To sketch or not to sketch? That is the question

Zafer Bilda, John S. Gero and *Terry Purcell*, Key Centre of Design Computing and Cognition, University of Sydney, NSW 2006, Australia

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 these 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, architectural 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 (Schon, 1983; Akin, 1986; Lawson, 1990) 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.

Corresponding author:
Zafer Bilda
zafer@arch.usyd.edu.au

Design researchers have studied why sketches have been an efficient medium for conceptual designing. One of the earliest finding is that

www.elsevier.com/locate/destud
0142-694X $ - see front matter *Design Studies* **27** (2006) 587–613
doi:10.1016/j.destud.2006.02.002

sketches store design solutions and seem to be essential for recognizing conflicts and possibilities (Akin, 1978). One of the most influential views is that sketching is a dialogue between the designer and what the drawings suggest (Goldschmidt, 1991; Schon and Wiggins, 1992). 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, 1990; 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; Hegarty, 1992; Bauer and Johnson-Laird, 1993) 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 (Schon, 1983; Akin, 1986; Cross, Christiaans and Dorst, 1996). Suwa et al. (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 interplay of mental imagery with sketching (Fish and Scrivener, 1990; Goldschmidt, 1991; 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 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 color. 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 achieves this objective by presenting the results of a protocol study involving three expert architects, and showing the differences between their sketching and non-sketching behaviors.

2 *Method*

The three architects who participated in the study (two females 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 five 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 includes 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 min.
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.

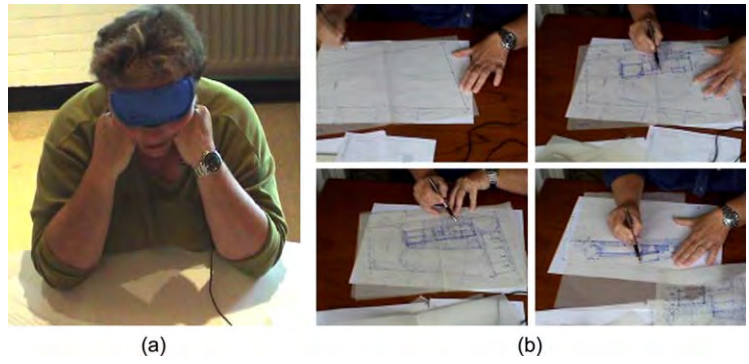

Figure 1 (a) Blindfolded session, (b) sketching session

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.

Sketching sessions have been conducted with the same architects at least 1 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.

2.2 Protocol analysis

2.2.1 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 supported decisions to flag the start and end of a segment. The drawing actions were inspected for cues to find the changes in intentions. In the blindfolded condition, information was extracted from the description of the current image or scene the architect currently talked about. When the architect's attention shifted to a different part or aspect of the current image, this became the cue for change of intention. Keeping track of the changes in the descriptions of images/scenes supported our decisions to flag the start and end of a segment. Table 2 shows an excerpt from a segmented BF protocol.

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). These action categories involve physical actions, which refer to drawing and looking; perceptual actions, which refer to interpretation of visual information; functional actions, which refer to attaching meanings to things; and conceptual actions, which refer to the planning of the actions and initiating actions for design decisions.

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 900 mm 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 m length along there, 6 m has been taken up with garage, 1 m with setback. So that immediately makes, 7 from 25…so we've got umm 18 left less the other 1 m 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.

The imagery coding scheme borrowed 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 are 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).

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

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	Re-interpretation 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

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 remembered his/her previous cases of designing process, a previous layout, the connected problems/issues and the functional solutions. This past case knowledge was mostly related to expertise in the area. Recalling the design brief (Rbf) helped the designer to remember/rehearse the requirements and restructure the design problem.

2.2.3 Coding

In this study, imagery processes were hypothesized to be similar to perceptual processes, thus the basic assumption was that all percepts are internal, whereas 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 demonstrated detailed descriptions of images, scenes and the concerns about the design that it was possible to extract the relationships between design elements as well as the visual features. The analyst could keep track of the verbal descriptions of the imagery content and confirm them with the elements in the sketch produced at the end. Figure 2 shows one coded segment from a blindfolded protocol.

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 1 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

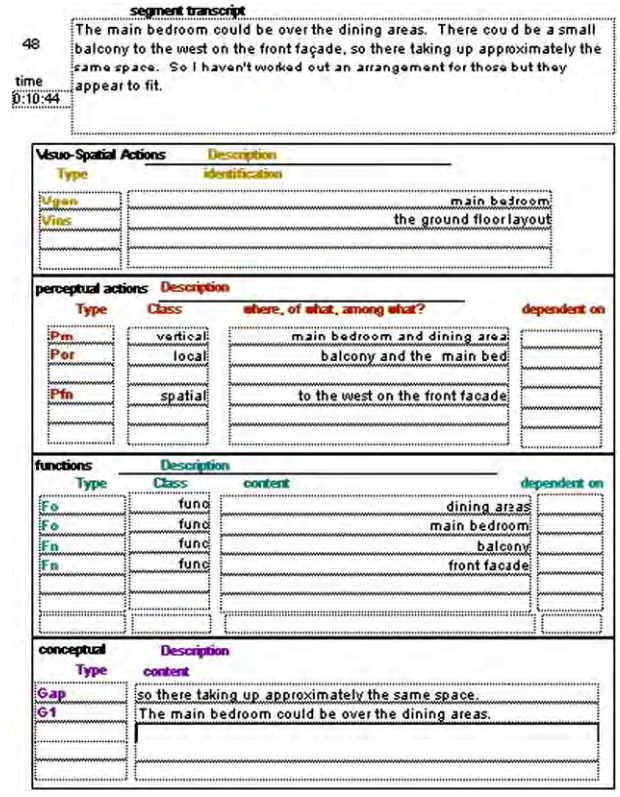

Figure 2 Excerpt from protocol coding

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 used 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 involved a word search in order to detect the words used more frequently where the analyser ended up with a list of frequently repeated words. Then another search was performed to obtain a list of the segments which included a frequently used word. The next stage was

browsing through the selected segments, to confirm that the word was used in the appropriate context. The related segments were then connected. This procedure helped us to connect the ideas, which were distant from each other and which might have been missed in a sequential analysis. In the second run, the analyst started from the first segment and sequentially connected the ideas/without reference to the first run of linking ideas. The analyser relied on the verbalizations only while linking the ideas in the blindfolded designing protocols. During linking the ideas of sketching protocols, verbalizations as well as video footage for each segment were visited.

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 produced during 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

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.

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.

The average length of the time interval for each segment ranges from 19 s to 25.5 s, Table 5. The average time length for a segment in BF condition is 21.4 s, while it is 22.4 s in SK condition. Standard deviations of time intervals of the three sessions average 13 s for both SK and BF conditions. Variances in time intervals of the BF conditions are close to that of the SK conditions (average variance 178 s in BF, 175 s in SK). Negative value of Kurtosis values in all participants' sessions shows 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 that the degrees of change in time intervals (fluctuation) were similar.

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

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.

Table 6 Occurrence percentages of action categories

	Perceptual (%)	Functional (%)	Conceptual (%)	Evaluative (%)	Recall (%)	Total number
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	

categories (excluding drawing actions for sketching and visuo-spatial actions for the blindfolded condition). Comparing BF and SK conditions for each architect, one important difference is that each recalled more information in his/her BF condition. 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) under the SK condition. A2 had relatively more evaluative actions in under the SK condition, and A3 had relatively more perceptual actions under the SK condition. Thus, the three architects seemed to use their cognitive resources differently. The reason for these differences might be individual differences on, memory capacity, spatial ability, different cognitive styles or designing strategies. The occurrence percentages of the other action categories are similar under the BF and SK conditions of the three architects except for the categories mentioned.

Table 6 also shows the three architects' average occurrence percentages of the action categories 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 tested if the differences between frequencies of cognitive actions were statistically significant for each action category.

3.3 Differences in occurrence frequencies of cognitive actions

We tabulated the occurrence frequencies of cognitive actions in each category for each architect, under BF versus SK conditions. For example, in Table 7, each participant demonstrates four different perceptual actions under each condition, thus the perceptual category has 24 data

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

points for variance testing. We tested if these occurrence frequencies were significantly different. Two-way ANOVA (with replication) was used to find the statistical significance between SK and BF conditions as well as between the participants. The ANOVA results for perceptual actions category are shown in Table 8. There is no significant frequency difference between the BF and SK conditions (F critical $= 4.41$, $P = 0.54$) nor between the participants (F critical $= 3.55$, $P = 0.74$).

ANOVA tests were 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 common 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.

The results were similar to the ones in the previous section, such that occurrence frequencies of perceptual, functional, conceptual and evaluative actions were not significantly different, but recall actions were.

Table 8 ANOVA test results

Categories	Between BF and SK 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

This result verified our previous observation that occurrences of recall actions were significantly higher in BF conditions.

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.

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 shows that link index number was higher for A1 in sketching condition (1.19, 1.41), higher for A2 in blindfolded condition (1.68, 1.48) and link index number was close for A3 (1.20, 1.28) in both conditions. The average number of the link index in BF versus SK conditions was very close (1.38 versus 1.36). Participants devoted similar amount of time in both conditions for developing and revisiting

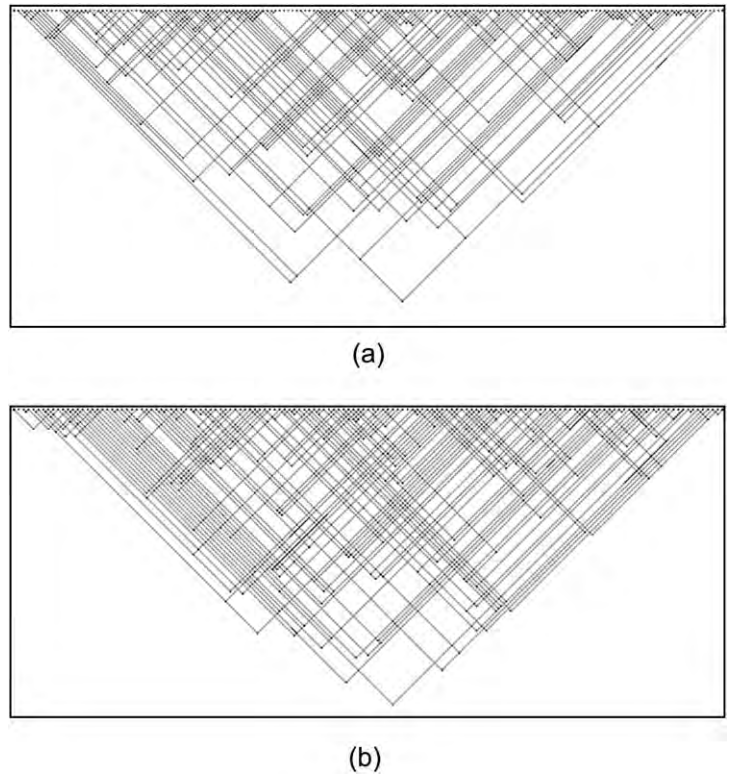

Figure 3 Linkography for A1
(a) blindfolded session,
(b) sketching session

Table 9 Link indexes of the conditions

		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 session, SK = Sketch session.Link index: Total # of links/total number of segments.

the concepts through their design process. The reasons for the individual differences will be further investigated.

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 the average grades of the three judges' assessments. The fourth column (Av) in each condition shows the three architects' average grade for each criterion.

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 SK, Figure 4(a) and the BF conditions, Figure 4(b). A1's blindfolded condition design outcome showed higher scores in terms of satisfying the design brief (7.7 versus 6.0) and practicality of the design

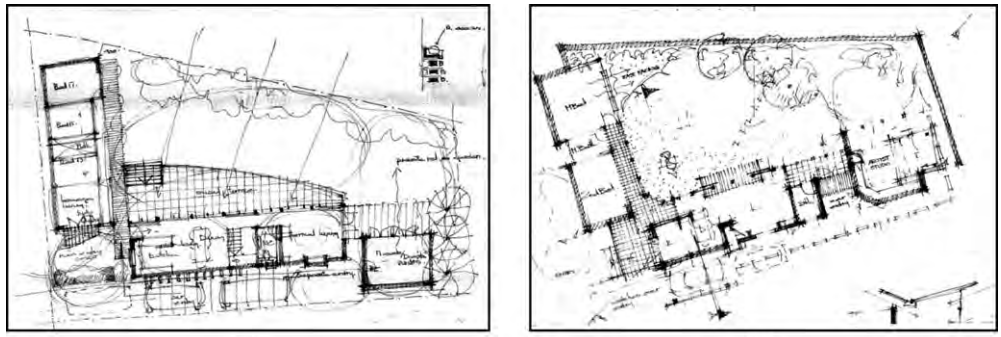

Figure 4 Architect 01 sketches (a) sketching, (b) blindfolded

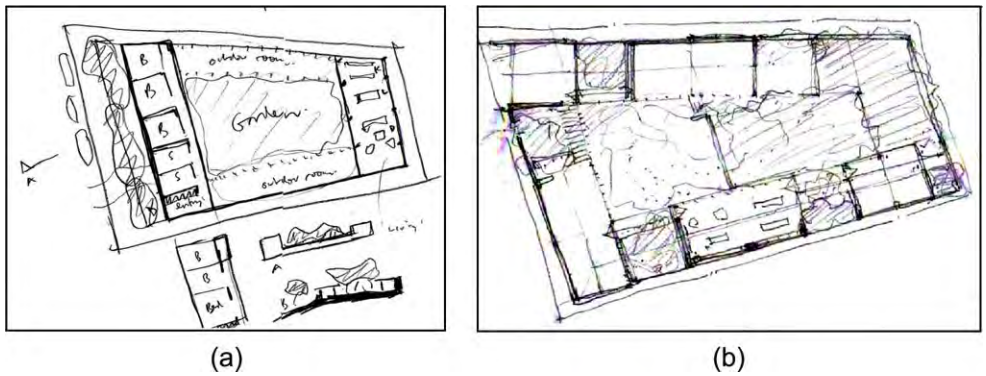

Figure 5 Architect 02 sketches (a) sketching, (b) blindfolded

solution (7.7 versus 6.0). The assessment of creativity score was closer for the two design outcomes (5.3 and 5.0).

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 SK session, Figure 5(a) and BF session, Figure 5(b). A2's BF design session outcome and sketching session outcome had the same scores in terms of satisfying the design brief (6.3 and

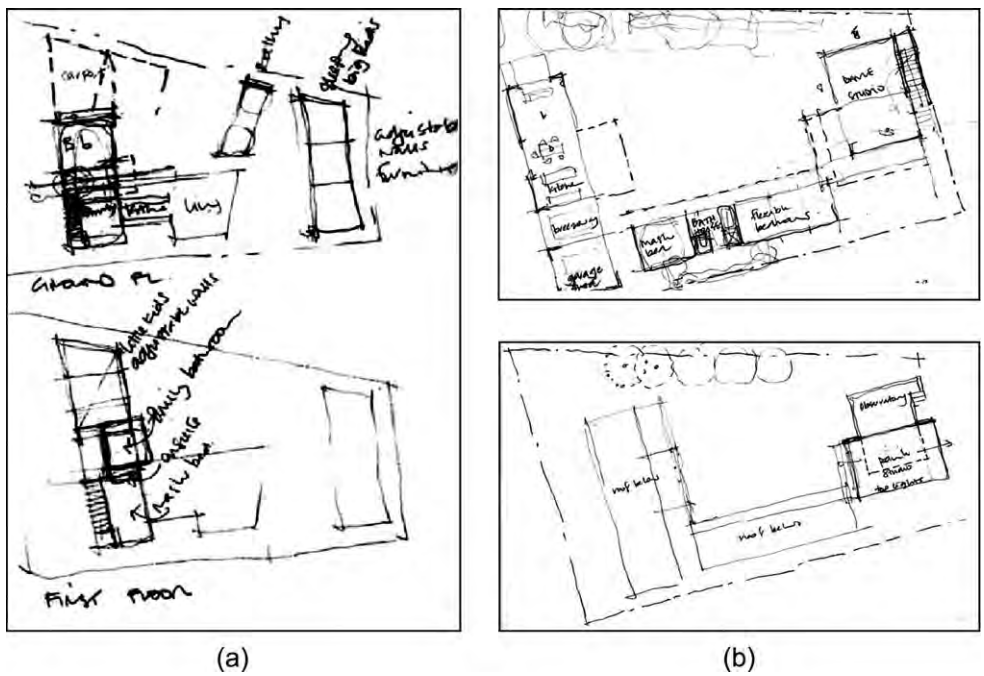

Figure 6 Architect 03 sketches (a) sketching, (b) blindfolded

Table 10 Grades for the design outcomes

Criteria	Blindfolded				Sketch			
	A1	A2	A3	Av	A1	A2	A3	Av
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
Av	6.1	6.0	6.9	6.3	5.4	5.9	6.5	5.9

6.3) and close scores for creativity assessment (6.0 and 5.7). The practicality assessment of the blindfolded session outcome was higher than that of the sketching session outcome (7.0 versus 5.7).

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 SK, Figure 6(a) and the BF, Figure 6(b) sessions. A3's blindfolded design session outcome had 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 (Table 10).

4 *Discussion*

This case study has shown that there were 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. However, our aim was to restrict the visual/sensory modality and to 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 hand gestures 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). By blindfolding the designers we avoided another variable and focused on the question of whether they could build an internal representation relying on their long-term and working memory.

Another argument concerning the BF condition was about the working memory load. Architects had to store and remember visual and sentential information (the site dimensions, layout geometry, and the brief requirements), which put a larger cognitive load on their working memory. 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 was asked to rapidly draw what s/he held in his/her mind's eye. During this period, we assumed the architect worked things out to fit the building layout to the proposed scheme and then faithfully drew the layout without changes. However, one might argue that the 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. Our observations showed that 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 quick sketching period was like explanation of these ideas via drawing, which could also be referred to as a drafting process rather than sketching to develop ideas. During this 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. This might have reduced the chances that architects used their sketches as a testing tool.

4.1 Participants' comments

The results of the protocol analysis and the participants' comments after the BF sessions were contradictory. The interviews with the participants pointed out to a single conclusion that they would not be capable of 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.

All participants believe strongly that sketching is essential. Categorizing the information we obtained from the interviews with our participant expert architects we summarized 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. Sketching helps for 'seeing it (the design) as parts and seeing it as a whole'. This view parallels the Gestaltist view which 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 was a common view. Some quotes from participant architects are as follows: '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, quoting one participant: '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, quoting one participant: '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. Sketching is like a language, learn to use it, quoting one participant: '…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 was 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: Quoting A2, '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: Quoting A2, '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 were different from what the results showed. All the comments supported the idea that sketching is essential for conceptual designing. For the participant architects, sketching was functional, conventional, and habitual but not the only way to efficiently design. We have demonstrated in this paper that the architects produced similar design outcomes, were engaged in similar rates of cognitive activity and similar rates of concept/idea development under both conditions. On the other hand, the interview outcomes imply that architects' perception of the two conditions favored the use of sketching during designing. Perhaps 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 require more executive control resources (Baddeley et al., 1998; Pearson et al., 1999; Vecchi and Cornoldi, 1999). 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 the same 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 min during the timeline of the design sessions. This drop in performance was 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.

In the BF conditions, the three architects demonstrated significantly higher recall actions (which included 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). 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; Ericsson and Kintsch, 1995; Saariluoma, 1998). 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 h the cognitive load would have been larger maybe ending up with fatigue and frustration of the participants. On the other hand, the results of the case study implied 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 of the technique 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. These techniques might

be useful for experts in practice provided that the architects are trained to use their imagery alone more frequently and efficiently.

This study showed that sketching might not be a necessary act for expert designers under certain conditions 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 design proposal and developing it into another one. Thus, students learn how to progress their ideas through sketching. On the other hand experts could have reached a state where they could progress a design via thinking only. 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 could be an important component of expertise, i.e. the ability to simulate how the ideas are developed, and thus this 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 (Saariluoma, 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. What the blindfolded exercise showed was that they can do it in their minds 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. 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 necessary for expert designers, in the early phases of the conceptual designing, for

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

Acknowledgements

This research was supported by an International Postgraduate Research Scholarship and a University of Sydney International Postgraduate Award, facilities are provided by the Key Centre of Design Computing and Cognition. We are grateful to the architects who participated in this study.

References

Akin, O (1978) How do architects design? in **J C Latombe** (ed) *Artificial intelligence and pattern recognition in computer aided design* North Holland, Amsterdam pp 65–119

Akin, O (1986) *Psychology of architectural design* Pion Ltd, London

Athavankar, U A (1997) Mental imagery, as a design tool *Cybernetics and Systems* Vol 28 pp 25–47

Athavankar, U A and Mukherjee, A (2003) Blindfolded classroom getting design students to use mental imagery in **U Lindemann** (ed) *Human behaviour in design* Springer pp 111–120

Baddeley, A D, Emsile, H, Kolodny, J and Duncan, J (1998) Random generation and executive control of working memory *Quarterly Journal of Experimental Psychology* Vol 51A pp 819–852

Bauer, M I and Johnson-Laird, P N (1993) How diagrams can improve reasoning *Psychological Science* Vol 4 pp 372–378

Bilda, Z and Gero, J S (2004) Analysis of a blindfolded architect's design session, in **J S Gero**, **B Tversky and T Knight** (eds) *Visual and spatial reasoning in design III. Key Centre of Design Computing and Cognition* University of Sydney, Australia pp 121–136

Bilda, Z and Gero, J S (2005) Does sketching off-load visuo-spatial working memory? in **J S Gero and N Bonnardel** (eds) *Studying designers 05. Key Centre of Design Computing and Cognition* University of Sydney, Australia pp 145–159

Bilda, Z and Purcell, A T (2003) Imagery in the architectural design process, in *9th European Workshop on Imagery and Cognition (EWIC 9)*, 24–27 April 2003, Pavia, Italy pp 63–64

Card, S K, Moran, T P and Newell, A (1983) *The psychology of human–computer interaction* Lawrence Erlbaum Associates, Hillsdale, NJ

Cross, N, **Christiaans, H and Dorst, K** (eds) (1996) *Analyzing design activity* John Wiley & Sons, New York

Do, E Yi-L, Gross, M D, Neiman, B and Zimring, C (2000) Intentions in and relations among design drawings *Design Studies* Vol 21 No 5 pp 483–503

Ericsson, K A and Kintsch, W (1995) Long term working memory *Psychological Review* Vol 102 pp 221–245

Fish, J and Scrivener, S (1990) Amplifying the mind's eye: sketching and visual cognition *Leonardo* Vol 23 No 1 pp 117–126
Goel, V (1995) *Sketches of thought* MIT Press, Cambridge, MA
Goldschmidt, G (1991) The dialectics of sketching *Creativity Research Journal* Vol 4 No 2 pp 123–143
Goldschmidt, G (1997) Capturing indeterminism: representation in the design problem space *Design Studies* Vol 18 No 4 pp 441–445
Hegarty, M (1992) Mental animation: inferring motion from static displays of mechanical systems *Journal of Experimental Psychology: Language, Memory and Cognition* Vol 18 pp 1084–1102
Kavakli, M and Gero, J S (2001) Sketching as mental imagery processing *Design Studies* Vol 22 No 4 pp 347–364
Kavakli, M and Gero, J S (2002) The structure of concurrent cognitive actions: a case study on novice and expert designers *Design Studies* Vol 23 No 1 pp 25–40
Kosslyn, S M (1980) *Image and mind* Harvard University Press, Cambridge, MA
Kosslyn, S M (1994) *Image and brain: the resolution of the imagery debate* MIT Press, Cambridge, MA
Larkin, J H and Simon, H A (1987) Why a diagram is (sometimes) worth ten thousand word *Cognitive Science* Vol 11 pp 65–100
Lawson, B (1990) *How designers think?* (2nd edn) Butterworth Architecture, London
Pearson, D G, Logie, R H and Gilhooly, K J (1999) Verbal representations and spatial manipulations during mental synthesis *European Journal of Cognitive Psychology* Vol 11 No 3 pp 295–314
Purcell, A T and Gero, J S (1998) Drawings and the design process *Design Studies* Vol 19 pp 389–480
Saariluoma, P (1998) Adversary problem solving and working memory, in **R H Logie and K J Gilhooly** (eds) *Working memory and thinking* Psychology Press, Hove, East Sussex pp 115–138
Schon, D A (1983) *The reflective practitioner: how professionals think in action* Basic Books, New York
Schon, D A and Wiggins, G (1992) Kinds of seeing and their functions in designing *Design Studies* Vol 13 No 2 pp 135–156
Simon, H A and Chase, W G (1973) Skill in chess *American Scientist* Vol l No 4 pp 394–403
Suwa, M, Gero, J S and Purcell, T (1999) How an architect created design requirements, in **G Goldschmidt and W Porter** (eds) *Design thinking research symposium: design representation* MIT, Cambridge pp 101–124
Suwa, M, Gero, J S and Purcell, T (2000) Unexpected discoveries and s-inventions of design requirements: important vehicles for a design process *Design Studies* Vol 21 pp 539–567
Suwa, M, Purcell, T and Gero, J S (1998) Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions *Design Studies* Vol 19 No 4 pp 455–483
Suwa, M and Tversky, B (1997) What do architects and students perceive in their design sketches? *A protocol analysis Design Studies* Vol 18 No 4 pp 385–403
Toker, F (2003) *Falling Water Rising: Frank Lloyd Wright, E.J. Kaufmann, and America's Most Extraordinary House* Knopf, New York

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, enjoy 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 five children (three from previous marriages, aged 17, 15 and 13; two 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 2 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 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 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 m^2	Study/workspace	15 m^2
Kitchen:	15 m^2	External play area	Flexible
Bathroom:	10 m^2	WC-shower:	9 m^2
Master bedroom:	20–25 m^2	Parking space:	36 m^2
Bedrooms arrangement for 5 children:	70–120 m^2	Family room/children's accommodation	30 m^2

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?