EMERGING TECHNOLOGIES IN A TELE-COLLABORATIVE DESIGN STUDIO BETWEEN THE PENNSYLVANIA STATE UNIVERSITY AND CARLETON UNIVERSITY

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EDITOR: John Messner

Katsuhiko Muramoto, Associate professor,
Department of Architecture, Pennsylvania State University
kxm15@psu.edu

Michael Jemtrud, Associate Professor
School of Architecture, McGill University
michael.jemtrud@mcgill.ca

Sonali Kumar
Department of Architecture, Pennsylvania State University
suk189@psu.edu

Bimal Balakrishnan
Department of Architectural Studies, University of Missouri-Columbia
balakrishnanb@missouri.edu

Danielle Wiley
School of Architecture, Carleton University
daniellewiley@hotmail.com

ABSTRACT: The research project investigates the use of a network-enabled platform (NEP) involving a combination of technologies that include: high bandwidth network infrastructure; high-performance visualization and computer cluster solutions; standard and high definition tele-presence/communication infrastructure; co-located immersive environments; and a range of modeling and imaging applications. The NEP enabled student teams in multiple locations to collaborate via on-demand, synchronous access to project data, visualization, modeling, simulation and multimodal interpersonal communication tools through a web service based dashboard interface that hid the logistic and technical complexities to the user.

As a preliminary report on a proof-of-concept design studio conducted during the spring semester of 2007 between the Carleton Immersive Media Studio (CIMS) at Carleton University in Ottawa and the Immersive Environment Laboratory (IEL) at Pennsylvania State University, the paper first describes the implementation of this network-centric collaborative design platform. The report articulates the "staging" of the conditions of possibility for a dynamic interplay between technological mediation and the reality of making, then compares the use of high bandwidth technology with customized symmetrical toolsets in the tele-collaborative educational environment, versus commercial toolsets deployed over moderate bandwidth connections. In each setting, the collaborative environment is assessed according to issues encountered by students and design outcomes. The effectiveness of the digitally mediated collaborative studio is also gauged in terms of student reaction to the learning process via feedback surveys and questionnaires.

KEYWORDS: design, collaboration, tele-presence, visualization, broadband

1. INTRODUCTION

The process of making a building is inherently collaborative due to the large number and diversity of professionals who are involved. Depending on the complexity of the project, the list of professional involvements can be large (a. site development: planners, civil and environmental engineers, and landscape architects; b. design team: programmers, architects, and interior designers; c. building systems engineers: structural, mechanical, electrical, and building performance engineers; d. construction professionals: estimators, project managers, tradesman, and craftsman; e. stakeholders: owners and building users; and municipality: local code and fire officials). This intense, intimate, and simultaneously creative and technical endeavor involves varying degrees and types of expertise and means of communication, and the success of any collaborative project largely depends on the effectiveness of communications amongst participating contributors. The collaboration in the architecture/engineering/construction (AEC) industry is becoming increasingly more complex and multidisciplinary as building technology advances.

The communication and sharing of assets, resources, and expertise in this context relies heavy on visual modes of communication incorporating a wide range of digital and analog assets. Participants are frequently located in geographically disparate locations from which they contribute a variety of primarily digitally mediated and extremely large data sets that constitute a rich heterogeneous work environment. The survey conducted by Harris Interactive for Adobe in 2006 indicated that the primary modes of communication in the AEC are still e-mail, fax and audio conferencing (66%), and only 16% use web conferencing (Aragon, 2006). The report also cites “the problems with interpreting input” and “the challenge of communicating design intent” as major difficulties in collaborations, brought by the modes of communication currently utilized the AEC industry, and advocates the needs of “more dynamic ways to exchange and communicates information”.

Recent improvements in visualization and communication technologies open up new possibilities for rich modes of creative activity and collaboration. The context of a diverse group of students, working collaboratively on what often may be open-ended design problem, can provide fertile ground for the development and study of systems and methodologies for improving collaborative group learning and problem solving - tools and approaches that can benefit the AEC industry.

During the spring semester of 2007, student teams in two locations participated in a collaborative digital architecture studio, between the Immersive Environment Laboratory (IEL) at Pennsylvania State University and the Carleton Immersive Media Studio (CIMS) at Carleton University, Canada. The experimental design studio investigated the use of a tele-collaborative educational environment in which broadband data networks, high-performance rendering and visualization resources, immersive visualization systems, and supporting multimedia applications were integrated into the design workflow. The objective of the tele-collaborative environment was to create an immersive, information and communications rich environment for dialogue, group problem solving and the shared experience of participatory design. The research agenda is to build upon previous research conducted at the IEL and in CIMS on advanced networks, broadband video, visualization technologies, middleware and interface design, and to investigate how digitally mediated design can facilitate the collaborative design process in ‘real-world scenarios’.

2. BACKGROUND ON DIGITALLY MEDIATED COLLABORATION

The notion of the technologically mediated collaboration has been around since the mid-1990’s as communication technologies evolved and became readily available. The Media Spaces experiment at Xerox PARC (Bly, 1988; Harrison, 1993) utilized video cameras in collaborator’s locations to create a shared virtual workplace. The first Virtual Design Studio (VDS) was conducted in 1994 between 4 universities in North America (Washington University, St. Louis; MIT; University of British Columbia, Vancouver; Cornell); one in Europe (ETSAB, Barcelona) and one in South East Asia (University of Hong Kong). The languages spoken by the students were English, Spanish, and Cantonese. The project was the redesign of Li-Long courtyard housing in Shanghai. Tongji University in Shanghai was responsible for the documentation of existing site conditions. The tools that were used comprised of CAD, Internet and teleconferencing. A “pinup” account was setup in UBC and an ftp server was used to transfer various files (scanned images, CAD files, text files, tiff, emails, DXF and ASCII). The local mirror of the pin-up and hard copies were available in all institutions (Cheng et al. 1994).

For real-time collaboration, interactive whiteboard, image sharing program and a 6-way video conference call were used, but these were slow for successful synchronous collaboration. Some of the problems faced were coordination issues between the 6 institutions along with limited duration of two weeks for the studio and inconsistent presentation skills between the institutions (Wojtowicz and Cheng, 1994). Following this, many tools were developed for distributed design collaboration such as a shared whiteboard program called SYCODE developed by Jabi (1995) that dealt with the issues of early design phase- client debriefing, data collection, architectural program formulation and schematic design generation.

Due to the lack of available collaboration technologies, they had to rely heavily on asynchronous communications such as e-mail, message bulletin boards ("digital pinup boards"), FTP, and the still developing Internet. With insufficiently powerful and crudely coordinated tools, collaboration was primarily in an asynchronous, task-based working process that did not allow for full participation by members of the design teams (Mitchell, 1997). As a result, participation was reduced to "simply submitting and giving oneself over" (Vaitkus, 1991) to the process and other participants.

Since then, various attempts were made (Cornell University, ETH Zurich, MIT, UBC, National University of Singapore and the University of Sydney, Brisbane and Tasmania, ETH, HKU, UW, UBC, and Bauhaus University Weimer in 1997, 1998 and 1999, etc.), and numerous terms have been coined to indicate such endeavors: participatory design, collaborative design, multi-disciplinary design, co-operative design (Achten 2002). The digitally mediated collaborative design studio has become an established part of teaching design within the digital realm (Maher, 2006). They vary in configuration ranging from primarily 2-D and text-based to include various forms of interactive synchronous or asynchronous collaborative function, but the emphasis of most research has been primarily on information exchange during the design process.

A steadily improving network infrastructure with higher bandwidth, lower latency connections and effective media technologies now offers us the possibility for greatly enhanced ways to communicate, contribute and collaborate, allowing real-time interactivity and rich media experiences amongst participants with quality and reliability. Although the recent development of synthesized networking and media technologies has led to significant progress in enhancing collaborative environments in academic settings (Stanford University, University of Strathclide, University of Sydney, MIT Media Lab, U.C. Berkeley, etc.), truly collaborative work is still rare. The transformative nature of these technologies has barely been tapped in design fields and little research has investigated how these recent developments in visualization and communications technologies might play out over long-term use in real-world settings (Viegas and Wattenberg, 2006). There is hardly any research done to speculate on how such a paradigm shift in the world of architecture brought by the recent development in visualization and communication technology opens up different modes of collaboration (Maver and Petric, 2001; Maher, 2006). Most prior research has studied short-term experiments mainly focusing on specific technology features. This research project is an attempt to study the long-term setting, laying more emphasis on the traditional studio and then determining the appropriate network-centric collaborative technological mediation based on their respective affordances.

Many experts predict that Building Information Modeling (BIM) will revolutionize the relationship between design team members and the relationship between design and construction. However, BIM is in essence a project management tool, not a collaboration tool. It only facilitates sharing of information. The sharing of understanding is a necessary condition for any collaborative efforts. Ken Sanders (2004), FAIA, observes that "the critical path isn't BIM, but rather process innovation squarely focused on people, partnerships, shared expertise, and timely decision making." Within such a context, this research is positioned to have a dramatic impact on the practice of architecture and engineering for the built environment.

3. PARTICIPATORY DESIGN STUDIO (PDS)

Design collaboration is to 'work together in a meaningful way, not just working together efficiently, but stimulating each other to contribute to the design task...toward mutual understanding and maximizing outcomes that satisfy not only own respective goals, but also those of other participants" (Achten, 2002). Thus, this "proof-of-concept" and "capacity building" phase of the PDS focused primarily on synchronous collaboration between Penn State University and Carleton University, allowing students of both university to conduct real-time work sessions in which they can exchange different points of view on design by sharing computational resources, geometry datasets, and multimedia content. Access to a high bandwidth Research and Education network allowed for low latencies and high-speed transfer rates to create a "next door phenomenon" thus effectively consolidated resources distributed across the two sites. In order for collaboration to be successful, the environment needs to foster a sense of presence among the participants and to enable transparent conversation and use of resources, and sharing of ideas and thoughts. Therefore, the initial goal of the project was to determine effective thresholds to accomplish a phenomenologically complex participatory experience.

3.1 Facilities and Equipment

The IEL at the School of Architecture and Landscape Architecture at Pennsylvania State University offers a three six-by-eight-foot, panoramic, passive stereoscopic VR display and is supported by multi-platform graphics workstations and software to allow VR-like display of student designs. Conceived as a lower-cost VR alternative to then first-generation CAVE and like systems, the IEL has evolved to support and reflect student work habits, in which VR capabilities often are used with other modeling, multi-media or presentation applications within an immersive information environment, in addition to the intended use purely as an immersive VR display. Figure 1 shows the schematic diagram of the IEL equipment (for further information on the IEL, please refer http://viz.aset.psu.edu/ga5in/ImmersiveEnvironmentsLab.html) The IEL is also equipped with the same SD tele-presence system and is connected to the APN and its associated resources through a 1Gb/s layer 3 PacketNet connection to CIMS. The user pattern at CIMS and IEL suggested that an integrated multimodal platform would best serve at the evaluative stage during the design process, especially in a collaborative setting (Balakrishnan et al., 2006). Current specifications of the IEL, specifically related to this research includes:

- Windows Workstation: IBM Intellistation A Pro workstation, nVidia Quadro FX 4500 PCI Express video adapter, 2x AMD Opteron 256 3.0GHz processors, 4GB RAM
- Projectors: 6x Dell 5100MP, 3300 lumen DLP technology, SXGA+ resolution
- Sound System: ClearOne RAV 900 conferencing system, 2x loudspeakers, 3x ambient microphones, M-Audio Audiphile Firewire external audio interface
- Video capture and processing:
    - AcessGrid: Sony EVI-D100 remote camera, Winnov Videum 4400 video capture card
    - Standard Definition: Sony HDR-FX1 High Definition DV camcorder, Blackmagic Multibridge Pro media bridge, Pleora Ethercast Video IP System.

CIMS at the School of Architecture at Carleton University has at its disposal a robust configuration of network and computer resources, a range of tele-communication platforms, displays and immersive environments. Through the financial and technical support of CANARIE (Canada's broadband agency) CIMS has developed a design specific "Network Enabled Platform" (NEP) to support the complex behavior involved in collaborative architectural decision making across distributed sites. The logistic complexities and configuration of the devices are made transparent to the user and virtualizes a series of workflows through a middleware "dashboard". The resources and devices include rendering and visualization clusters, storage arrays and servers, communication platforms, displays and immersive environments.

The resulting Articulated Private Network (APN) consolidates a variety of resources, assets, and expertise by utilizing an intelligent network that is secure, has low latencies and ultra high speeds. It has 10Gb/s connectivity utilizing User Controlled LightPath (UCLP) software for on-demand control and configuration of the optical network. Levels of connectivity (Layer 2 and 3) in 1Gb/s increments can be obtained by various sites depending upon the user's requirements through UCLP configuration and control. Standard-Definition (270Mb/s one way) and H323 (10-30 Mb/s) video conferencing options are available as well as High-Definition (1-1.5 Gb/s) tele-presence capability for real-time analysis of physical artifacts such as drawings and models. The specification of the CIMS set up was symmetrically to the IEL, with the exception of using two Plasma screens for a display system.

3.2 Participants

A total of 32 students (16 from each institution) participated for this project. They were all enrolled in the third year of five-year professional degree in architecture at the respective institutions. Participants were all under 25 years of age, and four participants were non-native speakers. The software used during the projects ranged from PowerPoint, PhotoShop, Form•Z, 3D Max, Maya AutoCAD, and other modeling software. The PSU students had intermediate level skill on Form•Z, while the CU students had entry-level skills that developed to an intermediate level through the duration of the project.

4. MEDIATION AND "STAGING" OF THE DIGITALLY MEDIATED ENVIRONMENT

The PDS was implemented through a series of collaborative design environments, each of which comprised a loose assemblage of geographically distributed platforms (or "scenes"), including traditional architecture studios at both Penn State and Carleton, immersive media labs, multiple communication and visualization technologies, and a web based network- enabled platform (NEP).

In investigating the modes of participation only achievable through the immediacy and contingency of real-time collaboration, the act of sharing and shaping ideas together 'in situ' became the defining characteristic. The efficacy of such a collaborative environment is governed by how technology and its formal features may shape user interaction, processing and perception of mediated content. Thus, we approached each collaborative design environment as a "staging" – choreographing of a palette of digitally mediated tools, from digital sketching, 3D parametric modeling to simulation within a NEP – in order to evaluate unique conditions for a dynamic interplay between technological mediation and making. The goal in "staging" a digitally mediated environment is to achieve "smoothness." In a "smooth" digital environment, the technological interface ceases to be a hindrance to collaboration and begins to facilitate the communication, creation and representation of an architectural idea. In the context of the PDS, components from the network, middleware, and applications to the computer resources, communications platform, and physical environments are considered the foundation for a given 'staging'.

The stagings, however, are identified reflexively, as they were not wholly determinable a priori to the implementation of the studio. While we began with a basic approach for a network-centric collaborative platform, this platform had to remain open to the emerging requirements of the student participants, to the inevitable logistical barriers and to the integration of new technologies as they became available through the course of the semester. Each staging thus developed, through improvisation and adaptation, into a loose ecology of technologies, locations, facilities and communication protocols.

4.1 Defining the Digitally Mediated Environment

We approached the "staging" of the digital collaborative environment as consisting of three primary "scenes": the IEL, the CIMS lab and, finally, the digital "scene" which, of the three, most urgently needs to be investigated and qualified. This third "scene" of the digital environment is created through a dynamic interaction between the students and the two distinct technological interfaces. Within this third "scene", unique modes of communication, embodiment and subjectivity might emerge.

None of the three primary "scenes" exists as a purely physical or purely virtual space. The IEL and CIMS labs are partially constituted by their extensions into the digital realm. Likewise, the digital "scene" requires a robust physical substrate. The virtual and the physical are interpenetrated and the boundaries between the three "scenes" are very porous. Transgression across these boundaries – the passing of data-sets and assets, but also bodily gestures, expressions and ideas - is the creative activity that actualizes the digital collaborative environment.

5. DESIGN PROJECTS

Two collaborative design projects were posed during the semester; a small museum dedicated to aerospace research in "vertical lift" (helicopters) - Vertical Lift Museum (VLM) at Penn State, duration of 6 weeks and an addition and renovation to the School of Architecture (SoA) at Carleton University, 8 weeks. The students were organized into groups of 4, with 2 students from each school for the VLM. For the SoA, some groups were combined or reorganized, resulting in a variety of group size (4, 6 and 8). The VLM utilized Access Grid, while SoA exploited the potential of the National LamdaRail (layer 3, PacketNet with 1Gb/s connection) and CA*net 4 (Canadian broadband layer 2 with 10gb/s lightpath connectivity) allowing Standard Definition videoconference, Web Service access and control of the APN devices through the dashboard, and utilization of Deep Computing Visualization (DCV), Remote Visual Networking (RVN) solution.

5.1 Project One (VLM – PSU local site) with AccessGrid

Since the proposed project was located at PSU, the Penn State students took responsibility for documenting the existing condition of the building and its context. They transferred these assets to CU students via FTP sites.

The information conveyed consisted of Form•Z digital models, pictures of existing conditions, conventional architectural drawings in PDF format (site plans, building plans, elevations and sections) and video documentation. This first staging was comprised of PSU and CU "conventional" architecture studios; tele-presence suites at CIMS Lab (Sony HDR-FX1 HD DV camcorder and UB1204FX Audio Mixer) and IEL (Sony EVI-D100 remote camera, ClearOne RAV 900 conferencing system with loudspeakers and 3 ambient microphones); a broad range of supplementary pair-to-pair communications, including instant messaging, email, phone plus an FTP site.

Scheduled videoconferences were held once a week for the first three weeks and twice a week for the rest of the project. After the initial meeting session, the students communicated their design intentions via Access Grid conferences, using primarily PDF format with images from Form-Z models and scanned hand drawings, as well as some AutoCAD and other modeling software (Figure 1). The Access Grid conference was easy to operate and robust enough to serve for productive conversation and exchange of concepts and critiquing, thus contributing to the establishment of a common ground for the projects. Most of the design collaboration on the projects, however, was task-based collaboration and happened asynchronously for the duration of the project.

FIG. 1: AG Session Videoconference at the IEL.

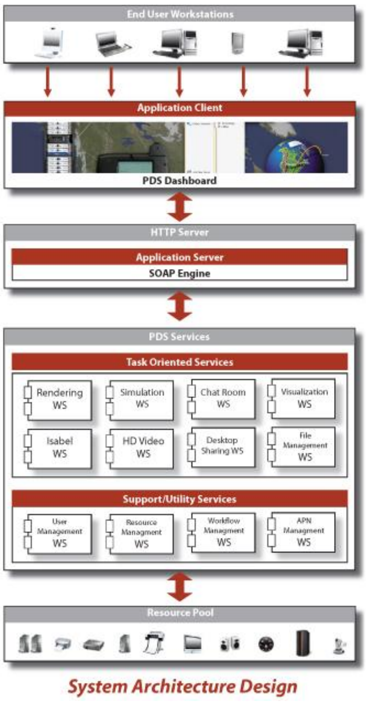
FIG. 2 (left): SD Videoconference Session at the IEL.   *FIG. 3 (right): SD Videoconference Session at CIMS*

5.2 Project Two (SoA – CU local site) with National LamdaRail and CaNet*4

The PSU and CU students thus reversed positions, in that CU students would now be responsible for communicating the unique existing conditions of a complex building, site remote to the PSU students. Similar to the first part of the term, this staging included previously listed items as well as remote sketching programs (Open Canvas) and desktop sharing applications such as TeamSpot. Most significantly, the connection between IEL and CIMS (Figure 2) was switched to the 1Gb/s National LamdaRail PacketNet and CAnet4, allowing the group to deploy uncompressed Standard- Definition (SD) Video using Pleora Technologies' EtherCast; PDS Web Service and Dashboard for ease of control and configuration of devices included in the APN such as the rendering farm located at CIMS and the communication platform (Figure 3); and DCV-RVN for real-time application sharing and high-performance visualization of assets. This PDS project is considered to be the first ‘in the wild’ real-life deployment of the components developed in Eucalyptus (Jemtrud et al., 2006).

5.2.1 PDS Web Service and Dashboard

Previously, there was no work being done to integrate and make the technology ‘smooth’, easy to use, and on-demand for the end users without large support and technical staff. The PDS Web Service and Dashboard brought different tool sets that encompass and streamline almost all stages of the digitally mediated process (Figure 4).



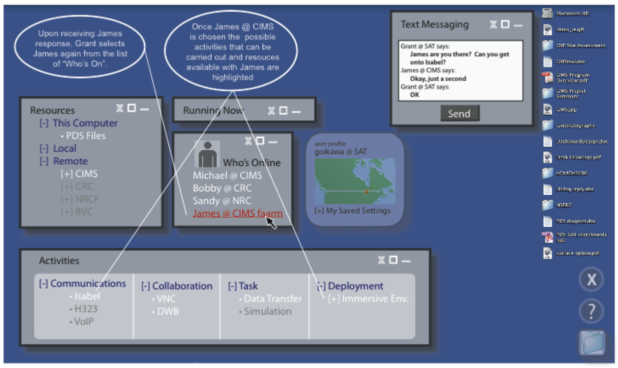


FIG. 4: System Architecture Diagram for PDS (left) FIG. 5 PDS Screen Capture of Dashboard log-in page (right top) FIG. 6: Screen Capture of PDS activity (right bottom)

The dashboard (Figure 5, 6) is a flexible, customizable workspace composed of specific floating interfaces for functions such as video conferencing; file transfer or resource management that allows each user to create the context in which s/he is working. It functions by adding intelligence to the mediated environment and removing actions such as configuration, establishing protocols, and the logical launching of applications in a coordinated manner. Since the workspace is designed by the user and based on his/her workflow, it is an essential part of a user’s practices. Once logged in, the user sees the resources, assets, and people that are located at distributed locations and that comprise his/her work environment and network. The dashboard integrates under a common interface, tools for: Communication: e.g. high- or medium-definition video conferencing, text messaging; Collaboration: e.g. shared computer desktops, digital white board, network capable visualization (IBM Deep Computing Visualization solution) and simulation clusters; Artifact Tasks: e.g. rendering of movies or images, real-time simulations; Deployment: Displaying in immersive environments, distributed and interactive visualizations and models.

The PDS Dashboard is activated (and deactivated) by a hot-key set by the user. When activated, the user’s desktop is dimmed and the floating interfaces come into the foreground. This type of interface operates in the depth of the screen rather than discretely or as a window (i.e. it becomes a layer over the user’s current desktop). This ensures that the desktop does not compete with the other application for space, as would be the case with a taskbar, but literally runs on top of them. The graphic nature and the spatial organization of the dashboard further hides each tool’s complexity from the user and becomes a contingent and responsive component in scenarios of work that are collaborative in nature – facilitating spontaneous participation and exchange (Jemtrud et al., 2006).

The Dashboard is flexible, robust and relatively transparent to users and will become a powerful multi-disciplinary collaboration enabler as more ‘Widgets’ are incorporated.

5.2.2 "Deep Computing Visualization" RVN

The discipline of architecture is dominated by digitally mediated tools and processes that are primarily 3D and time- based, and require sharing of computational resources, large geometrical data sets and multimedia content. Although available software at this point was limited to Maya, RVN immediately became an important element in our collaborative effort. Students were able to share 3D models of projects and examine and discuss design issues together. Manipulations of 3D models from either end were flawless even though the file was fairly hefty. Again, the potential benefit of DCV in a collaborative environment was proven. CIMS and IBM are currently working on the inclusion of Form•Z.

6. RESEARCH FINDINGS

The research aspect of this proof-of-concept design studio focused on the impact of digital communication media on the design process. We captured the communication between students as well as the impact of each extended mediated communication session on the design process through journals. These journals tracked the extent of time, modality, team members who participated in a particular design session and the before and after representations of the design artifact. We also conducted focus group discussions to capture the nuances of the collaborative process as well as surveys to capture the demographics, students' computer skills as well as their sense of social presence, i.e. the extent of 'being together'. We also captured the design presentation as well as the critique sessions through video recordings to analyze the impact of high bandwidth media on design communication and critique. The analysis examines:

- User interface and 'staging' - Analysis on how tools are used, ease of use and feasibility of implementing those tools in a digitally mediated environment
- Collaboration in the Design process

We are summarizing here our findings from the focus group discussions and our end of the semester questionnaire survey, which measured the sense of social presence and broad aspects of students' computer skills and use. Our observations from the field study during the studio and focus group session are discussed below, followed by a summary of results from the data analysis.

6.1 Overall Observations

The focus-group study conducted at the end of semester indicated the schematic implementation of the proof of concept supported a free- flowing, multi-user, participation scenario based around the presentation and manipulation of rich visual design media, and as a result project emerged through a series of interactions between the members of the design team negotiating for a shared understanding via the aforementioned digitally mediated environment.

6.1.1 Observations from Project One

The focus-group study at the end of semester also indicated that audio delay prevented team members from fully experiencing spontaneous idea exchange and generation, as counterparts had to wait to avoid talking over one another and students had to learn to speak slowly and clearly. Most importantly, poor video quality interfered with productive collaboration in the tele-conferences in that subtle communications, such as gestures and facial expressions, could not be clearly conveyed. It was helpful in explaining each other's ideas, but did not allow participants to think and act together. As a result, AG provided little opportunity for one pair to respond to their counterpart's design proposal, or to generate, represent and communicate revisions. This working process resulted in a predominantly asynchronous collaboration, in which each pair completed separate tasks outside of the tele-present meetings. Many PSU and CU pairs developed two parallel projects for several weeks and struggled to resolve their ideas into one shared proposal. In addition, the digital media presentation tools such as PowerPoint leave much to be desired. As it is acknowledged in the previous studies on the differences between remote sketching and computer modeling software during the design process (Maher, 2005; 2006), most of criticisms were that computer-based presentations tend to be formal and rigid, not allowing spontaneous exchange of ideas and interpretations necessary between participants, especially at the early stage of the design process.

6.1.2 Observations from Project Two

Mitchell (1997) pointed out that previous videoconferencing tools often failed to facilitate distributed discussion and negotiation, and often lead to miscommunication between participants. As Kvan (1997) emphasizes, design collaboration requires a higher sense of working together in order to achieve a holistic creative result. Thus the quality of audio/video feed was crucial to the collaborative work sessions as they contribute greatly to the ways that people can relate to each other and build a foundation of shared understanding. Although we could not utilize High- Definition (HD) Video for this experiment, the SD video signal was more than sufficient for team members to observe each other's expressions. Compared with AccessGrid that was limited to conversation only, students quickly took advantage of the quality of video feed by using physical models to explain their ideas and intentions and even quickly sketched their ideas on paper and showed it to partners during the conference. The increased high-quality interactivity at videoconference made it possible to discuss alternative approaches to their design and to explore their design issues more thoroughly. Their design adjustments became much easier and quicker as they became accustomed to the environment. The SD videoconference sessions sufficiently supported an argumentative process in which designers create an environment for a design dialogue (Simon, 1981) where the project is advanced in a team environment.

As with every new technology, a number of difficulties had to be overcome. Although we have experimented in many different settings, the placement of the camera interfered with establishing seamless communication between distributed teams. Since a camera is not placed inside the display screen (similar to iMac), we experienced an "eye-shifting" effect. This was particularly problematic with the IEL due to its screen size, although its large screen size changed the videoconferencing experience for the better.

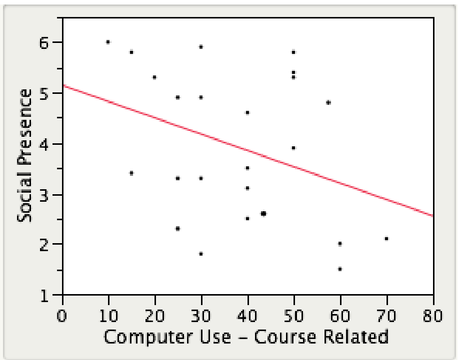
The audio delay observed during the Access Grid sessions was now hardly noticeable. However, even the utilization of the National LamdaRail, a slight delay caused an audio echo on the PSU side since CIMS Lab's lacked hardware echo canceling capacity. It is interesting to note that CIMS never had echo problems in their experiments between Ottawa and Montreal.

6.2 Measuring Social Presence

In our research, we adapted questionnaires from Nowak and Biocca (2003), Schroeder et al. (2001) and Basdogan et al. (2000) to measure social presence. Social presence was measured using a 25-item, 7-point likert-type scale. The questionnaire also included measures of computer use for academic and leisure purposes, expertise with various software used for architectural design representation and presentation. Responses were collected from 26 students who participated in the collaborative studio of which 48% were females and their age ranged from 20 to 23 years (S.D = 1.01).

The self-reported mean computer use for all course related purposes was 37.43 hours per week (S.D. = 16.95) and leisure related activities were 11.28 hours per week (S.D. = 5.3). Form.Z (mean use of 12.98 hrs per week) and Photoshop (mean use of 15.5 hrs per week) were the most commonly used software. At the time of the survey, the students had a little over 16 months (Mean = 16.36 S.D.= 9.84) of experience with 3-d modeling software and close to 3 years of experience with 2-dimensional graphics packages (Mean = 34.8, S.D. = 11.56).

Principal component analysis was used to analyze the dimensionality of the twenty-five items used to measure presence. Based on the scree plot, three underlying factors were identified accounting for 69.04% of the variance. On rotation using a Varimax procedure, sixteen items loaded clearly onto the three factors with their highest loading exceeding 0.6 and the other loadings less than 0.4. The remaining nine items, which cross-loaded across the factors, were discarded from further analysis. The rotated solution yielded three factors, social presence, relational distance and non-mediation. Social presence index (Cronbach's alpha = 0.96) was constructed by additively combining the 10 items measuring the extent of awareness and reciprocity between distributed team members. Similarly a non- mediation index (Cronbach's alpha = 0.67) was created by additively combining the 3 items measuring the extent to which the interface seemed to vanish. The third factor, relational distance comprising of three items measuring the extent of closeness between the team members was dropped from further analysis due to low reliability (Cronbach's alpha = 0.49). The students indicated a somewhat moderate effect for social presence (Figure 7), with a mean score of 3.78 (S.D. = 1.59) on a scale of 0 to 6 and a similar effect for non-mediation (Figure 8) with a score of 3.24 (S.D. = 1.32), again on a scale of 0 to 6.



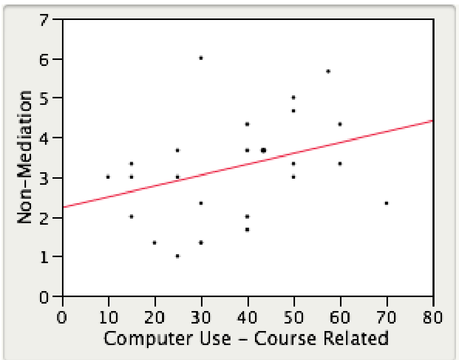


FIG. 7: Social Presence (left) and FIG. 8: Non-mediation (Right).

Table 1: Factor Loading.

	Item-1: Social Presence	**Item-2: Relational Distance**	**Item-3: Non-mediation**
1. Involved in online design interactions.	0.659	0.561	0.142
2. Design interactions stimulating	0.716	0.462	0.251
3. Communicated coldness rather than warmth*	**0.786**	0.078	0.355
4. Created a sense of distance between team-mates*	**0.870**	0.081	0.259
5. Seemed detached during our design interactions*	**0.819**	0.285	0.318
6. Unwilling to share personal information*	**0.671**	0.311	0.336
7. Made our conversation seem intimate	**0.655**	0.188	0.011
8. Created a sense of closeness	0.568	-0.227	0.186
9. Appeared bored by our conversation*	**0.795**	0.331	-0.004
10. Were interested in talking to us	**0.865**	0.284	0.087
11. Showed enthusiasm while talking to us	**0.873**	0.212	0.006
12. Did not want a deeper relationship with team mates*	0.197	**0.702**	0.262
13. Wanted to maintain a sense of distance*	0.279	**0.720**	-0.065
14. Were unwilling to share personal information*	0.158	-0.043	0.352
15. Wanted to make the conversation more intimate*	-0.015	**0.627**	-0.037
16. We tried to create a sense of closeness	0.465	0.455	0.454
17. Interested in talking	0.683	0.587	-0.079
18. Extent of collaboration	**0.900**	0,169	0.168
19. Future design collaboration with same partners?	**0.858**	0.111	0.254
20. Sense of being together with partners	0.006	0.391	**0.821**
21. Sense of being in the same room	0.190	0.612	0.588
22. Computer interface seemed to vanish feeling of directly working with the other person	0.047	0.413	**0.607**
23. Interacting with a computer as opposed to working with another person	0.267	-0.273	**0.764**
24. Similar to the face-to-face experience	0.742	-0.373	0.464
25. Merely responding to some screen images as opposed to being with another person	0.689	-0.227	0.478

Despite the differences in the display settings of the IEL and CIMS, the differences in average social presence score of Penn State students (mean = 3.77) was not significantly different, t (21) = -.03; p = 0.97, from that of their Carleton counterparts (mean = 3.79). Similarly there was no significant difference t (22) = .63; p = 0.53 in the non- mediation score between the Carleton (mean = 3.08) and Penn State students (mean = 3.42). While gender is often seen as a factor affecting presence, in this case there was no significant difference, t (21) = .03; p = 0.98, between males (mean = 3.79) and females (mean = 3.77) in their social presence scores. We also did not find any significant difference, t (22) = -.35; p = 0.72, between males (mean = 3.14) and females (mean = 3.33) in their non-mediation scores. Simple linear regressions seemed to indicate that increase in use of computers for course related purposes tends to decrease social presence scores, but tended to increase the feeling of non-mediation.

7. CONCLUDING REMARKS: CHALLENGES

The PDS project is still at the phase of identifying enablers and inhibitors, but the preliminary research results indicated that the SD videoconferencing via National LambdaRail PacketNet/CAnet4 sessions overcame previous limitations and fostered a higher sense of working together thus provided a true real-time collaborative opportunity for participating students. Based on our observations during this phase of the PDS, we identified the following issues.

7.1 Teamwork

The success of any collaborative project is contingent on the fact that participating students can come to a mutually agreeable concept, which ideally is the summation of all ideas of the design team members. Although it is becoming more popular in many schools, collaborative design studio is still rare. In contrast to the reality of practice, design activity in academia is usually considered to be an individual pursuit. By working alone on projects, many students distill a 'Fountainhead' syndrome; a creative protagonist who refuses to compromise his/her artistic visions in pursuit of an 'ideal' project. Thus many students are not exposed to *"a collaborative learning experience, one that brings students to understand how to explore and learn together in design without the ego of any individual dominating"* (Kvan, 2001). Collaborative team performance is affected by levels of mutual trust (Larsen & McInerney, 2002), and Chen et al (1994) emphasizes that "trust, which leads to rapport, is very critical in the germinating stages of projects when directions are being formulated". As Hinson (2006) describes, the importance of effective communication skills, expertise at managing collaborative relationships, and an understanding of interdisciplinary approaches to problem solving are just as, if not more, vital to the success of any project, we need to increase our students' exposure to the 'interdisciplinary reality of the professional world'.

7.2 Representation

The modes of representation, especially at the early stages of the design process are very critical to the collaborative design process. Traditionally sketching is considered to be a valuable design activity, functioning as both means of communication and generation/exploration of design concept. This 'quick and dirty' form of representation, although it is often rough, inaccurate and incomplete, is 'an essential part of the process of thinking about a design problem and developing a design solution' (Purcell and Gero, 1998). Contrary to sketching, computer-based presentations tend to be formal and rigid, not allowing spontaneous exchange of ideas and interpretations necessary between participants. The lack of ambiguity in most drawings often prevents design team members to conjecture, thus not allowing new concepts to emerge. Not being able to merge each other's concepts into one shared concept often leads to 'our idea' vs. 'your idea'. As we noted above, the SD teleconference somewhat overcame this issue and allowed participating students to exploit conventional sketching as a means of communication. This permitted students to instigate, evaluate and modify their project quickly in an attempt to collectively advance their project (Figure 9). This ability to support fast iterations is very important due to the limited conference time available to each group (Figure 10). Further research on how traditional tools and work processes can be transformed and integrated, and how to best harness the potentials of digital tools in the PDS, especially at early stages of the design process, is urgently needed.

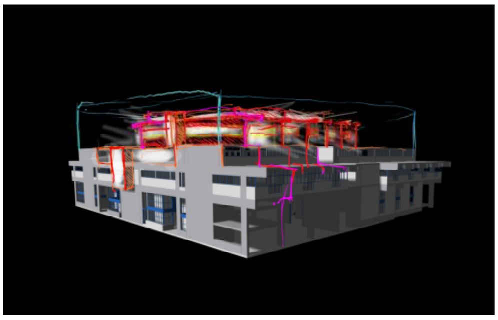


FIG. 9 (left): Final Proposal. FIG. 10 (right): Design process using Open Canvas

Table 2: Issues of Cyber enabled collaboration based on journal.

Lack of Sketching	**Decision-making**	**Gestures and Idea exchange**
Yes we should have sketches to explain to each other I wish I could just use the pen sketch tool on here, it would be so much easier	I think that we should each talk about the positive aspects of the opposite team's proposal, and then we find the right overlaps. We set ourselves down and really only work with the good things that we share in common.	Can we arrange with you guys for a videoconference tomorrow? So that we can sketch things out together
Skype would work right now if we were using a two way digital whiteboard	Well, it might be more useful to just compare differences and their intentional basis rather than criticisms on specific schemes	I think the problem here is just a lack of communication this past week

7.3 Decision making

Design decisions, both major and minor, are made all the time during the design process, quite often at the desk while working individually on a project. Overall design direction was discussed and major design decisions were discussed and decided during the teleconferences. However, the review of participants' journals indicated many, often crucial; decisions were made between the teleconferences, via telephone calls, emails and instant messaging without aid of real-time shared visual materials. Miscommunication and misunderstandings are almost unavoidable in such circumstances. As previous pictures from the IEL and SIMS illustrate, the PDS Dashboard interface is flexible enough to be employed in full-fledged immersive screen setting with broadband connectivity like the IEL in small board meeting utilizing large TV(s) or even on a computer display, with or without a broadband connection. The PDS Dashboard's effectiveness on one-to-one design desk settings needs to be tested in the next phase of the project. Further experimentations on staging of one-to-one and one-to-many synchronous and asynchronous visual and verbal communication methods, and formal and informal means of communications in each stage of design process are needed.

8. FUTURE PLANS

Research in 'staging' of the digitally mediated environment will continue by acknowledging the multi-stage architectural design process: program development, schematic design, preliminary design, design development, contract drawings, shop drawings, and construction (Laseau, 1980). Each stage necessitates various requirements and different kinds of collaboration, thus different communication scenarios need to be studied and evaluated. We believe that further work and experimentation in exporting key elements of immersive visualization experiences will produce a new immersive collaboration paradigm, widening the audience for both collaborative and immersive visualization technologies.

The report described here is 'collaborative' in a very limited sense in that it involved only architecture students. However, the process of AEC collaboration naturally involves more individuals with different disciplinary knowledge. In order for this experiment to be tested in such an endeavor, the first step is to identify and recognize the different interests of those involved. Also, disparate vocabulary, both visual and verbal, and diverse representation methods among different disciplines need to be acknowledged. Additionally, there is often a conflict with students' class schedules, preventing a smooth collaboration between involved students. Thus, pro's and con's of both asynchronous and synchronous collaboration needs to be investigated. Most importantly, there is a strong need to establish a common language and set of tools in order for a diverse group of disciplines, with different objectives and goals, to collaborate successfully.

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