Do We Need CAD during Conceptual Design?

BILDA Zafer[1], GERO John, S.[2]
[1,2] *Key Centre of Design Computing and Cognition, The University of Sydney*

Keywords: Representations, protocol studies, conceptual design

Abstract: This paper presents the results of experiments to test whether a designer necessarily needs to produce and utilize external representations in the very early phases of conceptual design. Three architects are engaged in two separate design processes, one is the experiment condition where they were not allowed sketch, and the other, the control condition where they were allowed to sketch. In the experiment condition, architects were required to put on a blindfold and think aloud while designing. The results show that in both conditions the design outcomes fit in the given dimensions of the site, accommodate the space requirements and allow an effective use for the clients. Thus, when the participants were blindfolded, they were able to produce designs by using their cognitive resources to create and hold an internal representation of the design rather than by sketching, or using a CAD tool. We finally raise the question: do architects need CAD representations during the conceptual phase of the design activity?

1 INTRODUCTION

In the early phases of designing architects often redefine their design space by reviewing the design requirements and consequently formulate a tentative solution. The tentative proposal is usually based on one or more concept(s). Then the design ideas are usually tested and evaluated around a stronger concept. Thus the early phase of designing is called the conceptual design phase. Architects often prefer sketching to externalize/represent their thoughts and concepts in this phase and it becomes the medium where they set out their thoughts on the fly. Relatively recently studies attempted to reveal why sketches have been an effective medium for conceptual designing. Some studies proposed that ambiguity is one of the key factors because it allows the seeing of new possibilities in the representations, thus it allows re-interpretations (Goel 1995; Suwa Purcell and Gero 1998). The debates about designers' use of CAD emphasize that CAD environments do not provide the ambiguous medium designers need for conceptual designing.

In this paper we question if externalization is an essential requirement for conceptual designing, i.e. whether a designer necessarily needs to produce and utilize external representations in the very early phases of conceptual design. This research focuses on "externalizations" in general and whether they are central or peripheral in

designing, rather than testing the impact of computer mediation on the conceptual design process. However the initial motivation of this study was based on a search for effective computer mediation in conceptual design. A previous study focused on comparison of traditional versus digital media in terms of differences in cognitive activities (Bilda and Demirkan, 2003). In the current study we attempt to measure the changes in the outcomes when designers can and cannot externalize, rather than comparing the outcomes with the use of different externalization media, such as sketches versus CAD. The implications of the study pose questions on how to develop CAD systems for conceptual design.

2 THE NEED FOR EXTERNAL REPRESENTATIONS

What purpose do external representations serve? In order to explore this question we have to consider design thinking within a time factor that is the timeline of the design activity. Through this timeline there are sequential design actions such that previous actions inform and change the next one. Thus the design features are constructed sequentially and in a situated way. Externalizations serve not only to store the record of this activity, but also serve as a tool to support reasoning between these sequential acts.

In the early phases of the design process architects read and try to understand the design brief, they might visit the site, meet the clients, review the requirements, etc.(Lawson 1997). Then the next stage is not usually starting to draw. There often exists an initial thinking period, and the length of this period varies for every designer. It can be extended without touching pen and paper i.e. without the need to externalize the ideas.

Do architects necessarily start designing with external representations in the early stages of design? Anecdotal examples are often quoted of major architects such as Frank Lloyd Wright who could conceive of and develop a design entirely using imagery with an external representation of the design only being produced at the end of the process (Weisberg 1993). Then it should be possible for some designers to develop and maintain an internal designing activity for a prolonged time. We refer to this activity as the use of imagery alone in designing.

How are the initial design concepts and proposals formed? Before a designer starts to draw we assume s/he is engaged in a thinking process that might occur during their daily activities; whether sitting at a desk, while having a shower or driving. We presume that this thinking is of a visual type; studies in cognitive psychology found evidence that this thinking is visual, not in the sense of “seeing” but a mechanism resembling perception (Kosslyn 1980; Psylyshn 1984,). It is possible that this visual thinking process produces design concepts, abstractions and eventually a mental design model which evolves through the timeline of an internal design activity. Consequently effective designing may be possible with this thinking process.

Most empirical studies of design problem solving have been based on an examination of design protocols collecting both graphical and verbal data,

emphasizing either verbal content (Akin 1986) or analysis of the drawings (Do 1995). Consequently, the analysis of cognitive activities in design has focused on the sketching process (Goldschmidt 1994; Goel 1995; Suwa and Tversky 1997; Suwa Purcell and Gero 1998) where the designer externalizes his/her thoughts using pen and paper. Although sketching studies emphasized the use of imagery with sketching (Kavakli and Gero 2002), the issue of how design is carried out using mental imagery alone has not been adequately studied. Athavankar (1997) conducted an experiment where an industrial designer was required to design a product in his imagery (with an eye mask on), so that the he had no access to sketching, and the visual feedback it provides. The study claimed that the designer was able to evolve the shape of the object, manipulate it, evaluate alternative modifications, and add details, and colour as well. Thus, expert designers should be able to use only imagery in the conceptual design phase, before externalizing their design thoughts. A similar study to Athavankar's has been conducted at Sydney University with the think-aloud method where an architect wears a blindfold and commences designing using his/her imagery. S/he is allowed to externalize only when the design is mentally finalized. The protocol analysis of the videotaped sessions showed that common imagistic actions are linked together to create and maintain an internal design representation (Bilda and Purcell 2003).

Reviewing the literature in design studies and cognitive psychology, we can present two views on imagery and sketching activities in design, which also make a distinction between them. 1. Sketching directly produces images, and ideas externalized on paper, and then the designer starts to have a dialogue with them via their perceptual mechanisms. In this way, the design problem space is explored, and restructured through this dialogue (Schon and Wiggins 1992; Goldschmidt 1994; Suwa Purcell and Gero 1998). 2. In contrast during the use of imagery alone for designing, a designer has to accumulate considerable amount of knowledge/meaning before an image is generated (Bilda and Purcell 2003), which suggests concept formation without drawings, and thus, without direct perceptual input. As with sketching activity, there is the dialogue with the images to restructure the design space; this probably is constrained within working memory capacities (Logie 1995).

The first view emphasizes the necessity of externalizing ideas during designing. The second view suggests a thinking process via use of imagery alone. This type of visual thinking has some features/mechanisms different to a thinking process which uses drawings, so that other cognitive mechanisms could take over and shape the thinking process. This visual thinking could encourage designers to a "take your time" approach, so that they conceptually explore the problem space well before producing any tentative proposals or design images.

3 METHOD

This paper presents design outcomes from architects' design sessions conducted under two different conditions: the experiment condition, in which they do not have access to sketching and the control condition where they are given access to

sketching. The design outcomes from the experiment and control conditions are compared to observe whether there are significant differences between them.

The three the architects who participated in the study (two female and one male) have each been practicing for more than 10 years. Architects A1 and A2 have been awarded prizes for their designs in Australia; they have been running their own offices, and also teaching part-time at the University of Sydney. Architect A3 is a senior designer in a well-known architectural firm, and has been teaching part-time at the University of Technology, Sydney. We had preliminary meetings with 9 potential architect participants where we asked whether they think they would be capable of using their imagery alone to come up with a design solution. They all gave positive responses however we selected 3 architects based on their statements that they easily can think-aloud when they are designing.

3.1 Experimental Conditions

Design brief 01, given for the experiment condition requires designing a house for two artists: a painter and a dancer, and includes two art studios, an observatory, a sculpture garden and the living, eating, sleeping areas. Design brief 02 for the control condition requires designing a house for a couple with 5 children aged from 3 to 17, that would accommodate children and parent sleeping areas, family space, study, guest room, eating and outdoor recreation spaces. Each design brief requires a different approach to the site and neighbouring environment.

The set-up of the study, Figure 1, involves a digital video recorder with a built-in or lapel microphone, directed at the designer to capture his/her verbalizations, gestures or sketching activity. The experiment condition of the study involves testing if architects are able to design without having access to sketching. We used a similar approach to that taken by Athavankar (1997); we had the designers engage in the design process while wearing a blindfold. At the start of the session they were told that they were to engage in a design activity but that they would do it while wearing a blindfold. In the beginning of the sessions the participants were given design brief 01 for the project, asked to read through it and then asked to recite it without reference to the written document. This process was repeated until they could recite the brief without mistakes. The aim of this procedure was to ensure that they would have similar access to the brief as an architect who could consult a written brief during the design process. They were then shown a montage of photographs of the site and allowed to examine them and ask questions if necessary. They were also instructed that they are required to come up with an initial sketch design to show the clients with the following criteria: the design should fit in the given dimensions of the site, accommodate the space requirements and allow an effective use based on the clients' requirements.

The participants were also given training in the think-aloud method. When this section of the experiment was completed they were asked to put on the blindfold and to start designing. During the blindfolded designing, they were free to ask about specific aspects of the design brief when they felt the need to do so. Five minutes before the end of the 45 minutes session participants were told that this was the

amount of time remaining. They were expected to produce an initial design for the house and at the end of the session, after the blindfold had been removed, they were asked to represent the design by drawing it as rapidly as possible and without any changes being permitted. If they are able to spend a particular amount of time designing without having an access to sketching and are able to end up with a reasonable design solution then that would be the evidence for the possibility of using imagery alone during designing.

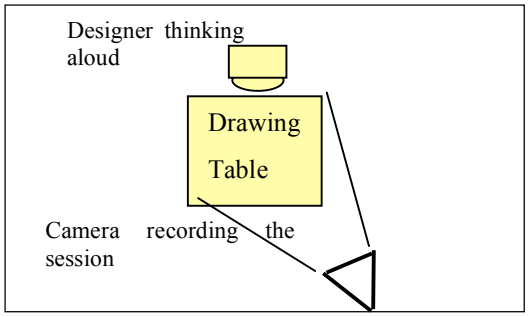

Figure 1 Set-up of the study

In the control condition of the study, the same architects were required to sketch their ideas for design brief 02 while thinking aloud for 45 minutes. Sketching sessions were conducted at least one month after the blindfolded sessions. Participants were asked to memorize the design brief, they were shown the same montage of the site photos and they were given the training session in the think-aloud method. They were given the same site layout to work with. They were asked to number each new sheet of tracing paper. Table 1 shows a summary of the methodological considerations for the experiment and control conditions.

Table 1 Summary of methods

	Experiment Condition	Control Condition
Activity	Blindfolded designing, only externalizing at the end of the session.	Sketching
Design Brief	Design a residential house for a painter and a dancer	Design a residential house for a family with five children
Method of data collection	Time-stamped video recording	Time-stamped video recording
Reporting Method	Think-Aloud	Think-Aloud
Coding Scheme	Imagery Coding Scheme	Sketch Coding Scheme

3.2 Assessment of the design outcome

In this paper we focus on the results from the assessment of the sketches that are produced at the end of the sketching versus blindfolded sessions. The resulting

sketches by the three architects were double-blind judged by three judges who have been practicing and teaching architectural design for more than 15 years. The judges were provided with the two versions of the design briefs, the collage of photos of the site, as well as the site layout. After inspecting the design brief materials, they inspected the photocopies of the sketches produced in both phases of the study. The judges were provided with one sketch layout for each session which is the final sketch produced in each condition. Additionally section drawings were included if there were any in the related session. The sketches did not have indication of which session they belonged to (either sketching or blindfolded) and the judges were unaware that some of the designs had been produced by blindfolded designers. The criteria for the assessment of sketches were as follows where each item was graded out of 10:

- How creative the sketched design is: defined as seeing opportunities for a design solution that is not the "norm".
- How well the sketched design satisfies the design brief: in terms of design solution meeting the client requirements.
- Practicality

4 RESULTS

The three architects were able to satisfy the space and client requirements in both design briefs, and in experiment and control conditions in their designs, Figures 2, 3 and 4. Table 2 shows the results of the assessment of the sketches by the three judges. The grades being out of 10 are calculated as the average of three judges' assessments. The end columns in each condition show the average grade of the three architects for each item.

Table 2 Grades for the design outcomes

Criteria	**Blindfolded Sessions**				**Sketching Sessions**			
	A1	**A2**	**A3**	**Aver**	**A1**	**A2**	**A3**	**Aver**
How Creative	5.3	6.0	6.3	**5.9**	5.0	5.7	7.3	**6.0**
How well it satisfies the design brief	7.7	6.3	7.7	**7.2**	6.3	6.3	6.3	**6.3**
Practicality	7.7	7.0	7.0	**7.2**	6.0	5.7	5.3	**5.7**
Average score	**6.9**	**6.4**	**7.0**		**5.8**	**5.9**	**6.3**	

Architect A1 produced similar layouts for the two design briefs in terms of using the site, and the relations between outdoor and indoor spaces even though the briefs were different. Figure 2 shows A1's sketches for the sketching (left-hand side) and blindfolded sessions (right-hand side). A1's blindfolded session design outcome has

higher scores in terms of satisfying the design brief (7.7 versus 6.0) and practicality of the design solution (7.7 versus 6.0). The two design outcomes have closer scores (5.3 and 5.0) for assessment of creativity (Table 2).

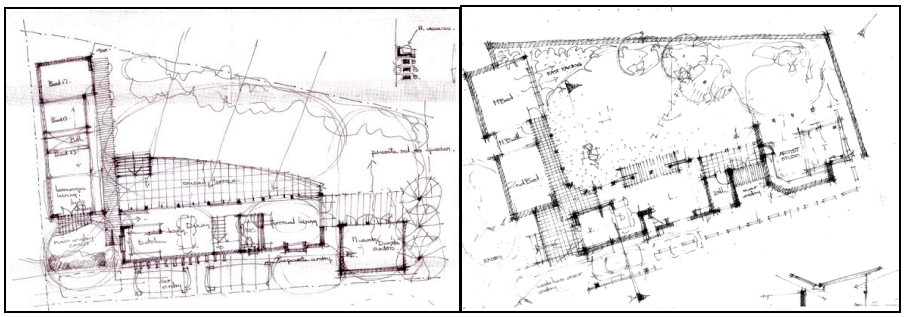

Figure 2 Architect 01 sketches (left: sketching; right: blindfolded)

Architect A2 produced different layouts for the two conditions in terms of typology and the relationship of the building to the site. Figure 3 shows A2's sketches for the sketching and blindfolded sessions. A2's blindfolded design session outcome and sketching session outcome have the same scores in terms of satisfying the design brief (6.3 and 6.3) and close scores for creativity assessment (6.0 and 5.7). On the other hand the practicality assessment of the blindfolded session outcome is higher than the sketching session outcome (7.0 versus 5.7).

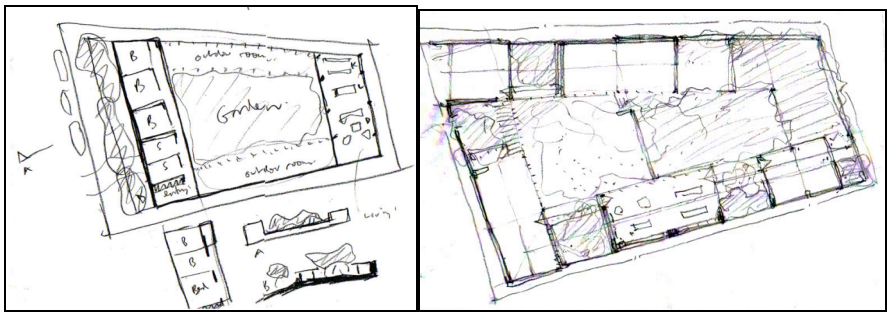

Figure 3 Architect 02 sketches (left: sketching; right: blindfolded session)

A3 produced quite different layouts for the two conditions, in terms of typology and the relationship of the building to the outdoor areas. Figure 4 shows A3's sketches for the sketching and blindfolded sessions. A3's blindfolded design session outcome has higher scores in terms of satisfying the design brief (7.7 versus 6.3) and practicality of the design solution (7.0 versus 5.3). However, the design outcome of the sketching session has a higher score (6.3 versus 7.3) in creativity assessment.

Average scores of the three architects showed that the blindfolded session design outcomes scored higher than sketching outcomes in terms of two assessment criteria; satisfying the design brief and practicality of the design solution. However the average creativity assessment scores are same. Two of the three architects' (A1 and

A3) average overall design outcome scores are higher for blindfolded sessions. These results are based on a small number of participants and cannot be generalized, however, they point to one important issue in this study: it is possible for expert designers to produce satisfactory designs through the use of imagery alone i.e. without the use of externalizations during designing.

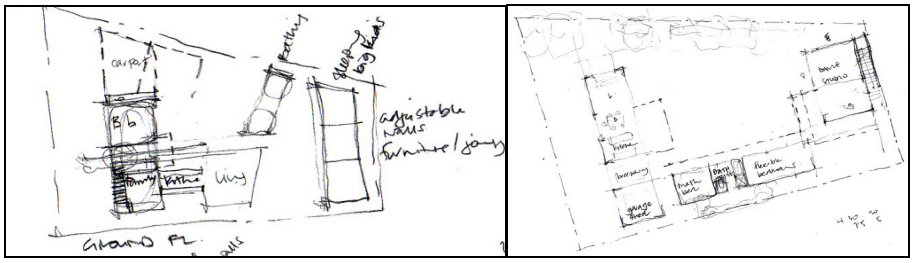

Figure 3 Architect 03 sketches (left: sketching; right: blindfolded session)

5 IMPLICATIONS FOR CAAD

Research on how designers think can provide clues on how to achieve effective computer mediation. Studies on sketching have been a major part of this research focusing on the designers' interactions with sketches. The development of conceptual CAAD tools is based on insights from sketching studies. In this paper, we have demonstrated that externalizing a design is not the only way to design visually. Sketches and in general externalizations are central to designing; they represent the development of designs, they have an interactive role and a crucial effect in the mechanics of the design activity. However based on our results from these experiments, we propose that "externalizing" is not necessary for a satisfying and reasonable outcome at the conceptual stage of designing.

There is anecdotal evidence in architectural practice that architects sometimes skip the early sketching process and start with a CAD representation of the initial design. This representation is usually worked out with a massing study that involves synthesizing volumetric shapes in a 3D CAD environment. In a collaborative work environment, senior architects might complain that those digital designers are too focused on how the volumes look together, rather than being able to see parts or details synthesized together vertically. Senior architects often use elevation drawings to explore and evaluate these 3D aspects of the design and they consider drawing an elevation as adequate for that. The reason for why such senior architects effectively use elevations is possibly that they developed a skill to see those 3D aspects elevating out of the paper space via drawing lines on a paper. Thus, it is the use of imagery in this case which enables these architects to understand the 3D volumetrics of the environment. Consequently every line on a drawing modifies or adds to the understanding of the 3D model. This supports the idea that architects externalize

their designs interactively with the use of imagery, sometimes called interactive imagery (Goldschmidt, 1994).

Design practice and design education continue to change, driven in part by the available technology. In design education, students are encouraged to start off designing using a digital medium, and then produce physical models from these digital models. Does this require a different style of thinking? As a consequence, does the initial thinking process or the skill for developing an internal mental representation gain more importance? And if so, what are the cognitive resources needed for this type of activity and further how can they be improved?

At the beginning of this paper we raised the question "Do we need CAD for conceptual designing", and this question was the trigger for exploring a more general question, "Do we need externalizations". Sketching in architectural design is still a central concern which shapes our understanding of the design process and the development of new tools. In this study we attempted to bring another view, questioning whether externalization is the only way to design. Our aim here was to indicate that constructing internal representations could be a strong tool for designing. We presented results from the sketching versus non-sketching experiments which supported this claim. The answer to the initial question is: we may not need sketching for the generation of designs during the conceptual phase. However, externalizations appear to serve other purposes than the simple dialectic suggested by Schon and Wiggins (1992) and confirmed by others. Externalizations whether they are sketches, CAD tools or models, serve other communicative roles. However, it is possible to extend our current understanding of CAAD by developing systems that take into consideration the strength of mental imagery in designing. As we develop a deeper understanding of the visual reasoning and imagistic capacities of the mind it is likely that future CAAD tools for conceptual design may look very different to the current CAAD tools used for detail design.

REFERENCES

Akin, Omer. 1986. *Psychology of architectural design.* London: Pion.

Athavankar, Uday A. 1997. Mental imagery as a design tool. *Cybernetics and Systems* 28 (January): 25-47.

Bilda, Zafer and Terry A. Purcell. 2003. Imagery in the architectural design process. In *Proceedings of the 9th European Workshop on Imagery and Cognition (EWIC 9)*, 41. Universita di Pavia, Dipartimento di Psicologia

Bilda, Zafer and Halime Demirkan. 2003. An insight on designers' sketching activities in traditional versus digital media. *Design Studies* 24 (January): 27-50.

Do, Ellen. Y.-L. 1995. What's in a diagram that a computer should understand. In *Global Design Studio: Proceedings of CAAD Futures 95 International*

Conference, ed. Milton Tan and Robert The: 469-482. Singapore: National University of Singapore.

Goel, Vinod. 1995. *Sketches of thought*. Cambridge MA :MIT Press.

Goldschmidt, Gabriella 1994. On visual design thinking: The vis kids of architecture. *Design Studies* 15 (April): 158-174.

Gross, Mark D. 1996. The Electronic Cocktail Napkin - working with diagrams. *Design Studies* 17 (January): 53-69.

Kavakli, Manolya and John S. Gero, 2001. Sketching as mental imagery processing. *Design Studies* 22 (July): 347-364.

Kosslyn, Stephen M. 1980. *Image and mind*. Cambridge, MA: Harvard University Press.

Lawson, Bryan. 1997. How designers think: The design process demystified. Oxford ; Boston: Architectural Press.

Logie, Robert H. 1995. *Visuo-spatial working memory.* Hove/UK: Erlbaum Associates.

Pylyshyn Zenon W. 1984. *Computation and cognition: Toward a foundation for cognitive science*. Cambridge, Mass: MIT Press.

Schon, Donald A. and Glenn Wiggins. 1992. Kinds of seeing and their functions in designing. *Design Studies*, 13(April): 135-156.

Suwa, Masaki, Terry Purcell, and John S. Gero, 1998. Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies* 19(October): 455-483.

Weisberg, Robert W. 1993. *Creativity: Beyond the myth of genius*. New York: W.H. Freeman.

This is a copy of the paper: Bilda, Z and Gero, JS (2005) Do we need CAD during conceptual design? *in* B Martens and A Brown (eds), *Computer Aided Architectural Design Futures 2005,* Springer, pp. 155-164.