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COMPARING DISTANCE COLLABORATIVE DESIGNING USING DIGITAL INK SKETCHING AND 3D MODELS IN VIRTUAL ENVIRONMENTS

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ABSTRACT

In today's global design world, architectural and other related design firms design across time zones and geographically distant locations. Virtual environments have the potential to make a major impact on the global design teams. However introducing new tools to the design process needs an understanding of their impact on the collaborative process and on design decision-making. 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 the 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 modeling of design solutions.

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

1.0 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 (Munkvold 2003). Protocol analysis has been accepted as a prevailing research technique allowing elucidation of design processes in designing (Cross et al. 1996). And whilst the earlier studies dealt mainly with protocols' verbal aspects (Akin 1986), later studies acknowledge the importance of design drawing (Akin and Lin 1995), associating it with design thinking which can be interpreted through verbal descriptions (Suwa and Tversky 1997; Suwa et al. 1998; Stempfle and Schaub 2002). 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 (usually sharing the drawings over the internet) 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. The first collaborative environment represents the traditional way of designing, sketching, the second environment was selected as representative of the current low-bandwidth technology (Group Board) and the third

[12] www.mangold.de

environment is a prototype of high-bandwidth technology (extended Active Worlds). The paper begins with a summary of the experiment design and then data collection methods. Finally, video and verbal protocol analysis of the design sessions and the results are presented.

2.0 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. We anticipate that the comparison of the same designers in three different environments would provide a better indication of the impact of the environment than using different designers and the same design 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.

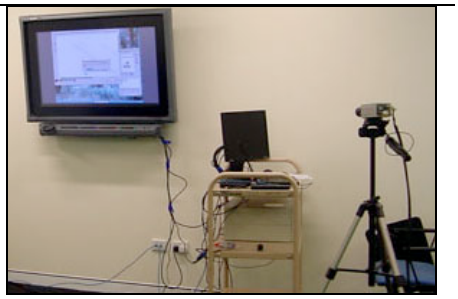
2.1 EXPERIMENTAL SET UP

Figure 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.

Figure 1 Face to face session

Figure 2 shows the set-up for the shared drawing board environment. In order to simulate high bandwidth audio and video, both designers are in the same room and can talk to each other, but can only see each other via web cam. The set up for designer 1 is shown in Figure 1a and the set up for designer 2 is shown in Figure 1b. The location of the cameras was an important issue, since we wanted to monitor the designers' movements, verbalizations, gestures and drawing actions. Cameras 1 and 2 capture the gestures, general actions such as walking, looking at, moving to the side, while the direct connections to the computers/screens capture the drawing process. One designer used a pen interface (Mimio) on a projection table, shown in Figure 2a. The other designer used a pen interface on a Smart Board, shown in Figure 2b. In this setting of the experiment, the designers used remote sketching software called Group Board, as shown in Figure 3.

(a)



(b)

Figure 2. (a) Camera 1, Desktop screen 1, and Mimio on workbench; (b) Camera 2, desktop screen 2, and Smart Board

In the third setting of the experiment, the designers used an extended 3D virtual world application in Active Worlds, shown in Figure 4. The 3D world includes a multi-user 3D building environment, video contact, a shared whiteboard, and an object viewer/insert feature. Again, the designers are in the same room with a similar camera set up. While the shared whiteboard was available in the third setting, the designers were only trained to use the 3D world and the web cam.

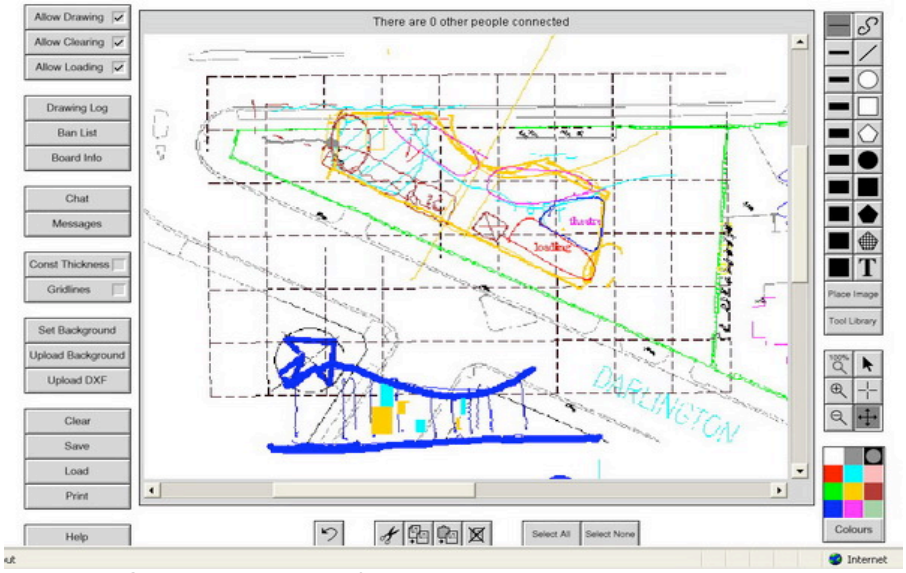


Figure 3 Group Board interface

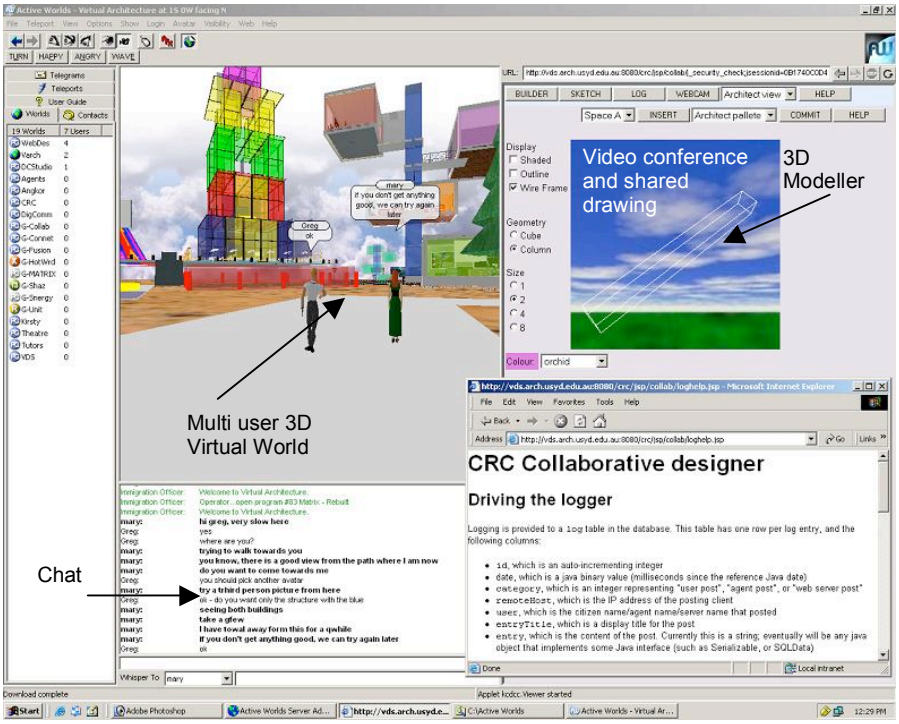


Figure 4 Extended virtual world

2.2 EXPERIMENTAL PROCEDURE

The experimental procedure was:

1. The designers were given a design brief and shown a collage of the photos of the site they are required to build on. They were given time to read through the design brief and inspect the site layout and photos. They were given paper and pencils and were asked to complete their design session in 30 minutes.
2. The designers were presented a short description of how they could use Smart Board or Mimio Tool. These are both pen and digital ink interfaces to a standard windows environment. The Smart Board is attached to a vertical plasma display and the Mimio is placed on a horizontal projection display.
3. The designers were given a 15 minute training session on the use of Group Board. In the training session participants were engaged in doing a tutorial in order to review and/or build their skills in using specific features of the software application provided for collaboration.
4. The designers were given a new design brief and shown a collage of the photos of the same site. They were given time to read through the design brief and inspect the site layout and photos. The site layout was set in the share whiteboard application as a background image on several pages so that the designers can sketch on them. They were asked to complete their design session in 30 minutes.
5. After a 5 minute break, the designers were given a 15 minute training session on the use of 3D world. They were asked to do a tutorial in order to review and/or build their skills in using specific features of the software application.
6. The designers were given a new design brief and shown a collage of the photos of the same site. They were given time to read through the design brief and inspect the site layout and photos. This time the designers used the extended virtual world to end up with a design solution for the given design brief. They were asked to complete their design session in 30 minutes.

2.3 VIDEO AND VERBAL DATA CODING

The data from the experiments comprises 3 continuous streams of video and audio data for each pair of designers. In this paper we report on the analysis and interpretation of three pairs of designers, each pair completing the design tasks in all 3 settings. The stream of data for each session is segmented for coding and analysis. We used a software called INTERACT[2] for our coding and analysis process; more information on the reasons for choosing this software and how it improved our coding process can be found in Candy et al (2004).

Each segment is coded according to a mapping from the activities and utterances to a set of coding schemes. Our segmentation is based on an interpretation of an “event”. In the study done by Dwarakanath and Blessing (1996), an event 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. This event definition is an optimal one for our study as well, since the occurrences of actions and intentions change spontaneously as architects draw and communicate interactively.

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

Communication on software features involves the questions about how to do specific tasks with the software, talking about individual experience of how to do things, problems faced during the use of the software, any feedback about the interface or use of software /statements of frustration about not getting something right etc.

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. The codes in the design process category are an adaptation of the coding scheme developed by Gero and McNeill (1998). The codes in this category are shown in Table 2.

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 (for eg. how to get this done? In terms of areas we have nothing to scale)

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. Table 3 shows the codes in the external representations category.

Table 3 External Representation

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

Working Modes:
The working modes category focuses on how individuals collaborate towards the design product: are they developing a product/solution together or are they doing this alone for a while and then work together again along the time line of designing. Similarly Kvan (2000) defined collaborative designing as a "closely coupled" process or a "loosely coupled" process. In a close coupled process, designers work together on the same artifacts simultaneously while in a loosely coupled process, design participants work with different artifacts at different or same time.

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.

3.0 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. This data shows how much time each participant spent on each action. The duration of each action is divided by the total time elapsed for each session (which is 30 minutes for each session). This gives us the duration percentages for each action or action category. Table 4 shows duration percentages of the three action categories form the coding scheme. These are the averaged values of the three architect pairs collaborating in the three different design environments. 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. Again 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. In face to face sketching (FTF) session, architects spent 70 percent of their time on design process actions, however in 3D World session they spent only 40 percent of the total time on design process actions. In Group Board session, 50 percent of the time is spent on design process actions, which is significantly lower than the amount spent in FTF session.

Table 4 Duration percentages of action categories

	FTF	Group Board	3D World
Communication content	72%	73%	72%
Operations related to 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.

It was observed that the amount of time spent on communication in the three design sessions is very similar (Table 4); however the content of communication varies between them. Figure 5 summarizes the coded communication content of the three pairs over the three design sessions. Average of the 3 pairs' communication duration percentages is shown in Figure 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 (Figure 5). This decrease is compensated by communication on awareness 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 (Figure 5). 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%).

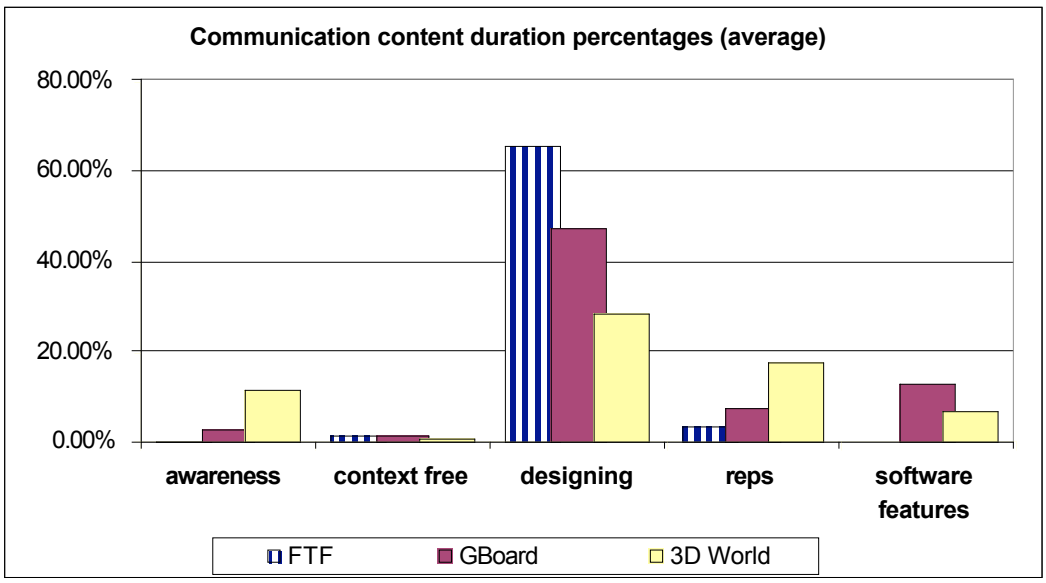


Figure 5 Bar charts for communication content (average of 3 pairs over 3 the design phases)

The analysis shows that the communication content in face to face sketching sessions is predominantly about the design rather than about the tools they are using, the external representaion, or where the other person is located. 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 and the physical access they have to each other. We noticed a similar phenomenon in the remote sketching environment, where the designers primarily talked about the design rather than the software features or the awareness of actions of each other. 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 of others 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 his

location in the world. However, in all 3 sessions, the designers spent most of the communication time on design tasks.

When we compare the communication content in the 3 environments, one significant difference was that the architects spent more time on the representation related context in the 3D virtual world. This involves talking about which elements they could use to represent their design ideas or how the representation looked like in the environment. The architects focused on the "representation" more in the 3D virtual world because they had to concretize their design ideas immediately, however in the sketching environment the representation could remain abstract.

The analysis of the operations on external representations averaged for three pairs is shown in Figure 6. The average activity percentages of three pairs would represent the common behaviour since there is no significant difference between the pairs' activity in each session (see ANOVA test results). This analysis is interesting because 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 (Maher et al, 2005). This activity pattern shows that the architects focused on relationships in the 3D world. 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.

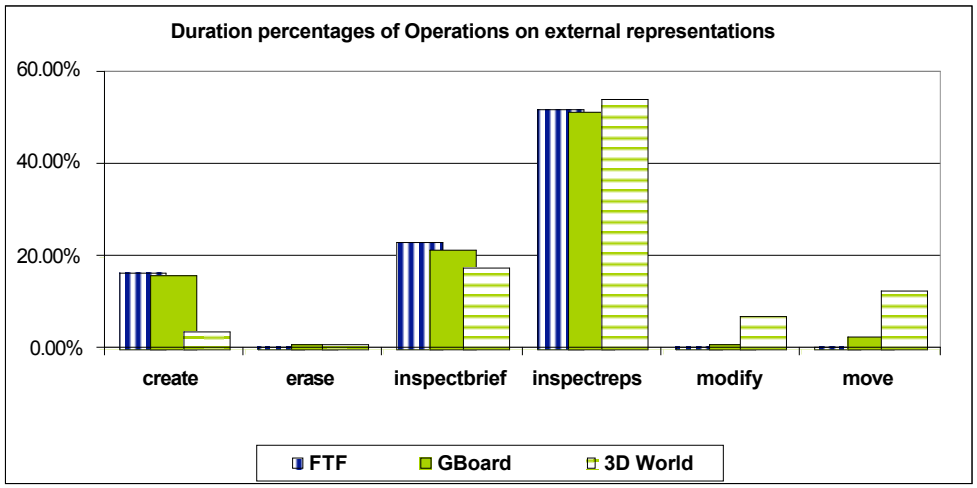


Figure 6 Bar charts for operations related to external representations (average of 3 pairs over 3 the design phases)

Figure 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, the diagonal stripes (propose) and the vertical stripes (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 (Figure 7). Each pair's design process could be interpreted as a case study, where the reasons for the differences

might be explored through the profiles of the participants, and the dynamics of the specific collaborative activity.

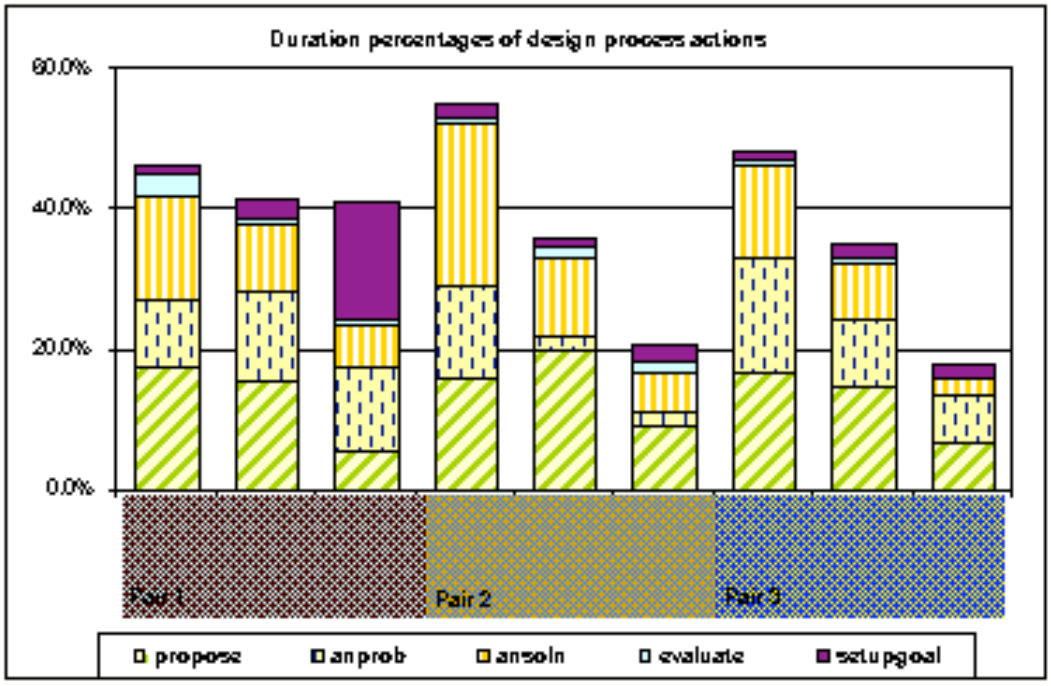


Figure 7 Bar charts for design process actions (3 pairs over the 3 design phases)

Figure 7 shows that, design behaviour of Pair 1 is quite different form the other two pairs, where they spent a similar amount of time in total for designing actions. However the proportions of design actions are quite different in FTF, Group Board and 3D world sessions. One of the architects in Pair 1 has been using the remote collaboration technologies and the virtual environment for a significantly longer period. This acquaintance might have improved the amount of time they spent on the design process.

A summary of our analysis of the working modes category is shown in Figure 8. When the designers were working face to face, they were always engaged in “meeting” mode, during which they were communicating and acting on the same aspect of the design. When the designers were working remotely, there was a small percentage of the time during which they were working on their own, focusing on different aspects of the design. 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%). This difference could be due to the nature of the 3D modelling environment, where participants have the opportunity to do task division and work separately (individual mode) on different aspects/parts of the design to be built. This result also shows that the 3D virtual world could support teams to work collaboratively but at the same time could support individuals to work separately in the different part/aspect of the design.

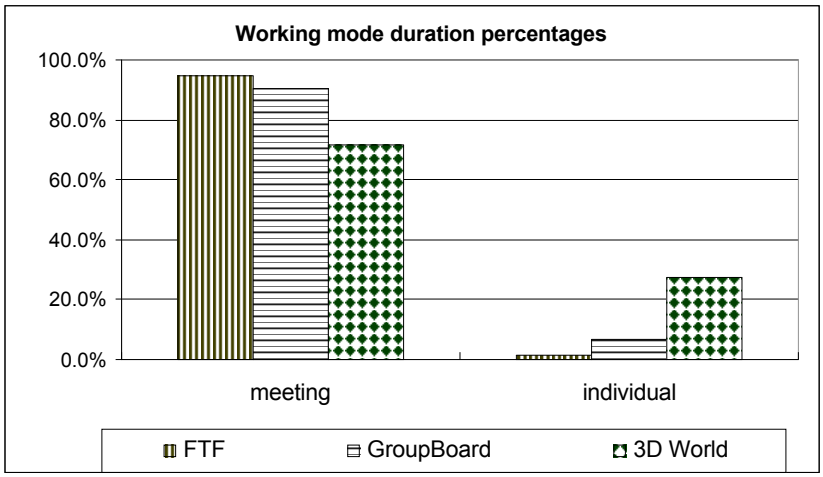


Figure 8 Bar charts for working mode of designers (average of 3 pairs over 3 design phases)

4.0 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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