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STUDYING EMBODIED INTERACTION WITH THE DESIGN ENVIRONMENT: WHAT IS THE ROLE OF PRESENCE IN DESIGN?

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1. Introduction

Recent virtual environments accommodate various activities such as shopping, virtual travel, banking, entertainment, education and design. During the last two decades, a variety of disciplines have participated in implementing, testing and developing information technology tools that are designed to address human activities and communication at work. 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 [Kalay 2004]. 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' behaviour and perception of presence. Studies point out that different virtual environments provide different affordances which have an impact on designer's actions, changing their interaction within the design space [Gül 2008]. Based on the different affordances of virtual environments, this study characterises the changes in designers' perception of space and interaction within the design environment while they are moving from freehand sketching to non-immersive 3D designing and to immersive 3D 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. In this study, designer's interaction becomes multidimensional, including interaction with the external design representation, given tools and the surrounding space in the physical and virtual places. The interaction becomes 'physical' when designers are sketching using pen-paper and it becomes 'virtual' when they are using 3D digital environments.

This study focuses on the utterances and activities (verbal and visual design protocols) of expert designers 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 3D design mode 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.

In the field of psychology, studies show that diagrams and models promote participants to take the perspective of a character surrounded by objects [Bryant and Tversky 1999]. In their study, Bryant and Tversky (1999) 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 generate 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" by the International Society for Presence Research (http://ispr.info/). Researchers point out one of the challenging problems today that is the achievement of a sense of presence in virtual environments which might replicated, replace, or enhance the human sense of "being there". 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 (2004) 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 (2005) 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 the above spaces 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 [Tversky 2005].

We are interested in the views of the designers when they are designing in the non-immersive and immersive 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

There is a need to gather the design protocols (verbal and visual) with and without the use of technology during the design activity: freehand sketching and 3D digital modes. Since we are interested in the impact of immersion on design cognition, two different types of digital design environments have been chosen: Google Sketch Up (GS) as a non-immersive 3D modelling platform and Second Life (SL) as an immersive 3D modelling platform. With these ideas in mind, the empirical data forms into two groups:

- Baseline study (freehand sketching): A design process in which designers work with traditional materials; and
- Comparison study: A design process in which designers use two different design technologies: designing in 3D non-immersive modelling mode (Google Sketch Up) and designing in 3D immersive modelling mode (Second Life).

GS (http://sketchup.google.com) is a 3D design platform which facilitates a platform for creating, modifying and sharing of 3D models. GS use lines and faces to create 3D shapes and objects which can be easily modified and transformed. GS does not include the user representation feature as avatars. There is a still representation of a human body, named as Bryce, which can only give a sense of scale.

SL (www.secondlife.com) is a virtual world which has been closely related to architectural design due to its use of the place metaphor in which 'the users experience as if they immersed in' [Bolter and

Gromala 2003] through the representation of the user. Unlike the general CAD systems designers in virtual worlds are represented as avatars (animated virtual characters) that are immersed within the design. Through this metaphor, SL can inherit many characteristics from architecture. SL supports the parametric design method which comprises 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 [Gül 2008].

3.1 Protocol Analysis

In this study, the impact of different design environments on design cognition is investigated by using protocol analysis. Protocol analysis that allows the characterisation of the processes in designing has been used in different design disciplines. Early studies focused on protocol's verbal aspect [Ericsson and Simon 1984]. For example, in the engineering domain, verbal protocol analysis is a well-documented approach to understand what a designer is thinking while solving a problem; it has been applied to the experts' [Cross et al. 1996] and to the novices' [Atman and Bursic 1998] design cognition. On the other hand, later studies acknowledged the importance of the design drawings that are associated with the design thinking which can be interpreted through verbal descriptions [Suwa et al. 1998; Akın 1996].

Akın (1982) pointed out the importance of the external design representations that facilitated the formulation of a mental representation of a design idea as well as the communication of design ideas. Akın (1982) said that: "(…) design consists of a series of representations to one's mind, or to the minds of one's co-workers, clients, user groups. (…) the mind has its own internal representations in order to communicate through external representations." That is, since we cannot as yet directly communicate our internal representations and thoughts, we must rely on the external representations which can be inform of visual or verbal descriptions. The protocol analysis, which is a qualitative approach, allows us to measure the changes that can be counted by the coding scheme. Similar to the previous design studies, the visual and verbal design externalisations are employed in this study.

3.1.1 Segmentation

In order to separate the utterances into meaningful units, which can be coded under a specific category relating to the design cognition, we segmented each utterance further using the actions-and-intentions segmentation method used in [Gül 2008]. Each segment can include combinations of visual and verbal design protocol data: (1) having verbal-conceptual only when there is no visual-graphic action, (2) having visual-graphic actions only when there is no verbal-conceptual data, and (3) having both the verbal-conceptual data and visual-graphic action when designers talk and sketch/model at the same time in a segment.

3.1.2 Coding Scheme

The segmented protocols are examined by using a coding scheme that has three main categories:
agent action, perceptual focus and self-referencing, as shown in Table 1.

The first category, agent's actions, capture 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 their body (fingers, hands, arms) and the cursor and the avatar.

The second category, perceptual focus, has two codes: the object and the spatial relationships which are based on Tversky's (2005) 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 include size, form,

colour, texture. The protocol is coded as spatial when designers discuss/engage with the spatial relationships of the objects which include alignment, adjacency, grouping and position of objects.
The final category, self-referencing, captures how designers locate themselves in the design environments. The egocentric code captures designer's engagements with the local relations based on their own body's (avatar) current position, for example, referring 'my left/right' or 'up/down'. The allocentric code captures designer's engagements with the global relations based on the environmental objects, for example, referring 'next to the building' or 'towards the sun'.

Table 1. Coding scheme

Categories	Codes	Descriptions
Agent actions	onTool, onElement, Gesture	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.
Perceptual focus	Object, Spatial	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
Self-referencing	Egocentric, Allocentric	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), (2) engaging with global relations based on environmental objects (the sun, road, a building)

3.2 Experiments

To investigate the impact of immersion on designer's behaviour, series of experiments were conducted. In order to test the coding scheme and the experimental settings, the experiments with the participation of three expert architects were performed. The participated designers have 6, 9 and 10 years design and CAD experience. Many design studies included a relatively small number of participants to seek an understanding of design behaviour and reported comparisons between designers [Akın and Lin 1995; Gero and Mcneill 1998; Suwa and Tversky 1997]. Similar to the studies in the field, in this study, three architects design sessions were examined in depth.
Figure 1 shows the experiment settings of the study. The designers were given a brief overview of Second Life and Google Skecth-up in the training session, which included the following sections: (1) exploring the interface, (2) using the tools, and (3) building a simple model. The training session took about one hour for each design platform. Once the designers were ready to build independently, they started the design session. The training site was adjacent to the site that they were asked to design. The designers were given a different design brief in each setting and were asked to finalise a conceptual design proposal in 30 minutes. Since the same architects worked in three design environments, they were given a different design brief with the same complexity in each setting. The designer's actions and speech are videotaped. Then these protocols are studied and encoded by using the coding scheme that has direct relevance to designers' cognition to solve a particular design problem.

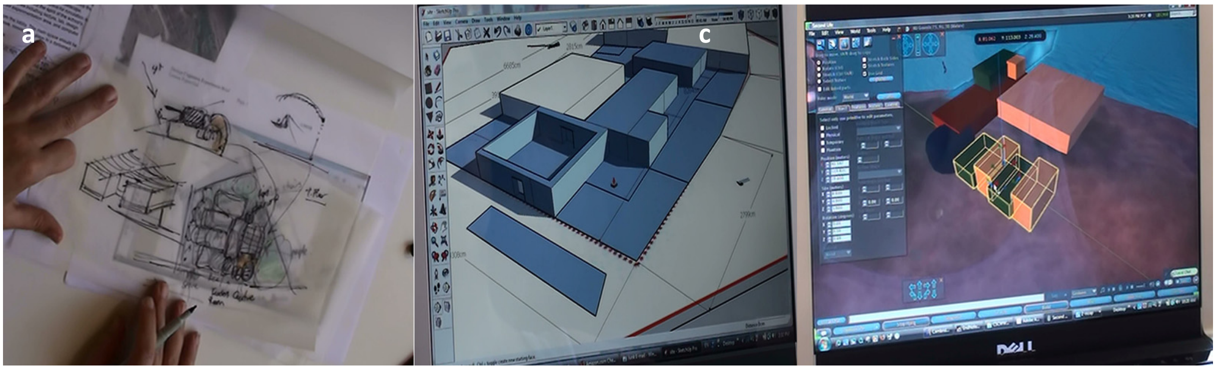


Figure 1. Design sessions in different environments; (a) Freehand sketching, (b) Google Sketch-up, and (c) Second Life

4. Results and discussion

The duration percentages of each action category (the average of three architects) are examined to measure the changes of designer's cognition in each design session. 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.

4.1 How does the designer's attention shift during designing?

The attention changes/shifts are examined by an analysis of the segment durations in each of the design sessions. The statistics of the average segment durations is shown in Table 2. Since we segmented the continuous stream of data according to a change in the verbal or visual design protocols, the numbers of segments in each session provide us with information about how frequently the changes/shifts occurred. In the baseline study (sketching), the mean (M) duration of segments is the shortest (M 1.33 second) and the number of segment is the highest (184 count). On the other hand, the segment durations increased and the number of segments decreased in the digital modes, as shown in Table 2. The longest segment durations (M 56.75 second) is observed in the (Second Life) SL session, when the designers spent time elaborating on the design model. The higher standard deviation values in the digital modes show this tendency. The segment durations for all sessions are positively skewed, as illustrated in Table 2. The high kurtosis values show that the distribution of the durations of segments is not flat. This result shows that the designers experienced more attention shifts in the baseline study (less time and more segments), and they had less count and longer attention shifts in the digital design modes (Google Sketch Up and Second Life). We can suggest that detailing design in 3D mode requires less frequent and longer attention to particular parts of the design model than designing in 2D mode. This results confirmed the findings of a collaborative design study in which the attention spans of designers were longer in the 3D virtual worlds [Maher et al. 2006].

Table 2. Statistic of the average segment durations

Seconds	Sketching	Google Sketch up	Second Life
Average count	184	129	104
Mean duration	7.64	11.04	13.61
Max	38.25	55.33	56.75
Min	1.33	2.67	3.88
Standard deviation	5.77	8.86	9.86
Skew	1.55	1.91	1.59
Kurtosis	3.60	5.39	3.79

The distribution of the average segment durations along the segment numbers in the design sessions is shown in Figure 2. The timeline demonstrates that the segment durations are longer in the digital mode; particularly it is longer in SL and shorter in the baseline study. This suggests that the designers had more new actions and shifted them quickly in the baseline study (freehand sketching session), but they spent more time on an action before they engaged in a new action in the digital modes. We could interpret that this consistent data showing longer segment duration in the digital mode may be due to: (1) the digital design environments slowed the designers down because they required more cognitive work and/or (2) the designers pursued each action in more detail in a design representation in the digital design environments.

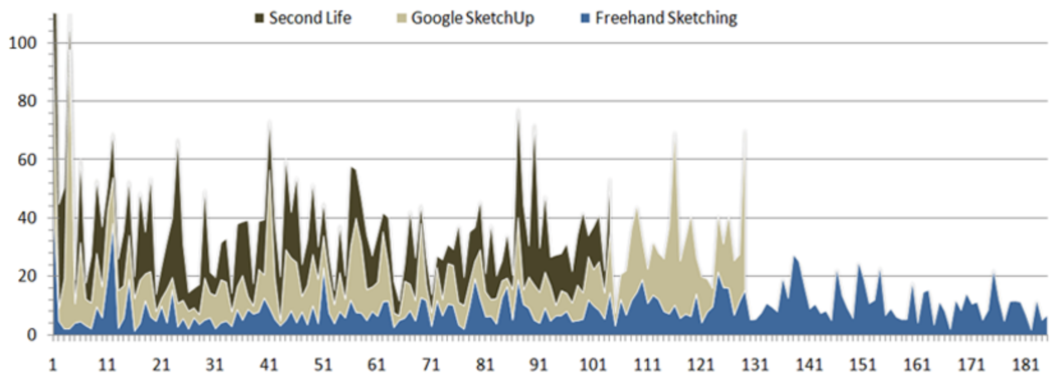
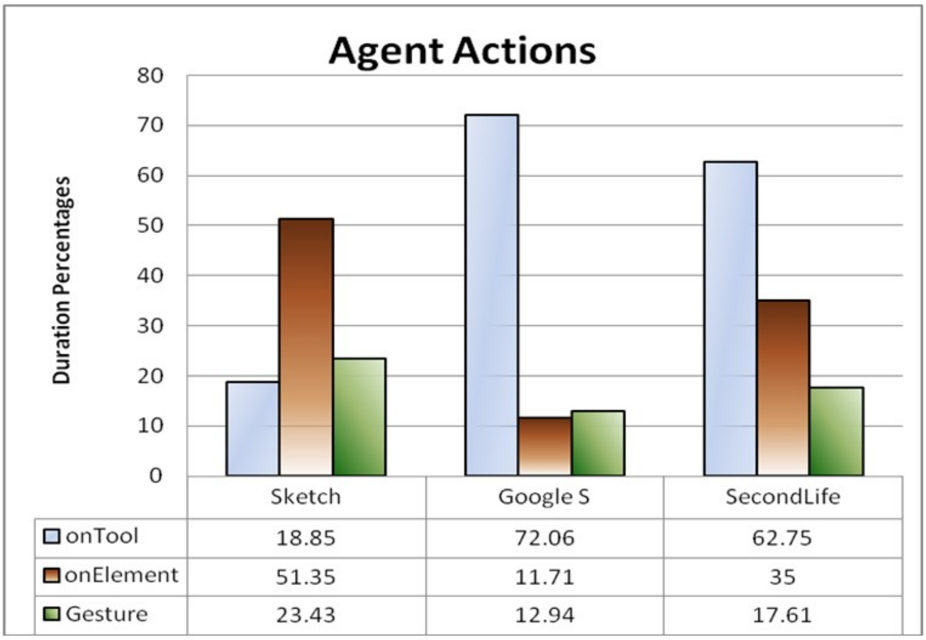


Figure 2. The distribution of the segment durations

4.2 Interaction with the environment and artefact

Figure 3 shows the duration percentages of the agent actions comparing the three design modes. The duration percentage of the onTool action is higher in the GS session, followed by the SL session. The duration percentage of the onElement action is higher in the baseline study, and it is lower in the GS session. The duration percentage of the gesture action is higher in the baseline study, followed by the SL session, as shown in Figure 3. This shows that the designers' engagements with the design space which includes inspecting the design artefact, looking at the representation, and drawing perspectives to inspect the design in several views become dominant in the baseline study. Similarly, designers inspect the design artefact visually and change the camera view for the orientation in the SL session. In addition, in the GS and the SL sessions, the designers engaged more with the tools and the interface of the application. We observe that while they were looking for a specific command and operating the modelling and modification features of the digital environments, they engaged more with the interface and tools.



	Sketch	Google S	SecondLife
onTool	18.85	72.06	62.75
onElement	51.35	11.71	35
Gesture	23.43	12.94	17.61

Figure 3. Duration percentages of Agent actions

The results of the analysis show that in the baseline study, (1) the designers engaged more with the inspection of the design representation, and (2) gestured a lot, which facilitate cognitive actions on the given materials. In the GS and SL sessions, the designers engaged more with the tools and the interface of the applications, and in the SL, the designers engaged with the interface and the visual analysis of the design model, inspecting it by flying over and walking through. In the baseline study, the inspections of the given materials and the gesture action are important for understanding the design problem and establishing an understanding of the design situation. In the GS and SL 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. In particular SL provided an environment for designers in which they could easily focus on the visual analysis of the design solution, thus the duration percentage of the onElement actions is higher than the duration percentage of the onElement actions in the GS sessions. 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 4. Each horizontal bar shows the beginning of the sessions, on the left, and the durations of each operation, on the right. In the baseline study (freehand sketching), the frequent object action occurred in small chunks at the beginning and larger chunks towards occurred at the end of the session. We observed a similar pattern in the spatial actions in the baseline study. When we move to the digital modes we observe a different pattern in the perceptual focus actions in the GS and the SL sessions, compared to the baseline study. In the digital modes, particularly in the SL sessions, the spatial relationships actions occurred more frequently and became longer during the sessions, as illustrated in Figure 4. This shows that the visual features of the design elements became the key reasoning elements in the 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' [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. 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.

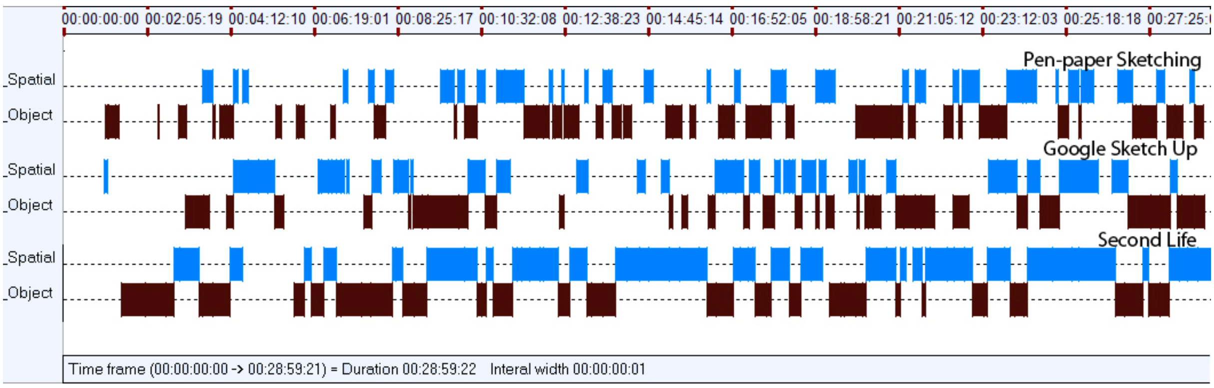
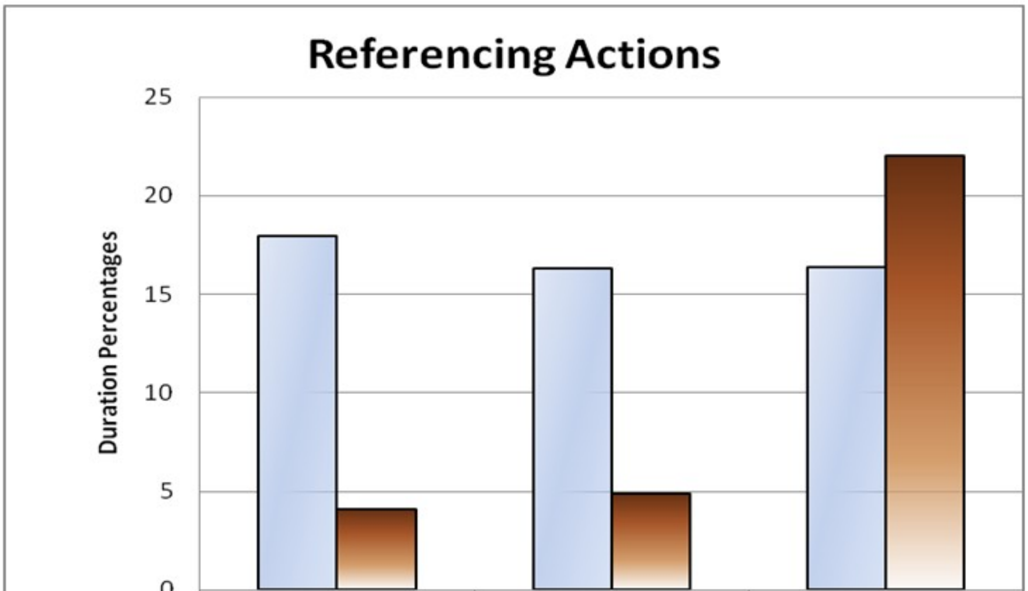


Figure 4. Timeline showing Spatial - Object actions

The durations of the self-referencing actions are investigated in order to understand how designers locate themselves in the design representation, as shown in Figure 5. The duration percentages of the egocentric referencing are low in the baseline study (freehand sketching). There is an increase in the duration percentages of the egocentric actions in the SL session, compared to the baseline study and GS session, as shown in Figure 5. The investigation of the designers' self-referencing has potentials to reveal the designers' perception of presence while they are designing in digital environments. In the field of psychology, studies have pointed out that people tend to position themselves differently in diagrams and models [Bryant and Tversky 1999; Tversky 2005]. 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' egocentric referencing in the digital modes, the highest in the immersive virtual world and they tended to position themselves outside the design representation in the baselines study and the GS session which are non-immersive design environments.



	Sketch	Google S	SecondLife
Allocentric	17.93	16.29	16.4
Egocentric	4.08	4.91	22.03

Figure 5. Duration percentages of referencing actions

We could suggest that designers tended to use more egocentric referencing in 3D immersive design environment, and they focused on different visuo-spatial properties of the design representation in sketching and 3D modelling modes. This finding indicates that the designers developed a sense of presence in the 3D immersive virtual environments that might have an impact on their visuo-spatial reasoning.

5. Conclusions

We have studied designers using three modes of designing; the freehand sketching as the baseline study and the non-immersive (GS) and immersive (SL) 3D modelling environments, allowing us to compare their behaviour and interaction within the environments. We conclude that designers adapt to different virtual environments showing different focus, self referencing and interaction in each environment. The findings of the study also confirm a collaborative design study [Gul 2008] which indicates that the experience of being immersed in a virtual world while designing is very distinct from interacting with real-world artefacts. Each design environment provides different experiences of embodiment. The results of the study imply the followings.

5.1 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. 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. 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.

5.2 Affording engagement within the environment

The results of the analysis show that in the baseline study, (1) the designers engaged more with the design representation, and (2) gestured a lot, which is facilitated cognitive activities on the materials. In the GS and SL, the designers engaged more with the tools and the interface of the applications, and in the SL, the designers engaged with the visual analysis of the design model, inspecting it by flying over and walking through it. In the baseline study, the inspections of the given materials and the gesture action are important for understanding the design problem and establishing an understanding of the design situation. In the GS and SL, 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. SL also 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.

5.3 Affording immersion in designing

The results of the analysis show that designers tended to use more egocentric referencing in 3D immersive design environment, and they engaged with global relations based on environmental objects, e.g. referring 'next to the building' or 'towards the sun' in the baseline and non-immersive environment. This finding indicates that the designers developed a sense of presence in the 3D immersive virtual environments that might also 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" [Gigante 1993]. 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 [Kalawsky 1993]. "The sense of immersion" is defined as the level of fidelity that virtual environments provide to the user's senses [Narayan et al. 2005], which could be enhanced with the use of human-shape characters (avatars) [Hoon et al. 2003]. In our experiments, the 3D virtual world is a desktop system 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.

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