Reasoning with Internal and External Representations: A Case Study with Expert Architects

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Abstract

Sketching in a design context serves not only as a visual aid to store and retrieve conceptualizations but also as a medium to facilitate more ideas, and to revise and refine them. We examine whether designing is possible without sketching by conducting a protocol analysis study with six expert architects. Each architect is required to think aloud and design in two different conditions: one where s/he has access to sketching and one where s/he is blindfolded (and not allowed to sketch). At the end of the blindfold condition the architects were required to quickly sketch what they held in their minds. The resulting sketches were assessed by judges and were found to have no significant differences in overall quality. The analysis of the design protocols did not demonstrate any differences in the quantity of cognitive actions in perceptual, conceptual, functional and evaluative categories. The results imply that expert designers could design without the use of external representations.

Keywords: Sketching, protocol analysis, imagery, conceptual design

Introduction

External representations such as diagrams, graphs, sketches, and memos not only serve as a memory aid but as a facilitator in problem solving. There is evidence in a design context that sketching facilitates ideas and design concepts (Goel, 1995; Goldschmidt, 1991; Do et al. 2001; Suwa & Tversky, 1997; Purcell & Gero, 1998). The importance of external representations has been emphasized in other problem solving domains (Larkin & Simon, 1987; Bauer & Johnson-Laird, 1993; Hegarty, 1992) for facilitating cognitive mechanisms.

The drawings used by designers are distinct from the drawings used to represent reality; they are used as a tool for thinking. Tversky (1999) states, “Drawings provide insights into conceptualizations not just imaginings” (p.94). The concepts and ideas are depicted on paper such that when the designer inspects the depiction potentially to retrieve the previously encoded information re-interpretation of the visual information can occur. In this way designers refine and revise their design ideas and the representations (Goldschmidt, 1991; Suwa & Tversky, 1997; Purcell & Gero, 1998). The draw-inspect-revise cycle has been emphasized in various design contexts (Goldschmidt, 1991; Goel, 1995; Lawson, 1990) often referred to as a reflective conversation (Schön & Wiggins, 1992).

Athavankar (1997) conducted an experiment where an industrial designer was required to design a product in his imagery without access to sketching and the visual feedback it provides. The study showed that the designer was able to evolve the shape of the object, manipulate it, evaluate alternative modifications, and add details and color as well. The results of this study led us to question whether expert designers may be able to use only imagery in the conceptual design phase, before externalizing their design thoughts.

In cognitive psychology research a link has been made between the use of imagery and the ability to rotate images (Shepard & Metzler, 1971), to generate-inspect-transform images (Kosslyn, 1980; 1994), to mentally synthesize images (Finke & Slayton, 1988) and make novel discoveries from visual mental images (Chambers & Reisberg, 1985; Finke et al., 1992). Design research also questioned whether re-interpretation of images is possible with or without externalization (Verstijnen et al. 1998; Pearson et al., 2001; Kokotovich & Purcell 2001).

The imagery related experiments in cognitive psychology literature do not deal with an ill-structured problem solving process (Simon, 1973) which is the nature of design problems, and the requirement to come up with a unique solution at the end of this process. How designers use their imagery alone during designing is distinctive in two ways: they construct and transform internal representations by synthesizing information stored in long term memory for extended periods of time, and they aim at developing a unique solution. As Pylyshyn (2003) puts it; “there is a difference between “imagining X” and “imagining that X is the case”. In other words imagining seeing X or considering the implications of X being the case. Clearly the latter is for planning or creative invention”. The use of imagery in design has this characteristic.

Method

The six architects who participated in the study (2 female and 4 male) have each been practicing for more than 15 years and were all award winners who either ran their own offices or were senior members of an office.

Design of the case study

The first group of the three architects is initially engaged in a design process where they are not allowed to sketch. In this 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. This phase is called the BF or experiment condition where they receive design brief 01. Design brief 01 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.

At least one month after the experiment condition the same three architects engage in a design process where they are allowed to sketch. This phase is called the SK or control condition where they receive design brief 02. 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 second group of three architects is first engaged in the sketching (control condition) session, where they receive the design brief 02. Then after one month they engage in the process where they are not allowed to sketch (experiment condition) and are required to work on design brief 01. Figure 1 shows frames from the videos from each of the conditions.

The procedure for the BF condition is as follows

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 participant is engaged in a think-aloud exercise
3. The participant is given the written design brief 01, shown the site layout, and a collage of the photographs of the site and the surrounding neighborhood. S/he is allowed to examine them and ask questions if necessary.
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 specific aspects of the design brief when s/he requires. If participant may chose to communicate with the experimenter then experimenter gives brief and neutral replies. If the participant pauses thinking aloud for more than 15 seconds, s/he was reminded to continue thinking aloud.
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. This period could extend to 5 minutes.
9. The participant is allowed to elaborate the sketch only after externalizing the layout as in his/her mind's eye in the 5 minute period.
10. After the externalization period, the participant is interviewed.

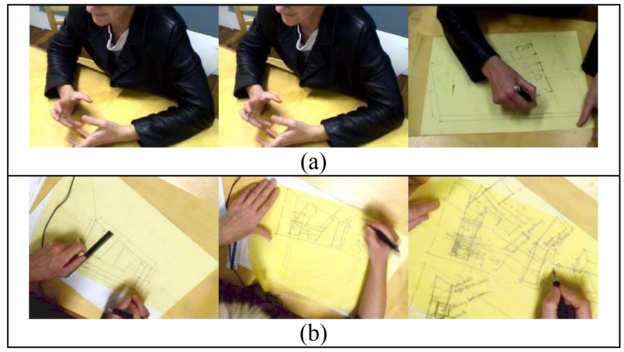

Figure 1. (a) Blindfolded session followed by quick sketching, (b) sketching session

The procedure for the control condition was similar to the first 5 steps in the procedure for the experiment condition. The three architects were asked to memorize the design brief and were given the training session on the think-aloud method. The participants received the written design brief 02 and, were shown the site layout and the site photographs. After the first 5 steps the procedure is as follows:

1. 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.
2. The participant is asked to think aloud and commence sketching directly (Figure 1(b)).
3. Five minutes before the end of the session, s/he is reminded that this is the amount of time remaining.
4. After the completion of sketches, the participant is asked to summarize her/his design briefly so that s/he verbalizes the important concepts/ considerations in his/her design.

Set up of the study

The set-up of the study for both BF and SK conditions has a digital video recorder with built-in and lapel microphones, directed to the designer. The room the designers are located in during both SK and BF sessions has no windows and the walls are blank, i.e. there is no reference to any visual material. In both conditions, the designers are provided with pen and tracing paper, scaled site layout, and a ruler on the table. The experimenter sits with the participant during the sessions, without intervening except as indicated.

Interviews

Group 1 participants (who were engaged in the BF condition first) were interviewed after the BF session. The Group 2 participants (who were engaged in SK condition first) were also interviewed after the BF session. The interview questions were open ended, and the participants were encouraged to talk about their experience of the blindfolded design process. There was no specified duration for interviews; they varied from 15 minutes to 1 hour.

Protocol Analysis

The protocols collected in the SK and BF conditions were segmented using the same approach as for segmenting sketching protocols i.e. by inspecting designer's intentions (Suwa & Tversky, 1997; Suwa et al., 1998). In the segmentation of sketch protocols, verbalizations and video recordings of the sketching activity support decisions to flag the start and end of a segment.

In the BF condition information about the internal design representation state is extracted from the description of the current image or scene the architect talks about. Details of the segmentation and coding of the BF protocols can be found in Bilda and Gero (2004).

Imagery and Sketching Coding Schemes

The coding scheme is based on a cognitive framework which models design thinking as physical, perceptual, functional and conceptual actions progressing in parallel (Suwa et al., 1998). 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 (Table 1).

The imagery coding scheme consists of six action categories: visuo-spatial actions (VS), perceptual actions, functional actions, conceptual actions, evaluative actions and recall actions (Table 1). Codes and results related to VS category in imagery coding scheme and physical actions category in SK condition are not presented in this paper.

Table 1 : 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
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 aesthetics, mention preferences
Recall Actions	
Rpc	Retrieve knowledge about previous cases
Rperc	Recall tacit knowledge
Rbf	Retrieve the design brief/requirements

Coding

Coding was carried out by one individual. The process included a first, a second run and an arbitration phases with at least one month between each phase.

Sketch Assessment

Three judges blind-judged the sketches produced at the end of BF and SK sessions by the six architects. Each judge is an expert architect in practice and in teaching with at least 20 years of experience. The judges were provided with the two versions of the design briefs, the collage of photos of the site, and the scaled site layout. The scanned images of the sketches were printed on A4 size paper so that all design outcomes were similarly scaled. The judges had access to every sheet of drawing produced at the end of the sessions and annotations for each drawn design element. The sketches did not have any indication of which condition they belonged to (SK or BF). The judges were unaware that half of the designs had been produced by blindfolded designers.

The criteria for the assessment of sketches were: 1. how well the sketches satisfy the brief, 2. how innovative is the design solution, and 3. practicality. Each criterion was graded out of 10.

Results

Differences and similarities in cognitive activity

Table 2 shows the occurrence percentages of each action category as a percentage of the total number of actions. The last column in Table 2 shows the total number of actions in each session[1]. The relatively different percentages of occurrence of each action category are shaded. Comparing BF and SK conditions for each architect, one significant difference is that they all recalled more information in their BF conditions.

The rate of perceptual activity was similar in BF and SK conditions for 4 participants (A1, A2, A4 and A6), and different for two of them (A3 and A5). The rate of functional activity was similar for the 6 architects' BF and SK conditions. Conceptual and evaluative activity rates were similar except for some slight differences highlighted for A1, A2, A4 and A5. The average values of occurrence percentages are not significantly different in perceptual, functional, conceptual and evaluative action categories.

[1] Total number of actions include Visuo-Spatial action category in BF and Physical action category in SK conditions

Table 2. Occurrence percentages of action categories

	Perceptual (Per) %	Functional (Func) %	Conceptual (Con) %	Evaluative (Eval) %	Recall (Rec) %	Total # of actions
BF01	27.2	39.6	8.9	13.6	10.6	1121
SK01	30.8	37.7	14.1	12.4	4.9	892
BF02	26.1	40.7	10.7	14.0	8.5	1208
SK02	25.7	40.5	9.6	20.6	3.6	1069
BF03	23.6	44.0	9.3	17.0	6.2	1120
SK03	31.2	43.5	8.3	14.7	2.3	747
BF04	31.3	40.8	10.1	12.9	5.0	1344
SK04	31.0	39.4	14.5	13.1	2.0	1061
BF05	25.1	40.3	11.9	18.6	4.0	880
SK05	34.5	39.6	12.4	12.2	1.3	921
BF06	19.8	46.9	11.1	15.4	6.7	712
SK06	22.3	45.1	14.2	14.9	3.5	1007
BF av	*25.5*	*42.1*	*10.3*	*15.3*	*6.8*	
SK av	*29.3*	*41.0*	*12.2*	*14.7*	*2.9*	

Interview results

The interview results present the way architects interpreted their experience when they were blindfolded. The first group's comments implied "frustration" in general. A2 and A3 during their BF sessions reported that they could not hold/maintain the image (the complete geometry of the layout) in their minds. They also reported that synthesizing the parts was difficult, since they could not retain the parts of the design together at once. The interviews with the first group pointed to a single conclusion, that they would not be designing anything 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. This view is in accord with the claim that sketching is a medium for a reflective conversation.

The second group's comments were quite different. They were more satisfied with their design solutions and they stated that the blindfolded exercise was another way of designing for them. A4 commented that architects in general do not rely on what is in the mind, but it is a skill they need to develop. A5 and A6 commented that thinking through the design issues without drawing gave them a clearer expression of the design solution.

Familiarity with the design context

The interview results showed a difference between the first and second group's attitude towards the blindfolded exercise. This could be due to second group's increased familiarity with the problem space under their BF conditions. They were more familiar with the design site, the environmental factors, and the sizes of the boundaries and the geometry of the layout, which in turn could have made their BF design process more manageable. We investigated the differences in cognitive activity rates for further evidence.

The last column in Table 2 showed that the total number of actions in BF sessions was higher than in the SK sessions of A1, 2, 3 and 4. Only A5 and A6 performed fewer actions in BF sessions. Thus the second group of architects performed at different rates of cognitive activity; A4's cognitive actions (1344) was significantly higher compared to A5 and A6's (880, 712) under the BF conditions.

We argued that when the second group of architects were exposed to the same site with a similar problem in the BF session, it is possible that the design synthesis and evaluation processes might have become easier for them, even without the access to drawing. This might explain the lower rate of cognitive activity for A5 and A6, however A4 did not demonstrate the same tendency. The different tendencies make it hard to determine whether the reason for this variation is the effect of familiarity or other factors related to cognitive styles and ability.

Comparison of the design outcomes

The six architects were able to satisfy the space and client requirements in both experiment and control conditions, Figures 2(a) and 2(b) show typical example. Table 3 shows the results of the assessment of the sketches by the three judges. The grades in Table 3 are the average grades of the three judges' assessments. The final columns in each condition shows the architects' average grade for each criterion. Table 3 also shows that the average grades for the BF condition are higher than the average grades in SK condition for two of the three critera.

Table 3: Sketch assessment scores

		Innovative	Satisfying Des Brief	Practical	Av
Blindfolded (BF)	A1	4.0	7.7	7.7	**6.1**
	A2	4.3	6.3	7.0	**6.0**
	A3	6.0	7.7	7.0	**6.9**
	A4	5.0	7.5	6.7	**6.1**
	A5	6.3	8.0	7.7	**7.1**
	A6	4.3	5.7	5.0	**4.9**
	BF av	**5.0**	**7.1**	**6.8**	
Sketching (SK)	A1	4.3	6.3	6.0	**5.4**
	A2	5.3	6.3	5.7	**5.9**
	A3	6.7	6.3	5.3	**6.5**
	A4	4.3	5.0	3.7	**4.3**
	A5	6.0	7.0	7.0	**6.4**
	A6	4.0	5.3	5.7	**4.9**
	SK av	**5.1**	**6.0**	**5.6**	

The first group's (A1, 2, 3) scores on innovativeness are higher in their SK conditions and second group's (A 4, 5, 6) scores on innovativeness are higher in their BF conditions. This difference in scores could be due to the change in the order which the architects performed the BF or SK conditions. The scores for satisfying the design brief and practicality are higher in BF in general (one exception is A6's practicality score).

Figure 2 shows A5's perspective drawings as design outcomes for the SK (Figure 2(a) and BF (Figure 2(b)) conditions. A5's BF outcome was scored higher in each criterion compared to the SK outcome scores.

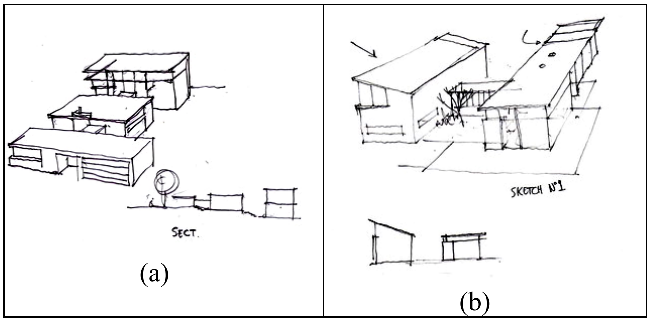

Figure 2. Sketches of A5 (a) SK condition, and (b) BF condition

Coding consistency and segment durations

The reliability of the coding process was measured by calculating the agreement percentages between the three phases of coding. They changed from 65% to 81% between the 1st and 2nd coding phases, 78% to 92% between the 1st and arbitrated coding phases and 85% to 93% between the 2nd and arbitrated coding phases.

The average length of the time interval for each segment ranged from 17 seconds to 26 seconds. The average durations of segments were similar under BF (20.4 sec) and SK conditions (21.5 sec) with standard deviations of 11.5 and 12.4 seconds. The average Kurtosis values in BF versus SK design sessions were also similar (-1.2 and -1.2) which means the distributions in time intervals were flat and similar.

Discussion

This case study showed that there are more similarities than differences between SK and BF conditions of the six architects, in terms of the percentage distribution of cognitive action categories and overall quality of design products. When the six expert architects did not have access to sketching, they were able to handle the cognitive processes required to produce a reasonable design solution. Due to the small scale of the experiment, the results cannot be generalized. The results cannot be generalized to other design disciplines since the use of mental imagery may be constrained when complex types of design transformations are involved in the process where drawing is not sufficient to visually reason about them.

The results of this study pose questions to the view that sketching is the only efficient medium for developing concepts/ideas, and testing them. If the expert architects can do this without being able to sketch, then the benefits of design externalizations become questionable. This implication goes against most of the work in design thinking research where sketching is central.

It might be argued that the BF design outcome is more a product of the reflective conversation which might occur during the quick sketching period, rather than it can be an internal construct. However quick sketching period was partly controlled by the experimenter such that s/he was able to intervene and remind them that they are not allowed to make significant changes to the layout.

Benefits of external representations

The current case study shows that the architects were able to produce reasonable and satisfactory design solutions by using their imagery alone. If this case study were replicated with a sample size large enough to show statistical significance supporting the similarity of the two conditions, then we would propose that sketching may not be the only way to design visually.

This case study showed that the six expert architects were able to benefit from both their external and internal representations. The question of how experts benefit from their diagrams was discussed by Larkin and Simon (1987). When the expert architects in our study were not allowed to use their vision, they might have utilized perceptual elements which carry equivalent information to the ones in drawings. These perceptual units might allow them to reason about the specific problem at hand. This possibility also suggest that the expert architects' skills of reading visuo-spatial information would not be solely dependent on drawings. They could create perceptual elements for each conceptualization. Then the designers might have their reflective conversation with the conceptualizations rather than the drawings.

Skilled imagery

Studies of expert chess players identified a skilled imagery (Simon & Chase, 1973; Saarilouma, 1998; Ericsson and Kintsch, 1995) which shows evidence of the use of imagery for longer periods and with higher cognitive loads. The theory states that the experts develop specific ways for chunking visuo-spatial information that enable them to rapidly retrieve and use it in a new context (Simon &Chase, 1973). In chess, it is clear how the pieces are initially arranged and the range of final arrangements that could win, therefore the problem and solution spaces are well defined. In architectural design, problem definition is incomplete because the design requirements have to be interpreted to reach an initial problem definition. In the same vein the final solution is never certain because there are many solutions that would satisfy the desired solution state.

According to the skilled imagery theory, architects in the current study relied on retrieving and using the visual and spatial information from their LTM. Similar to expert chess players, expert designers could have used pre-existing dynamic chunks of visual features or spatial relations encoded with their past experiences. The theory suggests that the previously learned visuo-spatial chunks would be distributed throughout the working memory subsystems which could result in a quick development of design solutions through the use of imagery. It is less likely that the architects were using pre-existing chunks, since they re-represent of their problem space for each new design problem and re-interpret the visuo-spatial information. This argument remains for further investigations of the study.

Conclusion

In this case study of six expert architects we compared two conditions of designing: BF condition where they were required to create a unique design solution via thinking aloud with a blindfold on and SK condition where they continuously sketch over the timeline of the design activity. The first group of three architects underwent the BF condition first and the second group underwent the SK condition first.

The design drawings produced at the end of the BF and SK sessions were judged and found to be not significantly different in overall quality. Analysis of the design protocols revealed that the cognitive activity in perceptual, functional, conceptual, and evaluative categories did not change significantly in quantity. This implies that these expert architects were able to produce design concepts/ideas and carry on a reflective conversation with them when they used their imagery alone. We conclude that design reasoning via constructing internal representations may be as efficient as reasoning via constructing external representations for expert architects, in the limited period of the conceptual design phase.

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