Transformative 3D Immersive Collaboration Environment in Support of AEC Global Teamwork

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ABSTRACT

Corporate experience claims that the most efficient interactions are when all project stakeholders are collocated. This is extreme collaboration when people, content, models, and processes are collocated. Nevertheless, the AEC industry experiences a continuous increase in mobility, globalization, collaboration, digital content, interactivity, and convergence of physical and virtual workplaces. This paper presents transformative impacts on product, process, and interaction of immersive 3D virtual collaboration environment in support of global teamwork. The empirical data and findings are based on longitudinal studies performed over four years observing 24 cross-disciplinary, geographically distributed AEC student project teams in the AEC Global Teamwork education testbed. The deployment and adoption of agile integrated project delivery work practices facilitated by the immersive 3D virtual collaboration environment demonstrate innovative and effective new ways of working such as co-creation of collaboration spaces, content in context, experiencing and troubleshooting design and construction issues in the virtual BIM models.

INTRODUCTION

The AEC industry experiences a continuous increase in mobility, geographic distribution of project stakeholders, globalization, collaboration, digital content, interactivity, and convergence of physical and virtual workplaces. Nevertheless, face-to-face work is considered to be the most efficient and effective interactions work environment. This is extreme collaboration when people, content, models, activities and processes are collocated.

How can we support a geographically distributed AEC project team to co-create a workspace for extreme collaboration that provides a sense of "being there, immersed in the content that reflects the context of the communicative event" in order to actively engage in a multi-modal dialogue and contribute to multi-disciplinary problem solving?

This paper presents an empirical study of an immersive 3D virtual world collaboration environment in support of global teamwork, its deployment, and transformative impact on product, team process and interaction dynamics. This study identifies new ways of working in the context of 3D virtual space that brodens and deepens capabilities, competences, and resources of a project team. Key objectives are to shorten design iteration cycles, reduce response latency, rework, and decision wait time, and increase participation and engagement.

POINTS OF DEPARTURE

This study builds on points of departure that include: distributed work and ICT use in virtual team research (Maznevski and Chudoba, 2000) (Hinds and Kiesler, 2002) (Chudoba et.al. 2005) (Fruchter and Bosch-Sijtsema, 2010), theoretical frameworks to analyze attention and engagement of project teams during collaborative activities that are mediated by ICT (Fruchter and Cavallin, 2011); two decades of ethnographic observations of multi-stakeholder project teams performed by PBL Lab researchers, state-of-practice integrated project delivery (IPD) in the AEC industry, AIA National/AIA California Council guide for IPD; agile software development, and studies of virtual world environments.

Global project teams need to coordinate their tasks across time and space (O'Leary and Cummings, 2007). Global teams have often a hybrid setting with collocated subgroups and remote members, which creates an asymmetry in terms of proximity, available social cues, focusing attention to collocated subgroup members often ignoring or forgetting remote members. This impacts team dynamics, identity, and collaboration processes. Building a shared understanding of tasks and processes can be difficult. Having a shared team space and context strengthens work relations, and allows for informal interactions (Nardi and Whittaker, 2002). When task interdependence is reciprocal (Thomson, 1967) it is critical to have a shared work space for effective task coordination and decision making. Another challenge global team members face is the lack of common spaces where they can interact informally, socialize and build relations remotely, which typcally foster building mutual understanding and trust (Crampton, 2001) (Fruchter and Medlock, 2013).

Studies of virtual worlds (Yee and Bailenson,2007) (Reeves and Leighton, 2009) (Blascovich and Bailenson,2013) (Sallnäs,2005) (Zhao,2003) identify key characteristics that transform interaction and impact collaboration, e.g. sharing a virtual space, leadership, creating artifacts, interacting through avatars as digital self-representations using established rules. Most studies of virtual worlds focused on synthetic lab experiments, design or use of virtual world games. Longitudinal studies of 3D virtual worlds in global project teams are limited. Studies of virtual worlds in the construction industry have reported benefits focused on reduction of coordination latency and navigation through BIM models (Anderson et al, 2013).

This paper presents transformative impacts on product, process, and interaction of an immersive 3D virtual collaboration environment in support of global teamwork. The empirical data and findings are based on longitudinal studies performed over four year observing 24 cross-disciplinary, geographically distributed project teams composed of architecture, engineering, construction, and MEP students in the AEC Global Teamwork education testbed.

INTEGRATED RESEARCH AND EDUCATION APPROACH

Methodology. This study used a grounded theory approach (Corbin and Strauss,2008) to observe and formalize transformative impacts of 3D immersive virtual collaboration environments on global teamwork. A series of exploratory experiments were carried out for the first two years, 2008-2010, in the PBL Lab and the AEC Global Teamwork course testbed at Stanford. A 3D virtual world platform called Teleplace Inc., and thereafter Terf 3DICC Inc. was used. Virtual project collaboration spaces were designed and tested to allow distributed team

members to set up any number of displays in any spatial configureation to import and share any project documents, display Web browser content, movies, share and display discipline applications running on their desktop such as Sketchup and Revit BIM models, Navisworks, simulation applications eTabs, 4D CAD, eQuest, etc. We developed a process by which team members can import their 3D BIM models into the virtual world. Empirical data was collected over four years, 2010-2013, from 24 AEC global student teams, 198 participants distributed in more than twenty geographic locations, coming from fourteen partner universities and corporate mentors worldwide. Each AEC global student team had their own 3D virtual collaboration space that they used for 4 months during their projects. The data collection and analysis focused on recording the two hour weekly project team meetings taking place in their 3D virtual collaboration space. More than 400 hours of recordings were collected and analyzed. The author, who teaches the AEC Global Teamwork course and mentors all student teams, played a dual role as observer and participant. This allowed the author to collect field observations that corroborated to the video protocol analysis of the meetings.

The AEC Global Teamwork course is based on the project-based learning (PBL) methodology that focuses on problem based, project organized activities that produce a product for a client, and processes that bring people from multiple disciplines together. It engages faculty, practitioners, and students from different disciplines, who are geographically distributed. It is a two Quarter course offered since 1993 that engages architecture, structural engineering, building systems MEP engineering, life cycle financial management (LCFM), and construction management (CM) students from universities in the US, Europe and Asia.

The focus in this PBL learning model is on the AEC global MS student team. Each team consists of an architect, two structural and one MEP engineers, one LCFM, and two CMs. All teams interact with an client team that expects a functional and sustainable building, on budget and on time. The students have four challenges – cross-disciplinary teamwork, use of advanced collaboration technology, managing task interdependence and coordination over time and space, and multi-cultural teamwork. A building project is the central activity. The project is based on a real university building project that was scoped to address the academic time frame and pedagogic objectives. The project specifications include: 30,000 sqft program for a university building; a university site with its local conditions and challenges for all disciplines, such as architecture style, climate, earthquake, flooding, hurricane, access roads, local materials and labor costs; a budget, and a time for construction. The project progresses from concept development in Winter Quarter to project development in Spring Quarter i.e. 3D BIM coordination, clash detection, 4D CAD, multi-disciplinary model-based simulation and performance evaluation the building. The teams experience fast track project process with intermediary milestones and deliverables.

VIRTUAL WORLD TRANSFORMATIONS OF GLOBAL TEAMWORK

All the AEC global student teams held weekly two hour project meetings. During these sessions they used their immersive 3D virtual collaboration space to present their concepts, explain, clarify, question these concepts, identify and solve problems, negotiate and decide on changes and next steps. Since the concepts, problems and challenges are defined by the students, their level of attention and engagement is maximized. The AEC students are highly motivated to exchange

and acquire as much data, information, and knowledge as they participate in the cross-disciplinary dialogue. The interaction between team members during project meetings evolves from presentation mode to inquiry, exploration, problem solving, and negotiation. Similar to the real world, the teams have tight deadlines, engage in design reviews, negotiate and decide on modifications. Most importantly, students learn to use and combine diverse communication channels and media to express and share their ideas and solutions. http://pbl.stanford.edu/AEC%20projects/projpage.htm. The following are key transformations mediated by the immersive 3D virtual collaboration environment that were formalized in this study.

*Presence***.** The 3D virtual collaboration environment create a sense of "physical presence" or "being there" enabling participants to interact through their avatar with other team members' avatars. This allowed the AEC distributed members to experience a sense of collocation through virtual co-presence, which impacted the behavior and team performance of the team members. Participants navigate through the shared space, negotiate the virtual space similar to the physical world, i.e. avoiding to occupy the same virtual space, e.g., position in front of a display to allow them to view or manipulate the content. Team members reported a high level of participation and engagement in the discussions. This was observed from the data analysis that indicated regular time on task and frequency of time on task. Figure 1 shows a typical AEC team meeting in the shared space.

*Co-Creation***.** Each AEC global student team was provided with their 3D virtual collaboration space that they configured and reconfigured, as well as re-purposed to address their current task and interaction needs and create a shared work context. This co-creation act builds a sense of ownership towards the team space, which becomes their collaboration place that has meaning and purpose. In addition to joint project content co-creation and interaction, e.g. problem solving, presenting and explain proposed solutions, brainstorming and decision making, the shared collaboration space allows for parallel coordinated action where each team member can be working concurrently on their specific data, document, model part in their 3D virtual collaboration place. Figure 1 shows a snapshot from a typical AEC global team meeting with five displays from left to right: task list, whiteboard with a sketch created to explore solutions to a conflict between structural system and architectural layout, a shared desktop with the architect's REVIT floor plan, a shared desktop with the CM's Navisworks clash detection problem, and a display from the team brainstorming.

Persistence of content in context. 3D virtual collaboration environment support both synchronous and asynchronous collaboration. Each AEC global team owns their virtual collaboration space data, information, and models as well as recording of meetings are persistently captured and archived in the context that they were created. This allows re-use or playback of content in context. Team members "*find things as they left them*," as well as geographically distributed team members in different time zones "*find things as you left them*" supporting round the clock team work. This is not the case where project teams meet either collocated in meeting rooms or distributed in video conference room, since all content is saved by each individual member responsible for the respective document, and stored in a project digital document archive.

*From "stacks of content" to "spreads of content in context"***.** It is important to note that the configuration of displays in Figure 1 was not preset but evolved as the dialog of the team progressed towards a solution. This co-creation

of the collaboration space that supports their current task and activities transforms the shared space into a collaboration artifact it self. A comparative analysis of two synchronous ICT used by the AEC global students teams - web conferencing that supports application sharing and the immersive 3D virtual collaboration environment showed the transformation from “stacks of content“ during web conferencing to “spreads of content in context“ in the shared 3D virtual space. “Stacks of content“ indicate that at any time all team members see and interact only with one document that is currently shared by one of the team members. The larger the number of shared documents during the meeting the higher the “stacks of content“ that needs to be constantly reshuffled to bring a needed document to the top of the stack and be shared. Standard cognitive tests show that between three and five visual images can be typically kept in the working memory. The higher the “stacks of content“ the harder it is to recall details from a document shared by another participant. In addition, if the current discussed topic is not relevant to a team member, s/he will switch attention to other unrelated tasks, which in turn will require to repair his/her attention when needed. In the case of “spreads of content in context“ all current and previously shared content and BIM models are visible and available in the context the shared collaboration place was co-created. This allows participants to navigate between what we coined action zone in front of the display with specific content being discussed to the reflection zone (Figure 1) to compare and correlate different types of displayed information.

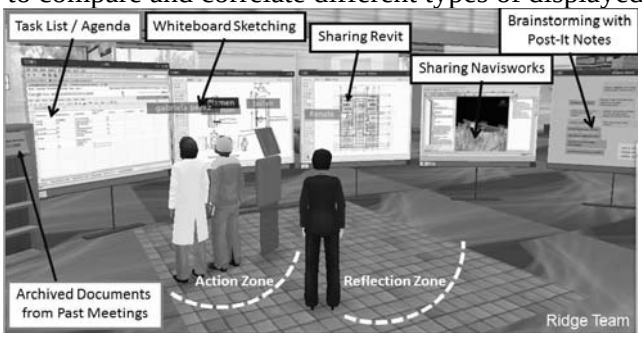


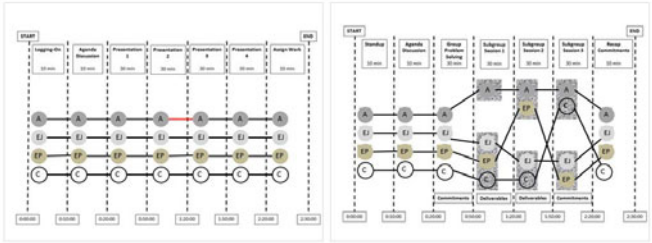
Figure 1. Shared Virtual Collaboration Team Space and Place: Co-creation, Presence and Persistence of Content in Context

From Multitasking to Engagement. AEC students reported that sharing the collaboration space with their team mates’ avatars built continuous awareness of their presence and led to higher degrees of participation and engagement. This is supported by findings from a study focused on attention and engagement comparing two collaboration environments, a web conferencing and application sharing technology and a 3D virtual collaboration environment (Fruchter and Cavallin, 2011). The study found that in intense multi-stakeholder project meetings participants were significantly more engaged in the 3D virtual world which kept participants‘ attention 24% more on task, in terms of time on task and frequency of time on task than in the web conference environment. Multitasking was a typical behavior in web conference meetings due to the “stacks of content” effect as participants optimized the use of their time since they did not have access to material that other members controlled. In contrast, in the 3D virtual collaboration environment multitasking was minimal.

From viewing to experiencing. Visualizing the integrated 3D BIM and multi-disciplinary model-based performance evaluation have led to increased collaboration, early identification and resolution of clashes, project cost and time

reduction. The immersive 3D virtual environment allowed AEC global student teams to import their 3D BIM model into their shared virtual space to experience it together through their avatars. Having the virtual BIM model and the avatars to scale allows them to further troubleshoot design and construction issues that cannot be identified through digital BIM data processing, e.g. egress experience of the stairs or corridors that are designed to code, nevertheless, the client would like to allow for larger groups of people to move together.

*From sequential to agile team process; from meeting minutes to results-driven meetings***.** Integrated project development (IPD) process is becoming increasingly central to large complex building projects. Stakeholders create explicit workflows through explicit production plans. Fruchter and Ivanov (2011) developed an agile IPD production plan process which extends the IPD state-of-practice by integrating the Task List, Production Plan, and Task Interdependence Types (Thompson, 1967). It facilitates the team to make timely and explicit decisions when and how to form sub groups in the case of reciprocal task interdependencies to engage in a sprint (an agile software development concept). Agile IPD is the process of organizing the production process into sprints based on explicit modeling of task interdependence types. The AEC team members co-create a detailed task list, explicitly models the task interdependencies and types. This enables the team to identify which issues lead to reciprocal task interdependencies, who is impacted and needs to be involved in a scrum subgroup sprint, when to schedule the sprint, and what the deliverable of the sprint is. This facilitates transparency of explicit task commitments, task tracking and status, interdisciplinary understanding, and goal oriented teamwork. The task list is revised at weekly meetings allowing planning and re-planning to respond to emerging challenges and client‘s changing needs. The agile IPD approach is implemented at project and meeting level. Figure 2 shows the typical team process transformation from traditional linear and meeting minutes driven session, to an agile IPD results driven meeting with subgroup sprints. The AEC teams use the shared 3D virtual space to display the agile IPD production plan in the central team space and go into virtual breakout rooms for concurrent subgroup sprints (gray boxes in Figure 2b). The weekly meeting ends with all subgroups reporting their spring results and revising the production plan.



(a) (b)

Figure 2. Team Meeting Process Transformation: (a) traditional, meeting minutes driven meeting; and (b) agile IPD, dynamic, results driven meeting

*From group to team***.** The sense of presence and ownership fosters project and task oriented collaboration events in the 3D virtual space, and informal interactions and socialization. This impacts team performance. All the 24 AEC global teams used their virtual collaboration space for diverse social and informal interactions, e.g., virtual surprise birthdays, weekly happy hour.

*From project presentation to unfolding project stories***.** Every two weeks and at project milestones the AEC global teams present their project progress or final solutions. Rather than having a linear power point presentation, the teams are challenged to construct the evolution of their project in a multi-disciplinary context and take advantage of the "spreads of content in context" approach in the 3D virtual collaboration environment. As they present the evolution of their project in the shared space they unfold the project story. This is an opportunity for the AEC students to reflect and deepen their understanding of the journey of their project product and team process.

CONCLUSION

The presented transformations lead to innovative and effective new ways of global teamwork in 3D immersive virtual spaces that address critical challenges for collaboration, coordination, knowledge co-creation and sharing in distributed teams. Both project content and the virtual collaboration space become artifacts of co-creation. This builds a sense of ownership of the team collaboration environment, presence, team identity allowing informal and social interactions. These are critical aspects missing in typical global settings that transform the project prarticipants from a group to a team.

Visualization takes place at multiple levels: (1) co-created collaboration space; (2) team members' presence through their avatars; (3) displayed content and models in context; and (4) experience of walking together with the clients through their virtual building BIM model.

The 3D immersive collaboration space transforms the product development, the team process, and the AEC global teamwork interaction (Figure 2). The product development takes the team product from "stack of content" to co-created persistent "spreads of content in context;" and from viewing to experiencing the BIM model together. The team process in the 3D virtual collaboration space enables the team to move from a sequential meeting process to an agile IPD process that is dynamic, non-linear, and results driven. This led to zero response latency and decision wait time. The teams that transitioned sooner and faster from a sequential process to agile IPD in the 3D collaboration space were winners and runner-ups in the Swinerton Sustainability Challenge, a product centric competition, and the DPR IPD Challenge, a process centric competition. These are indicators based on industry mentors'assessment. The 3D virtual collaboration space allows teams to move from linear presentation to constructing and unfolding their project story. This fosters deeper reflection of cross-disciplinary impacts of discipline proposals and evolution of the project. The 3D virtual collaboration space tranforms the team interaction, i.e. reducing multitasking and increasing participants'engagement.

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REFERENCES

Anderson, A., Dossick, C.S. and Taylor, J.E. (2013) Exploring the Impact of Individual User Navigable Virtual Worlds on Coordination Latency in Distributed CEM Work, EPOC 2013 Proc., eds. Carrillo P. and Chinowsky P.

Blascovich, J. and Bailenson, J. (2013) Infinite Reality: The Hidden Blueprint of Our Virtual Lives, Harper-Collins eBooks Publ.

Chudoba K.M., Wynn E., Lu M., (2005) Watson-Manheim M.B., "How virtual are we? Measuring virtuality and understanding its impact in a global organization" *Information Systems*, 15, 279-306.

Corbin J., Strauss A., (2008) *Basics of qualitative research*, third ed., Sage, Thousand Oaks.

Cramton C.D., (2001) "The mutual knowledge problem and its consequences for dispersed collaboration," *Organization Science*, 12, 3, 346-371.

Fruchter R. and Medlock, L. (2013) "The Journey from Island of Knowledge to Mutual Understanding in Global Business Meetings," *AAAI Spring Symposium Series, Proc. Shikakeology: Designing Triggers for Behavior Change*, eds. N. Matsumura and R. Fruchter

Fruchter, R. and Ivanov, P.V. (2011) "Agile IPD Production Plans as an Engine of Process Change," *Proc. ASCE International Workshop on Computing in Civil Engineering*, eds. Zhu. Y. and Issa R., Miami, June 2011, 776-784

Fruchter, R. and Cavallin, H. (2011) "Attention and Engagement of Remote Team Members in Collaborative Multimedia Environments." *Proc. ASCE International Workshop on Computing in Civil Engineering*, eds. Zhu. Y. and Issa R., Miami, June 2011, 875-882

Fruchter, R. and Bosch-Sijtsema P.M., (2010) "The WALL: participatory design workplace supporting creativity, collaboration and socialization," *International Journal of AI & Society. Journal of Knowledge, Culture and Communication*, Vol. 26, Nr. 3, 221-232.

Hinds P. and Kiesler S., (2002) (Eds.), "Distributed Work" The MIT Press

Maznevski M.L. and Chudoba K.M., (2000) "Bridging space over time: global virtual team dynamics and effectiveness," *Org. Science*. 11, 5, 473-492.

Nardi B.A. and S. Whittaker, (2002) "The place of face-to-face communication in distributed work," Hinds, P. and Kiesler, S. (Eds.), *Distributed work*, MIT Press, 83-110.

O'Leary M.B. and Cummings J.N., (2007) "The spatial, temporal, and configurational characteristics of geographic dispersion in teams. *MIS Quarterly* 31, 3, 433-452.

Reeves B. and Leighton Read J. (2009) *Total Engagement: Using Games and Virtual Worlds to Change the Way People Work and Businesses Compete*, Harvard Business School Publ.

Sallnäs E-L., (2005) "Effects of Communication Mode on Social Presence, Virtual Presence, and Performance in Collaborative Virtual Environments," *Presence* 14,4, 434-449.

Thompson J. D. (1967). *Organizations in Action*, McGraw-Hill.

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

Zhao S., (2003) "Toward a Taxonomy of Copresence," *Presence*, 12, 5, 445-455.