction with the model and with each other produces more positive outcomes in coordination. The dynamic viewpoints afforded by autonomous navigation allowed more items to be seen and, since all discoveries were triggered by visualizations that were within immediate view, more discoveries were made when “walking around” the avatar-sized 3D model. This has exciting implications for the industry. If the goal of a coordination meeting is to quickly find as many issues as possible in a consolidated 3D model, the ideal way to accomplish that task would be to have the team “walk around” the model in a virtual world. This implies the industry must consider changing the way the models are viewed in coordination meetings. Current practice brings numerous disciplines and stakeholders into the same room where a consolidated model that is being used for coordination is shared on a screen, viewed passively by all except the

navigator. It would benefit all parties on a project if the participants in these meetings could be actively engaged with the model and with each other.

Virtual worlds are well-suited to the construction industry for several reasons. One being that teams are often globally distributed, and meeting in a virtual world where people sense they are with others (copresence) increases team cohesion. Virtual worlds also alleviate the concern that those who are not proficient with BIM software must rely on a “BIM Specialist” to view the model. In a virtual world, navigation through a virtual building model only requires the use of arrow keys on a keyboard and does not require expertise with BIM software.

### **6.3 Future Studies**

A next step in this study would be to examine the effect of individuals versus team interaction with a model in the virtual world. It would be interesting to pre-load a model with specific errors to see how team interaction differs from individual interaction when discovering items in a model that had been imported into a virtual world. Additionally, interviews would be valuable to determine the participants’ perspective and increase validity of the findings.

There are numerous emerging technologies that could accomplish the goal of improved outcomes when using BIMs for coordination. In addition to 3D desktop virtual worlds, there are networked CAVEs and virtual reality goggles (like the Oculus Rift) that provide similar – though not identical – affordances. Effectiveness of those and other emerging technologies could be examined in future studies. Additional items to be explored in future studies include:

*Streamlining the import of 3D models into the 3D environment.* Interoperability between software platforms has been, and is still, a challenge. To be included in a productive workflow, the transfer of models from the BIM software into a 3D environment must be viable in today’s

fast-paced construction setting and workflow. There are several technologies under development, such as Fuzor, that allow two-way communication between a user in a virtual world and BIM software. The challenge now is to create software where the team can interact with each other in the model in addition to being able to interact with the model itself.

*Incorporating 3D environments into current industry practice.* One of the findings from the 2012 industry study was that it was difficult for participants to be simultaneously attentive to the 3D virtual environment and their physical surroundings. Before the technology can be adopted, it must be determined how it could be incorporated into industry practice. It would be an interesting challenge to develop a workflow that applies appropriate media to tasks involving BIM during the preconstruction and construction phases.

*Full immersion vs. semi-immersion.* Studies have shown that when a team meets in a virtual environment with one participant fully immersed and the others using a desktop virtual environment, the fully-immersed participant emerges as leader, even though the same participant does not emerge as leader in a face-to-face setting (Slater et al., 2000). A research design comparing fully-immersed teams in a BIM (using, for example, Oculus Rift VR Goggles) to semi-immersed teams using desktop 3D virtual worlds when coordination with BIMs might produce useful findings.

*And finally, would a persistent 3D environment be advantageous?* That is, a virtual world that was available all of the time, not just during walkthroughs. Autodesk has launched a BIM 360 suite in which all model information is stored in the cloud making it accessible at any time by any member of the team with permission. How would the industry benefit if this were a 3D virtual world in which members of the team could explore the avatar-sized model at any time?

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## Appendix A

### Ethnographic Observation Sheets

#### Spring 2013 CyberGRID Ethnographic Observation Sheet

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**Date:** \_\_\_\_\_ **Team:** \_\_\_\_\_  
**Start Time:** \_\_\_\_\_ **End Time:** \_\_\_\_\_  
**Observer:** \_\_\_\_\_ **Participants:** \_\_\_\_\_

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary** (meeting topics, goals, tasks, missing members):

- 

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

- 

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others' team walls?):

- 

**Communication Richness** (What communication channels were used? To what end?):

- 

**Emergent Leadership** (Who was the leader? How do you know?):

-

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

**Date:** February 19, 2013

**Team:** 1 cybergrid red

**Start Time:** 8:00am

**End Time:** 9:30am

**Observer:** Anne

**Participants:** UW1, VT1, VT2, IIT1, IIT2, IIT3, UT1, UT2

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Mode	Scale	Cue	Discovery
8-8:30	X	X	X	X	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:30-9:00	<input type="checkbox"/>	<input type="checkbox"/>	X (w/pens)	X	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9-9:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9:30-10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10-10:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary** (meeting topics, goals, tasks, missing members):

- UTX was out today – I heard UT1 say his sister was having a baby (UT is on holiday this week!)
- They spent the first few minutes adding everyone to g-chat (VT2 was adding people)
- Then VT2 suggested they go look at the new model. They started the meeting without need for intro which was great.
- They spent several minutes walking through the model and making note of things that don't make sense or need to be changed.
- Interesting. UT1 is standing inside the wall and sees that the walls aren't aligned. He scrolled his camera so he could see the walls.
- They went to the roof first, then the second floor where they spent quite a bit of time, then the third floor where they spend quite a bit of time.
- "Are we on the second or the third floor?" "Third."
- Then they went to the roof (top floor). The stair was not aligned with the door at the top. VT1 fell down the hole, and UW1 also fell down later.
- UW1 said "it looks pretty funky here." UT1 has opened the Revit model in addition to being present in the virtual world. He was describing that they did not use phasing. They just made everything new, so you can't tell what is existing and what is new.
- They decided that India had a bit of work to do to the model. (And this one actually looks pretty good!)

- UW1 asked if we could go through the list and VT2 suggested going to the red room because she had typed it up and could put it on the screen. (The list was long. See recording.)
- 8:40 UT1 is sharing his screen on the team wall, showing the Revit model. He is using pens on top (thick black and red) showing what he thinks could be done. UW1 then asked if he could show an idea and he used the blue pen (thin) to show what he was thinking. UT1 said he didn't understand (because there were too many marks) so he cleared the screen and asked UW1 to draw it again. He did, and then it was clearer.
- UW1 would like something that makes more sense instead of plopping a room on top of the building like they've done. The rest agreed. It was better to have a space they could justify. It was less important (to them) to make a "cheap" building.
- VT2 asked Josh and me if they could update the Revit model right now. Josh said (in chat) no, that's India's job. That was a good call because they said "How are we going to explain this to the Indians?" A communication conundrum. VT2 mentioned she would add screenshots to the document.
- Stopped the video at 52 minutes, just to be safe. It's taking a while to create the video file, so I will miss a couple of minutes of recording... This was a good time because UT1 was sharing his screen but others were having trouble seeing it due to lag (we could see it here at UW). Now Josh is explaining how to use the FPS when sharing. He suggested leaving it on "manual."
- UT1 is wondering what they should do now – just look at the list? VT2 suggested looking at the google chat to make sure the Indians understood all of their comments. UT1 said he'd just be gone for a little bit. (Yes, I picked a good time to pause recording.) VT2 also said feel free to make changes to the google doc. She asked for my gmail to add me to the chat. The video is still processing... 89%... Now I'm saving the file. It appears the whole process is taking about 15 minutes.
- UW1 said to VT2 it looked like they were confused by the columns. He said they just need new ones stacked on top of the old ones. VT2 said she would try to explain that better in the google doc.
- Started recording again, but things are still quiet in the CyberGRID. They are still working on the google doc.
- UT1 asked if UW1 could take a look at where the columns are to see if it makes sense. He is referencing a document in the Dropbox. Nothing is on the team wall. Other than voice, the CyberGRID hasn't really been used since about 8:50.
- VT2 said the notes in the google doc could be the minutes for today, unless someone was taking actual notes. The others agreed that was fine.
- 9:22 UT1 said he needed to leave in the next 15 minutes or so and they wound up wrapping up in the next few minutes after deciding they had completed their tasks for the day.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

- The big model used for over half hour at beginning of meeting.
- Team wall used to broadcast list of items found in the model and the Revit model (by UT)

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others' team walls?):

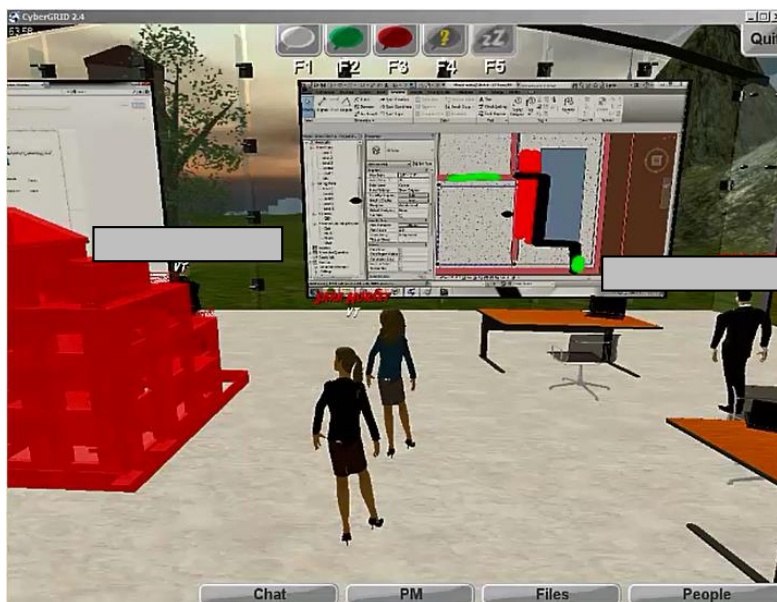
- GREAT use of space. First, sat in the conference room. Only spent a minute in there.
- Then spend over half hour in the model discussing items in detail.
- Then they used the work room (because they were able to use multiple screens) and two team walls at once. Avatars were facing the wall with the two screens.

**Communication Richness** (What communication channels were used? To what end?):

- Voice was used most often. Bubbles very rarely. With the exception of some trouble at the beginning with both of the Dutch students' headsets, voice was successful.
- Google docs were used to communicate about the issues with the model.

**Emergent Leadership** (Who was the leader? How do you know?):

- VT2 was primarily in charge. She suggesting walking through the model. Also took charge of noting the items found in the model and sharing on the team wall and in google docs for IIT.



41:38 UT1 sketching on the team wall ["Maybe they can try to do something like this."]. Red is empty space in the plan as designed by IIT. Black is possible new walls. Green is balcony. Afterward, UW1 sketched more lines with a blue pen.

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

<b>Date:</b> W3 Feb 19, 2013 <b>Start Time:</b> Duration – 1.5 hours <b>Observer:</b> Anne	<b>Team:</b> 2 sococo <b>End Time:</b> <b>Participants:</b> IITM4, UW2, IITM5, VT3, UT3, UT4, VT4, IITM6
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Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
<b>8:30-9:00</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>9-9:30</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>9:30-10</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>10-10:30</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>10:30-11</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary** (meeting topics, goals, tasks, missing members):

- UT4 began the meeting by asking if everyone had seen the agenda. [Silence]
- He asked: so can you put the 3D model on the screen, please? We have to talk about it a little more.
- IITM5 asked for a moment. A couple minutes later he said it’s in the dropbox.
- UT4 said ok and asked him again to put it on the screen. IITM5 said he was trying to open Revit – it takes some time. [Silence]
- 4:55 UT4 says “Virginia Tech, how are you?” VT3 answers fine. Returns the question. UT4 says they have the week off. UT3 says “and still working.”
- IITM5 asked how many subjects they have in this semester. UT4 said he didn’t understand the question. IITM5 repeated and he was asked to repeat again. Third time they understood and now they are talking about the classes they all have to take. UT4 abruptly changed topic by saying “so is the model on the screen yet?”
- Now IITM5 is sharing his screen and UT4 said “yeah I can see it” UT4 is outlining what they need to do now: confirm the changes are what they talked about, confirmed materials,... so let’s get started.
- UT4 asked if UW2 had any ideas what materials they’ll be using. UW2 said it would be nice to explore some different materials to different it from the existing building. Would like to use steel and glass to open up the new addition [he sounds like an architect!]
- 00:10:30 VT3 asked “did we determine this is going to be an office space?” He’s wondering if the offices with patios are for executives or for employees to walk out. He thinks there needs to be a purpose for putting the patios out there. Should they be roofs instead of patios? UT4 said at least one patio is nice.
- VT3 “I’m wondering about that door, why is it over in the corner?” [Must be a door projected on the screen?”

- 00:11:55 Now they are starting to have a back channel chat conversation. IIT is confirming that it's an office space. UT4 chatted, 'yes office' with a winky smiley face.
- They are discussing what they should do for the additions. Now UT3 said we could remove the balconies. For an office building they are pointless.
- UW2 says it would be nice to have a terrace on the third floor level so they don't have to look out at roof. [It's been referred to as three different things: patio VT, balcony/patio UT, terrace UW]
- 16:30 IIT is chatting that they are confused about what the others are talking about. "guys are u speaking about barriers or wat?? We are not getting ur points clear here..."
- Mitchel chatted we are talking about the patios on the first and second floor.
- Simultaneously, UT4 asked IIT what they think. Silence. "Hello?" A minute of people saying hello back and forth.
- IITM4 said patio is new to us in our language. Can you tell us what it is? UW2 said a place where you can walk onto a roof. IITM6 looked up patio on Wikipedia and pasted the definition into the chat.
- UT4 reiterated where the patios will go then ask if everybody agreed. UW2 said yes he agreed, then VT3 said yes he agreed. But there was a misunderstanding. UT4 only wants patio third floor and UW2 thought he said third and second. Now UW2 is arguing for a patio on the second floor. Saying they want glass to bring in more light and if they have glass, they need something nice to look at. VT3 is adding his opinion agreeing about more glass. IITM5 chatted again that IIT doesn't understand.
- IITM4 chatted what they understood them to mean and UT4 confirmed in chat. IITM4 chatted "fine..."
- 25:00 Now they are discussing the ground floor/first floor difference in terminology. UT4 said 1<sup>st</sup> floor is how they discuss it in America. They agreed to call it ground floor. VT3 said "my bad"
- UT3 is saying they may not be able to determine all of these options in terms of cost.
- 27:30 IITM6 is speaking. The IIT guys rarely speak. He is asking if they open the Revit model the others can point out what they are talking about. UW2 said he didn't understand what he was asking. UT4 said he didn't either. UT3 translated that he wanted them to open Revit from the Dropbox and share the screen. So UW2 said he would do that. He is sharing his screen now.
- IITM6 is asking in chat if there is a way to highlight the screen while they talk. UW2 was talking about "here ... here ... here..." and UT4 said you are sharing your model, you are sharing your internet browser. UW2 said oh, he thought he was sharing his model.
- IITM4 chatted to please stick to the ground floor, 1<sup>st</sup> floor, etc. terminology to avoid confusion in discussion.
- UW2 was asking if we are calling the ground floor the first floor. UT4 said yeah whatever you call it. IITM6 chatted "lets stick to one"

- UT4 asked UW2 if he could just change the walls to glass really quickly. UW2 said he's not that familiar with Revit. Now he is seeing there are no columns in the corners. He said they need columns.
- UT3 is sharing the model on screen 2 "how they discussed it" UT4 asked "are we all on screen 2?" UW2 said yes. UT4 asked "India?" They chatted yes. UT4 asked UT3 to explain his model.
- A lot of background noise coming from the IIT mics.
- IITM5 said "hello?" UT said go ahead. IITM5 explained their logic about the load bearing.
- They are discussing how much glass they should have. They will decide based on the cost estimate.
- UW2: We have to assume they are thickened slabs at the edge of the slabs. UW2 asked if IIT can show on screen the actual slabs. IIT manipulated the model but didn't really show a different view. Couldn't see the slabs.
- IITM5 said the highlighted ones are the slabs. UW2 said he couldn't tell from that view what... Now IITM5 is speaking a different language.
- IITM6 said "hello, can you hear me?" (this is how IIT typically starts their conversations) Now he is talking about glass vs. brick. Saying brick is cheaper than glass. UT4 said but it's cheaper to place glass than to place brick.
- UT4 said ok it's time to make a decision, okay?
- IITM6 is protesting. We need to think about material availability, too. UW2 intervened and said it will be based on the cost estimate. IITM6 said it depends on the location of the building regarding availability of materials.
- IITM6 said "hello, am I audible to you guys?" He repeated that they need to make a decision about the location about the building. UT4 said last week they decided the building is located in the Netherlands. IITM6 said ok, fine.
- IITM6 said we don't see any structural beams in the building. What about that?
- UW2 says they are assuming there is reinforcing at the edge to support the floor.
- IITM6 was talking about the walls... boundary walls.... UW2 said he didn't understand and asked if anyone else understood . Others said no.
- 51:50 IITM6 clarified are these glass ... etc. Exterior class, sandwich glass, 2 layers glass.... He said "I don't think this is the cheapest glass on the market."
- UW2 said in the Netherlands glass is cheaper than brick. IITM6 asked if UT4 had any site experience or data. UT4 said you'll just have to trust me on this one. IITM6 laughed and said okay.
- IITM6 is pointing out the gap between the wall and the slab.
- UT4 asked if they could extend the slab. IITM6 said it's not possible. UW2 explained no, they need a piece of steel, ledger, flashing, etc....

- IITM6 was disagreeing. UW2 said “well, how do you think it’s connected?” IITM6 said that’s a good question. UW2 said yes. (sounds slightly irritated?) UW2 reminded IITM6 that this is just an exercise, not a real building.
- VT3 added his opinion. So is IITM5. Wow, this conversation about how to support the brick wall is so long and (as UW2 pointed out) kind of pointless.... IITM6 is not giving up.
- UT4 is asking they make some assumptions. Detail is not the point of this assignment. UW2 agreed. IITM6 did not. 1:07:24 ...and still going!
- Now they are talking about just making windows bigger instead of using storefront. UT4 is agreeing. As long as they have “really really big windows which is essentially a glass wall.” Hmmm, is he agreeing or not?
- 1:10:05 Sounds like UW2 and UT4 are both getting frustrated with IITM6. IITM6 is still talking. He wants to know what a patio is. IITM6 occasionally apologizes for interrupting (even though he’s doing most of the talking) and asks if others can hear him.
- UT4 asked IITM6 to look at screen 2. It’s taking a long time for the screen to load for IITM6. So UT4 pasted a link in the chat. At about the same time, UT4 was able to see the screen.
- 1:14:00 IITM6 has suggesting moving on, that they have spent too much time talking about this. UT4 agreed. Summarized what they agreed on.
- 1:15:00 Then UT4 brought up that they need doors.
- \*\*Conflict: Then IITM6 came back to the walls not being supported. The others said we’ve already covered that. IITM6 says yes we always come back to this. Even IITM4 in chat is asking to move on. UW2 (frustrated?) is saying “India, what you don’t understand is.... [explains]” UT4 agreed with UW2. [More discussion]UT3 finally said he would put the support angle in the model. IITM5 asked him to do it right now and upload it. UT3 said he would do it by Friday. IITM5 said no he had to do it now. UT3 says he can’t be on Sococo and work on Revit at the same time. IITM5 said he can take 10 minutes out of the meeting, do it, then email it to them. IITM5 doesn’t seem to believe it’s possible to draw a steel angle attached to [???]. UT and UW seem to be frustrated with IIT and vice versa. UT just wants to make decisions now and draw later.
- 1:27:10 Finally made a decision. About materials. UT4 asked UT3 if he would make a note of that in the minutes. UT3 spoke over IITM6 and seemed to ignore him (?).
- Decided to just “leave it there.” UT is out. IITM5 said “hello?” “hello? can you hear me?” He continued to ask questions. UT4 ignored him and said goodbye. UT3 told IITM5 that he could find everything they decided in the meeting minutes.
- 1:32:00 Meeting over.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

-

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others' team walls?):

- 

**Communication Richness** (What communication channels were used? To what end?):

- Screensharing was used to show the Revit model but was only referenced a few times.
- Voice was used most.
- Chat was used to supplement voice when clarifying something. IIT4 mostly communicated through chat while the others mostly used voice. IITM5, UT4, UW2 and VT3 did most of the talking (roughly in that order from high to low quantity).

**Emergent Leadership** (Who was the leader? How do you know?):

- UT4 was the decider and moved things along.

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

**Date:** February 20, 2013  
**Start Time:** 8:05am  
**Observer:** Anne

**Team:** 3 cybergrid green  
**End Time:** 10:13  
**Participants:** UW3, VT5, VT6  
g-chat: IITM6, IITM7, IITM8

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
8-8:30	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<b>X</b>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>
8:30-9:00	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b> (w/pens)	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9-9:30	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9:30-10	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10-10:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary (meeting topics, goals, tasks, missing members):**

- The Dutch team is on holiday this week, so none of them are present.
- VT5, VT6, and IITM6 were on time.
- VT5 added me in g-chat. I see the IIT team signing in.
- UW3 arrived at 8:10 and IITM7 arrived at about the same time (in g-chat)
- 8:15 we are all in g-chat.
- 8:20 UW3 said he was going to check out the model. We all followed him into the model. He walked up the stairs, got to the top and he said “uh-oh.” It appeared there was brick in the door so looked like we couldn’t get through. UW3 asked the IIT team about it in chat. But when VT5 walked up, she walked through the door. UW3 said oops, nevermind!
- They are all on the top floor and noted that the hall was so narrow.
- Stepped away to check on the Sococo team.
- 8:37 Everyone is back in the team room. G-chat is displayed on the team wall.
- UW3 asked VT5 if they had started the construction scheduling yet. She said no that was on the schedule for next week. UW3 asked me if they could start on that and I said okay.
- They are all chatting in g-chat about the changes needed in the model.
- 8:47 Carrie just arrived in the physical space – back in the CyberGRID I see they’ve been sketching with pens on the team wall behind me. Good stuff! They used all four colors. Screenshot below.
- They are also sharing files in Dropbox.
- VT5 projected a file from IIT – a floor plan. They are using pens on the team wall to talk about changes at the roof. UW3 asked VT5 is using paint. She said no she is using the CyberGRID pens. VT5 said she wished CyberGRID had the option to type on the team wall.
- UW3 said it’s too bad the kids from India can’t join the CyberGRID.

- 9:05 Things have been quiet for a few minutes. Seems IIT is working on revising the model. At 9:05, UW3 said “now we wait...”
- We can hear the Sococo team in the background at VT.
- 9:20 VT5 received the Revit file from IIT (in chat they say “check mail” so they may be e-mailing it to VT5) and projected it onto the team wall
- ~9:36 VT5 received a new file from IIT and she projected it onto the team wall. She circled a short glass wall commenting perhaps that isn’t needed.
- They decided it looked fine.
- 9:40 Now they are g-chatting about what time to meet next week since IIT students have a class at night. (Just next week per g-chat)
- 9:53 stopped recording. They are wrapping up for the day – nothing happening in CyberGRID.
- Now they are wondering if they should just meet at the same time without the IIT students.
- VT6 and UW3 are discussing the meeting minutes. Sounds like they both assumed they were responsible for it today so they were both taking notes. They decided to upload both to dropbox.
- UW3 can’t see VT6’s file in dropbox so he asked her to email it to him.
- They are having a long discussion via g-chat about when to meet next week. IIT students are quite concerned about missing the meeting and are asking for a decision to be made. VT5 told them they can’t make a decision without the Dutch team. VT5 sent out an e-mail to the group and suggested they call it a day!
- 10:13 meeting over.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

- Bubbles were not used at all today. There were only three in the CyberGRID so maybe they didn’t feel it necessary.
- Team wall was used extensively (two walls). They projected g-chat and the roof plan. They used pens on the roof plan to discuss revisions.

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others’ team walls?):

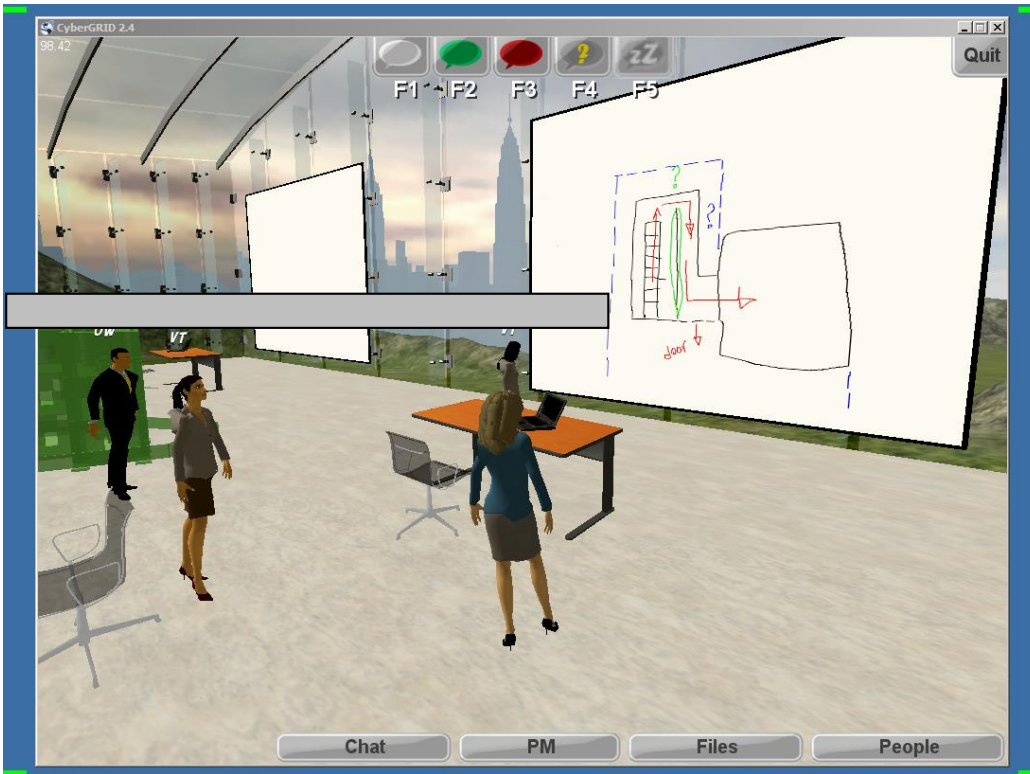
- After walking through the model for ~20-30 minutes, they primarily stayed in the team room. They would position themselves facing whatever team wall they were discussing at the moment.

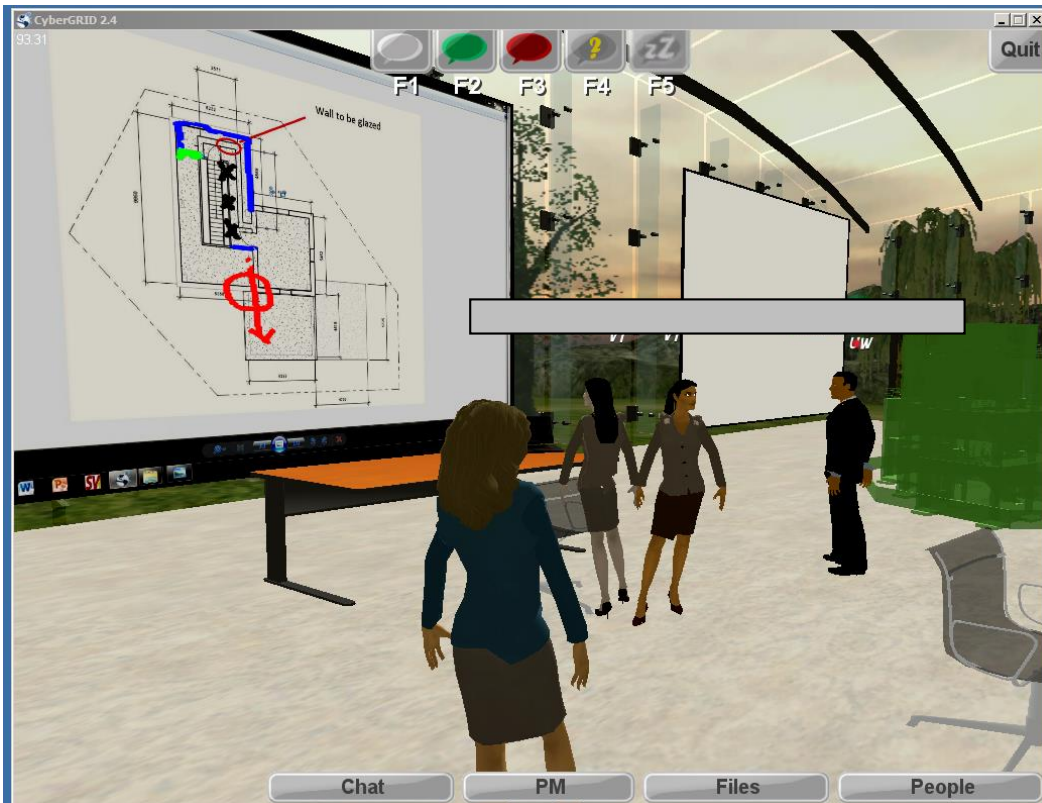
**Communication Richness** (What communication channels were used? To what end?):

- Voice, g-chat, Dropbox, team wall, e-mail
- Avatar position was not as salient in this team as in other teams. (Others would make references to their own position or that of others, for example.)

**Emergent Leadership** (Who was the leader? How do you know?):

- VT5 was in charge of most everything today. She was the primary liaison between IIT and the others, even though everyone now has access to everyone else via numerous channels.
- UW3 also had a tendency to move things along.





8:56 Using pens on a floor plan from IIT.

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

**Date:** February 20, 2013

**Team:** 4 sococo

**Start Time:** Meeting was supposed to start at 9:30, but chatting took place as early as 9:22.

**End Time:** ~10:05am

**Observer:** Anne (post-meeting)

**Participants:** IITM9, ELI, IITM10, VT7, IITM11, IITM12

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
8-8:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:30-9:00	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9-9:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9:30-10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10-10:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary** (meeting topics, goals, tasks, missing members):

- UT is not present.
- IITM12 is sharing her screen and it appears she is putting a spiral staircase in the model.
- Using voice, VTS asked if she should put a smaller spiral staircase in. She couldn't find one, though. VT7 said if there is a smaller one, that would be great, but if they have to use a regular one, that would be fine, too.
- We are watching her screen as she works. Her screen is the only one being shared right now. All avatars have eyes, so all must be watching. IITM11 just disappeared so there are only 5 (besides me) in the meeting.
- 5:55 VT7 is saying if they could agree on a spiral staircase, next week they can start the cost estimate.
- VTS thinks a regular staircase would be fine because it only takes up 3 meters. VT7 said let's see how it looks in the model.
- UW4 asked why they decided to try a spiral staircase. VT7 explained they thought it would be more compact but it doesn't appear to be the case. They need access to the new top floor, so they need to add a staircase. VTS is still working on the shared screen, placing a spiral staircase, though. (Didn't they just agree they'd see how a regular staircase would work in the model?) As she works, it's quiet.
- 10:00 Now IITM9 is sharing his screen. I don't know what's on it. Maybe he is working on a regular staircase? He had chatted that providing a normal staircase will resolve the issue. 12:00 IITM9 just said he had a normal staircase on Screen 3. VT7 said he couldn't really see the staircase. IITM9 must of changed the angle because then VT7 said it looked good and seemed to solve the problem. [Now the video shows IITM9's screen with the regular straight stair.]

- The stair was pretty tight and had no landing. VT7 asked if there was an “L” staircase available. The team is watching as IITM9 is adjusting the stair in the Revit model. Again, things are relatively quiet while he works.
- After a couple of minutes, he said an “L” would not solve the problem. It would occupy more space. VT7 said if you put it in the corner, it could work. IITM9 insists it would take up more space. UW4 asked what is the floor to floor height. IITM9 said 12 feet. (They switch between meters and feet when speaking during this meeting.) VT7 and IITM9 are still discussing straight vs. L. Definite disagreement, but very amicable. VT7 is using words to describe what he is thinking. Says “I’m not sure if it’s clear, what I’m saying”
- 20:30 UW4’s mic was on and something was crunching. VT7 said “hey UW4, I think your mic is on” UW4 said “Oh! I will be more quiet.” VT7 laughed and said that’s ok. Meanwhile, the team is still watching IITM9 put the new staircase in. It appears he is trying to put the L shaped staircase in....
- UW4 voiced an opinion that the spiral staircase would be more expensive in addition to occupying more space. VTS said she thinks the whole room will be taken up by staircase. IITM9 disagreed, saying there is plenty of space in the room.
- 24:50 IITM9 is showing the plan of the staircase and asked if they agree with it. The others said yes. UW4 asked that the stairs move closer to the exterior wall and that the two runs have equal number of treads (though he called them something else – not treads. “Lengths” maybe? Then clarified by saying “steps”)
- UW4 said he would be more comfortable if he knew what the building was being used for. VT7 said they didn’t know so they need to make an assumption.
- UW4 is now asking if they should rotate it 180 degrees and move it to a different wall. “I’m having a hard time describing it.” [Sure would be helpful to be able to write on the screen!] IITM9 is doing what UW4 is suggesting with no words, just doing it on the screen. Seems to be following what UW4 is saying. Making this run 3 steps shorter... etc.
- VTS chatted “do u want it as in screen 4?” She must be showing the idea that UW4 is suggesting. I don’t know if others switched over to look at her screen. UW4 was still discussing his idea.
- 31:25 VT7 chatted that he needed to take off. Then said see you all next week in chat. Interesting that he chatted this when he normally used voice. Even so, his voice piped in saying “there may be some clearance issues walking into that room.” UW4 said could we put an avatar in here? VT7 said wouldn’t that be nice to put an avatar in here? UW4 said yeah, let’s ask the cybergrid people to put an avatar in here. VT7 said ‘hey, we have avatars too’
- 33:27 IITM10 chatted “see you guys next week” and left. VT7 also said he really had to go now and “good luck” UW4 said “alright, thanks” This is 10:03am.
- VTS chatted “ya its time for us.....” that she’d email the model asap, and ‘cu next week’

- Meanwhile, IITM9 had put a person in the Revit model under the stairs and UW4 was talking as he manipulated things. IITM9 still wasn't talking as he worked. UW4 was doing all of the talking. It's now just IITM9 and UW4 in the meeting.
- 36:25 UW4 said VT7 was right, the stair didn't go all the way to the floor. IITM9 said (using voice) that he could fix that and "this is the final model" UW4 said since he is closer to the model, he would trust him to make decisions about the stair.
- UW4 said so we will leave until next week? IITM9 said ok bye. UW4 said bye. Everyone out.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others' team walls?):

**Communication Richness** (What communication channels were used? To what end?):

- Voice was used quite a bit in this meeting. Though there were times when IIT was working on the model and all was quiet. Even chat was quiet. Seems they were just watching the modeling taking place.

**Emergent Leadership** (Who was the leader? How do you know?):

- Hard to tell.... After a few minutes, IITM9 took control of the modeling from IITM12. IITM9, UW4, and VT7 were most vocal during the meeting, especially in the second half.

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

**Date:** February 21, 2013

**Team:** 5 cybergrid blue

**Start Time:** 7:30am

**End Time:** 9:35am

**Observer:** Anne

**Participants:** UT5, UT6, UT7, VT8, VT9, UW5

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
7:30-8:00	<b>X</b>	<b>X</b>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:00-8:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:30-9:00	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9-9:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<b>X</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9:30-10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary (meeting topics, goals, tasks, missing members):**

- UT6 was the first to arrive. There was noise from her headset, so she signed off to find another headset.
- UT7 arrived next at 7:23 then the rest of the dutch team. UT7 decided to initiate the g-chat with the India team while waiting for UW and VT. UT6, Josh, and I used CyberGRID chat to provide our emails to be added to the g-chat.
- When someone asked if everyone should go to the conference room, UT5 used his green bubble.
- I followed the group to the one-screen conference room. VT8 projected the agenda for today on the team screen.
- VT9 joined at 7:56.
- Well... we started the meeting half hour early for UW5 and at 8:00 she still isn't here yet. She showed up at 8:06.
- 8:10 VT8 just walked into the big model (on her own) and I can see she just got stuck at the second floor. They did not create an opening at the second floor stair for some reason. Now she is chatting that the Revit model does not have an opening in the 2<sup>nd</sup> floor. "your head hit the ceiling" Ah, here comes UT7 to investigate this. Now UT6 and VT9 are in the model, too, investigating.
- 8:19 Strange scene. UW5 is in the conference room, VT8 is in the team room, Josh is on the stairs leading to the center, UT5 is in the middle of the yard, UT6 and UT7 are standing on the second floor balcony, and VT9 is exploring the model. VT9 is the only one moving. Most are typing in g-chat.
- 8:35 I've stopped the video since it's been running for an hour and nothing is happening in the CyberGRID. As soon as it processes, I will start it up again. They are chatting about materials in g-chat.

- VT9 is walking around the model, but the others are primarily stationary. Still in the model. Oh, UT6 is moving, too. Still, everyone is chatting in g-chat.
- They are speaking in the CyberGRID again. UT7 is talking to VT8 about the columns.
- VT8 “Last week we didn’t have this column did we? This one?” (She walked over to column and stood next to it.)
- They are having a very detailed discussion (via g-chat) about materials and about the structure.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

- Team wall, green bubble once that I saw, the big model.
- 9:06 UT7 is talking about how they will pull numbers from the Revit file from IIT and put together a cost estimate. He said they will do it sometime this week and put it in the Dropbox so it will be ready for next week’s meeting. Seems he was addressing VT8 – she is the one who responds, anyway. And now they have decided to move the conversation to g-chat so IIT can be involved with the discussion about the columns.

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others’ team walls?):

- They spent the first half hour of the meeting in the conference room. Even though VT8 had projected the agenda onto the team wall, they spent most of their time in g-chat.
- They spent the rest of the meeting primarily in the model. After an initial exploration, they were mostly frozen in one position spread throughout the first floor while they chatted in g-chat.

**Communication Richness** (What communication channels were used? To what end?):

- Voice, g-chat, Dropbox (for file exchange), avatar position (yay!). G-chat was used extensively in this meeting. Interesting how the Tuesday team seemed more engaged in the CyberGRID even though they were also all g-chatting with each other.

**Emergent Leadership** (Who was the leader? How do you know?):

- UT7 and VT8 were most outspoken during the meeting. Difficult to tell who among the IIT team was leading since all of that conversation was via chat. Triveni was knowledgeable about structure and would often comment about what they needed structurally and how the given model was not modeled well from a structural standpoint. UW5 at UW is quiet. We should hear more from her when they get into the 4D modeling.



Two heads stuck in the second floor...

t.

**Spring 2013 CyberGRID Ethnographic Observation Sheet**

**Date:** February 21, 2013

**Team:** 6 sococo

**Start Time:** 7:30

**End Time:**

**Observer:** Anne (Post-meeting. Carrie recorded video: VIDEO 2)

**Participants:** UW6 (UW), VT10 (VT), IITM13(IIT), IITM14(IIT), UT8(UT), UT9 (UT)  
Later: IITM15, IITM16, VT11

Time	Tools/Communication				Presence/Copresence		
	Bubble	Chat	Team Wall	Model	Scale	Cue	Discovery
7:30-8:00	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:00-8:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8:30-9:00	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9-9:30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9:30-10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Meeting Summary** (meeting topics, goals, tasks, missing members):

- 7:30 VT10 started by saying good morning. UT9 said hello. Asked IITMA “how are you all?”
- UT9 said shall we begin? Asked if everyone has the drawing from IITMA. Told him it looks good.
- UW6 chatted that he couldn’t hear. VT10 chatted is there someone that can help you? UT9 suggested pressing the talk button in the upper left.
- IITMA chatted to let them know when he has it fixed. Then things went quiet except UT9’s mic was open and we could hear him speaking Dutch in the background. The video switched to Carrie’s screensaver for a minute. When the video returned, I could see that UW6 chatted he had the sound working.
- 7:50 UT9 asked if everyone agreed with the three rooms they discussed last week. IITM13 is sharing his screen, which is the Revit model.
- UT9 asked others if they agreed with the model. VT10 said yes. UT9 asked UW6. UW6 said Yep.
- IITMA was speaking but there was an echo. Others couldn’t understand him. He said he was sounding sound issues. He signed off. [Seems someone else’s mic was causing the echo, because it persisted after IITM13 checked out.
- IITMA logged back in and asked if it was better. There was still an echo. VT10 signed out, UW6 signed out, then back in. They might be trying to fix the audio issues.
- UT9 mentioned his UT teammates were on holiday, so it was just him today.
- IITMA asked the others to look at screen 2. He pointed out the text that was highlighted. He was sharing the weekly tasks document and had highlighted the sentence about how structural upgrades were required for multiple-story additions. UT9 said he didn’t

understand the sentence. Then it was quiet, other than UT9's open mic. UW6 chatted asking if anyone was talking. UT9 responded in chat that IITM13 signed out and in again. He also said so in voice.

- IITM13 chatted: wondering if they should ask Anne about today's deliverables. The structural upgrade sentence is confusing to them.
- VT10 said her teammate is joining them. He has a class so will be 20 minutes late. His name is VT11. Then she said she would type it (and she put "VT11" in chat).
- Carrie joined the conversation to answer their question about structure: if you are adding a single story, you don't have to increase structure underneath. It's intended to simplify the assignment. IITMA clarified what Carrie said.
- IITM13 asked if Carrie could see the Revit model he was sharing. He highlighted the three rooms they added. One of the additions was a two-story addition. She said they would need to add structure under, e.g. additional columns in the corners. No need to be exact since no one is a structural engineer. He asked if they put the room in a different place, maybe they would not need to add structure.
- IITM13 repeated this for his other teammates. UT9 suggested using whatever the other three-story part of the structure is already using (which, of course, won't work because it's all the same!)
- IITMA is suggesting to his teammates that they move one of the rooms to another part of the building so they don't have to upgrade. He is referring to the place where he wants to add a room by highlighting the railing in blue and pointing out where he has the handrail highlighted in blue. UT9, UW6, and VT10 all agreed using voice that the new location will be fine. IITMA said he would change it. UT9 said you can do that, IITMA?? He said yes, just give me two minutes. He kept sharing his screen as he worked.
- IITM16 asked IITMA to highlight where the new rooms would be. He has the old model open, so he highlighted the railings of all locations where new rooms would be. See Figure 1.
- IITM16 asked if they are considering materials.
- 36:00 They are discussing whether to use same or different materials for the exterior. The joints may be an issue. Asked others if it's okay. UT9 said yes, VT10 said sorry she was filling VT11 in on what's been happening. She clarified they were talking about materials.
- VT10 said they hadn't decided exactly where the building would be. UT9 said maybe America. IITMA asked if they were using heating or cooling equipment. It would affect wall thickness. UT9 suggested using the same as the rest of the building.
- 40:00 UW6 said he can't give structural advice, so he would follow the others. They said ok.
- IITM13 asked UW6 and VT10 to talk more about the 4d and scheduling part of the building.

- IITMV said, using voice, he finished two rooms. IITM13 is still sharing his screen and it appears he is working on the Revit model. All went quiet while he worked on the shared screen. He seems to be adding the rooms. I'm not sure why if IITM16 already has.
- VT11 said, while everyone's quiet I'll just introduce myself. Sorry I missed the last couple of weeks. I'll be able to add something as soon as I figure out what's going on. Look forward to working with you guys.
- Others said hello to VT11.
- Was still quiet for a few minutes while IITM13 worked. He said (using voice) if others had questions about what they were doing to please ask him and he said welcome to VT11. VT10 said she had shared with VT11 the team process plan and could somebody share the dropbox with him? UT9 said he could do that and asked for his email address. VT11 said he would type it, then it appeared in chat. Then things went quiet again....
- UT9 said 'I just invited you, VT11. Can you see it?' VT11 said he was in there now trying to find it. After a couple of minutes he said he could see and said thank you. UT9 said 'ok'
- It's quiet but I can hear others talking in the background. Sounds like the VT CyberGRID team. IITM13 is just working in Revit while the rest of the team watches.
- 57:30 IITMV said "IITMAam, what about walls" as he is watching IITM13 work on the model. IITM13 said (I think) he would do that last. IITMV said "when you are finished drawing, please check out my screen."
- On screen three, it appears IITMV has a completed Revit model. Are they working simultaneously on different models? The file name is blacked out on IITMV's screen so I can't tell if they are different models. I assume they are.
- 1:05:00 IITMV says "IITMAam, it is not necessary to select the entire wall." As he is watching him model.
- 1:10:00 It has been quiet for several minutes now as IITM13 works on Revit. Finally IITM13 says "IITM16, is it okay?" They have a very short, quiet conversation – almost in the background – then all is quiet again.... IITMAam continues to work on Revit.
- 1:15 [Break in the recording] When the recording returns, they are all saying the Revit model looks good. UT9 says they can do the cost estimate this week if they have the Revit model. IITM13 asks VT10 and UW6 if they have any questions or if there is anything they should discuss regarding the model. VT10 verifies they aren't demolishing anything.
- IITM13 says after class today they will put this in dropbox.
- VT10 asked how they are getting the materials to the upper floors. IITM13 says they will have access from the side. As he speaks, he highlights or hides (if he's talking about elements that will be gone) the elements he is talking about. He didn't really answer the question beyond access. Didn't suggest scaffolding or cranes. IITM13 asked VT11 and UW6 if they have any additional input. UW6 said no he didn't. He asked what sort of equipment they would use in America. UT9 asked you mean materials? IITM13 said no

he was talking about how to construct it. No answer, so he addressed VT10 directly. No answer, so UT9 said “VT10?” She said sorry, what did you say? VT11 said they were just talking about it. Able suggested a lift or scaffolding to bring materials up. IITM13 suggested a scissor lift or cherry picker. He thinks that would be okay for a small height. He asked if they understood what he was talking about. VT11 said yes. Then VT10 asked VT11 what a cherry picker was.

- After a couple minutes of silence, UT9 said for next week they would create a cost estimate.
- IITM13 said to let them know if they had any questions. UT9 said they could probably figure it out since they are familiar with Revit, but if they had questions they would ask.
- UT9 said he to go. VT10 told UT9 to let them know if he had any questions. She told him that RS Means is free for two days and she would send him the link. IITM13 asked her to put it in dropbox. UT9 said that’s a good idea so everyone would have access to it. UT9 left.
- IITM13 asked UW6 if he had any questions. He said no. Then he asked VT10. She didn’t answer. They asked for VT11. No answer. IITM16 chatted “VT10 u der?” VT10 finally came on and said “what??” She said she had been talking to VT11. They said yes, they wondered where both of them were. They asked her again if she had any questions. VT10 asked to see the model again. He rotated it in Revit so they could see it from all angles. VT11 said he didn’t have any questions. Asked VT10 if she had any. She said no.
- They discussed the need to decide about the cherry picker because it will be part of the cost estimate.
- VT10 opened the google doc they started and asked others if they could see her screen. She said it was getting crowded. The others suggested she open a new document. She is now inviting everyone to the document. Adding everyone’s emails. Said she didn’t know if there was a faster way. They suggested she add them later.
- She titled the document Weekly Updates (others’ suggestion). She’s typing what they discussed today. IITM13 is dictating to her. She types as he speaks – she asks for clarification.
- VT11 took over typing on the google doc while VT10 sent out the rest of the invitations to the google doc. IITM13 asked if UW6 had anything to add and he said he didn’t think so.
- IITM13 said he got the invitation.
- They all agreed to meet at the same time next week. VT10 said she was leaving. IITM13 said we are all leaving I guess. They said goodbye using voice. All 3 IIT guys said goodbye in chat.

**Use of Tools** (Were bubbles used extensively? How was the team wall used? Were the models used?):

-

**Use of space** (Where were avatars positioned in the space? Did they walk around? Sit? View others' team walls?):

- 

**Communication Richness** (What communication channels were used? To what end?):

- Chat was used very little. People mostly used voice.
- Screen sharing was the predominant method of communication. The Revit model was always running.

**Emergent Leadership** (Who was the leader? How do you know?):

- UT9 started, but then IITM13 took over as leader. It was Revit week, so that makes sense.

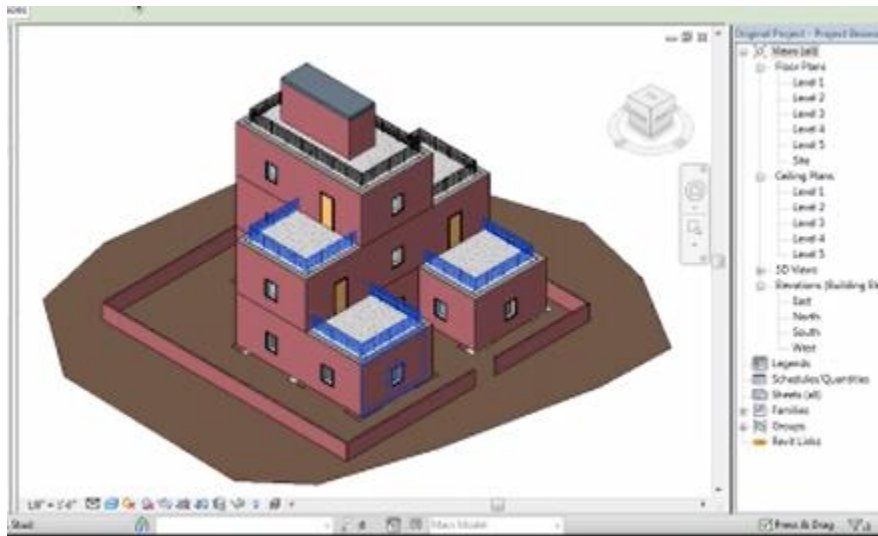



Figure 1. How IITM13 pointed out where the additional rooms will be (by highlighting the handrails in Revit)

## Appendix B

### ELAN Procedure

Use the following steps to transcribe and annotate using ELAN software:

1. Create .wav audio files from existing .mp4 video files for import into ELAN.
  - a. Using Camtasia video editor, open .mp4 file → Drag clip into track editor (make sure it begins at time zero by dragging file all the way to the left) → File menu → Produce Special → Export Audio as... → .wav
2. Import .mp4 and .wav files into ELAN
  - a. File → New... → select the .mp4 and .wav files on the left side of the dialog box and click the >> button to move them to the “Selected Files” area on the right → click OK.
3. Set up dropdown menus:
  - a. Edit → Edit Controlled Vocabularies... → Add “Team [#] Members” → Add names of team members present at the meeting
  - b. Add other Controlled Vocabularies here.
  - c. Type → Add New Linguistic Type → Name = “Team [#] Members” → Add → Close
  - d. Add other New Linguistic Types here.
  - e. Tier → Add New Tier → “Speaker” “Typist” “Transcript” etc. → Linguistic Type = “Team [#] Members” etc.
  - f. Add other New Tiers here.
  - g. Delete “default” layer
4. Transcribe/annotate in three steps:

- a. In Options → Annotation Mode, segment speaker (voice) and typist (chat) durations
    - i. Select the whole utterance within the segmented marks without spanning too much to obtain accurate durations.
    - ii. After segmenting a speaking span, use the  button to ensure the whole utterance was captured (make sure the span is selected first).
    - iii. On the speaker tier, select the speaker from the dropdown menu (double-click).
    - iv. Single-click the speaker segment, then double-click on the transcript tier to get an empty segment on that tier (this span verbiage will be added in transcription mode) .
    - v. Verify there are spans on the transcript tier under each speaker and typist span.
  - b. Options → Transcription Mode → Configure → Column 1 = default – It → Select tiers... → Transcript → Apply → Apply
  - c. In Transcription Mode, transcribe voice and text chat
    - i. Use tab key to pause/restart/replay
    - ii. Use shift key to move to next segment
5. In Options → Annotation Mode, complete annotations per Annotation Schema

## Appendix C

### Annotation and Coding Schema

Using ELAN, the video and audio from week 3 meetings were transcribed and then annotated as follows:

Speaker – Identify the participant who is communicating using voice.

Typist – Identify the participant who is using in world text chat.

Transcription – The words that were spoken or typed.

Discoveries – Defined as finding something for the first time.<sup>6</sup>

Notes

Other text communication channels such as Gchat and the chat feature associated with google docs were also annotated for discoveries as defined above. Each discovery was then coded as follows:

1) Who made the discovery? (Participant and school)

[From the speaker category in ELAN or identified in the Gchat or google doc chats.]

2) Discovery Trigger

- Model in yard (this applies to CyberGRID only)
- Small model in team room (this applies to CyberGRID only)
- Revit on own computer (sometimes one participant would have the model open on their own computer and would make a discovery in the model.)
- Shared screen

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<sup>6</sup>Retrieved from <http://www.merriam-webster.com/> on October 30, 2013.

2a) Where were the teammates located during discovery? (CyberGRID)

2b) What (specifically) was being viewed?

3) Was the discovery acknowledged?

- Yes or no (still significant because independent viewpoint allowed discovery to be made)
- If yes, by whom.

3a) How long did it take to explain (reach agreement) that it was an issue?

3b) How many words were needed to explain the discovery until it was understood? (Only words in explanatory phrases are counted – not words in agreement or acknowledgement phrases.)

4) Discovery type

- Error – an error in the Revit model
- Clarification – unclear whether an item is new, asking others to verify
- Confirmation – pointing out a new item
- Suggestion – not an error but could (or should) be changed

5) Was the discovery correct?

- Yes or no (Sometimes discoveries were made in error, but were still acknowledged as discoveries.)
- If no, what was incorrect?

6) Location of each participant's avatar

[CyberGRID 3D environment only]

## 7) Cue type

- **Locational:** Based on location in the environment.
  - *Example: “Where I’m standing ...”*
  - *Example: “The window next to so-and-so...”*
  - **Subcategory-- Directional:** Based on the direction avatar is facing.
    - *“The one **where I’m looking**...”*
    - *“What are you all looking at?”*
    - *“Do you see the bolts?” [Implies second avatar should look in same direction as the speaker.]*
- **Deictic only:** Use of words like “this” or “here” without avatar position
  - *“**These** boxes...”*
  - *“**This** is where we had a lot of issues.”*
- **Verbal descriptive:** Using descriptive phrases, esp. referencing typical model elements like floor levels, grids, or cardinal directions (N,S,E,W)
  - *“The walls that **surround the patio** on the **2<sup>nd</sup> level**... **above the entrance** ...”*

## APPENDIX D

### Supplementary Tables

*Table D-1. Weekly tasks performed by the students*

Week	Dates (2013)	Task
1	Feb 5 – 8	Virtual world training Team introductions and icebreaker exercise
2	Feb 12 – 15	Project planning and discussion regarding location and layout of three new rooms
3	Feb 19 – 22 UT Holiday	Review the Revit model with three new rooms, produced by IIT-Madras. Make suggestions for changes to model before submittal this week.
4	Feb 26 – Mar 1	Review and update the cost estimate produced by University of Twente
5	Mar 5 – Mar 8	Review and update the Simvision baseline schedule produced by Virginia Tech
6	Mar 12 - 15 VT Spring Break	Review and update the Navisworks 4D model produced by University of Washington
7	Mar 19 – 22 UW Exam week	Model optimization
8	Mar 26 – 29 UW Spring Break	Model optimization
9	Apr 2 – 5	Report preparation
10	Apr 8 – 12 UT Exams Week	Report finalization and presentation preparation
11	Apr 15 UT Exams Week	15-minute final presentation given in virtual world by all team members

*Table D-2. Time spent exploring the 3D model in CyberGRID each week*

Week	Task	Team	Time in Model (minutes)
w2	Project planning	1	10
w2	Project planning	3	<5
w2	Project planning	5	45
w3	Review Revit additions	1	25
w3	Review Revit additions	3	7
w3	Review Revit additions	5	87
w4	Cost estimate	1	20
w4	Cost estimate	3	<5
w4	Cost estimate	5	<5
w5	SimVision model	1	<5
w5	SimVision model	3	<5
w5	SimVision model	5	30
w6	Navisworks model	1	0
w6	Navisworks model	3	0
w6	Navisworks model	5	0
w7	Model optimization 1	1	0
w7	Model optimization 1	3	0
w7	Model optimization 1	5	15
w8	Model optimization 2	1	0
w8	Model optimization 2	3	0
w8	Model optimization 2	5	<5
w9	Report prep	1	0
w9	Report prep	3	0
w9	Report prep	5	<5
w10	Presentation prep	1	0
w10	Presentation prep	3	0
w10	Presentation prep	5	0

**Table D-3. State of Revit model in week 3**

3D Virtual World	Team 1	Complete and imported into the CyberGRID
	Team 3	Nearly complete. There was no exterior door in the new room on the roof, so the team members could not walk out onto the roof.
	Team 5	Nearly complete. There was no opening in the third floor slab, so they were only able to explore the bottom two levels of a four-level model (Figure 4-1). Two of the three new rooms were on a level they could not access.
Screen-sharing Platform	Team 2	Complete.
	Team 4	Nearly complete. They had added a new room on the roof that had no access from the existing structure, so spent the entire week 3 meeting modeling new stairs for the space. IITM shared their screen while they worked and others watched.
	Team 6	At the beginning of the meeting, IITM deleted the three rooms they had added prior to the meeting and started over with the original building, modeling three new rooms while their teammates observed.