TO SKETCH OR NOT TO SKETCH? THAT IS THE QUESTION

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Abstract: In this paper we question whether sketching is essential for conceptual designing. In order to test this hypothesis, we conducted think-aloud experiments with expert architects. They were engaged in two separate design processes: where they were not allowed sketch, and where they were allowed to sketch. The comparison of design activities in two conditions was based on a protocol analysis. The results show that there is no significant difference between sketching and not sketching based on three assessments: design outcome, cognitive activity and idea links. This case study shows that sketching is not an essential activity for expert architects in the early phases of conceptual designing.

Keywords: Sketching, Protocol analysis, Conceptual design

Conceptual designing is the phase where designers start developing ideas, come up with a proposed scheme, possibly develop it to another scheme, and then possibly move to another one. Designers progress by changing the direction of their designs. Sketching and conceptual designing are two inseparable acts for most architects (Akin, 1986; Lawson, 1990; Schon, 1983) possibly because sketches are the tools they learn to use to progress their designs. So sketching is a learned process during design education where architects learn to think with drawings, develop their ideas and solve complex problems with them. They practice using sketches until they become experts. Initially an architectural plan might comprise meaningless symbols to a novice designer, until s/he takes on the intended meaning through learning the conventions associated with them. Then sketches become aids for the progression of a design solution and play an essential part in knowledge acquisition and representation. The ability to read or produce sketches appears to be the only way to develop expertise in architecture.

Design researchers have studied why sketches have been an efficient medium for conceptual designing. One of the earliest finding is that sketches store design solutions and seem to be

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essential for recognizing conflicts and possibilities (Akin, 1978). One of the most influential view is that sketching is a dialogue between the designer and what the drawings suggest (Schon and Wiggins, 1992; Goldschmidt, 1991). Some studies proposed that ambiguity is one of the key factors (Goel 1995) because it allows the seeing of new possibilities in the representations, in other words re-interpretations (Fish and Scrivener 1991, Schon and Wiggins, 1992; Suwa et al. 2000). Sketches also seem to be essential for revising and refining ideas, generating concepts and facilitating problem solving (Do et al., 2000). The importance of external representations has been emphasized in other problem solving domains (Larkin and Simon, 1987; Bauer and Johnson-Laird, 1993; Hegharty, 1992) for facilitating cognitive mechanisms.

What would be the outcome if a designer develops ideas and design solutions without the support of sketching? It might be difficult to evaluate or discard design alternatives without seeing them on paper. This brings the question whether the outcome would be precise or realistic when a designer works only with mental images of a design. Would the essential dialogue between the designer and drawings be blocked when an architect does not have access to sketching? Perhaps not being able to sketch prevents designing. However, within the area of architectural design, there is anecdotal literature about designing with the use of imagery. In parallel with discussions of creativity in other areas (Weisberg, 1993), 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 (Toker, 2003). Anecdotal views of architectural design sometimes put considerable emphasis on the role of imagery.

1. Related Work

Most empirical studies of design problem solving have been based on an examination of design protocols emphasizing the verbal content sometimes with an analysis of the drawings as well (Akin, 1986; Christiaans and Dorst, 1996; Schon 1983). Suwa et al.l (1998; 1999; 2000) have studied an expert architect's design protocol focusing on the content of actions in four different categories to explore the underlying cognitive mechanisms of designers. They concluded that sketches are used as a design medium to set out the designer's thoughts on the fly, rather than only as drawings that could be used to construct a building. Sketch cognition studies suggested an interplay of mental imagery with sketching (Goldschmidt 1991; Fish and Scrivener, 1990; Kavakli and Gero, 2002), however 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. Expert designers may be able to use imagery alone 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 analysis of the design protocols aimed at modelling how

imagery alone was used during designing. The model shows that common imagistic actions are linked together to create and maintain an internal design representation (Bilda and Purcell 2003).

A background review of the design literature shows a common agreement that sketching is essential for conceptual designing. When a designer does not have access to sketching the hypothesis is that the early conceptual phase of designing would be very different as would be the outcome. Our objective is to test whether there is a difference. This paper presents the results of a protocol study involving three expert architects, and shows the differences between their sketching and non-sketching behaviours.

2. Method

The three 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 nine potential architect participants where we asked whether they thought they would be capable of using their imagery alone to come up with a design solution. Four out of the nine architects were hesitant about participating in a blindfolded exercise. Out of the other architects, we selected three based on their statements that they could easily think aloud when they are designing.

2.1. DESIGN OF THE EXPERIMENTS

The three architect participants are first engaged in a design process where they are not allowed to sketch. This phase is called the experiment condition where they receive design brief 01. The design brief 01 (Appendix) requires designing a house for two artists: a painter and a dancer. The house is to have two studios, an observatory, a sculpture garden and living, eating, sleeping areas. After at least a month after the experiment condition the three architects are engaged in a design process where they are allowed to sketch. This phase is the control condition where they receive design brief 02 (Appendix). Design brief 02 requires designing a house on the same site as design brief 01 this time for a couple with 5 children aged from 3 to 17, that would accommodate children and parent sleeping areas, family space, study, guest house, eating and outdoor playing spaces.

The set-up of the study for both experiment and control conditions has a digital video recorder with a built-in or lapel microphone, directed to the designer. In the experiment condition, we used a similar approach to that taken by Athavankar (1997); we had the designers engage in the design process while wearing a blindfold, Figure 1(a). The experimental procedure for the first condition was:

1. The experimenter reads the instructions to the participant explaining that s/he is required to engage in a design activity but that s/he does it while wearing a blindfold and that the blindfolded session will last for 45 minutes.

2. The experimenter explains what the think-aloud method is and asks the participant to do a short think-aloud exercise. The experimenter provides feedback about the participant's thinking aloud.
3. The participant is given the written design brief 01, shown the site layout, and a collage of the photographs of the site and surrounding neighborhood. S/he is allowed to examine them and ask questions.
4. The participant is asked to read the brief and then 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.
5. The participant is instructed that s/he is required to come up with an initial sketch design to show the clients with the following criteria: the design should fit the given dimensions of the site, accommodate the space requirements and allow an effective use based on the clients' requirements.
6. The participant is instructed that s/he can put on the blindfold and start thinking aloud and is free to ask about specific aspects of the design brief when s/he requires.
7. Five minutes before the end of the session, the participant is reminded that this is the amount of time remaining.
8. At the end of the session, the participant is asked to take off the blindfold, and is required to sketch quickly what s/he held in her/his mind's eye. The participant is asked to represent the design by drawing it as rapidly as possible and without any changes being permitted.
9. The participant is allowed to elaborate the sketch (this involves rendering and addition of details which were mentioned during the think-aloud session) only after externalizing the layout as in his/her mind's eye.
10. The participant is interviewed after s/he finalized the drawing process.

Insert Figure 1 here

Sketching sessions have been conducted with the same architects at least one month after the blindfolded sessions, Figure 1(b). Similarly the three architects were asked to memorize the design brief and were given the training session on the think aloud method. In this control condition the participants received the written design brief 02 and they were shown the same site layout and the site photographs. To start the design process each participant was given the site plan and tracing paper to proceed with a series of sketches. They were asked to number each sheet of tracing paper sequentially every time they start to use a new sheet. Then the participant is asked to commence sketching directly. Five minutes before the end of the session, s/he is reminded that this is the amount of time remaining. *Table 1* shows a summary of the considerations for the experiment and the control conditions.

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2.2. PROTOCOL ANALYSIS

2.1.1. Segmentation of protocols

The audio files of the concurrent verbalizations were transcribed, and then segmented. The protocol was segmented using the same approach as for segmenting sketching protocols i.e. by inspecting designer's intentions (Suwa and Tversky 1997; Suwa et al. 1998). In the segmentation of sketch protocols, not only verbalizations but video recordings of the sketching activity support decisions to flag the start and end of a segment. The drawing actions are inspected for cues to find the changes in intentions. In the blindfolded condition information is extracted from the description of the current image or scene the architect talks about. The architect's attention may shift to a different part or aspect of the current image, and this becomes the cue for change of intention. Keeping track of the changes in the descriptions of images/scenes supports our decisions to flag the start and end of a segment. *Table 2* shows an excerpt from a segmented BF protocol.

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2.2.2. Imagery and Sketching Coding Schemes

Recent research on sketching studies proposes that design thinking progresses at physical, perceptual, functional and conceptual levels in parallel (Suwa et al., 1998). Summarizing these action categories: physical actions refer to drawing and looking, perceptual actions refer to interpretation of visual information, functional actions refer to attaching meanings to things, and conceptual actions refer to the planning of the actions and initiating actions for design decisions.

The imagery coding scheme borrows action categories from sketching coding scheme. It consists of six action categories;

visuo-spatial actions (VS),
perceptual actions,
functional actions,
conceptual actions,
evaluative actions and
recall actions.

Visuo-spatial actions (VS), are based on Kosslyn's (1980) image operations: image generation, image inspection, image scanning, and transformation. We extended the types of image generation and added a spatial action that refers to the spatial component in our understanding of mental imagery. Details of the VS actions are explained in Bilda and Gero (2004).

The sketching coding scheme consists of five of the action categories in common with the imagery coding scheme plus drawing actions which is specific to the sketching activity. The majority of the drawing actions in Suwa et al. (1998) coding scheme is used in coding the protocols of the sketching condition in the current study. In this study our focus of analysis is not on the VS or drawing actions, but on action categories which are common to both

conditions. We selectively borrowed actions from perceptual, functional, and conceptual action categories in the Suwa et al. (1998) coding scheme. The selected codes, *Table 3*, are the ones found to be highly correlated with drawing actions during the sketching activity of experts (Kavakli and Gero, 2001).

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An evaluative action category has been formed during our explorations with the blindfolded and sketching design protocols. These actions refer to information at the conceptual level. During the designers' dialogue within the segments, we observed smaller scale idea evaluation or questioning cycles. In this dialogue some designers question ideas or emerging design issues (Ged) rather than evaluating them. They might generate a tentative functional solution (Gfs) in that evaluation cycle. The evaluation could be based on a function that is previously introduced, i.e. evaluating by making judgments about the possible outcomes of the function (Gdf). The evaluation could be based on the form of the design entity, i.e. evaluating by making judgments about form (Gap). Aesthetical preferences of the designer could be involved in that evaluation cycle as well (Gapa).

The recall action category includes two memory recall actions. Retrieving knowledge about previous cases (Rpc) is related to episodic memory, where the designer remembers his/her previous cases of designing process, a previous layout, the connected problems/issues and the functional solutions. This past case knowledge is mostly related to expertise in the area. Recalling the design brief (Rbf) helps the designer to remember/rehearse the requirements and restructure the design problem.

2.2.3. Coding

In this study imagery processes are hypothesized to be similar to perceptual processes, thus the basic assumption is that all percepts are internal, where in sketching they are dependent on externalization, and in blindfolded condition they are dependent on the internal representation. How do we access the content of the internal representation? The imagery protocols demonstrate such detailed descriptions of images, scenes and the concerns about the design that it is possible to extract the relationships between design elements as well as the visual features. It is possible to keep track of the verbal descriptions of the imagery content and to confirm them with the elements in the sketch produced at the end. Figure 2 shows one coded segment from a blindfolded protocol.

Insert Figure 2 here

The procedure of coding the protocols involved segmenting the transcripts with respect to the time code in videos. Each segment was time stamped and coded with the related coding scheme. The complete audio/video protocol for each session was coded twice by the same coder with a one month period between the two codings. Then the codes were arbitrated into a final coding.

2.3. LINKOGRAPHY

Linkography is a system that is developed to notate the moves in a protocol and the links between them (in a chronological order) to understand structural patterns in design reasoning (Goldschmidt, 1997). Through coding the links it is possible to represent the design activity/thinking in terms of sequence of acts/ideas. In order to establish a link between the ideas they have to be dependent on each other. Linkography is a network of the links between segments/moves. Goldschmidt's (1997) notion of the move is equivalent to the notion of a segment mentioned in this study. The links are established on the basis of understanding the content of each segment and connecting related one or more segments to each other. The linkography method establishes connections between a given move and previous moves. These links are called backlinks, because they go back in time. There are the links that a move connects to subsequent moves. These links are that move's forelinks, because they go forward in time.

The technique involves parsing the protocol into design moves and looking at the design process in terms of relationships created by the links between those moves. In this study we use the same segmentation intervals that were done for protocol analysis purposes. Thus the number of segments remained the same. We used a technique to reliably link the ideas which are at a further distance along the timeline of the design process. This involves a word search in order to detect the words used more frequently where the analyser ends up with a list of frequently repeated words. Then another search is performed to obtain a list of the segments which include a frequently used word. The next stage is browsing through the selected segments, to confirm the word is used in the appropriate context, and then connect the related segments. This procedure helps us to connect the meanings, which are distant from each other and which might have been difficult to catch in a sequential analysis. In the second run the coder starts from the first segment and sequentially connects the ideas and revisited meanings between the segments. The analyser relies on the verbalization only while linking the ideas in the blindfolded designing protocols. In linking the ideas of sketching protocols, video footage for each segment is visited as well.

2.4. ASSESSMENT OF THE DESIGN OUTCOME

The resulting sketches by the three architects were double-blind judged by three judges who have each 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 any indication of which condition they belonged to (either sketching or blindfolded) and the judges were unaware that half 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 innovative: as inventing a new prototype

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

Flexibility

3. Results

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We tested if the sketch judgement scores are significantly different. The design of the experiment requires the same participant receiving two conditions, thus we used two-way ANOVA (with replication) in order to find the statistical significance between the sketch (SK) versus blindfolded (BF) conditions as well as between the participants. There is no significant difference in scores between the conditions (F critical= 4.25, P=0.23) nor between the participants (F critical= 3.4, P=0.1).

3.1. PROTOCOL CODING

The reliability of the coding process was measured by calculating the agreement percentages between the different runs of coding, which are first and second coding, first coding and arbitrated coding and second coding and arbitrated coding. *Table 4* shows the agreement percentages between these different coding phases.

Insert *Table 4* here

The average length of the time interval for each segment ranges from 19 seconds to 25.5 seconds, *Table 5*. The average time length for a segment in BF condition is 21.4 seconds, while it is 22.4 seconds in SK condition. Standard deviations of time intervals of three participants average 13 seconds for both SK and BF conditions. Variance in time intervals of the BF conditions are close to that of the SK conditions (average variance 178 seconds in BF, 175 seconds in SK). Negative value of Kurtosis values in all participants' sessions show that the time interval of each segment fluctuated significantly compared to a normal distribution. The average Kurtosis values in BF versus SK conditions are also similar (-1.19 and -1.21) which means the degrees of change in time intervals (fluctuation) are similar.

Insert *Table 5* here

The segments had average of 8.5 (std dev = 4) concurrent actions in BF sessions and average of 8.0 (std dev = 3.3) concurrent actions in sketching sessions.

3.2. DIFFERENCES IN OCCURRENCE PERCENTAGES OF ACTION CATEGORIES

Table 6 shows the occurrence percentages of each action category as a percentage of the sum of the number action in common action categories (excluding drawing actions for sketching and

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visuo-spatial actions for the blindfolded condition). Comparing BF and SK conditions for each architect, one important difference is that they recalled more information in their BF conditions. The occurrence percentages of the other action categories do not demonstrate large differences between the architects' SK and BF conditions. Some action category percentages are relatively higher and these are shaded in Table 6. For example A1 had relatively more conceptual actions (goals) in SK condition, compared to her BF condition. A2 had relatively more evaluative actions in SK condition, and A3 had relatively more perceptual actions in the SK condition. Thus the 3 architects seemed to use their cognitive resources differently. The reason for these differences might be individual differences on image manipulation, memory capacity, spatial ability, or different cognitive styles or designing strategies. The occurrence percentages of the other action categories are similar in BF and SK conditions of the 3 architects except for the categories mentioned.

Insert *Table 6* here

Table 6 also shows the three architects' average occurrence percentages of the action categories in in BF and SK conditions. The average values of occurrence percentages are not significantly different in perceptual, functional, conceptual and evaluative action categories. In the next section, we test if the differences between frequencies of cognitive actions are statistically significant for each action category.

3.3. DIFFERENCES IN OCCURRENCE FREQUENCIES OF COGNITIVE ACTIONS

We tabulated occurrence frequencies of cognitive actions in each category for each architect, in blindfolded versus sketching conditions. In *Table 7* each participant demonstrates 4 different perceptual actions in each condition, thus the perceptual category has 24 data points for variance testing. We tested if these occurrence frequencies are significantly different. Two-way ANOVA (with replication) was used to find the statistical significance between SK versus BF conditions as well as between the participants. The ANOVA results for perceptual actions category are shown in *Table 8*. There is no significant difference in frequencies between the experimental and control conditions (F critical= 4.41, P=0.54) nor between the participants (F critical= 3.55, P=0.74).

Insert *Table 7* here

ANOVA tests are applied in the same way to test the significance of the differences in occurrence frequencies of all actions in the remaining action categories, *Table 8*. The ANOVA tests on the other action categories were based on, 36 data points in functional and evaluative categories, 18 data points in conceptual category, 12 data points in recall category.

Insert *Table 8* here

The results are similar to the ones in the previous section, such that occurrence frequency of perceptual, functional, conceptual and evaluative actions are not significantly different, but recall actions are. This result verifies our previous observation that occurrences of recall actions are significantly higher in BF conditions.

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3.4. LINKS BETWEEN THE IDEAS

Figure 3 shows the linkography representation for A1's BF, Figure 3(a) and SK, Figure 3(b) sessions.

Insert Figure 3 here

Table 9 shows a link index for each participant's design session in the two conditions (where the index is calculated by dividing the total number of links by the total number of segments). Link index is a nominal value referring to the overall intensity of the links in a design session. The link index numbers are different for each participant over BF versus SK conditions, *Table 9* such that link index number is higher for A1 in sketching condition (1.19, 1.41) higher for A2 in blindfolded condition (1.68, 1.48) and link index number is close for A3 (1.20, 1.28) in both conditions. The average number of the link index in BF versus SK conditions is very close (1.38 vs 1.36). Participants devoted similar amount of time in both conditions for developing and revisiting the concepts through their design process. The reasons behind the individual differences will be further studied.

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3.5. COMPARISON OF SKETCHES

The three architects were able to satisfy the space and client requirements in both experiment and control conditions, Figures 4, 5 and 6. Table 10 shows the results of the assessment of the sketches by the three judges. The grades in *Table 10* are calculated average grades of the three judges' assessments. The fourth column (Av) in each condition shows the three architects' average grade for each criterion.

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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 4 shows A1's sketches for the sketching, Figure 4(a) and blindfolded conditions, Figure 4(b). A1's blindfolded condition 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 assessment of creativity scores is closer for the two design outcomes (5.3 and 5.0).

Insert Figure 4 here

Architect A2 produced different layouts for the two conditions in terms of typology and the relationship of the building to the site. Figure 5 shows A2's sketches for the sketching session, Figure 5(a) and blindfolded session, Figure 5(b). 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). The practicality assessment of the blindfolded session outcome is higher than the sketching session outcome (7.0 versus 5.7).

Insert Figure 5 here

A3 produced quite different layouts for the two conditions, in terms of typology and the relationship of the building to the outdoor areas. Figure 6 shows A3's sketches for the sketching, Figure 6(a) and blindfolded, Figure 6(b) 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.

Insert Figure 6 here

4. Discussion

This case study has shown that there are no significant differences between sketching and blindfolded design activity in terms of design outcome scores, total number of cognitive actions (except for recall activity) and overall density of idea production. This result cannot be generalized to all architects/designers or all phases of design activity due to the small scale of the experiment. The design detailing/representation phases may require intensive drawing and various types of externalizations for the development and documentation of a building design.
Some might question the reason for using a blindfold during the experiment. The condition could have been set-up to give architects visual access to the site, design brief and layout, but still not allowing them to draw. The aim was to restrict the visual/sensory modality and give them no visual feedback to ensure that designers relied on their memory only. To be able to use their visual system might have distracted their attention or might have changed their whole approach to designing. Being able to see the scaled site layout on paper, they could have used their imagery differently, using their gestures (and drawing with their fingers) to decide on proportions and metric relationships on the layout rather than relying on their memory. Then what we tested would have been perhaps an "enacted imagery" (Purcell and Gero, 1998). This way we avoided another variable and focused on the question of whether they could build an internal representation relying on their long term memory. In the BF condition, architects had to store and remember visual and sentential information (the site dimensions, layout geometry, and the brief requirements), which could put a larger cognitive load their working memory, compared to the SK condition. Despite the cognitive load, it was surprising how the architects demonstrated higher numbers of cognitive actions in total, during the BF conditions,Table 6.

In the design of the blindfolded experiment, there is a stage where the participant is asked to rapidly draw what s/he held in his/her mind's eye. We assume the architect worked things out to fit the building layout to the proposed scheme and then faithfully drew the layout without changes. One might argue that it is not possible since the very act of drawing, even if it is quick, will change the nature of the scheme. If drawing is a tool of thinking, maybe it is not possible to eliminate this use and further thinking that the scheme will go through as it is being drawn since the dialogue with the sketch starts as soon as one starts to draw. In the BF period the architects decided on size and metric relationships of functional spaces, and during the quick sketching period they were generally focused on externalizing what they have developed in their minds. The period was like explanation of these ideas via drawing, which could be described as a drafting process rather than sketching to develop/test ideas. During the quick sketching period

participants generally kept on talking and explaining whether what they imagined was working on paper or not. Meanwhile the experimenter was able to intervene and remind them that they are not allowed to make significant changes to the layout. Thus the quick sketching period was semi-controlled by the experimenter.

4.1. PARTICIPANTS' COMMENTS

The results of our protocol analysis and participants' comments after blindfolded sessions are contradictory. The interviews with the participants pointed out to a single conclusion, that they would not be capable designing if they were not allowed to sketch. The common view was that if they were to put their ideas on paper they would have seen the problem quickly and that would actually divert their thinking to a different path.

They all believe strongly that sketching is essential. Categorizing the information we obtained from the interviews with our participant expert architects we summarize what sketching does for them:

1. Sketching is a dialogue: "Drawing is for testing and evaluating the ideas", "you can't stop the messages coming back from each line you put down".
2. Sketch helps for "seeing it (the design) as parts and seeing it as a whole": this view in parallel with Gestalts states: "the whole emerges from and cannot exist without parts but depends on the relationships between the parts". So a sketch is greater than the sum of the parts because it intimately depends on the relationships within the parts. Sketching is really essential because the parts themselves cannot emerge properly neither can be held without sketching.
3. Re-representation is the key to solve a design problem: "I'd draw a solution on paper, and draw it again and again and again. And then the standard process would be to pin them up. And so there's the theatre of your imagination, as a series of not even ideas but how your thoughts are developed through there". "Half the process is just drawing it, and drawing it, and drawing it and drawing it. And eventually when you draw it, something sort of creeps out at you".
4. Sketching captures the moment and stores it: "Sketching realizes things, it does make real what your thoughts are, it makes your thoughts concrete so that you can go and test them. Drawing brings the ideas to life, actually synthesizes all of your partial thoughts.
5. Sketching is for externalizing a mental image: "You have got a memory of some image and what you do is visualize it out there". "Then drawing is a practical tool for seeing. The vision is in your mind and then you are putting it down and visualization happens on the page. But is not after you draw it either, because it is the image what moves the pencil".
6. It is like a language, learn to use it: "…to me it s like speech, as you think you speak. Thoughts are constructed on the way you speak. If you would think first and then speak it will all come out differently. Thus it places a special emphasis apart from documenting your thought process". "So it's like a language then you learn to talk and its essential that you do".

During the BF condition, participants were frustrated at some stages of the experiments, thus their feedback on the blindfolded exercise were not positive. We classified the comments into

two groups, one related to difficulty of synthesizing elements in imagery and the other one related to image maintenance:

1. Synthesizing: "The whole sketch brings together the bits you imagined. And the drawing tells you whether you're in a fantasy land or not… that's the role of drawing that actually synthesizes remembered parts in new ways."
2. Image maintenance: "I can't hold in my head any visual memory of what the precise geometry of these spaces". "Can I find a pencil somewhere?" Umm, (35.03) because all I've got in my mind are these pathetic little lines that just keep dissolving and I want something concrete".

The participants' comments and the way they see and interpret their experience when they were blindfolded are very different from what the results show. All the comments support the idea that sketching is essential for conceptual designing. However, we have demonstrated in this paper that the architects produced similar design outcomes, similar rates of cognitive activity and similar rates of concept/idea development under both conditions. For these architects, sketching is functional, conventional, habitual but not the only way to efficiently design. The interview outcomes imply that the participating architects' attitude was towards to use of sketching during designing, and this makes the process of communicating our findings more challenging to the wider community of architects.

4.2. WORKING MEMORY LIMITATIONS

Research in visuo-spatial working memory (VSWM) has found evidence that the capacity of working memory is limited when visual and spatial tasks are done using imagery alone. Thus the cognitive load should be higher in a blindfolded exercise since image maintenance and synthesis of images requires more executive control resources (Pearson et al. 1999; Vecchi and Cornoldi 1999; Baddeley et al 1998). Participants' comments indicated difficulty in maintenance of images/geometries, and the problem of not being able to store the partial solutions to access them later during the design process. Thus sketching makes design thinking easier by "seeing it" and "storing it". In other words sketching puts much less load on the cognitive processes needed to design.

Bilda and Gero (2005) analyzed the cognitive activity differences of three expert architects along the timeline of the design activity, when they design in BF and SK conditions. It was observed that all participants' overall cognitive activity in the blindfolded condition dropped below their activity in the sketching condition, approximately after 20 minutes during the timeline of the design sessions. This drop in performance can be explained by higher cognitive demands in blindfolded conditions. Externalization is needed to off-load the visuo-spatial working memory, and for the same reason drawings and diagrams play an important role in designing.

Although a drop in cognitive activity was observed after 20 minutes of designing in BF conditions, the total cognitive activity frequency, and frequency percentages did not show significant differences. The reason is that architects started with much higher rates of cognitive activity in the first half of BF designing compared to the rates in SK conditions. Only after 20

minutes along the BF session did the rate of cognitive activity drop below the rate in SK condition (Bilda and Gero, 2005). In addition, the impact of VSWM load was observed on perceptual activity more dramatically than the impact on functional and evaluative activity. Hence, the architects were able to come up with satisfactory design solutions (as the design outcome scores demonstrate no significant difference) using imagery alone despite the working memory limitations.

In the BF conditions, the three architects demonstrated significantly higher recall actions which include recall of information about the site and the brief, past cases and previous perceptual experiences. This result is in accord with the view that mental imagery could be used to access the information in long-term memory (Kosslyn, 1980; 1994). The long term memory (LTM) has higher capacity than the working memory, but the access to LTM information is slower compared to access to short-term/working memory (Card et al., 1983). This assumption does not support our observations that architects were able to create internal representations relatively quickly and effectively when they use their imagery alone. In another stream of research, experts (chess players) were found to have a potential to use their working memory in a different way where they manage to rapidly access to LTM information and use that in their working memory (Simon and Chase 1973; Saarilouma 1998; Ericsson and Kintsch 1995) . This mechanism of long term working memory (LTWM) is hypothesized to be efficient in retrieval and use of dynamic cognitive chunks in LTM. The significantly higher recall actions in BF conditions could be explained by the possible use of LTWM by the expert architects.

4.3. IMPLICATIONS FOR EXPERTISE AND DESIGN EDUCATION

This study suggests that sketching might not be the only way to conceptually design for expert architects. If designers are able to design blindfolded and in their minds, then why do they prefer to sketch?. The answer may be that it is easier to sketch, in other words sketching puts much less load on the cognitive processes needed to design. If the BF condition went on for 1-2 hours the cognitive load would have been larger maybe ending up with fatigue and frustration of the participants. Another possibility is that the idea development would come to a saturation point where there is no further progress, since they are not able to see what the ideas are on paper, test them and further discover new relations or features of the drawings. For further progress of the design activity externalization might be needed. On the other hand the results of the case study imply that the use of imagery alone could be an efficient tool for quick and focused idea development in the early conceptual phases of designing. Another variation might be the use of externalization at some stages of major decisions, thus portions of design and related concepts are recorded. This would release the working memory load, allowing other tasks to be done effectively. The use of these techniques might be useful for experts in practice however, sketching should be cognitively easier to cope with unless the architects are not trained to use their imagery alone more frequently and efficiently.

This study shows that sketching may not be a necessary act for expert designers during conceptual designing; however we do not disregard the importance of sketching in learning how to design. Design education requires an intensive learning process through drawing, thus it is important to learn how to think with sketches. While design students learn how to sketch they are also learning how to develop ideas, such as starting with one proposal and developing it into

another one. Through sketching students learn how to progress their ideas. Experts have learned how to progress a design and they have learned how to do it by sketching. Consequently when they are in a situation where they have to do it in their imagery they might be using their experience of conceptually developing a design. This expertise in the way of thinking which simulates how the ideas are developed, may be the key to our participants' abilities in blindfolded designing. Similarly, in cognitive psychology research, studies with expert chess players identified a skilled imagery (Simon and Chase 1973), which shows evidence of the use of imagery for longer periods and with higher cognitive loads. An expert chess player can play more than 10 concurrent games while blindfolded (Saarilouma 1998). These studies showed that experts with skilled imagery performance can maintain and transform associative connections between the elements in their imagery effectively over an extended time period. Similarly, expert architects could have developed this skilled imagery through using and learning the architectural language with the use of sketches. They have this capacity to move from one idea to another and what the blindfolded exercise shows is that they can do it in their mind provided they are experienced enough. Another question from this argument is whether the novice designers would be able to come up with a reasonable design solution at the end of a BF session. Athavankar and Mukherjee (2003) showed that novice designers can handle design problem solving when blindfolded, however the authors did not study systematic analysis of protocols or comparison of the design outcomes when the novices would have access to sketching. This remains as a question for a future study.

5. Conclusion

In this paper we have demonstrated that externalizing a design may not be the only way to design visually. Sketches and in general externalizations are claimed to be 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" may not be essential for expert designers

1. for a satisfying and reasonable outcome
2. for pursuing cognitive activity needed for designing
3. for developing a coherent network of ideas/concepts

in the early phases of the conceptual designing.

6. Acknowledgements

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7. Appendix

Design Brief 01

Client: your task is to design a house for a couple, whose ages are 29 and 34. The female is a dancer, and the male is a painter. They are sensitive to colors and beauty, enjoying contact with the natural environment. In order to make their dream house come true, they have a budget of about $350,000.

Site: The site is located on the corner of the fully serviced home sites surrounded by a large central open-space recreation reserve in Matraville, one of Sydney's south eastern newly desirable locations. It is a trapezium in shape and slopes down to the edge of the recreation. The site has a view of the flame trees in the recreation reserve and the whole reserve. The site is 700 m^2. The floor space ratio for this site is 0.65:1, so the maximum floor plan can be 455 m^2.

House: the house is expected to be caressed by gentle sea breezes, and screened by a stately grove of magnificent flame trees along the edge of the estate. A sculpture garden is required for display of their art collections. According to the Randwick Development Control Plan No.4, the height of a dwelling house should not exceed maximum of 9.5 m. Your task is to give forms to and arrange the following spaces on the site with the approximate sizes:

Living/Dining area:	40 m^2	Painter's Studio:	50 m^2
Kitchen:	15 m^2	Dancer's Studio:	50 m^2
Bath:	10 m^2	Observatory:	20 m^2
Master Bedroom:	30 m^2	WC-shower:	9 m^2
Bedroom:	20 m^2	Parking space:	36 m^2

Design Brief 02

Client: your task is to design a house for a re-married couple, whose ages are 42 (female) and 50 (male). The female is a part-time University lecturer, and the male is a Consultant and a Business Analyst. They've got 5 children (3 from previous marriages- ages 17, 15 and 13; 2 children of the current marriage- aged 7 and 5). They've got busy lifestyles and they also enjoy contact with the natural environment. The female works from home 2 days a week. The male invites colleagues from overseas every two months to their house for consulting purposes. There should be a study or work space, possibly shared by husband and wife. She will work from home, and he will need to use the space for meetings with colleagues. In order to make their functional, dream house come true, they have a budget of about $450,000.

Site: The site is located on the corner of the fully serviced home sites surrounded by a large central open-space recreation reserve in Matraville, one of Sydney's south eastern newly desirable locations. It is a trapezium in shape and slopes down to the edge of the recreation. The site has a view of the flame trees in the recreation reserve and the whole reserve. The site is 700 m2. The floor space ratio for this site is 0.65:1, so the maximum floor plan can be 455 m2.

House: the house is expected to be caressed by gentle sea breezes, and screened by a stately grove of magnificent flame trees along the edge of the estate. A garden is required accommodating for children's recreational activities. According to the Randwick Development Control Plan No.4, the height of a dwelling house should not exceed maximum of 9.5 m. Your task is to give forms to and arrange the following spaces on the site with the approximate sizes:

Living/Dining area:	40 m2	Study/ Workspace	15 m2
Kitchen:	15 m2	External play area	flexible
Bathroom:	10 m2	WC-shower:	9 m2
Master Bedroom:	20 - 25 m2	Parking space:	36 m2
Bedrooms arrangement for 5 children:	70-120 m2	Family Room/ children's accommodation	30 m2

Design Discussion

The participants were interviewed after the blindfolded sessions, before they do a sketching session. They were asked open-ended questions which are listed below.
1. Can you describe how you went about the design process?
2. What role did talking play in the process?
3. How well developed do you think the design is?
4. If you were sketching in this session, do you think you would have produced a more developed, less developed or design of about the same level development?
5. How important is sketching in your design process?
6. What role did visual or other imagery play in this design process?

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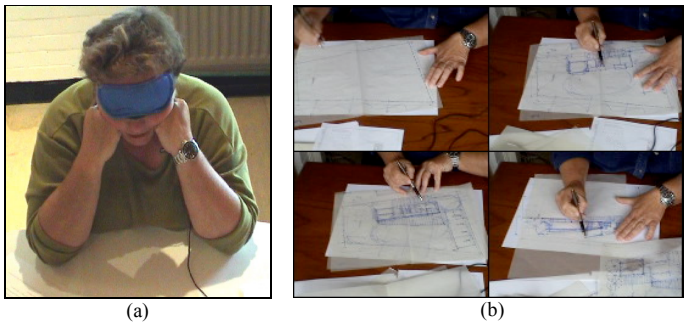
FIGURES



(a) (b)

Figure 1 (a) blindfolded session, (b) sketching session

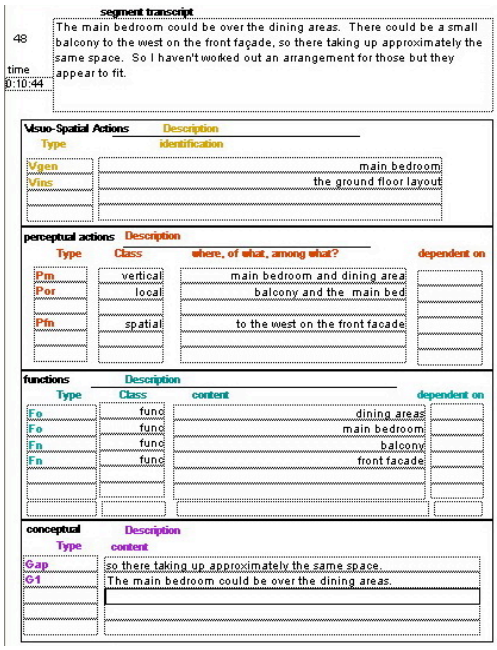
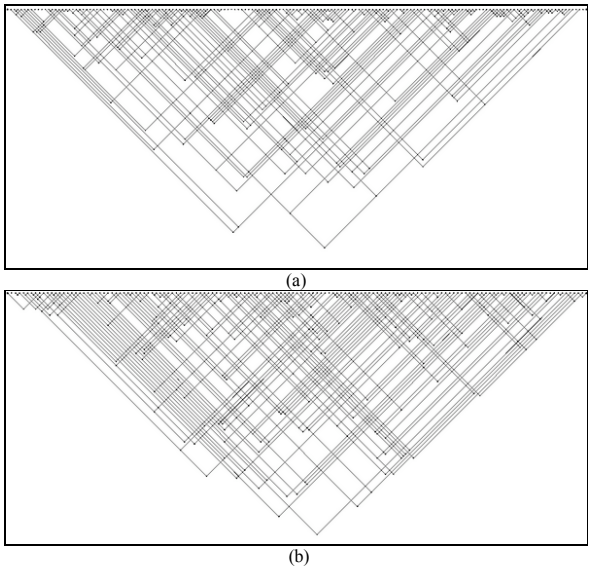


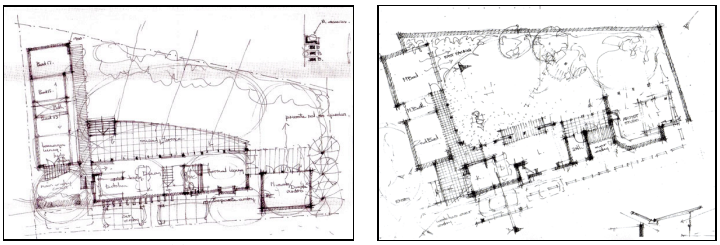
Figure 2 Excerpt from protocol coding



(a)

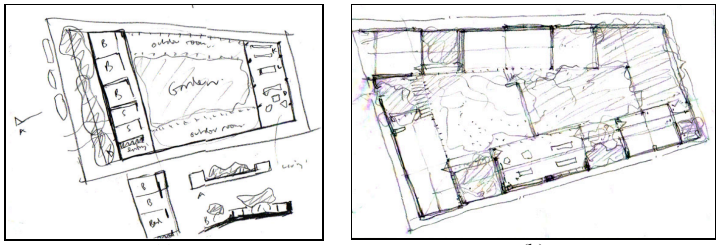
(b)

Figure 3 Linkography for A1 (a) blindfolded session, (b) sketching session



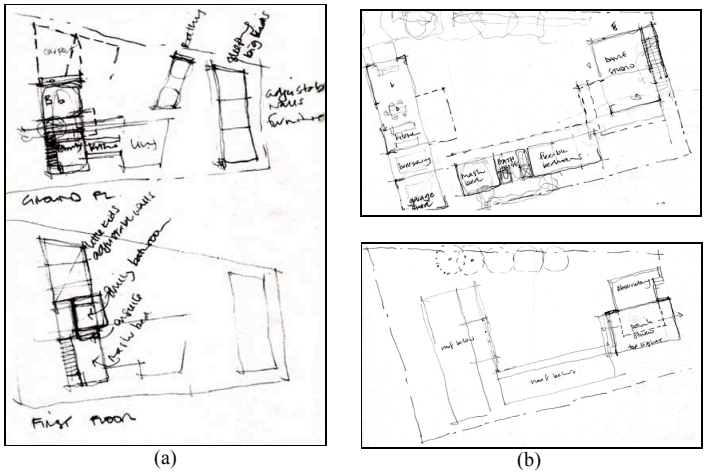
(a) (b)

Figure 4 Architect 01 sketches (a) sketching; (b) blindfolded



(a) (b)

Figure 5 Architect 02 sketches (a) sketching; (b) blindfolded



(a) (b)

Figure 6 Architect 03 sketches (a) sketching; (b) blindfolded

TABLES

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

Table 2 Example segmentation of a BF protocol

Time	Seg No	Segment Content
0:08:05	29	(08.05) IM: OK. I'm just trying to think, Rosie's Dance Studio is a sort of a rectangle, roughly 2 by 1. So I suppose I'd plumb for that. 5 by 10 means you'd get a good run up.
0:08:18	30	(08.18) So that means that then on the street side we've got the dancer's studio which, if we go for either the L-shape or the courtyard arrangement, is going to have….(08.31) one side facing west, up to the street, which is less than perfect particularly with the 900mm setback where you can't really arrange for much planting…(08.46) On the eastern side…obviously you're going to have it partially built over.
0:08:54	31	(08.54) We've got a 25 metre length along there, 6 metres has been taken up with garage, 1 metre with setback. So that immediately makes, 7 from 25…so we've got umm 18 left less the other 1 metre setback, so that's 17 left. (09.15) So 10….we can probably configure that, that dancer's studio to have some northerly aspect in it. If its perhaps twisted around to the…to the north more.
0:09:27	32	(09.27) Although I'm just thinking now what sort of light ideally would you have for a, a dancer's studio, and I'm thinking I suppose that, that, it would be advantageous to have some sunlight in there. I'm just thinking of the arrangement of bars and mirrors and so on that you need in a room like that….
0:09:50	33	(09.50) The ones that I've seen in the past that have been really beautiful have been the ones that have had an even light through them. On one side, on the long side, and then having mirrors and bars and so on, on the other side.
0:10:03	34	(10.03) So, it might even be advantageous with that dancer's studio to put it not long axis onto the street but short axis onto the street and arrange to have some south light, or north light even, with mirrors along that south side.

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Table 3 Perceptual, Functional, Conceptual, Evaluative, Recall Actions

Perceptual Actions	
Pfn	Attend to the visual feature (geometry/shape/ size/ material/color/thickness etc) of a design element
Pof	Attend to an old visual feature
Prn	Create, or attend to a new relation
Por	Mention, or revisit a relation
Functional Actions	
Fn	Associate a design image/ boundary/part with a new function
Frei	Reinterpretation of a function
Fnp	Conceiving of a new meaning
Fo	Mention, or revisit a function
Fmt	Attend to metric information about the design boundary/part (numeric)
Conceptual Actions (Goals)	
G1	Goals to set up a new function
G2	Goals to set up a concept/form
G4	Repeated goals from previous segments
Evaluative Actions	
Gdf	Make judgments about the outcomes of a function
Gfs	Generate a functional solution / resolve a conflict
Ged	Question/mention emerging design issues/conflicts
Gap	Make judgments about form
Gapa	Make judgments about the aesthetics, mention preferences
Recall Actions	
Rpc	Retrieve knowledge about previous cases
Rbf	Retrieve the design brief/requirements

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Table 4 Coding consistency between different coding phases

	Agreement Percentages between		
	1st and 2nd coding (%)	1st coding and arbitrated coding (%)	2nd coding and arbitrated coding (%)
BF_01	75.2	91.5	89.8
BF_02	78.6	90.3	85.1
BF_03	67.5	78.4	87.3
SK_01	76.7	86.2	91.6
SK_02	83.2	92.3	90.8
SK_03	73.6	81.3	88.9
BF= Blindfolded Session SK= Sketch Session			

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Table 5. Segment time intervals

	BF_01	BF_02	BF_03	SK_01	SK_02	SK_03
Number of segments	166	154	170	145	184	143
Total time elapsed	0:41:35	0:53:18	0:43:08	0:44:27	0:49:54	0:42:44
Mean	0:19:12	0:25:49	0:20:05	0:21:49	0:24:42	0:21:20
Std. Deviation	0:11:38	0:15:41	0:12:25	0:12:54	0:14:35	0:12:07
Variance	135:25	246:17	154:12	166:29	213:03	146:53
Kurtosis	-1.15	-1.25	-1.18	-1.24	-1.26	-1.14

BF= Blindfolded Session SK= Sketch Session

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Table 6 Occurrence percentages of action categories

	Perceptual (%)	Functional (%)	Conceptual (%)	Evaluative (%)	Recall (%)	Total number of actions
BF_01	27.2	39.6	8.9	13.6	10.6	1366
SK_01	30.8	37.7	14.1	12.4	4.9	1307
BF_02	26.1	40.7	10.7	14.0	8.5	1417
SK_02	25.7	40.5	9.6	20.6	3.6	1414
BF_03	23.6	44.0	9.3	17.0	6.2	1359
SK_03	31.2	43.5	8.3	14.7	2.3	1064
SK Average	29.2	40.6	10.7	15.9	3.6	
BF Average	25.6	41.4	9.6	14.9	8.4	

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Table 7. Occurrence frequency table

	Perceptual Actions			
	A1	**A2**	**A3**	**codes**
BF	132	91	99	Prn
	77	86	58	Pfn
	38	43	38	Pof
	58	95	69	Por
SK	135	78	90	Prn
	48	48	51	Pfn
	22	46	36	Pof
	70	103	56	Por

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Table 8 ANOVA test results

Categories	Between control and experiment conditions		Between participants	
	P-value	F critical	P-value	F critical
Perceptual Actions	0.54	4.41	0.74	3.55
Functional Actions	0.48	4.17	0.93	3.32
Conceptual Actions	0.76	4.75	0.81	3.89
Evaluative Actions	0.55	4.17	0.42	3.32
Recall Actions	0.001	5.98	0.008	5.14

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Table 9 Link indexes of the conditions

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		Total # of links	Total # of segments	Link index
BF	A1	201	169	1.19
	A2	259	155	1.68
	A3	217	171	1.28
	Average	226		**1.38**
SK	A1	205	145	1.41
	A2	272	184	1.48
	A3	171	144	1.20
	Average	216		**1.36**

BF= Blindfolded
SK= Sketching

Link index: Total # of links/ total number of segments

Table 10 Grades for the design outcomes

Criteria	Blindfolded				Sketch			
	A1	A2	A3	Ave	A1	A2	A3	Ave
How Innovative	4.0	4.3	6.0	4.8	4.3	5.3	6.7	5.4
How Creative	5.3	6.0	6.3	5.9	5.0	5.7	7.3	6.0
Satisfying Design Brief	7.7	6.3	7.7	7.2	6.3	6.3	6.3	6.3
Practical Solution	7.7	7.0	7.0	7.2	6.0	5.7	5.3	5.7
Flexibility of the design	6.0	6.3	7.3	6.5	5.3	6.3	6.7	6.1
Average	6.1	6.0	6.9	6.3	5.4	5.9	6.5	5.9

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