Communication, Coordination and Collaboration: Media Affordances and Team Performance in a Collaborative Design Environment

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Advances in digital media are encouraging designers to adopt digital tools during early stages of design ideation as well as to facilitate collaboration in design teams. Collaborative environments for design teams should take into consideration both the multimodal nature of design representation as well as the complexity of team cognition. Collaborative tools that take a "black-box" approach often limit affordances for design ideation and collaboration. We describe here a collaborative environment that we put together using a kit-of-parts approach and underlying theoretical considerations. We also describe systematic usability evaluation of the collaborative environment by constraining select media affordances and qualitatively examining the impact on a team's design process. Preliminary findings were used to improve the environment and lay the groundwork for developing tele-collaborative environments.

Keywords: *Digitally-Mediated Design Collaboration, Transactive Memory, Team Performance, Design Presentation*

INTRODUCTION

Design practice, over the decades, has moved away from the ideal of the multi-skilled renaissance man to that of renaissance teams (Buxton 2007). With advances in the development of specialized software for design drawing (e.g. Autodesk Sketchbook Pro) and input devices such as the stylus and tablets that afford more natural drawing experience (e.g. Wacom tablets), digital tools are increasingly used in early stages of the design process. Designers still work with a variety of representational media that help with ideation at different levels of abstraction. Sharing representations seamlessly with collaborators even in a co-located setting remains a challenge when designers continue to use their familiar computing tools that are good at representation, but not on sharing or communication. Many collaborative tools for design overlook the multimodal nature of design representation and take a "black-box" approach that forces the designer to work with a given set of tools within the collaborative platform. We believe that a "sand-box" approach where designers can bring familiar tools and workflow will be better suited to facilitate design collaboration. We took a kit-of-parts approach to developing a digital collaboration environment for co-located teams. This collaboration environment was developed based on theoretical considerations and was built on existing workflows and practices in our studios. We then tested our collaborative environment by constraining select media affordances and qualitatively examined the impact on the design process.

THEORETICAL CONSIDERATIONS FOR DEVELOPMENT OF A COLLABORATIVE ENVIRONMENT

In developing our collaborative environment, we draw on two theoretical areas. The first one deals with the role of representations in the design process and implications for digitally-mediated design environments and, the other dealing with the concept of shared cognition in the context of the team mind.

Representation-Presentation Distinction

In developing our collaboration environment, we make a critical distinction between representation and presentation in the context of architectural design. Representation according to Carpendale and Montagnese (2001, p. 61) is "the act of creating an image that corresponds to the information" and presentation as the "act of displaying this image, emphasizing and organizing areas of interest. " Representations are primarily tools to aid reasoning and creative process and presentations primarily serve a communication purpose. The representation-presentation distinction is further complicated by the fact that they lie in a continuum. This is analogous to MacEachren's (1995) depiction of cartography as a cubic map-use space with visualization and communication occupying opposite poles. In the design process and communication, representation and presentation can be respectively mapped on to the visualization - communication poles. This also will help to clarify distinctions between the two such as the level of interaction (at value level for representation - at view level for presentation), purpose (exploration of unknown - communicating known) and intended domain (private - public). We build on our prior work (Balakrishnan et al. 2007) that leverages these ideas to develop display environments for architectural design.

Theories of Team Mind

Transactive Memory. Another important theoretical idea underlying the development of our collaborative environment is that of transactive memory system (Wegner 1987) through which a given group encodes, stores and retrieves knowledge. Transactive memory systems support the underlying performance of group efforts on solving problems by providing access to more efficient and much larger stores of information as well as a much faster recall of pertinent knowledge to address a problem (Ren et al. 2006). The success and performance of the group in carrying out these activities become dependent on a large pool of information being divided amongst the members of the group while, still allowing each individual direct access to the information (Brandon and Hollingshead 2004). In this way, transactive memory systems provide a platform for accessing individual memory as well as to indicate each member's expertise. From this perspective, transactive memory consists of three main parts: task, expertise, and person or TEP (Brandon and Hollingshead 2004). Tasks pertaining to the overall group task and each individual task taken on along with knowing what expertise is available to accomplish the task and the person who holds the information. In considering these three parts, transactive memory system development becomes highly dependent on each group member's perception of cognitive interdependence as each individual's outcome was linked to the performance of other's in the system (Brandon and Hollingshead 2004; Wegner 1987). Meaning that without members of the group knowing the task, what expertise is available and who holds what information, a group may not be successful in forming a true transactive memory system.

One aspect of transactive memory systems that considers how these three parts occur is through specialization within a group (DeChurch and Mesmer-Magnus 2010). Specialization allows for the reduction of the individual work load for each member while adding immense coordination efforts amongst all members as the group must not track not only who knows what but who is doing what (Brandon and Hollingshead 2004). Choi et al. (2010) noted that information technology is one avenue to help facilitate this type of coordination amongst groups. Mechanistic memory is the medium for storing and sharing all the files and records of work on a task (Akgün et al. 2006). Collaboration software and other information technology pieces offer different forms of mechanistic memory available for groups to use. Using a transactive memory system that utilizes a mechanistic memory can improve the overall effectiveness of the team while reducing the overall misuse of information (Akgün et al. 2006; Choi et al. 2010). Collaboration tools in particular work to encourage and enhance certain types of communication, furthering the development of the transactive memory system. These tools provide information on authorship of files, require minimal effort to retrieve files, and allow for multiple files to be view simultaneously all while providing an avenue for continuous forms of communication (discussion boards, voice chat, etc.).

Our shared digital workspace acts as a seamless mechanistic and transactive memory where artifacts from individual memory could be shared with the group and interacted by all group members. Team members can use specialization to organize their coordination in completing a task by knowing who knows what information as well as to see who is carrying out which task. This leads us to believe that key differences in the collaborative environment can facilitate how transactive memory is utilized in conducting an architectural task.

Shared Cognition. One of the biggest strengths in groups or teams is the shared team mental model that forms, or the aggregate of individual mental models (Cooke et al. 2013). This idea of shared team mental models have been identified from two key constructs: team mental models (TMMs) and shared mental models (SMMs). Cooke et al. (2013) makes a distinction between the two models where TMMs refer to stored team-level representations and SMMs refer to changes in individual member's mental models due to influences of the team. Both types of mental models work to influence the performance of the group where TMMs aid in the overall solutions produced by the team and SMMs aid in the interpersonal communications between group members. In particular, TMMs are the emergent states in which teams can organize, anticipate and execute actions based on knowledge, which is important to the team (DeChurch and Mesmer-Magnus 2010).

The group mental model is a representation of the knowledge the team has to support their overall performance in an endeavor based on similarity, overlap, and complementarity (Dong et al. 2013; Badke-Schaub et al. 2007). In the creative setting such as with design teams, the team mental model is one built off of diversity and an understanding of what that diversity can bring to the task at hand. Badke-Schaub et al. (2007) describes this diversity as a setting for distributing the cognitive load across different members of the team to not only form the transactive memory system but, to also aid in broadening the solution space for the designated problem. Three main factors are listed as having influence on team mental models and subsequent performance: the operational environment the team resides in, the nature of the task, and at which stage in the design process the group is working (Badke-Schaub et al. 2007; Dong et al. 2013).

However, knowledge in design problems and tasks are not as concrete as facts and other forms of knowledge thus making understanding of the design team mental model more challenging (Badke-Schaub et al. 2007). This is due to the individualistic nature of how a designer explores different factors of the problem through various proposed solutions to aid in determining the overall success of a solution (Dong et al. 2013). Therefore, design team mental models are dependent on the collective agreement of the factors to be addressed with a design concept, or having a common operational picture of what the end solution should aspire to become, while still having divergent individual perspectives. To date, exploration of design team cognition has been mostly

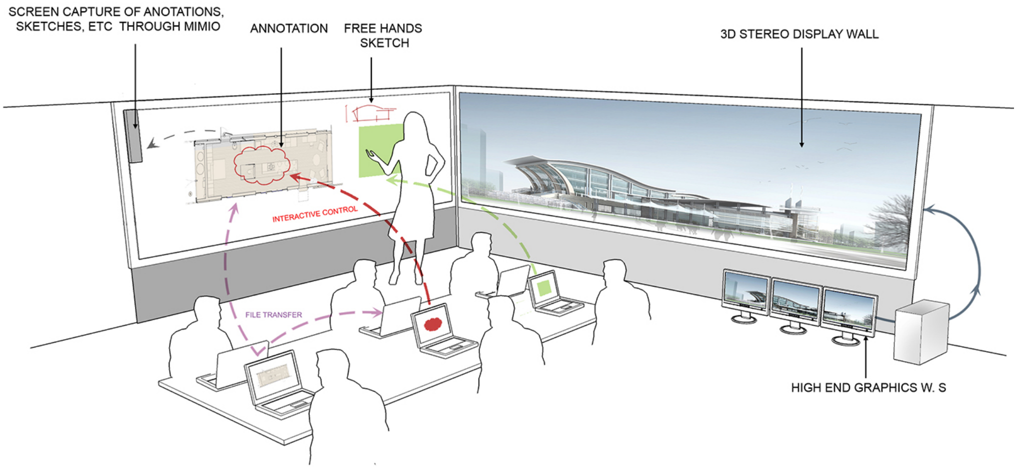

Figure 1
Schematic of our collaborative environment

focused on the study of artifacts developed instead of the actual team interactions and communication (Dong et al. 2013).

DEVELOPMENT OF THE COLLABORATIVE DESIGN ENVIRONMENT USING A KIT-OF-PARTS APPROACH

Our collaborative environment as illustrated in figure 1, comprised of a 12 feet by 8 feet whiteboard that acted as the primary shared workspace for digitally mediated collaboration. The whiteboard is augmented by a short throw projector to share digital content as well as eBeam technology from Luidia Inc. for digitally capturing the interactions on the whiteboard whether using whiteboard markers or using stylus for projected content. In addition to the whiteboard-capture technology, the TeamSpot collaboration software suite from Tidebreak Inc. form the heart of the collaborative environment. The TeamSpot software connects the individual laptops and desktops to the shared digital work surface. It allows movement of information and artifacts across devices to the shared workspace or to other team members. This transfer of documents and drawings irrespective of the file type or software origin and web URLs is achieved through an intuitive drag and drop transfer. Individual users can also edit any file in the shared workspace. TeamSpot software facilitates this collaboration using the PointRight system (Johanson et al. 2002) that facilitates pointer and keyboard redirection in collaborative environments that include a multi-machine, multi-display set-up. A set of graphics workstations including laptops and desktops equipped with a variety of 3-d modeling, image editing and presentation software and input devices like Wacom tablets complete the collaborative environment. The collaborative environment is also connected to our 18 feet by 6 feet stereoscopic display to facilitate immersive visualization of designs. The number of workstations in our collaborative environment is flexible and we have used varying configurations from 3 to 9 workstations.

USABILITY TESTING AND EMPIRICAL EVALUATION OF THE COLLABORATIVE ENVIRONMENT

We evaluated the usability of our collaborative environment during implementation with undergraduate students after obtaining informed consent (see figure 2). Participation of human subjects in these evaluations were also approved by our Institutional Review Board for research. During the usability evaluations, the overall experience was seen as positive with many appealing features. The feedback also included some good suggestions for improvement and directions for future development. We took a systematic approach to the usability evaluations. We first provided participants with training to use the TeamSpot software and hardware components such as the e-Beam tracker for collaboration. We then provided them with short-structured tasks, for example editing a simple geometric model collaboratively or share and edit files individually. We recorded our observations of their use of our collaborative environment to identify areas of strength and weakness.

We also conducted a systematic empirical investigation into the theoretical ideas underlying the collaboration environment. We created three scenarios with different media affordances for collaboration, drawing on the conceptual distinctions made by Kvan (2000) between collaboration, coordination and cooperation. We restricted certain features of our collaborative environment to investigate the impact of those features on collaboration dynamics and team performance systematically. The first scenario utilized all the features of the collaborative environment including the shared digital workspace allowing interactions with original representations as well

Figure 2
The collaborative environment in use

as the ability to share screen views and files between team members on a one-to-one basis facilitated using the TeamSpot software. In the second scenario, we used Teamviewer software in place of TeamSpot as the main collaborative platform. This scenario did not include the shared digital workspace where all team members could work simultaneously on a representation. However, it allowed one-to-one collaboration between the team members through screen and desktop sharing. In the third scenario, while the team members where still co-located, no electronically mediated collaborative platform was used. We assigned single-family residential projects of similar scope and type for each of the scenarios, but varied the context and persona of the end users for the design. We collected a variety of dependent measures drawing on existing design collaboration literature (e.g. Gabriel and Maher 2002; Gao and Kvan 2004).

Data collected included coding of cognitive data, design activity and communication control among other measures of design performance. In addition to observation and analysis of each team's use of the collaborative environment in a given scenario, the team members completed a questionnaire evaluating it. The questionnaire included Likert type items evaluating the quality of the teamwork as well as the formal features of the collaborative environment for that scenario. The team members also completed a detailed, open-ended questionnaire assessing their overall experience, identifying appealing features; pointing out frustrations, their perceptions of the collaborative environment's impact on team performance and suggestions for improvement. A summary of the usability evaluation and empirical investigation into the collaborative affordances of our environment is provided below after a brief description of the design task and team composition.

Design Task and Team Composition for Evaluation

The design task was kept comparable for all three scenarios tested. The team was tasked with designing a single-family residence for a young couple. Programmatic requirements included a foyer, formal living and dining areas, a master bedroom, and a kitchen and laundry space. Some changes were introduced in the design brief for each scenario to encourage the team to start with fresh ideas such as new site and slight changes in programmatic requirements. The time to develop design ideas and generate presentation drawings was kept consistent across scenarios. The team completed the design task in a given scenario in three consecutive sessions with a short break between them. The three sessions focused respectively on conceptual design, design development and design presentation. The team was also presented with a set of deliverables for each stage in the form of digital drawings, images or 3-d models. Three students in the final year of our undergraduate program in architectural studies were identified for the project. The selected students had worked together extensively as a team on many class projects as well as during their internship.

User feedback from usability testing and empirical evaluations

The participants pointed out that overall experience was highly positive. The ability to use common design and CAD tools on familiar computing hardware along with the opportunity for any team member to bring any digital representation to the shared workspace and allow it to be manipulated it by others was seen as the key. The transparency of the collaborative interface, the streamlining of the communication process and the ease of use were pointed out as other positives. The participants liked the large display of the shared workspace, the ability to show and share screens with other users as well as the ability to interact with another user's screen from their own computer. Ability to take a "snapshot" and "record" key decisions and ideas as the happen during the collaboration process and the ability to "archive" collaborative sessions was seen as a useful feature. These features taken together in the opinion of one participant can be seen as a design recorder that allowed the team members to reflect on the collaborative design process and retrace design steps during the revision process. The ease of switching back and forth from working individually on their own computers to working in a truly collaborative fashion in the shared workspace was another highlight.

Participants suggested the need for more practice sessions for both technological and for social reasons. Some features such as multiple mouse-ins on the shared workspace while easy to learn needed some getting used to. We also noticed that our collaborative platform aimed at democratizing the collaborative environment for all team members presented some interesting modifications to group dynamics. The e-Beam could only track one marker or stylus at a time on the white board, which slowed down the process and affected the natural rhythm of interactions. Participants suggested Wacom tablets as peripherals for the graphics workstations so that other users can "sketch" at the same time. We have since implemented this in a more recent upgrade of our collaborative environment. Remaining suggestions had to do with room layout and furniture arrangement. Wherever possible, we made improvements in the implementation to enhance the collaborative experience.

CONCLUSION AND NEXT STEPS

Usability analysis and preliminary data from our empirical study suggests an overall positive reception to the collaborative environment discussed here. We are currently engaged in detailed analysis of the empirical data that we collected from this project. We expect to have a more nuanced understanding of the relationship between media affordances and efficacy of design collaboration and to see the overall impact on the occurrence of transactive memory and overall team cognition. This will inform further development of our own collaborative environment as well as help others take a kit-of-parts approach to implement their own collaborative environment that best fits their need. We are now working to extend this co-located design collaboration approach to facilitate remote collaboration by integrating video conferencing that can work across different network bandwidths as well as devices. If successful, this remote collaboration initiative can inform development of online design studio courses that retains the richness of the interaction between the design instructor and the student in traditional design studios that are taught face to face.

REFERENCES

Akgün, AE, Byrne, JC, Keskin, H and Lynn, GS, 2006, 'Transactive memory system in new product development teams', *IEEE Transactions on Engineering Management*, 53(1), pp. 95-111

Badke-Schaub, P, Neumann, A, Lauche, K and Mohammed, S, 2007, 'Mental models in design teams: A valid approach to performance in design collaboration?', *CoDesign*, 3(1), pp. 5-20

Balakrishnan, B, Kalisperis, LN and Muramoto, K, 2007 'Implications of Representation-Presentation Distinction in Developing a Presentation Environment for CAAD', *Proceedings of the Annual Conference of Education and Research in Computer Aided Architectural Design in Europe (eCAADe)*, Frankfurt am Main, pp. 133-139

Brandon, DP and Hollingshead, AB, 2004, 'Transactive memory systems in organizations: Matching tasks, expertise, and people', *Organization Science*, 15(6), pp. 633-644

Buxton, W, 2007, *Sketching user experiences: Getting the design right and the right design*, Morgan Kauffman, San Francisco

Carpendale, MST and Montagnese, C, 2001 'A framework for unifying presentation space', *Proceedings of UIST '01*, Orlando, pp. 61-70

Choi, SY, Lee, H and Yoo, Y, 2010, 'The impact of information technology and transactive memory systems on knowledge sharing, application, and team performance: A field study.', *MIS Quarterly*, 34(4), pp. 855-870

Cooke, NJ, Gorman, JC, Myers, CW and Duran, JL, 2013, 'Interactive team cognition', *Cognitive Science*, 37, pp. 255-285

DeChurch, LA and Mesmer-Magnus, JR, 2010, 'The cognitive underpinnings of effective teamwork: A meta-analysis', *Journal of Applied Psychology*, 95(1), pp. 32-53

Dong, A, Kleinsmann, MS and Deken, F, 2013, 'Investigating design cognition in the construction and enactment of team mental models', *Design Studies*, 34(1),

pp. 1-33
Gabriel, GC and Maher, ML, 2002, 'Coding and modelling communication in architectural collaborative design', *Automation in Construction*, 11, pp. 199-211
Gao, S and Kvan, T, 2004, 'An analysis of problem framing in multiple settings', in Gero, JS (eds) 2004, *Design Computing and Cognition*, Springer, Netherlands, pp. 117-133
Johanson, B, Hutchins, G, Winograd, T and Stone, M, 2002 'PointRight: experience with flexible input redirection in interactive workspaces', *Proceedings of the 15th annual ACM symposium on User Interface Software and Technology (UIST '02)*, Paris, pp. 227-234
Kvan, T, 2000, 'Collaborative design: what is it?', *Automation in Construction*, 9, p. 409–415
MacEachren, AM, 1995, *How maps work: Representation, visualization, and design*, The Guilford Press, New York
Ren, Y, Carley, KM and Argote, L, 2006, 'The contingent effects of transactive memory: When is it more beneficial to know what others know?', *Management Science*, 52(5), pp. 671-682
Wegner, DM, 1987, 'Transactive memory: A contemporary analysis of the group mind', in Mullen, B and Goethals, GR (eds) 1987, *Theories of group behavior*, Springer-Verlag, New York, pp. 185-208