

Studying design behaviour in collaborative virtual environments

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Abstract

Developing and including new collaborative virtual environments in the design process needs an understanding of their impact on the collaborative process and on the focus of a design meeting. The study reported in this paper compares two types of remote collaboration environments with face to face sketching. The two remote environments are remote sketching and a 3D virtual world. The experimental study involves collecting data while pairs of architects work on a prescribed design task. The collected data includes video, verbal protocol data, and screen images. The analysis of the data highlights the differences in the collaborative process, communication content and the representation of the design solution. Our preliminary results show that the remote sketching encourages a broader exploration of design ideas and the 3D virtual world encourages collaborative modelling of design solutions for improved visual evaluation.

Keywords: Collaborative design, 3D virtual worlds, remote sketching, design process, protocol analysis

1. Introduction

Recent developments in networked 3D virtual worlds and the proliferation of high bandwidth communications technology have the potential to transform the nature of distance collaboration in professional design. There have been numerous developments in systems that support collaboration that have resulted in system architectures to support information sharing and remote communication. Whilst these initiatives have led to important advances in the enabling technologies required to support changes in global economic practices, there remains a gap in our understanding of the impact of the technologies on the working practices of the people who are the primary users of such systems.

Research into the characteristics of collaborative work can assist in our understanding of how the collaborative design process can be supported and how new technologies can be introduced into the

workplace. An understanding of collaborative design includes such factors as the role that communication media play, the use of physical materials and computer tools, and the way people communicate verbally and non verbally [1]. Protocol analysis has been accepted as a prevailing research technique allowing elucidation of design processes in designing [2]. And whilst the earlier studies dealt mainly with protocols' verbal aspects [3], later studies acknowledge the importance of design drawing [4], associating it with design thinking which can be interpreted through verbal descriptions [5,6,7]. By gathering information about the rich and complex picture of collaborative design we can understand the characteristics and needs of the practitioners as well as the factors which contribute to their professional effectiveness.

1.1. Studying team collaboration

In order to understand the potential impact of high bandwidth environments on collaborative design, we first need to have data that characterizes collaborative design activity without the high bandwidth environment, i.e. face to face designing. We considered that the change in collaborative technologies should be incremental; moving from the technology already in use to the use of a high bandwidth virtual environment. With these ideas in mind, an experimental study with 3 design settings was developed in order to study the impact of high bandwidth environments on design collaboration:

1. A collaborative design process in which designers work face to face with pen and paper.
2. A collaborative design process in which designers use a remote sketching system with synchronous voice and video conference.
3. A collaborative design process in which a 3D virtual world is used with synchronous voice and video conference.

We collected video and verbal protocol data in these three phases. Then we coded the behaviours we observed in the videos as well as the verbal communication. We analysed the codes and finally aimed at comparing the collaborative activity in the three different settings, so that we could determine the impact of the change in collaborative technology. This paper presents the analysis of the data; comparing three pairs of architects' collaborative design processes in the three design environments: face to face sketching, remote sketching and 3D virtual worlds.

2. Experiment

In our experiment, we studied pairs of designers collaborating on three different design tasks of similar complexity using a different setting for each task. Our designers are architects, so the design task is the design of a small building on a given site. We used the same site for each task, but specified a different type of building (gallery, library, and hostel) for each design task. This allowed the designers to become familiar with the site and to focus on the design of the building.

2.1 Experimental Set up

Fig. 1 shows the face to face session of the experiment where the designers are provided drawing materials (pen- paper), brief and a collage of the photos showing the existing building on the site and the neighbouring buildings.



Fig. 1: Face to face session

Fig. 2 shows the set-up for the shared drawing board environment. The set up for designer 1 is shown in Fig. 2a and the set up for designer 2 is shown in Fig. 2b. One designer used a pen interface (Mimio) on a projection table and the other designer used a pen interface on a Smart Board. In this setting of the experiment, the designers used remote sketching software called Group Board, as shown in Fig. 3.

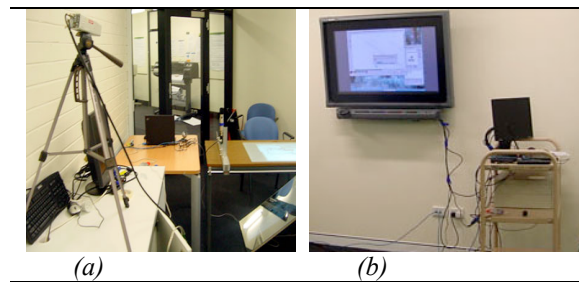


Fig. 2: (a) Desktop screen 1, and Mimio on workbench; (b) Desktop screen 2, and Smart Board

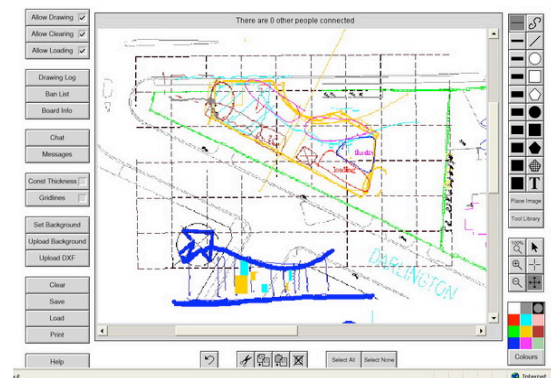


Fig. 3: Group Board interface

In the third setting of the experiment, the designers used an extended 3D virtual world application in Active Worlds, shown in Fig. 4. The 3D world includes a multi-user 3D building environment, video contact, a shared whiteboard, and an object viewer/insert feature. (For more information about the experiment setting and experiment procedure see

Maher et al [8]).

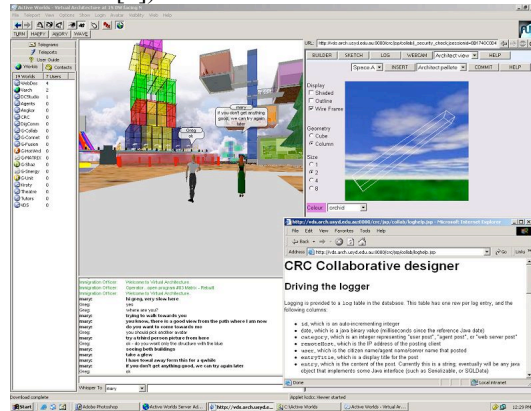


Fig. 4: Extended virtual world

2.2. Video and verbal data coding

The data from the experiments comprises 3 continuous streams of video and audio data for each pair of designers. The stream of data for each session is segmented for coding and analysis. We used a software called INTERACT for our coding and analysis process. Our segmentation is based on an interpretation of an event that was defined as a time interval which begins when a new portion of information is mentioned or discussed, and ends when another new portion of information is raised [9]. An event can change when a different person starts speaking in a collaborative activity if s/he is introducing a new portion of information. In some cases the conversation goes on between the actors however the intention or subject of interest remains the same. In this paper we refer to the designers as Alex and Casey. For example, in Segment 48 both Casey and Alex take turns in one segment, however their subject of interest is still the “ramp to a car park”:

Segment 48:

“Casey: This is... there is a photo of there. That is actually a ramp to a car park. And then there is a building and a little...”

Alex: And that is the ramp?

Casey: That is the ramp.”

Each segment is then coded according to a coding scheme. The coding scheme allows us to compare and measure the differences in the three design sessions. We present the results of 4 coding categories: communication content, design process, operations on external representations, and working modes.

Communication content:

The communication content category is applied to the transcribed conversation between the two designers, and one code is assigned to each segment. This code category has 5 codes as shown in Table 1.

Table 1
Communication Content

Software features	Software features or how to use that feature
Design Process	Conversations on design exploration, analysis-synthesis-evaluation.
Awareness	Awareness of presence or actions of others
Reps	Communicating a drawing/object to others
Context free	Conversations not related to the task

Design Process:

The design process category characterizes the kinds of design tasks the designers are engaged in for each segment. Assigning a design process category takes into consideration the words spoken during each segment as well as the actions observed in the videos (see Table 2). The codes are an adaptation of the coding scheme developed by Gero and McNeill [10] .

Table 2
Designing Process

Propose	Propose a new idea/concept/ design solution
Clarify	Clarify meaning or a design solution, expand on a concept
AnSoln	Analyse a proposed design solution
AnReps	Analyse/ understand a design representation
AnProb	Analyse the problem space
Identify	Identify or describe constraints/ violations
Evaluate	Evaluate a (design) solution
SetUpGoal	Setting up a goal, planning the design actions.
Question	Question / mention a design issue

Operations on external representations:

The external representations category looks specifically at the actions the designers perform while using the software. Each segment is interpreted using the video of the designers’ behaviour including movements or gestures, and the video stream of the computer display showing how the software was being used (see Table 3).

Table 3
External Representation

Create	Create a design element
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Modify	Change object properties or transform
Move	Orientate/Rotate/ Move element
Erase	Erase or delete a design element
Inspect Brief	Looking at, referring to the design brief
Inspect Reps	Looking at, attending to, referring to the representation

Working modes:

The working modes category focuses on how individuals collaborate towards the design product. Kvan [11] defined collaborative designing as a “closely coupled” process or a “loosely coupled” process. In this category “meeting” code refers to designers working together on the same design/artifact, and “individual” code refers to designers working individually on a different part/aspect of the design.

3. Analysis and interpretations of the results

After coding each segment, the coding software INTERACT provides us with the total duration of each action in each category. We calculated duration percentages for each action or action category. Table 4 shows that around 72 percent of the total time is spent on collaborative communication in face to face sketching, Group Board and 3D world session. Thus the amount of communication is nearly the same in the three environments. The architect pairs spent 92-97 percent of the total design session time on operations related to external representations. The time spent on dealing with external representations does not seem to be significantly different over the three different design environments. However there is a significant difference between duration percentages of the design process actions category.

Table 4
Duration percentages of action categories

	FTF	Group Board	3D World
Communication content	72%	73%	72%
External representations	94%	92%	97%
Design process	69%	50%	41%

We tested if there are significant differences between the pairs in terms of their design behaviour (coded activity categories). The ANOVA test (ANOVA with replication, $P < 0.05$) results show that there is no significant difference between the pairs' communication content, their operations related to

external representations and their working mode. Note that only design process activity is significantly different ($P = 0.0015$) between the pairs. We also tested if there are significant differences between the three design sessions in terms of activities of pairs. The ANOVA results (ANOVA with replication, $P < 0.05$) show that the activity in all categories are significantly different over the three sessions.

Average of the 3 pairs' communication duration percentages is shown in Fig. 5. The average values would demonstrate the correct behaviour trends since there is no significant difference between the communication content of the pairs in each session. The architect pairs talk more about designing (65%) in FTF session, and then the duration percentage of communication on design process steps down significantly in Group Board (48%) and 3D World (28%) sessions. This decrease is compensated by communication on awareness of the other designer's avatar and communication on the features of the design representation. The percentage values of “awareness” (0.3%, 3%, and 12%) and “representation” (4%, 7%, and 18%) step up consecutively in FTF, Group Board and the 3D World sessions. The percentage of communication on software features is zero in FTF session, highest in Group Board session (13%) and that is followed by the 3D World session (7%).

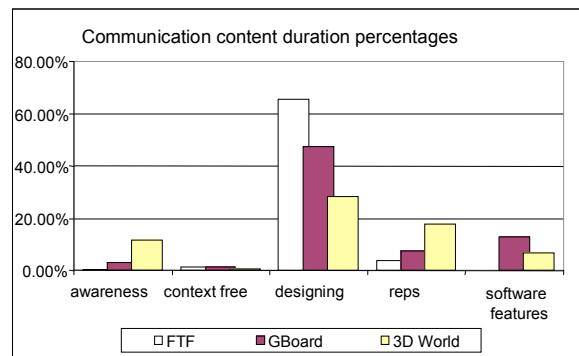


Fig. 5: Bar charts for communication content (average of 3 pairs over the 3 design phases)

The analysis shows that the communication content in face to face sketching sessions is predominantly about the design. During the face to face (FTF) sessions, we observed that designers were intensively engaged in exploring and creating design concepts interactively while drawing on paper. This is explained by the familiarity of this environment for the designers. In the 3D virtual world we found that architects conversation was about features of the

design representation and awareness of each others' location and action as much as their conversation about design process. The discussion on awareness is due to the significance of the information about the other designer's location in the 3D virtual world and their actions with respect to the design model they are creating. In a 2D sketch, both designers have the same view. In a 3D world, the view of the designer depends on the location of the avatar in the world.

The analysis of the operations on external representations averaged for three pairs is shown in Fig. 6. The three sessions look very similar in terms of inspection activity. The operations of inspection on the brief and on the representation of the design dominated, with the other operations being comparatively small in percentage of time. It can be observed that "move" and "modify" actions are significantly higher, while "create" action is significantly lower in the 3D virtual world design environment. In 3D modelling tasks, designers usually moved or modified objects after they created them, and this sequence formed a pattern which demonstrated their behaviour of constructing a representation in a virtual world [12]. In summary, the 3 architect pairs' average results show that the ratio of the actions in constructing an external representation are similar in sketching environments but quite different in the 3D virtual world.

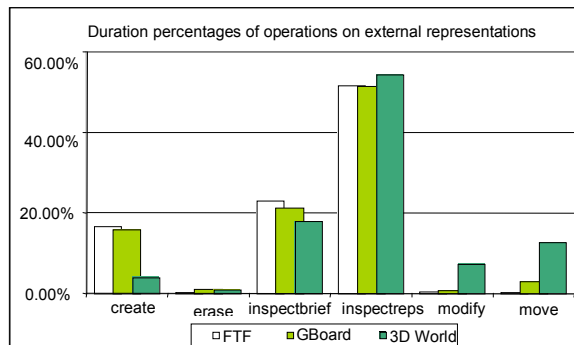


Fig. 6: Bar charts for operations related to external representations (average of 3 pairs over 3 the design phases)

Fig. 7 shows the duration percentages of some design process actions of the three pairs separately over the three design phases. The graph demonstrates whether there are significant percentage differences between the pairs in occurrence of the different action codes. There is a drop in duration of the design process actions (except for pair 1) over the three design phases, FTF showing the highest percentages. For example, propose and analyse solution in bar charts show that proposing a design idea and analysing a proposed

design solution is higher in FTF and GB sessions, compared to the 3D virtual world environment. Setting up goals during the 3D world session is highest for Pair 1 but not for the others. Thus, there is no common tendency in occurrence of design process action types, because the percentage proportions of the design actions for each pair is quite different in the same type of design environment.

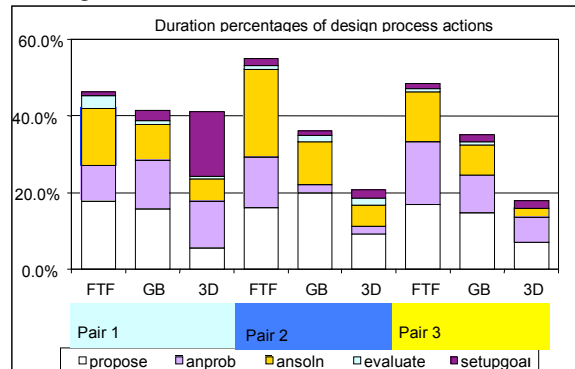


Fig. 7: Bar charts for design process actions (3 pairs over the 3 design phases)

A summary of our analysis of the working modes category is shown in Fig. 8. For the three architect pairs' sessions analysed, the percentage of meeting working mode is highest for face to face and remote sketching sessions while the percentage of individual working mode is negligible. However in 3D world, architects worked less in meeting mode (72%) and relatively more in individual mode (28%).

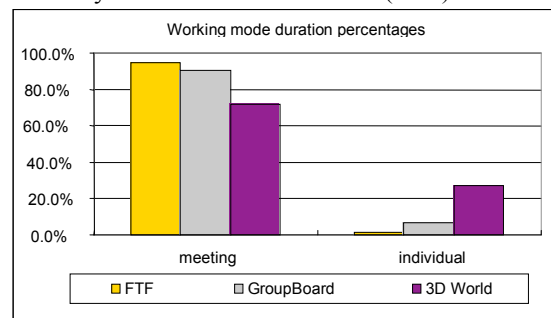


Fig. 8: Bar charts for working mode of designers (average of 3 pairs over 3 design phases)

This result shows that the 3D virtual world can support teams to work collaboratively but at the same time could support individuals to work separately in the different part/aspect of the design.

4. Conclusions

We have studied a small set of designers using high bandwidth environments while designing collaboratively, allowing us to make comments on the similarities, rather than the significance of the differences in their behaviours. Our main goal in this study was to look at the impact of high bandwidth virtual environments on collaborative design, and our findings fall into two categories:

1. The ability of designers to communicate and collaborate in remote virtual environments
2. The difference in designers' focus and behaviour in different kinds of virtual environments.

Our studies have shown that designers are able to adapt to different environments, from the traditional face to face environment to a variety of virtual environments, and still be able to effectively communicate and collaborate. This result is substantiated by the finding that the designers spent the largest percentage of their time focussed on communicating about the design task and on actions to produce an external representation in all environments studied. That is, there was no significant difference in the designers' overall collaborative behaviour in high bandwidth virtual environments when compared to face to face environments. Strategically, this is an important finding because it implies that the introduction of high bandwidth virtual environments into the design process preserves the essential aspects of designing, and allows designers to communicate and collaborate while in remote locations without the use of excessive financial and time resources.

The second category of impact has to do with the differences in the virtual environments we studied. These differences are basically whether the designers were able to represent their design ideas/solutions in a 2D sketch representation or a 3D virtual world environment. We found that the major difference was that the designers focussed on more abstract representations of the design and had more iterations on synthesis and analysis while using a 2D sketch; and that they focussed more on the visual analysis of a design concept in the 3D virtual world. The strategic decisions that can follow from these results are:

1. The initial collaboration about design concepts is more efficiently done face to face.
2. Additional collaboration that is needed for generating more design ideas is better done in a verbal only or sketching virtual environment than in a 3D virtual world.
3. Additional collaboration to clarify the design or to collaboratively develop a design concept as a 3D model is best done in a 3D virtual world.

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