Studying Design Collaboration in DesignWorld: An Augmented 3D Virtual World

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Abstract

New technological developments offer new collaborative design environments to designers. There is a great interest in these new tools however it is clear that we know very little about how these new design media would affect the way architects collaborate. The study reported in this paper characterizes the collaborative design behaviour of a pair of designers in a prototype which has a 3D modelling tool and 2D sketch pad. The experimental study involves collecting data while a pair 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 nature of the collaborative process, communication content and the development of a design solution as a sketch and separately, in a 3D world. Our study shows that while 2D sketching encourages development of design ideas, the 3D virtual world encourages collaborative modelling of design solutions, in particular designers collaboratively refine the 3D model to visually analyse the design idea as they effectively develop realistic design representations.

1. Introduction

Recent developments in virtual environments and the availability of high bandwidth networks have the potential to bring significant changes in the way that Architecture, Engineering and Construction professionals collaborate and design. This paper presents a case study that characterizes collaborative design in an augmented collaborative virtual world. The prototype of the virtual world developed in the University of Sydney as a part of a research project. [1] The aim of the study is identify the collaborative design process, and external design representation and communication in order to have a better understanding of the impact of virtual environments on design collaboration.

Research into the impact of the technology on collaborative design can lead to a more critical understanding of how collaborative design can be facilitated. An understanding of how to facilitate collaborative design includes various factors including the role that communication media play, the use of materials and computer tools and the way people communicate verbally and non verbally [1]. Previous studies of differences in collaborating using remote sketching and virtual worlds show that a major difference in design process occurs when designers use sketches to communicate when compared to 3D models while in virtual environments [2, 3].

Characterising the collaborative work can assist in our understanding of how the collaborative design process can be facilitated and how new technologies can be introduced into the workplace. The role of communication media, the use of external representation and computer tools and the way people communicate verbally and non-verbally are important issues in this study. The aim is to study designers' activity so that it may be better understood and this understanding may be employed in the creation of better computer support that will improve the efficiency and effectiveness of collaborative design activity.

The project undertakes a case study of how designers work collaboratively using an augmented virtual world. The designers use a prototype, DesignWorld, that is an augmented virtual world (a combination of 3D modelling and sketching tools). Figure 1 shows the interface of DesignWorld. The 3D virtual world client, SecondLife, is on the left, and a web-base browser interface that has a link to the 2D sketching application, GroupBoard is on the right [see [4] for more information about the system architecture].

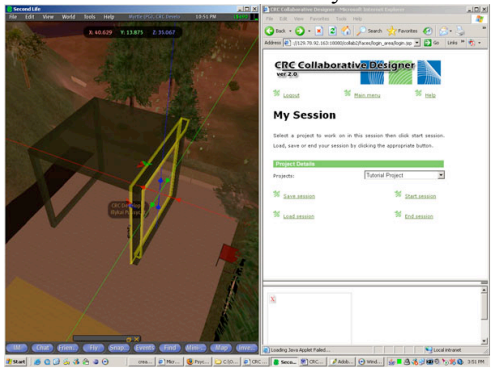

Figure 1 Interface of DesignWorld

[1] CRC Construction for Innovation project title is Team Collaboration in High Bandwidth Virtual Environments.

In DesignWorld designers have a choice of working in 3D virtual world or remote sketching in a shared white-board at the same design situation.

2. DesignWorld Study

The aim of the DesignWorld study is to understand the collaborative design processes where the designers have a choice to sketch in a shared whiteboard (GroupBoard) or to model in a 3D virtual world (Second Life). A key objective will be to identify the factors that support design process improvement. The specific question to be addressed is what the impact of using high bandwidth technologies and tools for collaborative design would be. The section below describes the experimental set up for the DesignWorld study. We conducted a series of structured and controlled experiments with the participation of the professional architects. Figure 2 shows video data collected while two designers collaborated in DesignWorld.

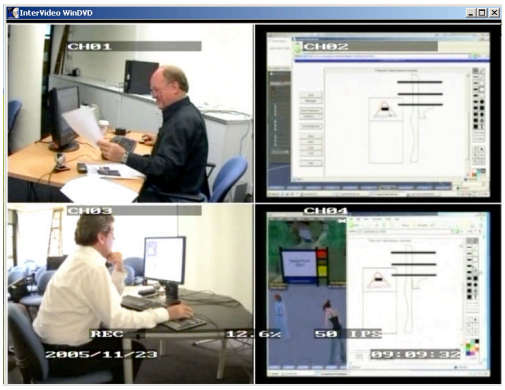

Figure 2 Two designers collaborating in DesignWorld

2.1 Study methods

Protocol analysis is used to study and compare the impact of the virtual environments on collaborative design behaviour. This has been accepted as a research technique allowing characterisation of processes in designing [5]. While earlier studies generally focus on the protocols' verbal aspects [6], later research acknowledges the importance of design drawing [7] together with design thinking which can be interpreted through verbal descriptions [8-10]. We can understand how virtual environments impact on designers' focus during the design session by gathering information about their communication and behaviour.

In the DesignWorld study, we studied pairs of designers collaborating on the same design task. Our designers were architects, so the design task was the design of a tower that includes a small shopping centre (a gift shop), viewing area, and a café/restaurant. They were given a tower brief and asked to complete the design in one hour. We asked that the viewing area should be high enough to provide a view over the water.

The designers trained in a neighbour site where they were asked to build a tower, so they become familiar with the environment. In this paper we present a case study of a pair of architects working in DesignWorld.

2.2 Experiment

We recorded the designers' activities and communications in the session with the surveillance digital video recording (DVR) system. In order to simulate high bandwidth audio and video, both designers were in the same room and can talk to each other, but can only see each other via a web cam. In the experimental set-up, two cameras, two microphones and two computers were connected to the DVR. Figure 3 shows the equipment set-up where two participants are located in the same room with a panel in between them.

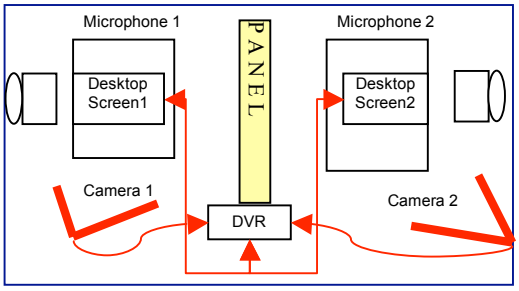

Figure 3 Experiment setup

The cameras and video streams were connected to a typical desktop computer configuration with a vertical screen, keyboard and mouse. The DVR system was set to show four different views on one monitor. Two cameras were used to monitor the two participants' behaviours and the other two views were 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.

2.3 Video and verbal data coding

The data from the experiment includes a continuos stream of video and audio data. The stream of data for the session is segmented for coding and analysis. We used a software called INTERACT2 for our coding and analysis process. The protocol is flagged based on an interpretation of an event. Dwarakanath and Blessings'[11] event definition is the most favourable one for the study, since the occurrences of actions and intentions change spontaneously as architects draw/model and communicate interactively. We interpreted the event as two ways. The first is that 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. The second one is that an event can change when a different person starts to

[2] www.mangold.de

change his /her representational activities such as creating an element or engaging the visual features of the elements. In this paper we refer to the designers as Alex and Brown. For example, in the following discussion, designers take turns in one segment; however their subject of interest is still a slab object.

"Brown: Oh, you just moved it!
Alex: Oh, sorry.
Brown: I had it perfectly.
Alex: Did you? Hehe…
Brown: Go away, hehe. OK, you…
Alex: No, no, you finished it.…Well, I am on it. I will just move it if you want.
Brown: OK, I will do the other one then.…
Alex: You play with that one. I will clone another one of these to make the platform a bit bigger."

Each segment is then coded according to a coding scheme. The coding scheme allows us to characterize the designer's behaviour in the 3D virtual world. The coding scheme has the following categories:

- Communication in collaborative design: *design communication, awareness and communication technology;*
- Design Representation: *realization, agents actions and perceptual focus;*
- Working mode; *individual and meeting*, and
- Representation mode: *2D and 3D.*

Communication in collaborative design:

Communication in collaborative design refers to verbal design communications that have direct relevance to designers' collaboration to solve a particular design problem as well as their interactions with each other and the tools. This category has subcategories that are *design communication, awareness, communication technology and others. Design communication* category aims to capture the discussions in terms of 'design collaboration', 'design ideas', 'design scope', and 'design semantics'. *Communication technology* looks at the discussions held between participants related to the use of the tools and the collaborative environments in terms of 'problem', 'howTo' and 'things and properties'. *Awareness* is another code that looks at the discussions held between participants related to the presence and activities of others. *Other* code is to capture utterances that are not related with designing.

Design representation:

The second main category, design representation, was designed to capture when and how designers create and use visual information that is mostly accompanied by verbal information. The design representation coding scheme has three subcategories: Agents actions, realization and perceptual focus.

Agent actions:

Agents[3] actions looks specifically the interaction of the designers with his/her surrounding that is the physical world and the virtual worlds. The interaction occurs in three ways; gesturing, engaging with Elements and Tools, as summarised in Table 1. First, designers use gestures when they want to point an element, describe shapes, sizes and height, show directions or locations of objects. Second, designers inspect design elements (onElement) that could be drawings on the paper and shared white board or 3D models in the virtual environment. Third, designers engage with the tools (onTools) that could be pen-pencil, paper or clicking drawing tools on Groupboard or searching the tool plate, or clicking buttons/ objects in the 3D world.

Table 1 Agent actions

Gesturing	Hand gesturing in face to face, moving avatar for pointing the objects, using cursor
OnElements	Inspecting the design, changing views
OnTools	engaging with the tools (paper, pen or clicking and/or dragging objects/buttons on digital environments)

Realization:

This category has two subcategories; realization process and realization actions.

Realization process, is adapted from Atman and Bursics' [12] design step category and is shown in Table 2. The aim of these codes is to capture discussions held between participants related to the realization of the design ideas that includes *decisions, modelling* and *describe.*

Table 2 Realization process

Modelling	Modelling, describing how to build an idea, how to make it, measurements, calculations
Decision	Select one idea or solution among other alternatives
Describe	Define the design to others

Realization actions, shares characteristics of Kavakli and Gero's [13]'drawing actions' category and has Cardella et al's[14] 'representation' category. The category looks at the interaction of the designers with the visual information that is drawing in GroupBoard or 3D modelling in SecondLife and is shown in Table 3. This category has the following codes; write, create elements, continue elements, add elements, delete elements.

Table 3 Realization actions

Write	Creating a written response or writing down ideas to be used later
Create Elements	Engage with (creating/drawing) point, line, plane, volume or in 3D virtual world cloning, duplicating an object
Continue elements	Continuing sketching or modelling/ developing the same representation further

[3] We used the term "Agent" that represents the designer in the physical and virtual environments.

	(modifying, moving, transferring, grouping)
Add to elements	Returning to the previous element after engaging in a different activity or working on different part of the representation.
Delete elements	Erasing elements

Perceptual focus:

Perceptual focus has two codes; *object/entity and spatial relationship* as shown in Table 4. This category looks at the visual information as well as the verbal information. When designers engage with the visual features of the design product that are size, shape, colour or texture...etc. it is coded as *object/entities*. When designers engage with the spatial relationship of the objects that includes positions, locations, alignments …etc it is coded as *spatial relationship*.

Table 4 Perceptual focus

Object/ entity	Engage with visual features of elements; shape, size, dimensions, colour, texture, material,
Spatial Relationships	Engage with spatial relation of elements; position, direction, gravity, alignment, x,y,z coordinates, being up, down, left, right

Working mode:

The third main category, working mode, includes two codes; individual and meeting. The descriptions of individual and meeting codes are adapted from Kvan et al's cognitive model of collaborative design [15]. In the model, it is *meeting mode* when designers work together on the same design outcome/product and it is *individual mode* when they separately work on the different parts of the design problem.

Representation mode:

The last category, *representation mode,* has two codes; *2D and 3D*. This category is to capture which mode the designers are working in, sketching in GroupBoard or modelling in SecondLife.

3. Observations from the design session

The designers started by developing a scheme on the GroupBoard and identified the maximum size of the individual pieces that they would make in Second Life. Their ideas on the building involved 3 block-structures and a triangle theme. They spent some time in talking about various options on the shape of the tower, which included a cantilevered slab, interesting fillet shapes and a triangular type arrangement. Then they separated functions such as a viewing area, café, restaurant and shopping arcade and confirmed the dimensions for them.

When Alex built a column for the tower, he did not create new one but copied one of the towers from the other side and resized it. Then he cloned other copies and moved them upward to increase the height of the tower. Brown made the triangles on the ground level and moved it to the top of the tower, which would be a basic structure for the roof and other levels. From time to time, they were just flying out to have a look at the design from out in the sky. They cloned the triangles and put them in different height respectively for making each floor. Brown made the thin walls connecting the levels while Alex worked on the triangles. At this point, they did not talk to each other but concentrated on their own work. They kept inspecting where the partners were working and what they were producing. Figure 4 shows the final design in SecondLife.

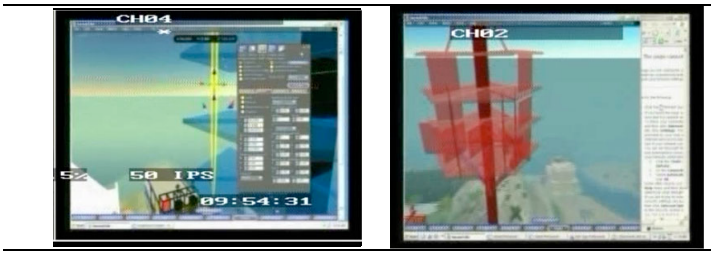

Figure 4 The final outcome in SecondLife

4. 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. Figure 5 shows how much time the designers spent on communication content category codes. Time is expressed as the percentage of the total elapsed time for each session (which is approx. 1 hour). Communication content durations were divided by the total time elapsed in each session, where duration percentages are obtained for each code. Design communication (designCom) duration percentages are highest, which are followed by communication about software features (Comm Tech) and awareness.

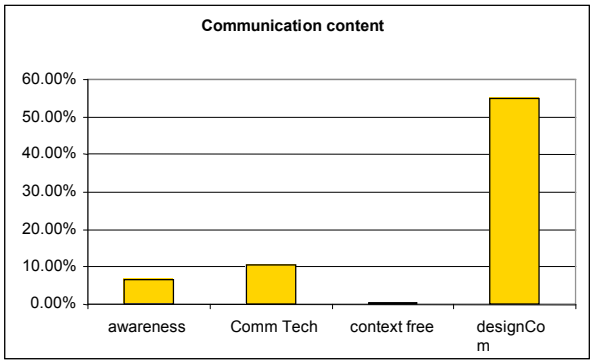

Figure 5 Bar charts for communication content

Figure 6 shows the duration percentages of realization process action of the designers (Alex is d1 and Brown is d2). The figure shows that modelling actions is the highest followed by describe and decision actions. The time spent for communication on how to build the model is relatively higher compared to the other two actions (29% modelling, 10% describe and 6% decision). This shows that they focused on modelling/ refining the design idea and on the details of building the tower.

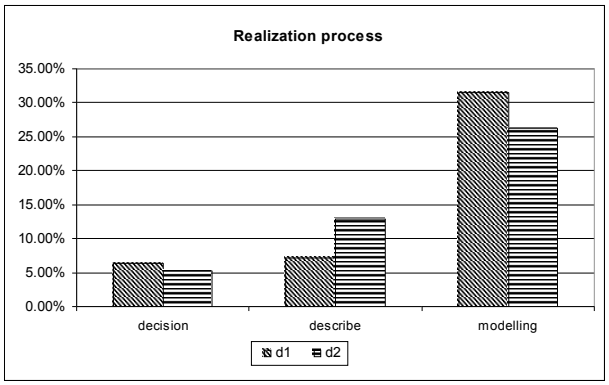

Figure 6 Bar charts for realization process actions of the designers (d1 and d2)

Figure 7 shows the duration percentages of perceptual focus actions of the designers (Alex is d1 and Brown is d2). The graph shows that spatial relationship action is the highest in both designers perceptual focus. This demonstrates that designers focused on spatial relationship of the objects.

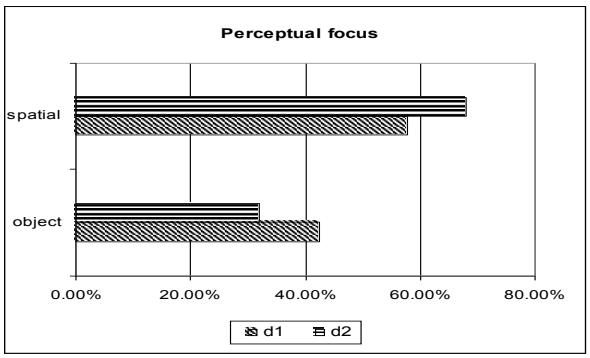

Figure 7 Bar charts for perceptual focus of the designers (d1 and d2)

Figure 8 shows the duration percentages of realization actions of the designers (Alex is d1 and Brown is d2). Continue element action is significantly high followed by create element and add element actions. This demonstrates that the designers engaged more with modifying/ moving objects in DesignWorld than creating new objects. This is due to the nature of the 3D modelling where one simple click creates an object but then the user needs to move it to its place, and position, rotate or modify its properties. Our previous studies also showed a similar modelling action cycles where designers inspect representation, create, move and modified the design objects in 3D virtual worlds [16].

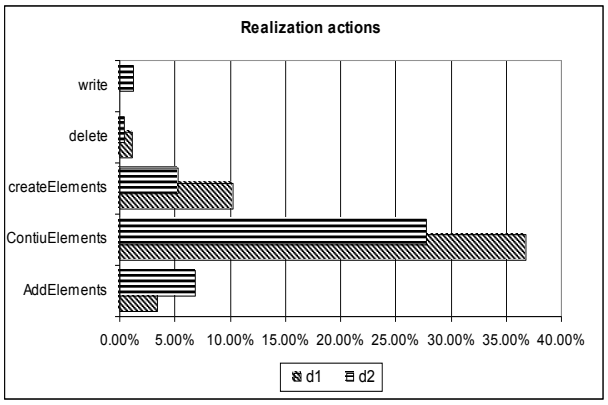

Figure 8 Bar charts for realization actions of the designers (d1 and d2)

Realization actions and perceptual focus actions are shown along the timeline of the session in Figure 9. The beginning of the session is on the left, and the length of each horizontal bar indicates how long the designer spent on each action. The graph shows only Alex's actions over time. It can be observed that create element action and object focus actions were parallel actions in some cases however continue element actions and spatial focus actions were parallel in most cases. The continue element action in DesignWorld includes modelling and developing the same design representation further. This demonstrates that when the designers develop/ model the external design representation, most of the time they focused on the spatial relation of design objects.

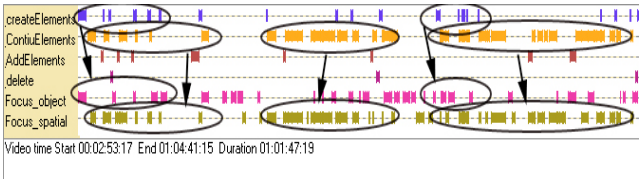

Figure 9 Realization actions and perceptual focus

The designers worked both individually and together during the session shown in Figure 10. This is due to the nature of the 3D world, where participants have the opportunity to do task division and work separately (individual mode) on different aspects/parts of the design product. 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 10 Timeline of working mode

Figure 11 shows the timeline of the representation mode action of the designers. They used 2D sketching pad mostly at the beginning and then most of the time they worked in the 3D modelling mode.

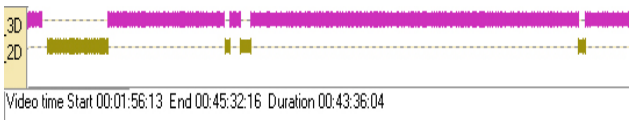

Figure 11 Timeline of representation mode

Our preliminary results can be summarized as follows: First, the analysis of the communication content showed that the designers are focussed on the design task indicating that the virtual world does not distract them from designing. The designers in the virtual world spent relatively small amount of time talking about digital tools and awareness of each other. Second, the analysis of the design representation category shows that in the 3D virtual world they spent more time on spatial relationships of the design elements and modifying existing objects to develop the design further rather than creating new objects. Third, the analysis of working mode showed that the designers spent more time in individual mode which means they designed their parts of the product separately (towards one design) rather than working on the same elements. And finally, the analysis of the representation mode shows that the designers spent around 10 percent of their total time working in the sketchpad and the rest working in 3D modelling mode. Working with the sketchpad occurred during the first quarter of the session, where the designers developed the basic concepts of the design, followed by working in the 3D virtual world to construct the design.

Conclusions

As available bandwidth increases and new augmented virtual environments are developed to support collaborative design, designers are provided with a broader range of choices in how they communicate and collaborate at various stages of the design process. While it is essential and expected that the basic requirements for effective verbal communication are available during the collaborative session, there are numerous options for providing a shared representation of the design problems and solutions. In this study we focused on the impact of the technology on collaborative design behaviour in DesignWorld. We presented a case study of a pair of designers collaborating in an augmented 3D virtual world.

The case study described here characterizes and compares design behaviour and representational focus of two designers using DesignWorld. We demonstrated that designers were able to effectively communicate in DesignWorld. Our preliminary results showed that the 3D virtual world encouraged collaborative modelling of design solutions, in particular designers collaboratively refined 3D model and visually analysed the design idea as well as they effectively developed realistic design representations. The designers focussed on the concretization of design ideas in the 3D world, while in 2D sketching mode, designers stayed with abstract design concepts. In the 3D world, our designers spent time on refining/ modelling the design concept that agreed upon in the sketch pad. We also observed that the designers spent time on individual work and successfully integrated their part of the design.

In this paper the nature and benefits of a 3D augmented virtual world are revealed by analysing the design behaviour of a pair of designers. The results showed that they focussed on the details of how objects come together and are synthesized.

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