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Designing Together While Apart

The Role of Computer-Mediated Communication and Collaborative Virtual Environments on Design Collaboration

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***Abstract*—This paper presents an empirical study of two student pairs collaborating on two small products design session in both face-to-face and distributed settings while using Computer-Mediated Communication (CMC) technologies and a Collaborative Virtual Environment (CVE). To gain insight about the way designers communicate and collaborate, the observation focused on how much time the students worked together and individually in the design process. The study shows that teams worked together more in the distributed setting than in the face-to-face setting. In the post-test questionnaires, participants reported that they found the distributed setting a more engaging environment to work with teammates. Findings of the study suggest plausible design criteria for a communication system for distributed collaboration that supports interaction and sharing design information.**

***Keywords*—Collaborative Design, Computer-Supported Collaborative Design, CMC, CVE**

I. Introduction

Individuals working on design teams are increasingly geographically distributed. That is, they work in different locations. In addition, they are becoming more proficient with 2D or 3D Computer-aided design (CAD) tools, increasing their ability to collaboratively share, evaluate, and critique virtually (e.g., by sharing drawings via email) [10]. Despite the increase in collaborative design, the majority of designers are not completely satisfied with the way their company shares project information [13]. In a recent study, 71 % of questionnaire respondents said that they were dissatisfied with the CAD review capabilities at their company. Current CAD software for viewing and commenting on another's work is limited, so designers typically end up sending CAD files via email [13].

Some would argue that design is the product of highly talented individuals. Studies investigating the creativity of designers, however, have suggested that only a few are highly creative [9]. In fact, many studies have demonstrated that the outcomes of a team of designers are often better than those of individual designers [7,15].

Collaboration in design is considered an activity in which teams of designers work towards a final solution [2,9,14]. Many studies demonstrate that collaboration in design depends heavily upon negotiation strategies from social interaction. Whereas a designer working alone does not have to deal with negotiation, design teams must reach consensus [1,6,11,12]. Indeed, social interaction is the key for successful collaboration because the quality of design is not driven by technology alone but also the quality of communications [2,11].

Although social interaction is difficult when members of a design team are not located in the same place (i.e., distributed geographically), computer-supported systems may enhance design communication when designers are distributed [2,8]. One such system is computer-mediated communication (CMC) technologies, such as email or instant messenger for file exchange and interaction on shared digital models, support collaboration such as proposing ideas on the development of the design, exchanging archived information, and presenting ideas to others (e.g. clients) [4,5,11]. Another system that supports collaborative design is the collaborative virtual environments (CVEs) that support group activities by enabling multiple users to meet as avatars and to see and experience the same virtual objects and virtual paces [3].

The main research focus of the study is to investigate the role of computer-supported systems in promoting effective collaboration among designers in a distributed environment as compared to a face-to-face setting. Therefore, the study reported here focused on understanding whether CMC technologies could facilitate design collaboration in distributed settings, and if so, types of technologies were most effective in promoting collaboration.

Thus, this study asked the following research questions:

- How do designers communicate and collaborate using CMC technologies and CVE during the design process and perform virtual collaborative work?
- How does collaboration by distributed design teams differ from face-to-face teams in their use of traditional tools and computer-supported tools through the design process?
- What are the important elements for a new computer-supported system for distributed collaboration that will support the interaction and the sharing of design information?

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To answer these research questions, we to examine the way designers communicate and collaborate using CMC and CVE technologies while performing collaborate work in the design process. The main purpose of this research was to develop recommendations for a computer supported system for distributed collaboration that promotes the interaction and the sharing of design information.

II. RESEARCH METHODOLOGY

An experiment entailed studying pairs of design students who collaborated on two different tasks in both face-to-face and distributed settings. Participants were randomly assigned to teams of two. Each team participated in two separate sessions that lasted 1.5 hours.

A. Participants

Participants were design students, three of whom were graduate students and one a 3rd year undergraduate student, from the College of Architecture at the Georgia Institute of Technology. All participants were male, and all were familiar with CMC technologies and CAD software.

B. Communication and Design Tools

During each session, both designers were provided a laptop with the Windows XP professional operating system and software available for the design tasks. TABLE I shows the tools provided to the designers. The CMC technologies included email, Skype, and Instant Messenger.

TABLE I.

Design Workshop 1 Task 1	**Design Workshop 2 Task 2**
Team A (Distributed) Team B (Face-to-face)	Team A (Face-to-face) Team B (Distributed)
Provided Tools (Required to use Unreal in both settings)	
CMC	•Email •Skype (Video Chat) •Instant Messenger (IM)
CVE	•UnrealEngine2 Runtime 2226.20.02 (Unreal)
CAD	•Autodesk® 3ds Max® 2009 32-bit (3dsMax) •Adobe Illustrator CS / CS2 (Illustrator) •Adobe Photoshop CS / CS2 (Photoshop)
Others	•Pen and paper •Webcam and headset

The CVE was ARCH8803, a program built on top of the UnrealEngine2 Runtime 2226.20.02, and developed by the IMAGINE Lab at the Georgia Institute of Technology for the Introduction to Online Visualization Environments course in the College of Architecture. Participants were also provided with traditional design tools such as a pen and paper and digital communication tools such as a webcam and a headset for the distributed setting.

C. Experimental Setup

The experiment took place in a Usability Lab equipped with four IP cameras, commonly referred to as network cameras, used for the observation of the participants' behaviors, specifically their choices of tools. Figure 1 illustrates the Smart VS-IP Surveillance System, which shows four different views of one observer monitor.

During one of the two sessions, team members were seated in a face-to-face setting, so they were able to see and communicate with one another (illustrated in Figure 2). During the second session, the same team members were seated in a distributed setting, so they were in different locations, and they were not able to see or talk to each other except via CMC and CVE technologies, (illustrated in Figure 3).

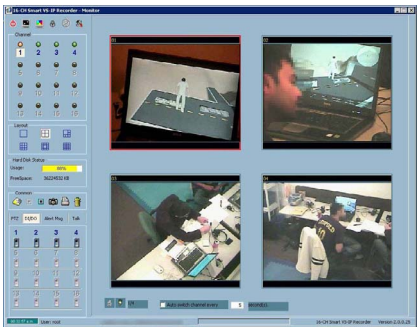


Figure 1. Monitor for the Smart VS-IP Surveillance System Screenshot

Figure 2. Two designers collaborating in face-to-face setting

Figure 3. Two designers collaborating in a distributed Setting

D. Procedure

Design students were randomly assigned to teams. Each team was given one hour to redesign two small products. The products included: 1) a pill box for a woman with mild memory loss and 2) an extension cord for a man with only one functioning hand. Each redesign had to meet certain criteria, such as the pill box had to be able to hold three types of pills. Each participant received a printed copy of the redesign problem and criteria were provided to each participant. Both teams had the pill box redesign problem during the first session and the extension cord redesign problem during the second session.

In the first design workshop, design team A was in the distributed setting whereas design team B was in the face-to-face setting. In the second design workshop design team A was in the face-to-face setting whereas design team B was in the distributed setting.

Both teams received a 3ds Max file with an existing product; the model was also placed in the Unreal virtual environment. Figures 4 and 5 show the existing pill box and extension cord, respectively, in the Unreal environment.

Figure 4. Task 1: Pill Box in the Unreal virtual environment

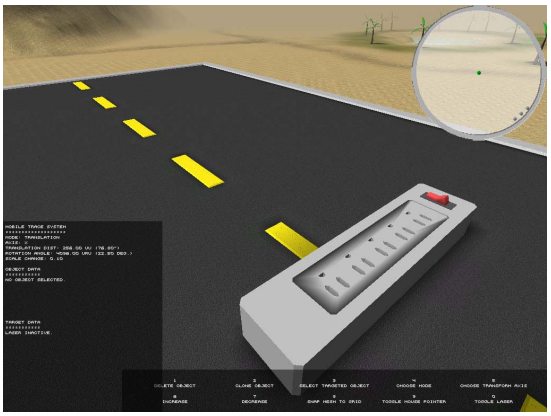


Figure 5. Task 2: Extension cord in the Unreal virtual environment

Design teams had one hour to complete each task during which time they were required to use the CVE (Unreal); however, they could choose any other tools they wished to use. By the end of the hour, the team submitted a 16"x16" poster (pdf format) of their final design outcomes. The teams were provided with a template of the poster, which had been placed in a shared resources folder accessible from each participant's laptop.

After finishing the design task, the participants completed a questionnaire that asked their level of satisfaction, their expectations of collaborative work in face-to-face and distributed situations, the benefits they foresaw for the design process, and concerns they had about the communication tools. The questions were designed to gather users' experiences in the design workshop and their opinions about the design tools that they used. The participants rated themselves based on the following categories: the product (final outcomes), the design process, and the design communication tools. They also answered open-ended questions about the CVE in the design process.

At the conclusion of the second design session, participants were responded to additional questions about the setting in which they preferred to work with their teammate and that in which they felt more engaged in the design process.

E. Video and Data Coding

The data from the two design workshops included four continuous streams of video and audio data. We segmented the stream of data for each workshop for coding and analysis using Observer XT 8.0 software. To code behaviors and events within the design session, we used a coding scheme, a condensed version of which is presented in TABLE II. Observers focused on the design activities, the use of communication tools, and the working mode of the team members, working either together or individually. The information gathered from the observations was used to determine the impact of design tools on the collaborative design process. Of primary interest was the technology used when teammates worked together.

TABLE II. Coding Scheme

WHO	**Subject1/ Subject 2**
WHAT	**Design Activity**
Discuss problem	Clarify meaning of design problem
Generate ideas	Propose and share a new idea/concept/design solution
Observe current design	Discuss/analyze the current design
Discuss design details	Discuss detail such as dimension/ texture
Modeling	3D modeling and rendering for proposed design
Presentation board	Prepare for the poster that shows the design concept
Other design activities	Conversation about software/application features
Not related to the task	Not related to the task
HOW	**Communication Tool**
Talking	Verbal communication
Gestures	Non-verbal communication
Sketches	Sketch on paper
Email	CMC
Chat	CMC tool such as IM
Video Chat	CMC such as Skype with webcam
Unreal	CVE
Others	i.e., shared white board
Working Mode	
Together	Meeting and sharing the proposed design
Individual	Working individually on the proposed design

III. RESULTS

Results of the study found that the teams exhibited showed similar patterns of design activities in both the face-to-face and distributed settings. However, they used communication tools very differently in the settings.

A. Design Activities

One of the main categories of the coding scheme was to identify the teams' design activities such as idea generation,

sketching, and modeling. The teams showed similar patterns of design activities in face-to-face and distributed settings. In both settings, they discussed the problem, observed the current design, and generated ideas through discussions and sketches at the beginning of the design process. Following these activities, they divided the work into separate tasks: one designer did the 3D modeling and the other did the 2D graphic work for the presentation board.

B. *Use of Communication Tools*

Because the design tasks were team projects, participants needed communication tools to achieve agreement in the design process. Among communication methods, designers used verbal communication (i.e., talking) most often to share their ideas. Gestures also played a large role in their design communication when they were talking or showing their sketches. Because they were able to see and talk to other face-to-face, they did not use CMC technologies. However, in the distributed setting, they used CMC technologies to share and discuss the design ideas. During about 70 percent of the entire design process, both teams used Skype, which allowed them to talk to and even see each other by video call. They used Unreal to see, move around, and observe the existing products within the Unreal virtual environment. However, they used Unreal less than 10 percent of the time because they could not design and manipulate the objects in the Unreal virtual environment. In addition, they never used e-mail as a communication tools in this setting; only one team member used Messenger and only once to send the shared white board link address to his teammate.

Both teams used webcams in unconventional ways for sharing design information. Figure 7 shows designers sharing their 2D/ 3D graphic models using a webcam by pointing it at the screen. Sharing screen images appeared to be an important part of the communication process.

Figure 6. Sharing 2D/ 3D graphic using a webcam (Team A)

When the participants showed their visual information, either sketches or 3D models, they asked for the other person's opinion through questions such as "Is this okay?" or "What do you think about the shape?"

C. *Working Mode*

After agreeing on a proposed design, both teams divided up the various design tasks to produce a concept design. However, each team in each setting exhibited different behaviors relating to how much time they worked together and individually.

Figure 7 shows the percentage of time each team in each setting worked together and individually. In the face-to-face setting, Team A worked together about 62 percent of time and individually about 37 percent of their time. However, this team worked together about 33 percent more in the distributed setting than in the face-to-face setting. Thus, in the second workshop, the team was able to come up with a design idea more quickly than it did the first time and to start working individually sooner.

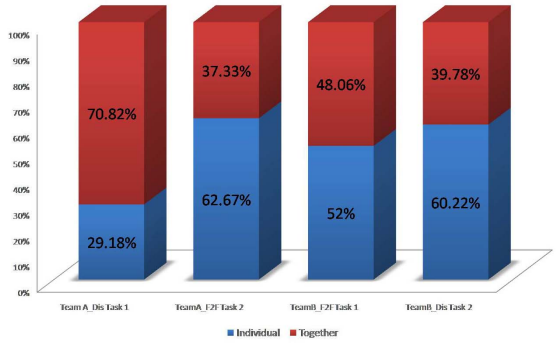


Figure 7. Working modes (together/individual)

In contrast, Team B worked together more in the face-to-face than in the distributed setting: about 48 percent of the entire design process in the face-to-face setting and about 40 percent in the distributed setting. Figure 8 shows that the teams, on average, worked together more in the distributed setting than in the face-to-face setting. Both teams worked together in the face-to-face setting an average of about 42 percent of the time and in the distributed setting about 55 percent. That is, teams had more time to work individually in the face-to-face setting.

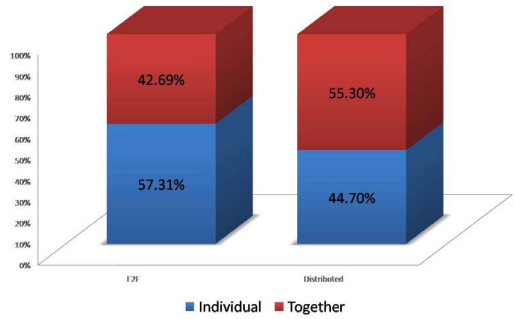
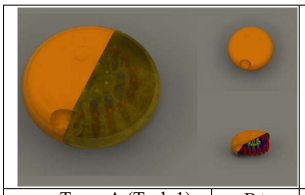
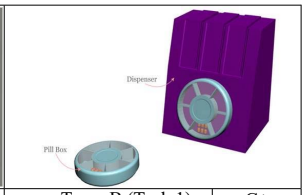
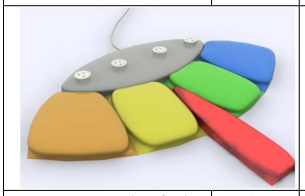
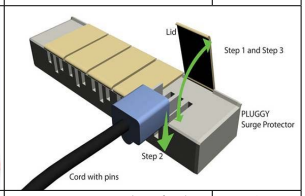


Figure 8. Average working mode in face-to-face and distributed settings

D. *Design Outcomes*

The design teams provided the final design outcomes of each task in a pdf file at the end of each session (see TABLE IV). Their designs were evaluated by two faculty members who had no knowledge about the team assignments and the settings of the design workshops. The grades, reported in TABLE IV, were, contrary to what was expected, similar across conditions.

TABLE III.

			
Team A (Task 1) in distributed	B+ A	Team B (Task 1) in face-to-face	C+ C-
			
Team A (Task 2) in face-to-face	A- A+	Team B (Task 2) in distributed	A A

E. Questionnaires

After the second design workshop, participants were asked to compare working in the two settings. The four questions and the participants' responses are presented in Figure 9. The participants were asked to explain why they believed one setting was better than the other. They mentioned that the differences were due to the different tasks rather than the different settings. All the participants thought face-to-face communication was more conducive to sharing design information; and they simply preferred face-to-face to distributed communication. However, 75 percent of the participants felt that they more engaged in working with their teammate in the distributed setting

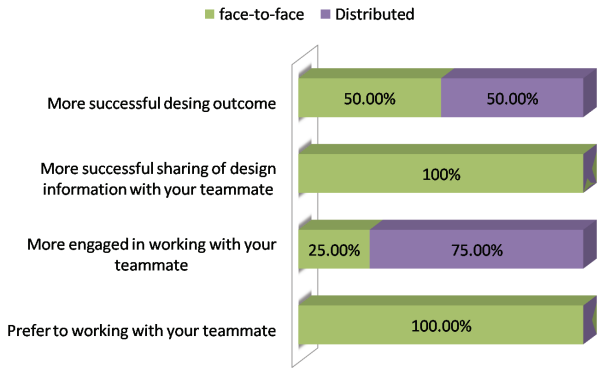


Figure 9. Responses from the Participants

At the end of the questionnaire, participants shared their opinions about the use of Unreal for the design process and the collaborative system. TABLE V presents a summary of the participants' opinions about Unreal. Despite the potential impact of real-time visualization, participants reported that Unreal engine did not sufficiently enhance design communication for the teams.

TABLE IV. Participants' Opinions about Unreal

Unreal	
Positive Comments	***Negative Comments***
•Laser pointer was helpful in conveying what they were referring to on the model •Liked multiple people sitting around a model in a virtual environment •Easy to talk about model •Great for visualization •Real-time visualization	•Difficulty using Skype video with Unreal because it takes up the whole screen •Laser pointer was less effective than just pointing to the actual screen •Lack of communication tools such as shared drawing •Lack of sharing thoughts and ideas •Lack of manipulation

Participants stated that the Unreal virtual environment lacked communication tools and did not allow users to share ideas or manipulate objects, so they could not do much beyond viewing 3D objects together. In addition, they found it difficult to other applications (e.g., Skype) in conjunction with the Unreal virtual environment because the latter took up the entire monitor screen.

F. Collaborative System

After finishing the design sessions, all design teams expressed their opinions about how to create a better collaborative system for designs. TABLE VI summarizes the participants' opinions about what a better collaborative system might entail based on their experience in the design workshops. The concern most often cited was the lack of sharing capabilities between team members. Participants indicated that they wanted to see their teammate's screen, even in the face-to-face setting, because they believed it would lead to more effective collaborative conditions by giving them the ability to share visual information (e.g., 2D sketches on paper, 3D objects), make suggestions and review each other's work continually. Rather than drawing or modeling them separately and then sharing; they indicted wanting to see the process of their teammate's drawing. Participants also mentioned that integrating these sharing systems into the 3D virtual environment would facilitate the collaborative effort.

IV. DISCUSSION

The study yields several interesting findings about the design process and the working modalities (together mode & individual mode).

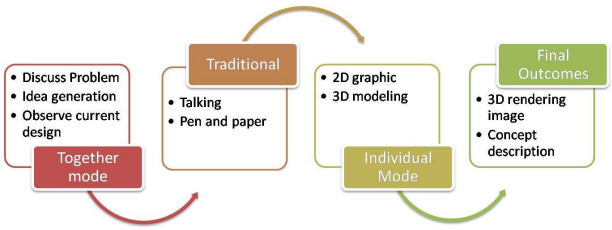


Figure 10. Design process in the face-to-face setting

Figures 10 and 11 illustrate the overall design process teams used in the face-to-face and distributed settings, respectively. As the diagrams show, the only difference

between the design process in the face-to-face setting and that in the distributed setting was the way teammates used technologies to communicate.

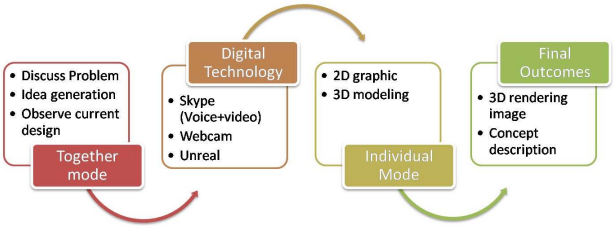


Figure 11. Design process in the distributed setting

It is obvious that teams did not need technologies to communicate in the face-to-face setting but instead used talking and pen and paper. One interesting finding was that both teams in different settings showed similar working patterns despite their use of different communication tools. They worked together until they arrived at a design concept. At that point they divided the work into either the 3D modeling task or the 2D graphic task to provide the final design outcomes. Moreover, both teams generated ideas more quickly in task 2 than they did in task 1. One explanation may be that teams had already worked together on task 1 before working together on task 2, so they were more knowledgeable about their teammate's strengths and weaknesses and able to start the design process faster. Another explanation could be that task 2 was simpler to solve than task 1, so the teams were able to produce a design in less time.

TABLE V. Recommendation for a Collaborative System

Collaborative System
Sharing
•Ability to manage time -A way to quickly store paper sketches with annotations -Sharing real time information -Ability to see teammate's screen and mouse -Sharing 2D sketches as they are drawing them -Sharing 3D object model in a shared view •A file sharing system that can auto save and keep a revision •Ability to sketch together
3D Virtual Environment
•Integrated tools such as a sketching tool in the virtual environment •An integrated 3D modeler and 2D sketching tool with an audio and a web browser to search for precedence material •Ability to manipulate 3D objects within the environment •Ability to record conversations for later use •Holographic display of a 3D model

Surprisingly, the teams, on average, worked together more in the distributed setting than in the face-to-face setting. This finding was not unexpected, as working together in this design workshop required teams to discuss or propose their ideas to solve the problem. In only one hour, the design teams needed to come up with a proposed design more quickly to achieve their goal. Therefore, because they could see and talk to each other in the same place, the teams were able to come up with a design more quickly in the face-to-face setting than in the distributed setting. Thus, it appears that the settings themselves were unrelated to the participant's perceptions of the success of their design outcomes.

As was anticipated, all participants preferred working with their teammates in the face-to-face setting and indicated that they believed they were more successful at sharing design information with their teammate when face-to-face because they could easily share ideas instantly and see each other's screens. However, 3 out of the 4 designers thought that the distributed setting was more engaging to work with their teammates in. They claimed they were "forced to be engaged" and "forced to communicate better," and that they "concentrated more using hand gestures on camera."

In general, this study demonstrated the way design teams communicated and collaborated in face-to-face and distributed settings using CMC technologies and CVE. Clearly, the CVE used lacked sufficient communication capability for distributed teams, although it had the potential to improve the collaboration. More importantly, the study resulted a number of design criteria that will be used to develop and test an enhanced communication system that supports interaction and information sharing in distributed settings. These design criteria (see TABLE VI) include sharing real time information such as sketch, 3D modeling, and integrated visualization tools in the 3D virtual environment.

REFERENCES

[1] M.F. Brereton, D.M. Cannon, A. Mabogunje and L.J. Leifer, Collaboration in Design Teams: Mediating Design Progress through Social Interaction., Chichester, UK, 1996.

[2] M.-L. Chiu, An organizational view of design communication in design collaboration, Design Studies 23 (2) (2002) 187-210.

[3] E. Churchill, D. Snowdon, Collaborative virtual environments: An introductory review of issues and systems, Virtual Reality 3 (1) (1998) 3-15.

[4] C.D. Cramton, The Mutual knowledge problem and its consequence for dispersed collaboration, Organization Science 12 (2001) 346-371.

[5] N. Cross, Designerly ways of knowing, Springer, London, 2006

[6] N. Cross, H. Christiaans, K. Dorst, Analysing design activity, Wiley, Chichester ; New York, 1996.

[7] G.W. Hill, Group versus individual performance: Are N+ 1 heads better than one?, Psychological Bulletion 91 (3) (1982) 517-539.

[8] P.J. Hinds, & Bailey, D. E. , Out of sight, out of sync: Understanding conflict in distributed teams, Organization Science 14 (2003) 615-632.

[9] B. Lawson, How designers think : the design process demystified, Completely rev. 3rd ed., Architectural Press, Oxford ; Boston, 1997.

[10] B. Lawson, What designers know, Elsevier/Architectural Press, Oxford [England] ; Burlington, MA, 2004.

[11] M.L. Maher, S.J. Simoff, A. Cicognani, Understanding virtual design studios, Springer, London ; New York, 2000.

[12] S.L. Minneman, The social construction of a technical reality: Empirical studies of group engineering design practice, Stanford University, 1991.

[13] J. Reinke, Challenges that exist between design and production teams, Advantage Business Media, 2009.

[14] M. Saad, M.L. Maher, Shared understanding in computer-supported collaborative design, Computer-Aided Design 28 (3) (1996) 183-192.

[15] P.W. Yetton, P.C. Bottger, M. Australian Graduate School of, Individual versus group problem-solving: an empirical test of a best member strategy, Australian Graduate School of Management, University of New South Wales, Kensington, N.S.W. 1981