COMPARING COLLABORATIVE DESIGN BEHAVIOR IN REMOTE SKETCHING AND 3D VIRTUAL WORLDS

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Abstract. The aim of this study is to compare two architects' collaborative design behaviour while using a shared whiteboard application in one design session and a 3D virtual world in a second design session. Our preliminary analysis shows that designers spend more time discussing design ideas while sketching and more time creating the design model and inspecting spatial relationships while in a 3D virtual world.

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. Only by

gathering information about the rich and complex picture of collaborative design can we understand the characteristics and needs of the practitioners involved as well as those factors which contribute to their professional effectiveness.

2. Team collaboration in high bandwidth environments

The comparison presented in this paper is part of a larger study funded by the CRC for Construction Innovation in Australia[1]. In studying the impact of high bandwidth environments on design collaboration, an experimental study with 3 design settings was developed:

1. A collaborative design process in which designers work face to face with their current design and communication tools.
2. A collaborative design process in which designers use a shared drawing system with synchronous voice and video conference.
3. A collaborative design process in which a 3D virtual world is used in addition synchronous voice and video conference.

The reason for including the first setting is to understand the nature of the collaboration process as it takes place using traditional methods and without digital systems for designing and communicating. The study has been carried out over three months using an open ended exploratory approach into gathering data on existing design practice.

This paper presents an analysis of the data collected from the 2nd and 3rd settings, comparing two architects' collaborative design processes while using a shared whiteboard application and while using a 3D virtual world on a desktop computer. The two collaborative environments were selected as representative of current low-bandwidth technology (Net Meeting) and a prototype of high-bandwidth technology (extended Active Worlds). The paper begins with a summary of relevant methodologies and studies, and then the experiment design and data collection methods are described. Finally, protocol analysis of the design sessions and the results are presented.

3. Background

There are many studies that reveal the nature of design thinking and the characteristics of early conceptual design as distinct from detailed or embodiment design. The results of those studies can assist in our understanding of how the processes of design can be supported and how new technologies can be introduced into the workplace (Munkvold 2003).

Protocol analysis has been accepted as a prevailing research technique allowing elucidation of design processes in designing (Cross et al. 1996).

[1] <http://www.construction-innovation.info>

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).

The protocol analysis technique has been adopted to understand the creative nature of collaborative design (Cross 1997), the design behavior of teams in terms of coherent idea production (Goldschmidt 1996; Van der Lugt 2003), process-oriented designing (Gero and McNeill 1998); and reflection-in-action (Valkenburg and Dorst 1998). Another stream of studies were concerned with the impact of use of different communication channels on design process (Vera et al. 1998; Gabriel and Maher 2002).

The ROCOCO project studying protocols of collaborative design presents one of the early approaches to detailed analysis of drawings together with analysis of verbalizations (Scrivener et al. 1992 cited in Mazijoglou et al. 1996). Consequently recent design protocol studies employed analysis of physical actions such as drawing, moving hands (referring to hand gestures in sketching) and also seeing/looking which provided a comprehensive picture of constructing external representations during designing (Suwa et al. 1998; 2000; Kavakli and Gero 2002).

Protocol studies in the engineering design domain focused on the work environment context and the social interaction discourse (Buciarelli 1994) as well as design behavior and communication (Badke-Schaub 2003; Glock 2003). These studies emphasized the analysis of conversation patterns, in order to gather information about the team dynamics, individual motivations, social interpretations etc. Protocol studies of this kind have been done relatively less in architectural design practice because of the difficulties in collecting protocols.

The internet and the expansion of international design practices have initiated our interest in studying "collaboration at a distance" both within the same profession and across professions. We believe that design work would be conceived as a social process, rather than design being influenced by social factors (Suchman and Trigg 1991; Bucciarelli 1994). Consequently the architectural design process could be conceived as a process of communication and interaction between designers and different domains instead of a process where the architect is a self-sufficient individual mind.

4. Method

In this study we worked with two architects from Woods Bagot, who were selected on the basis of observations carried out in the workplace/baseline study. In these observations, the collaborative roles of the participants were determined, and their face to face interactions were recorded. We name the

designers as Alex and Casey, the same names as their avatar names in the virtual world environment, rather than using their real names.

A series of pilot studies have been conducted for testing the experiment set up and maintaining participants' acquaintance with the technologies. Before the experiment sessions, the participants were given a training session on the use of software and related tools. Then in the experiment sessions they were asked to work on a hypothetical design brief that they are exposed to for the first time.

4.1. EXPERIMENT SET-UP

We record the designers' activities and verbal exchanges in each session with a surveillance DVR (digital video recording) system. The DVR system was set to show four different views on one monitor. Two cameras were used to monitor the two participants' behaviors and the other two views are video streams directly from the two designers' computer display screens. Two separate microphones for each participant were fed into the DVR system through a sound mixer. Figure 1 shows the equipment set-up where two participants are located in the same room with a panel in between them. We placed the designers in one room to simulate high bandwidth audio, using the LAN for video and shared applications.

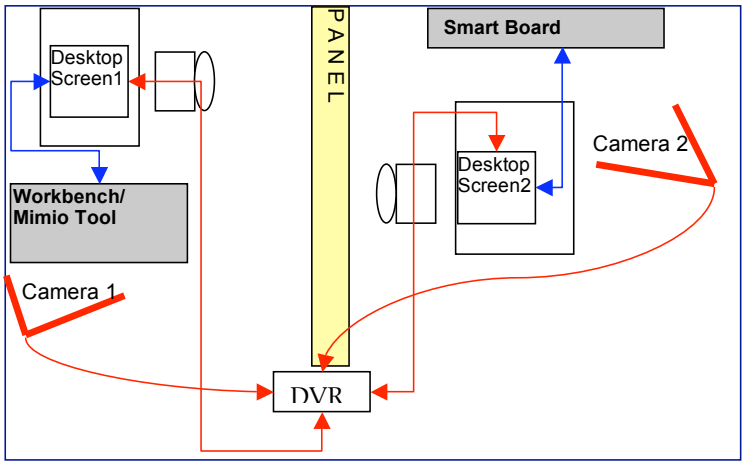
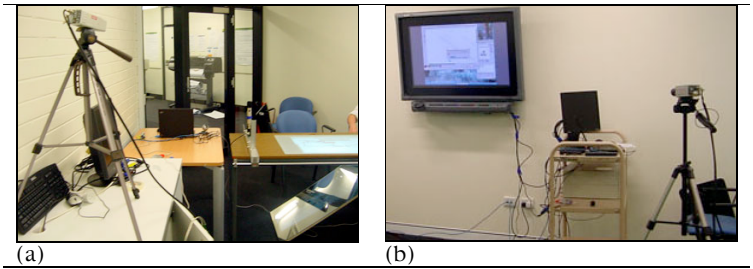


Figure 1. Diagram of equipment set up

In the experimental set-up, two cameras and two computers are connected to the DVR. "Desktop screen 1" was projected on a horizontal

workbench (with glass top) and a Mimio Tool[2], and "desktop screen 2" was connected to the Smart Board with flat panel plasma display[3]. In the first setting, the plasma display and the horizontal workbench were used so the designers had a large drawing surface. In the second setting, the cameras and video streams were connected to a typical desktop computer configuration with a vertical screen, keyboard and mouse.

Figure 2 shows the set-up on the left side (Figure 2a) and right side of the room (Figure 2b) in the first experiment setting. The location of the cameras was an important issue, since we aimed at monitoring participants' movements, verbalizations, gestures and the drawing actions. Cameras 1 and 2 capture the gestures, general actions such as walking, looking at, moving to the side etc. while the direct connections to the computers/screens capture the drawing process in detail.



(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 first setting of the experiment, the architects used Microsoft Net Meeting, one participant via a Smart Board (Figure 2b), the other participant via the Mimio on a projection table (Figure 2a). Net Meeting includes a shared whiteboard application and web-cam application. The architects were able to see each other via the web-cam and also were able to talk to each other because they were located in the same room.

In the second setting of the experiment, the architects used an extended 3D virtual world application in Active Worlds (Figure 3). The 3D world includes a multi-user 3D building environment, video contact, a shared whiteboard, and an object viewer/insert feature. The participants can talk to each other because they are in the same room.

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[2] http://www.mimio.com

[3] http://www.smarttech.com

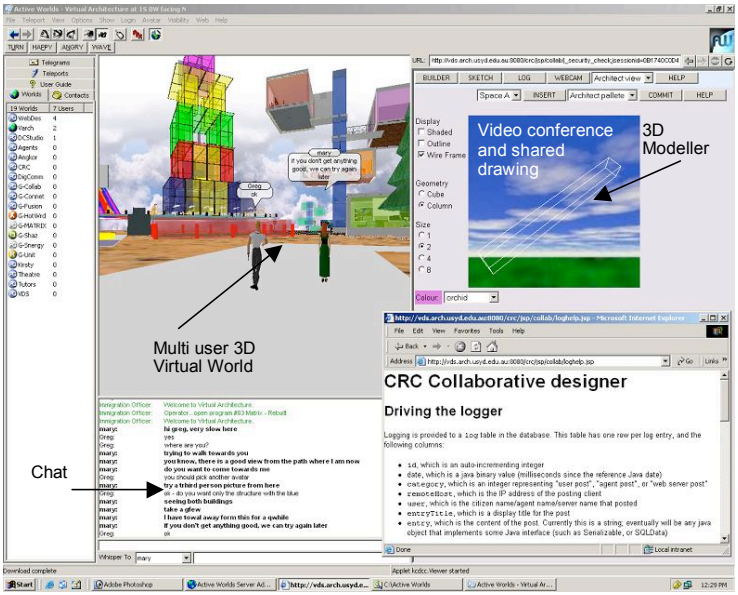


Figure 3. Extended virtual world

4.2. EXPERIMENT DESIGN

The experiment followed a 6 step procedure.

1. 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.

2. The designers were given a 15 minute training session on the use of Net meeting. 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.

3. The designers were given a design brief (see Appendix) and shown a collage of the photos of the site they are required to build on. The design brief involves designing an art/craft gallery on a site in Sydney. 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 participants can sketch on them.

4. The designers commenced designing using Net meeting. The duration of the session was half an hour. Five minutes before the end of the session they were reminded that this was the amount of time remaining.

5. After a 5 minute break, the designers were given a 15 minute training session on the use 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 commenced designing collaboratively on the same design task/design brief, this time using the extended virtual world. The duration of the session was half an hour. Five minutes before the end of the session they were reminded that this was the amount of time remaining.

Table 1 shows the summary of methods, tools and activity of participants:

TABLE 1. Experiment sessions

	1st Phase	**2nd Phase**
Participants	Alex and Casey	Alex and Casey
Interface	Smart Board and Mimio on a glass table	Desktop Screen
Software	Net Meeting	Active Worlds
Application	Shared White Board	Construction Space
Webcam	√	√
Training tutorial	√	√
Design Brief	Architect Version	Architect Version

Figure 4 shows the shots from the recorded activities of the architects collaborating during Net meeting (Figure 4a) and 3D world session (Figure 4b).

(a) (b)

Figure 4. Architects collaborating during (a) Net meeting session (b) 3D world session

4.3. PROTOCOL CODING

The software used for the analysis of the experiment sessions is called INTERACT[4], with the interface as shown in Figure 5 for coding the recorded videos. More information on the reasons for choosing this software and how it improved our coding process can be found in Candy et al (2004).

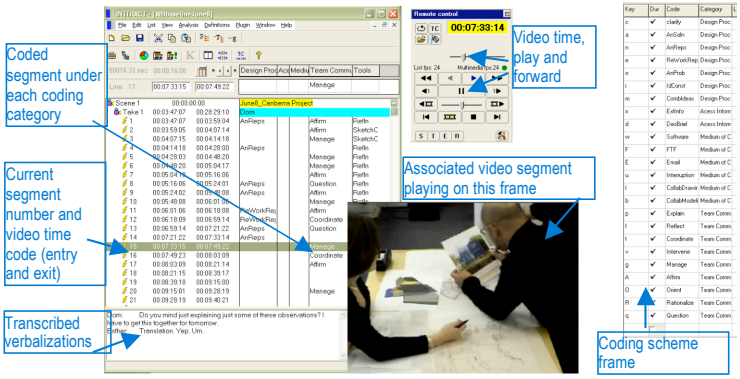


Figure 5. INTERACT Coding interface

4.3.1. Segmentation

The continuous stream of video and audio date needs to be segmented for coding and analysis. A single filmed session is called a Scene in INTERACT. There are "Takes" in a Scene which we refer to as design episodes. We utilized one take for coding one actor's activity, and second take for second actor's activity separately in a scene. "Events" are smaller activity definitions building up the "Takes" which are also the smallest segment definitions in the current study. In the study done by Dwarakanath and Blessing, an event was defined as a time interval which begins when new portion of information is mentioned or discussed, and ends when another new portion of information is raised (Dwarakanath and Blessing 1996). 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. For example, in Segment

[4] www.mangold.de

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 <inaudible>

Alex: And that is the ramp?

Casey: That is the ramp."

Then this conversation could be put into one segment despite the change in speaker. Table 2 shows the segmentation of a protocol excerpt from the study.

TABLE 2. Segmentation in terms of event definitions

Segment 11	Casey: You were feeding, the lobbies there but not facing the void. You saw the void from around this way. Alex: Yeah but this is again Site Specific it is related to the <inaudible>
Segment 12	Alex: That is ok. I mean again within that model... Just keep that. I guess the point is
Segment 13	Alex: I think even in this model you can still to have a lift opening up this way or a lift going this way. But what he was suggesting was maybe if we pulled the lifts out
Segment 14	Alex: but I think you could actually put the lifts here.
Segment 15	Casey: You know this... what I am saying... do that, you face this way and you come out and you turn a corner and that is hanging off the edge of the void there is a void there so this is like you come out, like when you are waiting for the lift you come out and you are off the edge.
Segment 16	Alex: I like that with glass under that... you walk past the sort of lobby as you come in Casey: and as you go up this thing jumps out.... Alex: yeah so you could put that line there...

4.3.2. Coding Scheme

The purpose of the coding scheme is to provide categories for the collected data that will highlight the similarities and differences in collaborative designing using the two different design environments. These differences provide the basis for understanding the impact of introducing a new design environment. We have developed 3 coding categories: communication content, design process, and operations on external representation. The communication content category partitions each session according to the content of their conversation, focusing on the differences in the amount of conversation devoted to discussing design development when compared to other topics. The design process category characterizes the different kinds of designing tasks that dominate in the two different design environments. The operations on external representation category looks specifically at how the

designers interacted with their external representation of the design to see if using 2D entities or 3D objects was significant.

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 3.

TABLE 3. 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
Context free	Conversations not related to the task
Tech Prob	Talking about a technical problem

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.

Communication on design process involves statements about design issues, environmental or structural issues, design ideas, design solutions, judgments about design solutions, functional issues or design constraints, client requirements, comments on design brief, in other words any conversation about the design process.

Communication on awareness refers to conversations on participants' presence and actions in a digital environment, for example:

"I see where you are, I'll come down and join you and here I'm".

"aaaha you re working on the NE corner…."

"Did you manage to put walls?

Yes there are a couple of panels at the southwest corner".

Context free communication refers to the conversations that are not related to the design, the software, or awareness of others, for example "shall we have a beer after this?".

Communication on technical problems is coded separately from software features because they are problems that may be resolved in future experiments. The technical problems include software crashes, computer hardware or server failures, internet disconnection.

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 4.

TABLE 4. 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 5 shows the codes in the external representations category.

TABLE 5. External Representation

Create	Create a design element
Group	Group elements
Move	Orientate/Rotate/ Move element
Erase	Erase or delete a design element
Inspect	Attending to, referring to the representation

The actions required to construct external representations differ in each media. Thus the definitions of the codes in this category need to be explained for Net meeting and 3D worlds, as shown in Table 6.

TABLE 6. External Representation Actions

Code	**Net Meeting**	**3D World**
Create	Drawing a new entity.	Inserting a design object (wall, column, beam, slab, box) into the

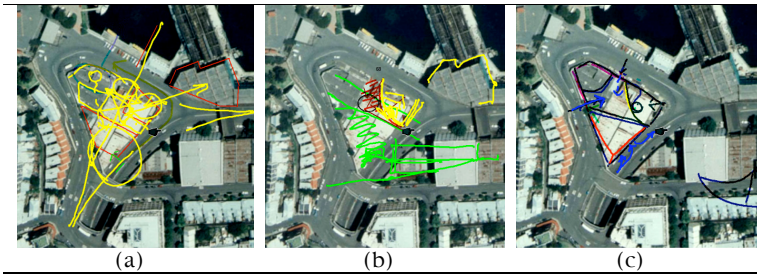
		environment.
Group	Creating entities next to each other, which form a group.	Duplicate an object next to the previous in one segment duration.
Move	Move action is not frequently used in a shared white board, because designers tend to use it like a sketch paper.	Designers move around the objects after they are created. This is to align them, change their arrangements or to carry them for using in another location.
Erase	Select a drawn entity and delete it	Select a created object and delete it.
Inspect	--Looking at the representation and refer to its parts/aspect --Using hand gestures over the representation --Attending to a visual feature of the representation --Zooming in and out --Scanning	--Looking at the model and refer to a design object. --Using hand gestures over the representation --Attending to a visual feature in the environment --Changing the view point in the environment

5. Interpretations

5.1. OBSERVATIONS

In the different design environments there was a noticeable difference in the designers' focus. The sketching environment encouraged the designers to stay at a high level of abstraction and the 3D virtual world encouraged the designers to focus on the relationships between the objects in the design solution.

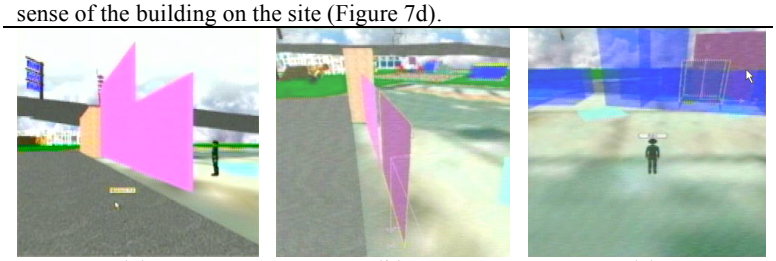
In the Net Meeting session, the architects produced sketches on the aerial view of the site layout. In page 1 (Figure 6a), the participants focused on organization of the layout and the relationships between the larger elements in the environment. Then, in page 2 (Figure 6b), the participants focused on the elements of the building, where they deal with form and structure in parallel to functions and the organization of the building elements (such as the location of loading dock suggesting two levels on the south side, the plaza and open gathering space suggesting a curved façade). In page 3 (Figure 6c), they mainly worked on the form of the building, evaluating the form and how successfully they satisfied the design brief requirements. In pages 4 and 5 they produced section drawings where they worked out the form of the design and considered 3D aspects of the building.



(a) (b) (c)

Figure 6. Net meeting drawings (a) page 01 (b) page 02 (c) page 03

In the 3D World session the two architects constructed the design they previously worked on in the Net Meeting session. They started with placing the (pink) walls next to each other (Figure 7a), and then moving them around, aligning them. Alex managed to put the walls on top of each other, and get the look of a second floor (Figure 7b). Then they started using the space elements (blue transparent boxes) to represent the space, the building should cover (Figure 7c, 7d). The construction of the blue spaces was relatively quick and towards the end of the design they managed to get a sense of the building on the site (Figure 7d).



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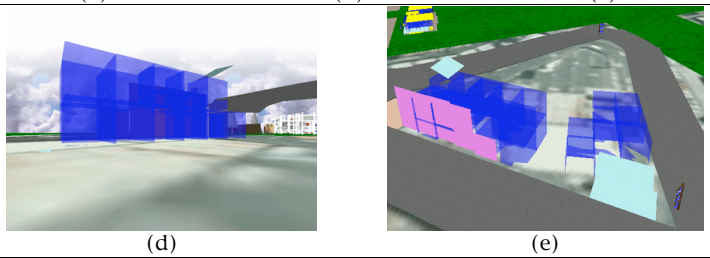

(d) (e)

Figure 7. Progress of the design in 3D World

5.2. PROTOCOL ANALYSIS

In the protocol analysis, we consider each of the three categories of codes separately.

5.2.1. Communication Content

Figure 8 shows the percentages of the percentage of time in each of the communication content codes. Most of the communication in Net Meeting session was on "designing" (85 %) followed by relatively little percentages of "software features" (8.5 %) and "awareness" (5.7%) (Figure 8a). In the 3D world session nearly half of the communication was on software features (Figure 8b). The remaining communication was primarily about awareness and designing (22% and 28%). The significant amount of time on the 3D virtual world on the features of the software may be due to the unusual experience of being in a 3D virtual world while creating and editing a building model. It is significant that the designers in the 3D world session focused on expressing issues related to their awareness of each other. This is relevant because the location of the avatar determines what each designer can see, so the ability to collaborate depends on knowing where the other avatar is and what the avatar is facing.

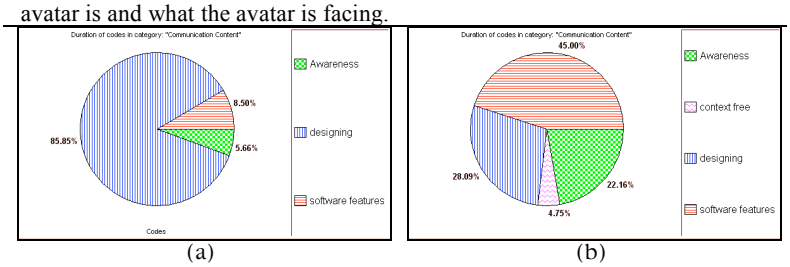

Figure 8. Percentage of time on communication content (a) Net Meeting (b) 3DWorld

5.2.2. Design Exploration

Figure 9 shows the percentages of time on design exploration codes in Net Meeting versus 3D World sessions. The designers spent significantly more time in proposing and analyzing solutions during the Net meeting session (Figure 9). However in 3D world session participants spent most time on setting up goals and then on analyzing external representations (Figure 9). This is consistent with our observations that the designers were focused more on high level issues in Net Meeting and were more focused on building the 3D models in the 3D world.

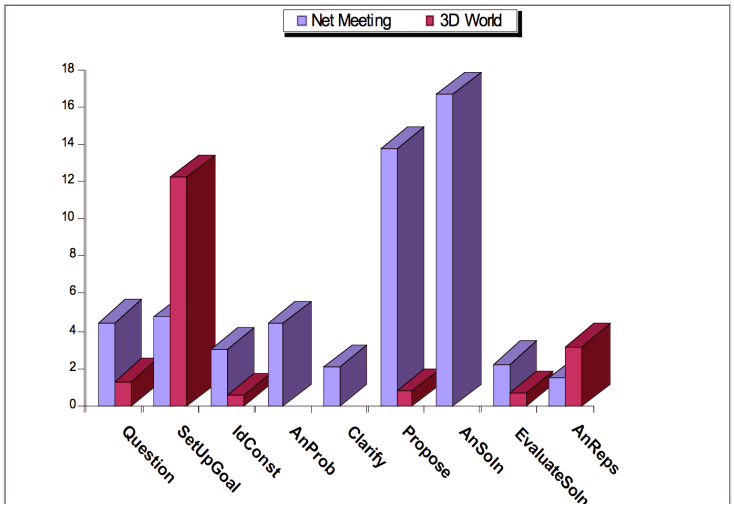

Figure 9. Percentages of time for design process actions (a) Net Meeting (b) 3D World

Figure 10 shows design process actions over time for each individual in Net meeting and 3D World sessions where "1" refers to Alex and "2" refers to Casey. In the Net meeting chart (Figure 10a) one can observe the cluster at the beginning of the session which is formed by analyzing a problem (AnProb), questioning (Question), and setting up goals (SetUpGoals) actions. Then proposal of ideas/ solutions (Propose) start to occur (Blue bars). Meanwhile analyzing solutions (AnSoln) are triggered by proposal actions (the pink arrows point to this relationship). Evaluation of solutions/ ideas (EvaluateSoln) occurs only after the first half of the session; in smaller time intervals in between analysis of solutions (orange ellipse markers point out to this relationship). However in the 3D world session there is hardly any pattern in occurrence of certain actions (Figure 10b). Fewer segments are coded as "designing" in the 3D world than in Net Meeting, as explained in the section on communication content. This may account for the lack of patterns in their behaviour.

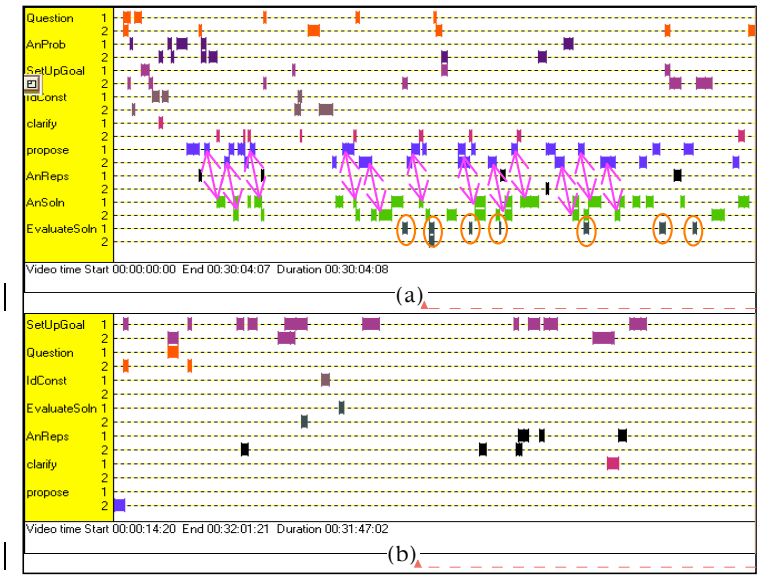

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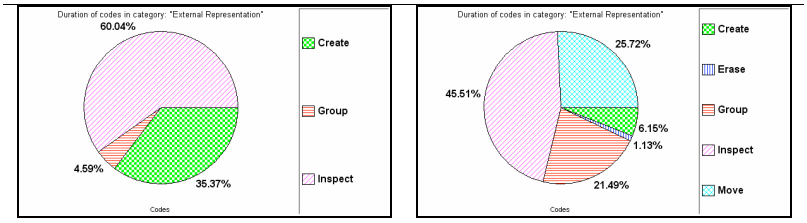
Figure 10. Individual design process actions over time (a) Net Meeting (b) 3DWorld

5.2.3. External Representations

Figure 11 shows the percentage of time related to operations on the external representation in Net meeting and 3D world sessions. "Inspect" was a dominant behavior in the Net meeting session that covers more than half of the total design session (60%) followed by "Create" (35%). Grouping elements consists of only 4.5% of the total actions time. In the 3D world session inspection is observed in nearly half of the total duration of the session (45%), and this is followed by moving and grouping elements (26% and 21%). Time spent in creating elements is significantly small (6%) in 3D world session compared to Net Meeting (35%). Thus the ratio of the actions in constructing an external representation seems to be quite different when participants are engaged in a different media.



(a) (b)

Figure 11. Percentage of segment on operations on external representations (a) Net Meeting (b) 3DWorld

Figure 12 shows actions for operations on external representation over time for each individual in Net meeting and 3D World sessions where "1" refers to Alex and "2" refers to Casey. Looking at the occurrence of actions for each individual in the Net meeting session (Figure 12a), we see Inspect-Create and Create-Inspect patterns (see the pink arrows), as a frequently observed combination. Create and Inspect actions are observed to trigger each other rather occurring in parallel.

Looking at the occurrence of actions in 3D World, we again observe the Inspect-Create pattern (see pink arrows). Then, Create is usually followed by Move forming the Create-Move pattern (see orange arrows), and then Move is followed by Group action, forming a Move-Group pattern (see purple arrows). This chain of actions i.e. Inspect-Create-Move-Group pattern occurs at least three times during the session for each individual (see yellow ellipses). Note that Inspect can be observed as a continuous action, either in parallel with or immediately after Create, Move or Group actions. Thus the pattern of constructing external representations (Inspect-Create-Move-Group) is not one directional chain-like pattern only but interacting with the Inspect action frequently.

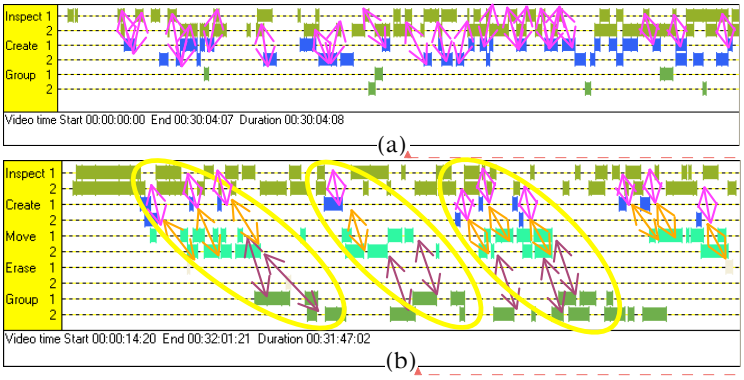


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Figure 12. Individual actions over time to construct external representations (a) Net Meeting (b) 3DWorld

6. Discussion

Based on our insights from the baseline/workplace studies, the communication content in face to face sketching sessions is predominantly about the designing rather than about the tools they are using or where the other person is located. 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 talked about the design rather than the software or the awareness of each other. However, in the 3D virtual world we found that the conversation was predominantly about the software, and then only secondarily about the design and about their awareness of each other. The large percentage of the discussion on the software can easily be associated with the novelty of the experience, and the split between designing and awareness of others is due to the significance of the information about the other designer's location with respect to the design model they are creating. This result emphasizes two aspects regarding the nature of the 3D world that is different to remote sketching: 1. Participants may communicate about their existence since they are in a virtual world, 2. participants may need to communicate about their actions, and location or presence of the objects since they can choose a different viewpoint to visualize the current representation.

Comparing the design tasks in Net Meeting and 3D World sessions, we showed that in Net Meeting the architects explored the design ideas more frequently (Figure 9) with the highest occurrences of segments on proposing and analyzing design solutions. Further these actions frequently triggered

each other over the timeline of the design session. In protocol studies, this behavior refers to a design thinking cycle which involves analyzing a problem, proposing a (tentative) solution, analyzing the solution and finally evaluating it (Gero and McNeill, 1998). A similar cyclic process was emphasized in creative cognition literature as explore-generate-evaluate actions (Finke et al., 1991). However in many cases, it is only after designers synthesize a solution that they are able to detect and understand important issues and requirements of the given problem. Lawson (1990) called this phenomenon 'analysis through synthesis". Then analysis of tentative solutions (in other words exploration) could be means to an evaluation which is an expected behavior during the conceptual phase of designing. In the Net Meeting session, the designers designed in a similar cyclic pattern where they propose and then analyze solutions, and in between evaluate them (Figure 10a).

In the 3D World session, no significant patterns for designing were observed (Figure 10b). This indicates a different behavior to the analysis-synthesis-evaluation cycle. In the 3D World, the designers set up goals in terms of building parts of their design or plan their actions. Then they analyzed the external representation, in terms of attending to parts and relationships, rather than thinking about the problem at an abstract level. This shows that designers' aim in the 3D world session was to construct a representation of the design which we call "design making" rather than design exploration.

Comparing the operations on external representations in Net Meeting and 3D world sessions, we observed significantly different ratios in occurrence of actions; particularly of Create, Move and Group actions (Figure 11). This difference is mainly to do with the nature of representations the designers were dealing with; they construct with lines in a 2D media in Net Meeting, and with objects in a virtual environment in the 3D world (Figures 6 and 7).

Constructing external representations was a more complex issue in the 3D world session. The architects were engaged in the Inspect-Create pattern during the Net Meeting session (Figure 12a), while they were engaged in a more complex pattern involving Inspect-Create-Move-Group actions during the 3D World session (Figure 12b). In the 3D World the designers were synthesizing objects, through Create-Move-Group actions and continuously inspecting how they looked. This can also be interpreted as an "analysis through synthesis" process. Thus in the 3D world the designers were engaged in that similar pattern however with different tools; in Net Meeting they were dealing with abstract concepts, in 3D world with objects.

The results show that the designers' behavior was different when they were engaged in remote sketching via Net Meeting and when they were engaged in modeling via the 3D World. They would not have focused on the details of how objects would come together and be synthesized if they were

not using a 3D environment. In the same sense they would not be engaged in design process on an abstract level i.e. through design exploration, if they were not using the remote sketching environment. Thus the distinction between the nature and benefits of the two design environments were revealed by analyzing the design behavior of the participating designers: 3D World is for design making, remote sketching is for design exploration. In parallel to this view, there are also participant comments in the recorded sessions that they considered the 3D world environment as a modeling tool rather than a conceptual tool.

Further studies will focus on engaging more designers in the 3D World environment. In these studies the designers will be encouraged to engage in design exploration rather than only design making. They will be given a new design brief where they need to develop concepts, explore possible design solutions and evaluate them. We will increase the time dedicated to training on the extended virtual world, to assure that they utilize the software efficiently during the experiment rather than learning it.

6. Conclusions

Introducing new tools to the design process requires understanding of what purpose they serve. A design environment could be beneficial either for conceptual phase, detailing phase or modeling phase, however analysis of design behavior is needed for understanding the benefits of the tools/environments. This case study was an attempt to characterize and compare the design behavior of two architects using two different tools/media for designing. We demonstrated architects developed abstract concepts, analyzed synthesized and evaluated them when they were involved in remote sketching via Net Meeting shared whiteboard. The same architects focused on synthesis of the objects and the making of the design, when they were involved in 3D modeling via the extended virtual world.

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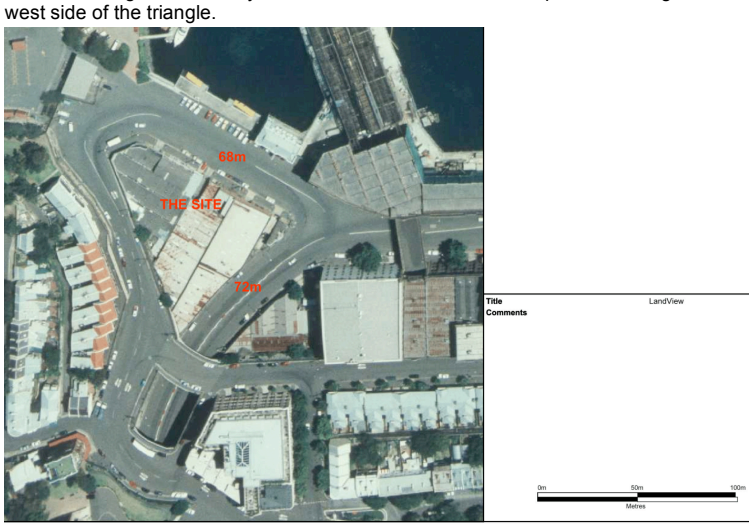
Appendix

Brief for a Harbourside Gallery (Architect Version)

During this design session you are asked to prepare a block model esquisse scheme for a proposed art/craft gallery on this site. The site and information below provide details about the location and use of the site. There are 30 minutes available for this investigation.
This project is to prepare a block model esquisse scheme for a proposed art/craft gallery on this site. You should assume that all existing buildings have been demolished before your scheme commences construction. There is no floor space ratio or height restriction applicable for this project so you may choose to liberate as much or as little of the site for open space as suits your scheme.

Site

The site is a triangular block as shown below. Site area is approximately 2800m2.North is to the top of the picture where the harbour and wharves are visible. There are roads on all 3 sides of the site at varying heights relative to the ground floor of the existing buildings. You will see that one road crosses the other on an overhead bridge immediately to the south of the site, then ramps down along the west side of the triangle.



Accommodation Required	Area (m2)
Galleries and performance space	
Permanent exhibition suite	1500
Sculpture garden	600
Temporary exhibition suite 1	750
Temporary exhibition suite 2	150
Forum	750

Front of house public areas

Entrance/foyer		xx
Reception		30
Cloak store		20
Café (with after hours access)		200
Shop		100
Shop storage		30
Ticket office		25
Members lounge		60

Back of house support areas

Staff entry		xx
Loading dock		to suit truck 12.5 x 2.5 x 4.5 high
Unloading		60 (min. opening 4.5 x 4.5)
Bay for forklift		10
Exhibition receiving and preparation	200	
Restoration and repair workshop		200
General storage		50
Chair storage		30
Cleaning		10
Board room		60
Director		30
Assistant directors and manager		20 x 3
Curators		15 x 12
Accounts		10 x 4
Security		20
Technical support		30 x 2
Volunteers		20
Toilets and showers		xx

Notes

No car parking required
Maximize energy efficiency and passive solar principles
All galleries to be naturally lit
Forum minimum span 25 metres
Separate delivery for café and shop

The participants were also given a collage of the photos showing the site and the surrounding area (Figure A1)

Figure A 1 collage of photos