Studying the Impact of Immersion on Design Cognition

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Abstract: With the recent developments in information and communication technologies, designers have adapted digital tools and new ways of designing into their practice. In order to develop efficient systems for designing, the adaptation of new tools and techniques in design practice requires a better understanding of how designers employ the digital medium and what impact the digital medium have on designers’ cognition. The latter one is the subject of this paper. The paper presents the methodology and the initial results of a pilot to investigate the impact of immersion on design cognition. The initial result of the pilot study indicates that the designers were able to adapt to each design environment which affords different kinds of activities and requires different cognitive load.

Keywords: Design cognition; digital design environments; virtual worlds; protocol analysis; immersion.

Introduction

The recent developments in information and communication technologies achieved the creation of computer tools that are technically and financially feasible to use. This new media enables the capture of more information that it would not be possible to capture with the use of traditional design media and makes the refining and developing design ideas more efficient. Design professionals are exposed to these design technologies, especially regarding the ability to interact, record and recall data. During the last decade, most architectural design firms have adopted CAD applications for different stages of the design processes, usually accompanied by traditional sketching. With the recent developments in design tools, the designing activity can start on the computer in the early stage of the process. It is not proposed that only use of digital tools is ideal (the traditional ways of designing should not be discarded), but the digital design process raises many questions and challenges for the design profession that deserve attention (Achten and Joosen, 2003). There is certainly a need for an understanding of design behaviour and cognition that would be used to develop better design medium and tools.

Based on the recent developments on design medium and tools, we are interested in designers’ cognitive activities when they are working in different design environments, in particular, what is the impact of immersion on design cognition?

Studying design representations and cognition

During the process of designing, the external design representations, which may be in the form of sketches, physical and digital models, diagrams,
graphs and notations, are employed. Because of the limitations of human mental capacity (or the working memory) (Miller, 1956), the external design representations work as accessible data storages for designers that reduce the information-processing load. In the field of psychology, Sweller (1988) defined Cognitive Load Theory (CLT), which points out that optimum learning occurs in humans when the load on working memory is kept to a minimum to best facilitate the changes in long-term memory. CLT assumes that working memory is connected to an unlimited long-term memory (Baddeley, 1992). Working memory, especially for instructional designers, is that limited to about seven items or elements of information at any one time (Miller, 1956; Baddeley, 1992). Long-term memory is the repository for more permanent knowledge and skills and includes all things in memory that are not currently being used but which are needed for understanding (Bower, 1975).

The designers’ interaction with the external representations is seen to represent mental activity. Studies show that design externalisations that are off-loaded designers’ mental capacity facilitate increasing the cognitive abilities (Norman, 1993). The external design representations have two forms: verbal-conceptual and visual-graphic. The complementary nature of the two was viewed as one of the key concepts of design cognition (Akin and Lin, 1995, Goel, 1995). Akin (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. Akin (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.”

External representations, sketches in particular, serve as visual aids for design thinking in a variety of ways (Laseau, 1989). Architects sketched and examined the sketches to discover visual cues that suggested ways to refine and revise the design ideas (Suwa and Tversky, 2002). This cycle-sketch-inspect-revise was similar to Schön and Wiggins’s (1992) reflective conversation with oneself.

Suwa et al. (1998) examined the verbal-conceptual externalization of individual designers who were working on a design task using freehand sketches. They looked at four cognitive levels: physical, perceptual, functional and conceptual. Suwa et al’s (1998) coding scheme has two benefits. First, design actions are definable in a systematic way using verbal design externalisations which is the foundation of analysis of how particular types of actions contribute to developing key design ideas. Second, the scheme provides evidence of how designers cognitively interact with their own sketches.

In the field of design, researchers also investigated the relationship between designers’ own body and design artefact. Bryant and Tversky (1999) pointed out that with models, participants adopted the character’s perspective, and with diagram, participants took an outside perspective. Gül (2008) investigated the multidimensional presence of designers’ in virtual environments in a collaborative design setting. In particular, she suggests that the experience of being immersed in a virtual world while designing is very distinct from interacting with real-world artefacts (Gül, 2008).

In this paper, the both types of design representations which are the verbal-conceptual and the visual-graphic are employed to determine to changes on designers’ cognition when they move to different design environments. Suwa et al’s (1998) design cognition coding scheme is adopted and further developed. The initial coding scheme allows us to examine intensely the physical and perceptual aspects of design cognition, as well as idea generation processes in different design environments.
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 digital modes. Since we are interested with the impact of immersion on design cognition, two different types of digital design environments have been chosen: Google SketchUp (GS) and Second Life (SL). With these ideas in mind, the empirical data forms two groups:

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

Google SketchUp (http://sketchup.google.com) (GS) 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.

Second Life (www.secondlife.com) (SL) 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 in 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 of the 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 L F et al., 2008). Maher and Simoff (2000) first characterize the design activities in 3D virtual worlds as “designing within the design”.

Protocol analysis

In this study, the impact of different design environments on design cognition is investigated 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). 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 (Akın, 1986, Suwa et al., 1998). The protocol analysis, which is a qualitative approach, allows us to measure the changes that can be counted by the coding scheme. Similar to latter design studies, the visual and verbal design externalisations are employed in this study.

Coding scheme

The expected result of the study is to find some changes in the designers’ activities and cognition when they move to different design environments. Thus, measuring the changes is one of the key for the development of the coding scheme. The first step in the development of the coding scheme is the literature search. We reviewed existing coding schemes in design studies, and then borrowed and adapted the categories to measure the changes in the above aspects. Secondly, through the coding of the experiment data, new codes to the initial coding scheme are added to capture different aspects of the collaborative design activity. Thus the initial coding scheme evolves through the analysis of the protocol. The initial design cognition coding scheme refers to verbal and visual design protocols that have direct relevance to designers’ cognition to solve a particular design problem. This scheme is adopted from Suwa et al.’s (1998) design cognition coding scheme.
In addition, the scheme also shares the characteristics of Gül's (2007) realisation category, the perceptual focus and the solution moves categories, as shown in Table 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 (Mcneill et al., 1998). 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 (see Gül, 2007 for more detail).

**Pilot study**

To investigate the impact of different design environments on design cognition, a series of experiments will be conducted. In order to test the coding scheme and the experimental settings, a series of pilot study with the participation of three expert architects were conducted. Figure 1 shows the experiment settings of the study. 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 have worked in three design environments, they are given a different design brief with the same complexity in each

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Physical</td>
<td>Realisation actions: create, continue, delete, write based on definition in (Gül, 2007), gestures and inspecting design representation</td>
<td>Drawing actions, modelling actions, Move a pen or navigating an avatar, move elements, gesture, and visual analysis of the representation.</td>
</tr>
<tr>
<td>Perceptual</td>
<td>Attend to visual and spatial features of elements, organising and self referencing: egocentric- allocentric based on definition in (Gül, 2007)</td>
<td>Shapes, sizes, textures, proximity, alignment, intersection, grouping, similarity, contrast, using own body-local elements and global elements for referencing.</td>
</tr>
<tr>
<td>Functional</td>
<td>Explore the issues of interactions between artefacts and people/nature, and consider psychological reactions of people</td>
<td>Functions, circulation of people, views, lighting conditions, and fascination, motivation, cheerfulness</td>
</tr>
<tr>
<td>Structural</td>
<td>Explore the issues of structural aspects of elements</td>
<td>Columns, beams, slabs</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Make preferential and aesthetic evaluations, set up goals, retrieve knowledge, solution-move: progress or change based on definition in (Gül, 2007) and re-formalisation</td>
<td>Like-dislike, good-bad, beautiful-ugly, setting goal for her/himself, recalling past knowledge, proposing new ideas and developing the same idea further, reconceptualising the design solution</td>
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Table 1
Design cognition coding scheme
setting. The designers’ 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.

**Results and discussion**

The duration percentages of each action category (the average of three architects) are examined to measure the changes of designers’ 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.

**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, the mean (M) duration of segments is the shortest (M 7.64 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 13.61 second) is observed in the 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 (GS and SL).

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 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.

**What is the overall tendency of actions?**

Figure 3 shows the duration percentages, mean and count of each action categories from the coding scheme. These are the average duration percentages of the three architects designing in the three different design environments. Figure 3 shows that the duration percentages of the physical (74.64 %), functional (33.47 %) and conceptual (56.5 %) categories are higher in the baseline study, when we compared across the design sessions. The duration percentages of the perceptual and the structural actions categories drop in the baseline study but increase in the digital designing modes. In particular, the duration

<table>
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<tr>
<th>Seconds</th>
<th>Baseline</th>
<th>GS</th>
<th>SL</th>
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<tbody>
<tr>
<td>Average count</td>
<td>184</td>
<td>129</td>
<td>104</td>
</tr>
<tr>
<td>Mean duration</td>
<td>7.64</td>
<td>11.04</td>
<td>13.61</td>
</tr>
<tr>
<td>Max</td>
<td>38.25</td>
<td>55.33</td>
<td>56.75</td>
</tr>
<tr>
<td>Min</td>
<td>1.33</td>
<td>2.67</td>
<td>3.88</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>5.77</td>
<td>8.86</td>
<td>9.86</td>
</tr>
<tr>
<td>Skew</td>
<td>1.55</td>
<td>1.91</td>
<td>1.59</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.60</td>
<td>5.39</td>
<td>3.79</td>
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(Table 2: Statistic of the average segment durations)
percentages of the perceptual actions (79.17 %) is higher in the SL session, as shown in Figure 3.

The physical and conceptual actions are shown along the timeline of the sessions in Figure 4. Each horizontal bar represents the average durations of actions: the beginning of the sessions is on the left, and the end of the sessions is on the right. In the baseline study (freehand sketching), the conceptual action and the physical actions were parallel. This means that designers spent time on the design conceptualization, development, evaluation while they were simultaneously sketching in the baseline study, as shown in Figure 4. When the designers moved to digital design modes, the conceptual and the physical actions became separated activities. In particular, there are segments that only included the physical actions or the conceptual actions in the SL session, as shown in Figure 4.

**Conclusion**

The designers’ verbal and visual design protocols have been collected and analysed. The initial results of the pilot study indicate that designers adapt to different design environments showing different focus and interaction in each environment. We confirmed that the experience of being immersed in a virtual world while designing is very distinct from interacting with real-world artefacts, as suggest by (Gül, 2008). Each design environment provides different experiences of embodiment.

The initial results of the analysis show that in the baseline study (freehand sketching) the designers engaged more with the physical activities to create the design representation, spent time on the functional aspect of the design solving how the artefact and people would interact, and spent time on the conceptual issues considering possible solutions and design concepts, refining and evaluating them. In addition, the results of the protocol analysis show that in the baseline study, the physical actions and the conceptual actions are parallel actions occurred
in shorter attention spans, and those actions become separated and become longer in both digital modes. This finding suggests that the type of representations might have an impact on designers’ cognitive load, which is concerned with the limitations of working-memory capacity.

In the GS and SL sessions, our observation indicates that the designers engaged with the tools and the interface of the applications which caused a break in the designing activity. The designers engaged more with the visual analysis of the design model, inspecting it by flying over and walking through it. In the freehand sketching, 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 digital design environments, in particular in SL, the designers spent more time on the perceptual action. The virtual environment provided a platform for designers in which they could easily focus on the visual analysis of the design solution. The reasons for that may be the ease of using different camera views and navigation that could be controlled by simple mouse movements, and the relatively realistic appearance of the design model, which afforded the visual analysis of the design model.

In summary, the preliminary results of the pilot study shows that different design environments afford different activities and requires different cognitive load. Considering these differences, the paper points out that it is necessary to develop a methodology to study design cognition in different design environment. The next phase of the study is to conduct the experiments with the participation of a large group of designers and conduct more detailed analysis on the protocol data.

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