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# Affording Embodiment in Collaborative Virtual Environments: What is the Role of Presence in Collaborative Design?

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## Abstract

*Collaborative virtual environments have potential to change the ways in which designers communicate and work. Different virtual environments provide different affordances which have an impact on designer's actions. We conduct a study to investigate designers' interaction and behaviour in four collaborative environments, using protocol analysis. The results indicate that types of representation and kinds of interfaces and tools have an impact on designer's engagement, perception of presence and interaction within the environments.*

**Keywords---** Presence, Collaborative Virtual Environments, Protocol Analysis, Collaborative Design

## 1. Introduction

Recent virtual environments accommodate various activities such as shopping, travel, banking, entertainment, education and design. In the past two decades, a variety of disciplines have participated in implementing, testing and developing information technology tools that are designed to address human collaboration at work, commonly known as Computer Supported Collaborative Work (CSCW) systems. Most of these technology-driven developments paid little attention to the core principles of place-making and presence which both should inform the essence of the virtual experience and help steer its developments [1]. Although these developments have led to important advances in the enabling technologies that are required to support the changes in the design practice, we know very little about the impact of these technologies on designers' perception of presence.

Studies point out that different virtual environments provide different affordances which have an impact on designer's actions [2]. Based on the different affordances of virtual environments, this study characterises the changes in designers' perception of space and interaction while they are moving co-located (face-to-face) sketching to remote designing. The perception of space includes the perception of the position of objects and their spatial relationships to each other, to the perceiver and to the general surroundings [3]. In

this study, designer's interaction becomes multidimensional, including interaction with the external design representation, other designers and the surrounding space in the physical and virtual places. The interaction becomes 'physical' when designers are sketching around a table, using pen-paper and it becomes 'virtual' when they are using virtual environments.

This study focuses on the utterances and activities (verbal and visual design protocols) of two designers' in a collaborative design context, concerning with:

- the reasoning of the visuo-spatial features of the design representations: perceptual focus,
- the interaction with the surrounding space: agent actions, and
- the perception of the body in the environments: self-referencing.

## 2. Studying affordances of embodiment

Studying affordances of embodiment in collaborative virtual environment has several key areas: The first area of the study examines designers' interaction with the design representations that captures visuo-spatial properties of the world, including visual and spatial information. The visual information includes static properties of objects, such as shapes, texture, colour, or between objects and reference frames, such as distance and direction. The spatial relations include the properties that are "close or above or below" in the world preserve those relations of the representations. [4].

In the field of psychology, studies show that diagrams and models promote participants to take the perspective of a character surrounded by objects [5]. In their study, Bryant and Tversky [5] pointed out that with models, participants adopted the character's perspective, and with diagrams, participants took an outside perspective.

Another area of the study, presence, is defined as "a psychological state or subjective perception in which even though part or all an individual's current experience is generated by and /or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience" [6]. Researchers point out one of the challenging problems today is the achievement of a sense of presence in virtual environments

which might replicated, replace, or enhance the human sense of 'being there'[7]. Clearly, the sense of 'being there' (presence) in computer-mediated platforms is associated with varies of factors that are perception, content, cognitive processes and affordability. Kalay [1] points out three determinates of presence:

- the richness of sensory information communicated by the medium;
- the level of control one has over the simulated environment, and
- the degree of engagement one feels being part of the simulated world, rather than a passive observer of it.

The concept of 'being there' is also relevant with the interaction with the surrounding space. Tversky [8] defined four types of space in which human activities occur:

- the space of the body,
- the space around the body,
- the space of navigation, and
- the space of external representations.

Each of them is experienced and conceptualised differently. The space of the body has a perceptual side, the sensations from outside and inside the body, and behavioural side, the actions the body performs. The space around the body includes the space in which it acts and sees, including surrounding objects. The space of navigation is the space for travel, depending on the knowledge and memory, not the concurrent perception. Finally, the space of external representation includes a space on paper meant to represent an actual space, as in a map, diagram or architectural drawing [8].

We are interested in the views of the designers when they are designing in the physical and the virtual space and how the space around the body (physical and virtual) affects their interaction with the design representation and how they locate themselves in the design space.

### 3. Method

The method of measuring presence which is still in its infancy could be based on subjective, behavioural and physiological measures, as pointed out in [9]. We apply protocol analysis as the behavioural measure to investigate the ways in which designers interact and perceive the design environments and representations. Think-aloud protocols have been used by Chan and Weng [10] in a presence study, reporting several methodological problems. The study indicated that the interpretation of what s/he is thinking and how s/he really feels are the most intriguing issues when people are asked to think aloud [10]. Unlike many protocol studies which examine mental reasoning of individuals, we focus on how two designers communicate their ideas to each other while they are solving a design task in virtual environments.

Protocol analysis, which was first adopted by Eastman [11] to study design cognition, has been accepted as a research technique allowing for the clarification of designers' cognitive

abilities [12]. In the late 1980s, a rapid change occurred in the protocol studies by extending single-subject design activity to the team's design activity [13, 14]. Cross and Cross [15] said that a team's design protocols resembled the "think aloud" method, since a joint task seemed to provide data indicative of the cognitive abilities that were being undertaken by the team members. Consequently investigating the team's design protocol was not substantially different from investigating single-subjects' design thoughts. In our study, two architects' design actions and communications are video-taped, transcribed, segmented and then encoded by using a specific coding scheme that has been developed for this study.

In this paper, we present two designers collaborating over four different design environments and report a comparison of those environments, using protocol analysis<sup>25</sup>: [16, 17]

- the baseline study (FTF) in which designers used pen and paper,
- the remote sketching (RS) in which designers used Group Board<sup>26</sup> (GB) with digital pen-based systems (Mimio and Smart Board),
- 3D modelling, (3D) in which designers used Active Worlds (AW) with desktop, and
- 3D modelling with sketching (3DS) in which designers used a prototype, Design World<sup>27</sup>, (DW) which has 3D modelling mode (Second Life) and 2D drawing mode (Group Board) in the same screen [ 18].

Figure 1 shows the interface of the three collaborative virtual environments of the study.

### 3.1 Collaborative virtual environments

Based on the research aims, three different kinds of design virtual environments with the same communication channels (audio and video) are chosen and developed<sup>28</sup>: (1) remote sketching in Groupboard (GB), (2) 3D modelling in Active Worlds (AW), and (3) 3D modelling with sketching in Design World (DW). The design and collaboration features of the environments are summarised as follows:

GB is a set of multi-user java applets including a shared-whiteboard, communications channels, drawing and manipulations tools and file management tools. Our designers used digital-ink based tangible interfaces during the remote sketching: (1) the Mimio Capture<sup>29</sup> tool which is set up on a

<sup>25</sup> 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). The results of this research have been published in several conferences [16-18]. With a different research focus, this paper analyses a subset of experiment sessions of the CRC study.

<sup>26</sup> <http://www.groupboard.com>

<sup>27</sup> This prototype was developed as part of the CRC CI Study.

<sup>28</sup> See [16-18] for the details of the CRC CI study.

<sup>29</sup> [www.mimio.com](http://www.mimio.com)

large horizontal projection table, and (2) the Smart Board<sup>30</sup> 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 offers a shared design representation which provides a basis for the collaborative design activities. 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.

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 design environments, studies show that designers with less modelling experience can rely heavily on the use of standard library objects provided by AW [19]. As a result, the affordances of library-based designs provide the uniformed "AW look" due to the repetitive use of standard library objects.

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.

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). GB does not provide the user representation and the place metaphor; however it offers a platform where the users become aware of each others actions and activities on the design representation. 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. In AW, users could only manipulate/rotate/change the properties of their own object. 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.

### 3.2 Segmentation and Coding Scheme

During segmentation, the protocols are divided into smaller units. The data of the study consist of a continuous stream of video and audio that has two sources, the designers 1 (Greg) and designer 2 (Lee). There is a need for a thorough investigation of each designer's actions and utterances. Consequently, the two major segmentation rules, which are the utterances-based segmentation method [20] and the actions-and-intentions based segmentation method [21] are combined in this study [see 22 for more details on segmentation].

The segmented protocols are examined by using a coding scheme that has four main categories:

- communication content,

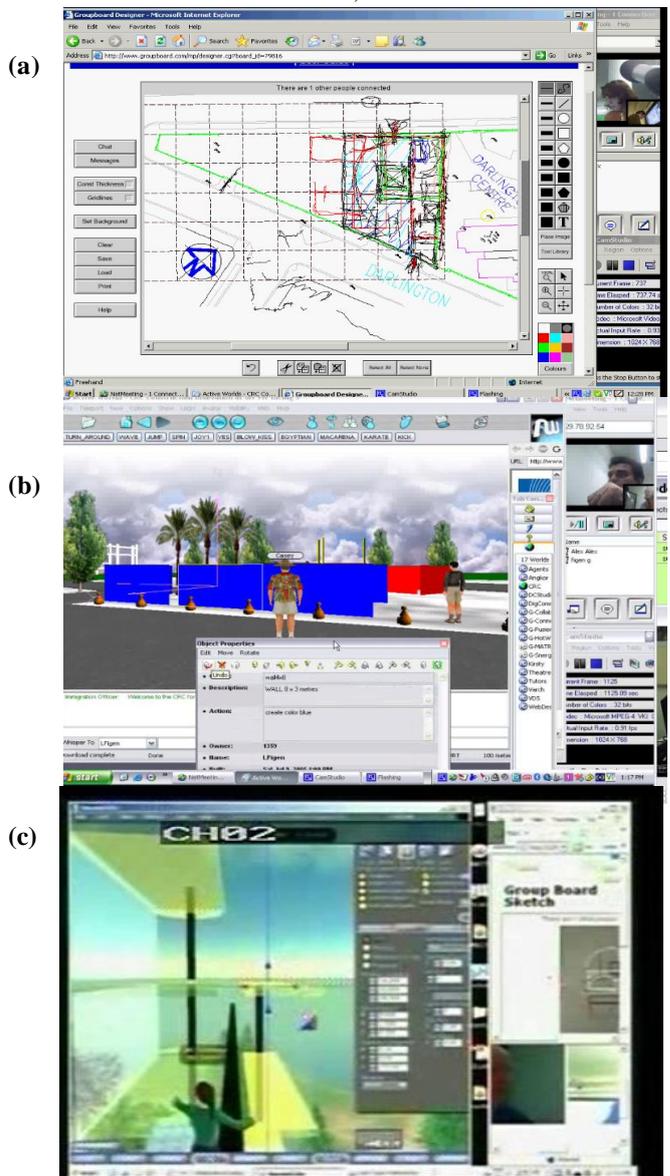


Figure 29 Collaborative virtual environments of the study, (a) Group Board, (b) Active World, (c) Design World (Second Life and Group Board)

<sup>30</sup><http://www2.smarttech.com/st/en-US/Products/SMART+Boards/Overlays/Default.htm>

- perceptual focus and
- self-referencing, as shown in Table 1.

categories	codes	descriptions
<b>Communication content</b>	Design communication, Technology,	Looking at discussions between designers in terms of (1) developing design solution, (2) talking about technology and/or interface, and (3) talking about each others' presence and activities.
	Awareness	
<b>Agent actions</b>	onTool,	Looking at discussions and activities of designers in terms of (1) engaging/ interacting with the design tools/ environments, (2) engaging/ interacting with the design artefact, and (3) gesturing.
	onElement,	
	Gesture	
<b>Perceptual focus</b>	Object,	Looking at discussions and activities of designers in terms of (1) engaging/ interacting with the visual features of design artefact, and (2) engaging/ interacting with the spatial properties of design artefact
	Spatial	
<b>Self-referencing</b>	Egocentric,	Looking at discussions and activities of designers in terms of (1) engaging with local relations based on one's current location (being left, right or up/down), and (2) engaging with global relations based on environmental objects (the sun, road, a building)
	Allocentric	

**Table 10 Coding Scheme**

The first category has three codes: The *design communication* code captures the discussions between the designers in terms of how they develop and generate design solutions and communicate the design ideas. The *communication technology* code looks at the discussions held between participants that are related to the use of technology in collaborative environments, in terms of how to use the tools, how to manipulate objects, and their properties. The *awareness* code looks at the discussions held between the participants that are related to each other's presence and activities.

The second category, agent's actions, captures the engagements/interactions of the designers with her/his surrounding space. First, designers engage with the interface/tools and given materials. The *onTools* action captures the designers' actions when they engage with the given materials and environment searching and clicking buttons/ objects in the interfaces. Second, designers inspect the design artefact (*onElements* action) that could be the drawings or 3D models. Third, designers *gesture* when they want to point an element, to describe shapes, sizes and height, and to show the directions or the locations of the objects. In the physical world, people gesture using their own hands, body and face, and in the virtual environments, they gesture using the cursor and the avatar.

The third category, perceptual focus, has two codes: the object and the spatial relationship which is based on Tversky's [8] view on the visuo-spatial properties of the world. It is coded as *object* when designers discuss/engage with the visual features of the artefact which includes size, form, colour, texture and it is coded as *spatial* relationship when designers discuss/engage with the spatial relationships of the objects which includes alignment, adjacency, grouping and position of objects.

The final category, self-referencing, captures how designers position themselves in the environments. The *egocentric* code captures designers' engagements with local relations based on their's current position, e.g. referring 'my left/right' or 'up/down'. The *allocentric* code captures designers' engagements with global relations based on environmental objects, e.g. referring 'next to the building' or 'towards the sun'.

## 4. Results and discussions

The four design protocols that were gathered from the experiment sessions were analysed. To understand qualitative differences between the design environments, the encoded protocols were compared. Encoded protocols represent the context of collaborative designing, how designers collaborate and communicate, and what kind of interactions they have with the design representation and their surroundings.

### 4.1 Design communication and awareness

The duration percentages of the communication content actions are shown in Table 2. The durations are divided by the total time elapsed in each session (30 minutes), where the duration percentages are obtained for each communication code. Naturally they talked about designing most of the time in the entire sessions. When the designers move to the remote virtual environments, the communication content was still mainly about designing, followed by the communication about software features and the awareness actions. These two actions did not occur in the baseline study (FTF), since the designers were located in the same room and were using traditional media for designing. The discussions relating to the software features were higher in the RS session and the awareness is higher in the 3D session, in which the designers discussed the locations and each other's actions, as shown in Table 2. The highest percentages of the actions are shaded in grey.

%	FTF	RS	3D	3DS
Design Communication	93%	70%	72%	61%
Communication Technology	0%	23%	13%	14%
Awareness	0%	3%	20%	6%

**Table 11 The duration percentages of communication content actions**

Since there is only design communication in the baseline study, a comparison between remote environments has been undertaken. In the remote sketching session, it has been observed that the designers have more technology-related dialogue and less awareness-related dialogue, when the three remote environments are compared. The reasons for that might be: (1) the complexity of the application's interface and (2) the shared nature of the design representation. First, 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 (Groupboard). The findings of the agent action category also support this view, whereby the duration percentages of the onTool action are higher in the RS session (see 4.2). Second, in Groupboard, the design representation is a shared representation that provides a shared workspace, ensuring awareness of the drawing actions. The interface does not support any user representation, as a result, the designers spend less time on the discussions that are related to presence.

In both 3D virtual worlds, on the other hand, the analysis shows that 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 compared the remote environments. This finding could suggest that the difficulty/simplicity of using both 3D virtual worlds might be the same, or the designers had gained similar knowledge and skills to use these tools. However, the provided sense of presence each other's actions and locations, is different in both 3D virtual worlds.

The virtual world of the 3D session, Active Worlds, 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 Active Worlds, 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 a topic which designers need to discuss.

In contrast, the application of the 3DS session, Design World (Second Life and Group Board), provides more workspace awareness through "consequential communication" and "feed-through". For example, in Second Life, 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 supports workspace awareness through "consequential communication". In addition, in Second Life, when a designer is transferring or moving an object, these manipulations are visible to others. This "feed-through" behaviour supports workspace awareness. Due to these features of Second Life, the designers have developed a sense of

presence of other's activities, and as a result, they spent less time on discussions which were related to the awareness action.

#### 4.2 Interaction with the environment and artefact

The duration percentages of the agent action category are shown in Table 3. The duration percentages of the onTool action are high the RS session, followed by the 3D session. The duration percentages of onElement actions are high in the 3DS session, and they are similar in the baseline and the 3D sessions. The duration percentages of the gesture actions are high in the baseline study, followed by the RS session, as shown in Table 3. This shows that the designers' engagements with the surrounding space were similar in the baseline study and the 3D session. The designers visually examined the design representation, which consisted of the drawings in the baseline study and of the 3D model in the 3DS session. In contrast, in the RS and the 3D sessions, the designers engaged more with the tools and the interface of the application.

%	FTF	RS	3D	3DS
onTool	42%	72%	69%	46%
onElement	46%	35%	46%	59%
Gesture	29%	12%	5%	4%

**Table 12 The duration percentages of agent-actions**

The results of the analysis show that in FTF, (1) the designers engaged more with the design representation, and (2) gestured a lot, which facilitate 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. 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 sessions, 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.

#### 4.3 Visuo-spatial features and self-referencing

The perceptual focus actions are shown along the timeline of the sessions in Figure 2. Each horizontal bar shows the

beginning of the sessions, on the left, and the durations of each operation. The numbers 1 and 2 indicate each designer's actions, which are coded separately. In the baseline study (FTF), the frequent object action occurred in larger chunks during the session. We observed a similar pattern in the perceptual focus actions (the object/entity and the spatial relationships) in the RS session and a different pattern in the focus actions in the 3D and the 3DS sessions, compared to the baseline study. In the 3D and the 3DS sessions, the spatial relationships actions occurred more frequently and became longer towards the end of the sessions, as illustrated in Figure 2. This shows that the visual features of the design elements became the key reasoning elements in both sketching sessions, and the spatial relationships of the design representation became the principle focus point in the 3D modelling sessions. Analysis of the protocol shows that the type of presentation has an effect on designers' perceptual focus on the spatial properties of the design solution: (1) the designers focused more on the visual features of the design, 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 the 3D representations have different properties and they "instil slightly different mental models" [5]. 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



**Figure 30 Perceptual focus actions over time**

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. 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.

The durations of the self-referencing actions are investigated in order to understand how designers locate themselves in the design representation, as shown in Table 4. The duration percentages of the egocentric referencing are low in the baseline study (FTF). There is an increase in the duration percentages of the allocentric and the egocentric actions in the collaborative virtual environments, compared to the baseline study, except the RS sessions (allocentric actions is lower), as shown in Table 4. The highest percentages of the actions are shaded in grey.

The investigation of the designers' self-referencing has potentials to reveal the designers' perception of presence while they are designing in virtual environments. In the field of psychology, studies have pointed out that people tend to position themselves differently in diagrams and models [5, 8]. For example, when learning from diagrams, participants adopted an outside point of view and imagined the scene rotating in front of them, and a 3D model encouraged participants to take the internal viewpoint of the object. Our analysis showed that there was an increase in the designers' referencing (both egocentric and allocentric) in 3D virtual worlds, and they tended to position themselves outside the design representation in sketching.

%	FTF	RS	3D	3DS
egocentric	0.5%	3.1%	2.6%	2.3%
allocentric	4.7%	3.7%	7.8%	5.7%

**Table 13 The duration percentages of self-referencing actions**

We could suggest that designers tended to use more referencing in 3D modelling, and they focused on different visuo-spatial properties of the design representation in sketching and 3D modelling. This finding indicates that the designers developed a sense of presence in the virtual environments that might have an impact on their visuo-spatial reasoning. 3D virtual worlds are intended to create "the illusion of participation in a synthetic environment rather than external observation of such an environment" [23]. Depending on the used external devices the 3D virtual environments could enable people to become "immersed in the experience" of interacting with the external representations [24]. "The sense of immersion" is defined as the level of fidelity that virtual environments provide to the user's senses [25], which could be enhanced with the use of human-shape characters (avatars) [26]. In our experiments, the 3D virtual worlds are desktop systems wherein the designers are represented by the avatars. The avatars can fly, walk, sit and touch the objects, thus this

real-life-like behaviour of the avatar creates an illusion of immersion.

## Conclusions

We have studied two designers using virtual environments while designing together, allowing us to compare their behaviour and interaction within the environments. We conclude that designers adapt to different virtual environments showing different focus and interaction in each environment.

We could suggest that the experience of being immersed in a virtual world while designing is very distinct from interacting with real-world artefacts. Each virtual environment provides different experiences of embodiment. The results of the study imply the followings.

### Affording workspace awareness

The results of the analysis show that each virtual environment affords different levels of awareness and presence. In RS, the design representation is a shared representation that provides a shared workspace, ensuring awareness of the drawing actions. 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 "feed through." For example, in SL, when the designer is modelling/manipulating an object, a light particle 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" [27]. In addition, in SL, when a designer is transferring or moving an object, these manipulations are visible to others. This "feed through" [28] behaviour affords workspace awareness.

### Affording visuo-spatial reasoning

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" [5]. 3D models convey all three spatial dimensions directly. In particular, the properties of the design representation: The three dimensions, the location, 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 [5]. 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.

### Affording engagement within the environment

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.

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 collaborative virtual environments.

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