AFFORDANCES OF VIRTUAL ENVIRONMENTS: *Do design media change the interaction with the design representation?*

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Abstract. The paper focuses on characterising design environments and on identifying design behaviour in different collaborative virtual environments and discusses the behaviour change based on the affordances theory. In this paper, we present two designers collaborating over three different design environments and report a comparison of those environments with face-to-face (FTF) sketching, using protocol analysis. The analysis of the protocol shows that different virtual environments provide different affordances.

Keywords. Affordances, collaborative virtual environments, design collaboration, protocol analysis.

1. Introduction

Recent developments in virtual environments (VEs) have the potential to bring significant changes in the way which design-related professionals collaborate and design. Although there is a variety of research on collaborative design that examines the way architects design and collaborate using traditional and/or digital media (Hennessy and Murphy, 1999, Seitamaa-Hakkarainen et al., 2000), examining the effects of computer mediation on design communication (Gabriel, 2000) and on design collaboration (Vera et al., 1998) and the impact of VEs on collaborative design (Maher et al., 2006a), it is still not clear how different types of design environments (DEs) affect designers' interaction with the design representation and how affordances of design media change designer's behaviour. This study provides empirical evidence that compares designers' behaviour in co-located sketching with designing in remote environments. The paper focuses on the differences and similarities of designing in different design environments (DEs) and discusses the behaviour change based on the affordances theory.

2. Affordances of Collaborative Virtual Environments

Affordances theory was developed by Gibson (1977) who suggests that humans perceive in order to operate on the environment. The theory was introduced to HCI field by Norman (1988) and further developed by Gaver (Gaver, 1991, B rentsen and Trettvik, 2002) with others. Norman (1988) believes "[…] that affordance results from the mental interpretations of things based on our past knowledge and experience applied to our perception of the things about us" [p.219]. According to Norman (1988), "the term affordance refers to the perceived and actual properties of the thing […] that determines just how the thing could possibly be used" [p.9]. Later studies differ from Gibson's conception of affordances which is based on visual perception. In these later studies, researchers (Vyas et al., 2006, B rentsen and Trettvik,

2002) conceptualised affordances “in interaction” which suggest that affordances emerges during a user’s interaction with environment. In this view, users are actively taking part in the interaction with the artefact and constantly interpreting the situation and constructing and re-building meaning about the artefact (Vyas et al., 2006). A study in affordances in the design of VEs points out “(1) that substituting designed cues via sensory stimuli in available sensory modalities for absent or impoverished modalities may enable the perception of affordances in VEs, (2) that sensory stimuli substitutions provide potential approaches for enabling the perception of affordances in a VE, and (3) that affordances relating to specific action capabilities may be enabled by designed sensory stimuli” (Gross, 2004).

Based on the above framework, we assume that each collaborative virtual environments (CVEs) affords different kinds of designing and collaboration. We investigate designer’s interaction in four different CVEs, which facilitate collaborative design, and discuss their affordances.

3. Method

In this paper, we present two designers collaborating over three different DEs and report a comparison of those environments with face-to-face (FTF) sketching, using protocol analysis. There are the four different DEs[1]: (1) the baseline study (FTF) in which designers used traditional design materials; pen and paper, (2) the remote sketching (RS) in which designers used Groupboard[2] (GB) with digital pen-based systems (Mimio and Smartboard), (3) 3D modelling, (3D) in which designers used Active Worlds (AW) with desktop, and (4) 3D modelling with sketching (3DS) in which designers used a prototype (see G l and Maher, 2006b, Maher et al., 2006b, for more details), Design World (DW)[3] which has 3D modelling mode (Second Life) and 2D drawing mode (Groupboard) in the same screen.

The protocols are examined by using a coding scheme that has two main categories and the following sub-categories: (1) collaborative design process: design collaboration, design processes, design semantics and design scope, and (2) interaction with the design representation: realization actions and process, agent’s actions, perceptual focus, design space, collaboration mode and representation mode. The paper only focused on the following coding categories, as shown in Table 1. The details of the experiment set-up and procedures, design tasks and the protocol coding scheme, coding and segmentation procedures can be found somewhere else (G l and Maher, 2006a).

Table 1. *Interaction with the design representation coding scheme*

Category	**Sub-category and description**
Communication content	Design related- awareness- technology (software features)
Realisation Action	Looks at actions about concretisations of design ideas: create – write – continue – delete
Agents Actions	Looks at actions that are related to designers’ engagements with the surrounding space: onTools (engage with tools) – onElements (engage with the visual analysis of the design product) – gesture (engage a physical activity)
Perceptual focus	Looks at discussions and actions that are related to visual features/form articulation -object/entity-, and spatial relationships of the design elements -spatial relationships-

[1] The empirical data that are used in this paper were collected for a research project, “Team collaboration in high bandwidth virtual environments”, and were provided by the Cooperative Research Centre for Construction Innovation (CRC CI) (CRC study). The results of this research have been published in several conferences (Maher et al. 2006 a,b). With a different research focus, this paper analyses a subset of experiment sessions of the CRC study.

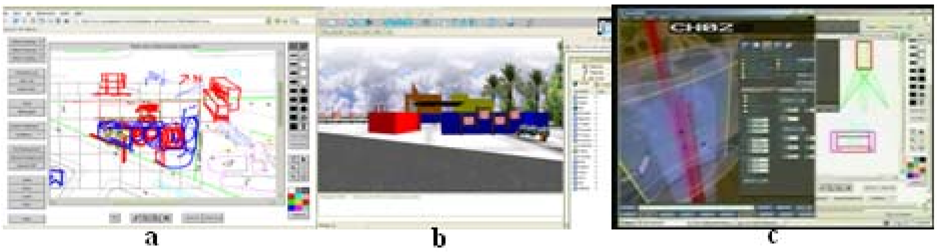
[2] http://www.groupboard.com

[3] This prototype was developed as part of the CRC Study.

4. Collaborative virtual environments and their affordances

Based on the research aims, different kinds of design media with the same communication channels (audio and video) are chosen and developed: (1) remote sketching in Groupboard (GB), (2) 3D modelling in Active Worlds (AW), and (3) 3D modelling with sketching in Design World (DW). The differences of the DEs based on the affordances of the design features, collaboration and awareness are summarised as follows:

Design features: GB is a set of multi-user java applets including whiteboard, chat, message board, drawing and editing tools and file-uploading and saving on the server. The designers used tangible interfaces with digital pen: (1) the Mimio Capture[4] tool which is set up on a large horizontal projection table, and (2) the Smart Board[5] which has a large vertical liquid crystal display (LCD) panel. In both systems, the designers used the digital pen as a mouse and wrote in digital ink on the screen. GB affords sketching providing line drawing tools with different thicknesses, hatch, shapes, editing, colouring tools, etc. The design outcome was similar to pen-based sketches, as shown in Figure 1a. AW supports the so-called 'library-based' design method which includes a set of objects whose forms are pre-defined outside the world and provided by the object library of the design platform. To modify the forms require object library updates. In library-based DE, our observations show that designers with less modelling experience can rely heavily on the use of standard library objects provided by AW. As a result, the affordances of library-based designs provide the uniformed "AW look" due to the repetitive use of standard library objects, as shown in Figure 1b. The designers preferred to employ the cube objects provided in the construction site during the experiment. DW supports the so-called 'parametric design' method which includes a set of objects whose forms are determined inside the world by selecting geometric types and manipulating their parameters. They can also be freely adjusted within the world at a later stage. Design platforms that support the parametric design method are therefore modelling tools as well. The affordance of DW encourages designers to generate models that look unique. Figure 1c shows the design outcome, a tower building, in DW. In addition, DW has the 2D drawing mode, GB, in the same screen which also affords sketching activity. Designers used GB screen as a place for idea generation and decision making.



a b c

Figure 1. Design outcomes, (a) a sketch of the library building in GB, (b) a view from the dance school in AW, (c) a view from the tower building in DW.

Collaborative design and workspace awareness: GB, AW and DW support synchronous collaboration. Most of the VEs have a text-based communication features. Users can communicate by typing onto the chat dialogue box in GB and AW. In SL, similar to AW, the text appears on the avatars head. Both AW and SL also afford the presence (awareness of self and others), architectural metaphor/place (awareness of the place); navigation and orientation (wayfinding aids). However GB does not support presence and place metaphor. In GB, users could draw/delete/edit concurrently the drawing or a part of the drawing. The ownership of the elements is not a problem. However, the screen requires update to show the current drawing and a delay on updating the current situation of the floor plans can occur. In AW, users could only manipulate/rotate/change the properties of their own object. In the design sessions, it was

[4] www.mimio.com
[5] http://www2.smarttech.com/st/en-US/Products/SMART+Boards/Overlays/Default.htm

observed that the affordances of ownership of the objects require a structured-task division whilst designing collaboratively. That means that designers need to determine the overall concept of the design and distribute the tasks to construct the model. In SL, the ownership of the objects is not an issue, but one user only can manipulate an object's properties/location at a time. Thus these affordances of the 3D virtual worlds (3D VWs) might encourage the designers to work individually on separate parts of the design model in a collaborative design situation.

5. Results from Protocol Analysis

The duration percentages of each action category are examined to measure the changes of designers' behaviour in each design session comparing to the baseline study. The duration of each category is divided by the total elapsed time for each design session (30 minutes). Then the duration percentages for each category are determined. The results are presented as follows:
Communication content: The duration percentages of the communication content category actions are shown in Figure 2. Not surprisingly, they talked about designing most of the time in the entire sessions. When the remote VEs were introduced to the design situation, the communication content was still mainly about designing (designCom), followed by communication about software features (Comm Tech) and the awareness actions. The discussions relating to the software features are higher in the RS session, as shown in Figure 2. In addition, the percentage of the awareness code is higher in the 3D session, in which the designers discussed the locations and each other's actions. In both 3D VWs, however, the duration percentages of the technology-related discussions are similar, but the duration percentages of the awareness action are different in the 3D and the 3DS session when we compare the remote environments.

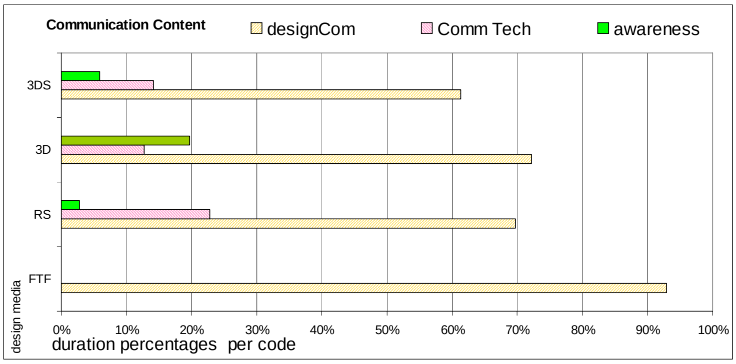


Figure 2. The duration percentages of the communication content

Perceptual Focus: Figure 3 shows the duration percentages of the perceptual focus actions of the designers. The duration percentages of the object/entity action are higher in FTF, as shown in Figure 3. The RS session shows a similar trend, with a drop in the duration percentages. In the 3D and 3DS sessions, there is an increase in the duration percentages of the spatial relationships actions, compared to the FTF and RS, as illustrated in Figure 3. This shows that the designers focused on the visual features of the design solution in both sketching sessions, and they focused more on the spatial relationships of the design model in both 3D VWs.

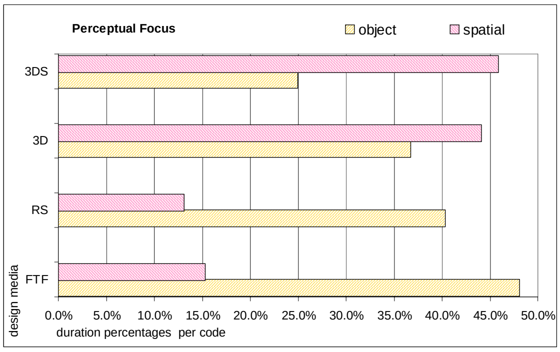


Figure 3. The duration percentages of the perceptual focus actions

Agent Actions: The duration percentages of the agent action category are shown in Figure 4. In the FTF, the architects engaged in the 'onElement' action most of the time, followed by the 'onTool' and the gesture actions. In the RS session, the duration percentages of the 'onTool' action are higher, followed by the 'onElement' and the gesture actions. A similar trend is observed in the 3D session. In the 3DS session, similar to the FTF the duration percentages of the 'onElement' action are higher, followed by the onTool action and the gesture action, as shown in Figure 4.

Realisation Actions: Figure 5 shows the duration percentages of the designers' realisation actions. In the FTF, the duration percentages of the 'create' and the 'write' actions are higher, when the designers spent time on writing down the areas and listing the requirements, and drew the design solution. In the RS session, there is an overall increase in the duration percentages of the realisation actions compared to the FTF. The 3D and the 3DS sessions show different trends of the realisation actions. The percentages of the continue element action is significantly high, followed by the 'create' and the 'write' action categories in the 3D modelling environments, as shown in Figure 5. The 'continue' action includes editing and modifying an existing object.

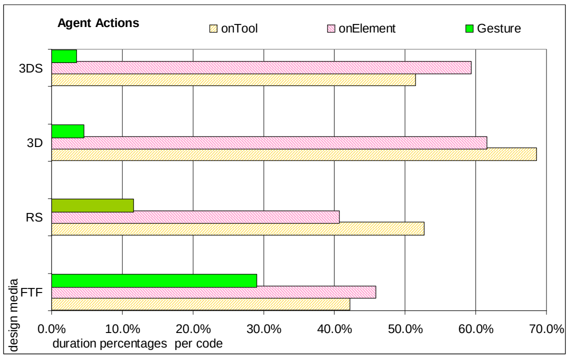


Figure 4. The duration percentages of agent actions

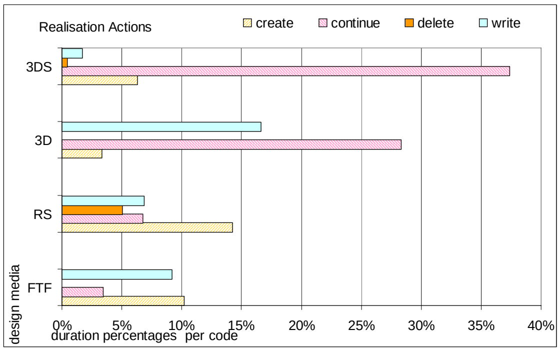


Figure 5. The duration percentages of the realisation actions

6. Discussions and Conclusions

The designers' verbal and visual design protocols have been collected and analysed. The findings of the study indicate that the sketching (FTF-RS) and the 3D modeling environments (3D-3DS) afford similar types of design behaviour and interaction with the design representation. The results of this research imply the followings.

First, the duration percentage of technology related communication is higher in the RS session and the percentage of awareness action is higher in the 3D session. The reasons for that might be: (1) the drawing activities in the remote sketching, which require constant drawing, loading, choosing the colour and the thickness of the pen, seem to require certain knowledge of and skills in using the application (GB). The findings of the agent action category also support this view (see the previous section), whereby the duration percentages of the onTool action are higher in the RS session. (2) In RS, the design representation is a shared representation that provides a shared workspace, ensuring awareness of the drawing actions. This finding also suggest that the difficulty/simplicity of using both 3D VWs (AW-DW) might be the same, or the designers had gained similar knowledge and skills to use these tools. However, the affordance of the sense of presence of each other's actions and locations, is different in both 3D VWs. AW allows individuals to move freely around the 3D workspace while still providing information about the shared design representation and the position of the others (via the presence of the avatars), but the technique of manipulating the design objects does not support workspace awareness. In AW, the designers are not able to see others' modelling actions, unless the command is finalised. Therefore maintaining collaboration and monitoring each other's actions become an issue. In contrast, SL provides more workspace awareness through "consequential communication" and "feedthrough". For example, in SL, when the designer is modelling/manipulating an object, a light blob that shows a link between the avatar and the object appears, and when the designer types on the keyboard, the avatar also types, this behaviour affords workspace awareness through "consequential communication" (Segal, 1995). In addition, in SL, when a designer is transferring or moving an object, these manipulations are visible to others. This "feedthrough" (Dix et al., 1993) behaviour affords workspace awareness.

Second, the analysis of the protocols shows that the types of representation afford different perceptual focus on the spatial properties of the design solution: (1) the designers focused more on the visual features of the design object, which are size, form, colour and materials, while sketching, and (2) the designers focused on the spatial relationship of the design objects, which are spatial adjacency, arrangements, position, etc., while 3D modelling. The reasons for this difference might be that the 2D and 3D representations have different properties, and they afford and "instil slightly different mental models" (Bryant and Tversky, 1999). 3D models convey all three spatial dimensions directly. In particular, the properties of the design representation: the three dimensions, the location and the relative position and the depth cue, are expressed directly. 2D sketches may depict three-dimensional relations but they are two dimensional. In sketches, designers use a number of conventions for conveying depth, size, height in a picture plane, as well as possibly using verbal and symbolic information to express spatial information (see Bryant and Tversky, 1999 for more information). It could be that because of the above different properties of the 2D-3D representations, the designers' perceptual focus was also different in sketching and 3D modelling.

Third, the results of the analysis show that in FTF, (1) the designers engaged more with the design representation, and (2) gestured a lot, which is facilitated collective focus on the materials. In the RS and 3D, the designers engaged more with the tools and the interface of the applications, and in the 3DS, the designers engaged more with the visual analysis of the design model, inspecting it by flying over and walking through it. In the FTF, the inspections of the given materials and the gesture action are important for understanding the design problem and establishing a collective understanding of the design situation. In the RS and 3D, due to unfamiliarity with or difficulty in using the applications and navigation, the designers spent time on clicking buttons/objects and on searching for help. DW provided an environment for designers in which they could easily focus on the visual analysis of the design solution instead of engaging with the tools and the interfaces of the applications. The reasons for that may be: (1) the ease of using different camera views and navigation that could be controlled by simple mouse movements, and (2) the relatively realistic appearance of the design model, which afforded the visual analysis of the 3D model.

Fourth, the results of the analysis show that the realisation actions are different between sketching and 3D modelling. Based on our analysis of the visual design protocols, we conclude that the two sketching sessions show a similar trend, that the realisation actions of the design representation are based on the "create" and the "write" actions. In both sketching, they first listed the programme components and constantly sketched new depictions using translucent paper or using the shared whiteboard. In contrast, in the 3D modelling, the realisation actions were based on the "continue" action. This is due to the nature of modelling in 3D virtual worlds: one mouse click creates the basic object, and then the designers need to manipulate the object's properties to make other things. This also consisted of a cycle of actions such as move/rotate/transfer/group, etc., as pointed out by Maher et al. (2006a). Thus this "continue" action consists of a series of actions that require a continuing attention on the particular object.

In conclusion, the analysis of the protocol shows that different virtual environments provide different affordances. Considering these differences, the paper provides knowledge of implications of the differences in collaborative design and designer's interaction with the representation, which can form the basis for guidelines on future developments in CVEs.

References

B rentsen K. and Trettvik J. (2002). An activity theory approach to affordance. Proceedings of NordiCHI 2002. New York, NY, ACM Press, 51-60.

Bryant D.J. and Tversky B. (1999). Mental representations of perspective and spatial relations from diagrams and models. Journal of Experimental Psychology: Learning, Memory, and Cognition, 25, 137-156.

Dix A., Finlay J., Abowd G. and Beale R. (1993). Human-computer interaction Prentice Hall.

Gabriel G.C. (2000). Computer mediated collaborative design in architecture: The effects of communication channels on collaborative design communication. Architectural and Design Science, Faculty of Architecture. Sydney, University of Sydney.

Gaver W.W. (1991). Technology affordances. Proceedings of the SIGCHI conference on Human factors in computing systems: Reaching through technology. New Orleans, Louisiana, United States ACM Press, 79-84

Gibson J. (1977). The theory of affordances. in Shaw, R. and Bransford, J. (Eds.) Perceiving, acting and knowing: Toward an ecological psychology. Hillsdale, NJ, Erlbaum Associates, 67-82.

Gross D.C. (2004). Affordances in the design of virtual environments. United States — Florida, University of Central Florida.

G l L.F. and Maher M.L. (2006a). The impact of virtual environments on design collaboration. 24th eCAADe Conference Proceedings, ISBN 0-9541183-5-9. Volos, Greece 74-83.

G l L.F. and Maher M.L. (2006b). Studying design collaboration in DesignWorld: An augmented 3D virtual world. in Banissi, E., Sarfraz, M., Huang, M. andWu, Q. (Eds.) Proceedings of 3rd International Conference on Computer Graphics, Imagining and Visualization Techniques and Applications (CGIV'06). IEEE Computer Society: California, 471-476.

Hennessy S. and Murphy P. (1999). The potential for collaborative problem solving in design and technology. International journal of technology and design education, 9, 1-36.

Maher M.L., Bilda Z. and G l L.F. (2006a). Impact of collaborative virtual environments on design behaviour. in Gero, J. (Ed.) Design Computing and Cognition'06. Springer, 305-321.

Maher M.L., Rosenman M., Merrick K. and Macindoe O. (2006b). DesignWorld: An augmented 3D virtual world for multidisciplinary collaborative design. CAADRIA 2006. Osaka, Japan.

Norman D.A. (1988). The psychology of everyday things New York, Basic Books.

Segal L. (1995). Designing team workstations: The choreography of teamwork. in Hancock, P., Flach, J., Caird, J. andVicente, K. (Eds.) Local applications of the ecological approach to human-machine systems. Hillsdale, NJ., Lawrence Erlbaum, 392-415.

Seitamaa-Hakkarainen P., Lahti H., Muukkonen H. and Hakkarainen K. (2000). Collaborative designing in a networked learning environment. in Scrivener, S.A.R., Ball, L.J. andWoocock, A. (Eds.) Collaborative design. London, Springer-Verlag, 411-420.

Vera A.H., Kvan T., West R.L. and Lai S. (1998). Expertise, collaboration and bandwidth CHI'98. Los Angeles, CA: ACM SIGCHI, 502-510.

Vyas D., Chisalita C.M. and Veer G.C.V.D. (2006). Affordance in interaction. Proceedings of the 13th European conference on Cognitive ergonomics: trust and control in complex socio-technical systems Zurich, Switzerland ACM Press, 92-99.