SKETCHING INTERPRETATION IN NOVICE AND EXPERT DESIGNERS

MANOLYA KAVAKLI, MASAKI SUWA, JOHN GERO AND TERRY PURCELL
Key Centre of Design Computing and Cognition
Department of Architectural and Design Science
University of Sydney NSW 2006 Australia

Abstract. This paper focuses on the differences in visual reasoning between a novice and an expert architectural designer during the conceptual design process. The cognitive actions of each designer while sketching were categorized into four main groups (each consisting of a number of sub-groups): physical, perceptual, functional, and conceptual. Based on this analysis, we found that the expert differs markedly from the novice in productivity in terms of the number of sketches and the number of alternative ideas. We focused on the differences between them in terms of the frequencies of cognitive actions, with the hypothesis that the difference in productivity could be attributed to the differences in some or all types of cognitive actions. Differences between the expert and the novice were found for revising features (in the subcategory of drawing actions in the physical action category), for paying attention to the relations of depicted elements (perceptual category) and for the rates of new and revisited functions (functional category). These results are discussed in terms of the types of visual reasoning processes that could be involved in expert design and the possible implications of these results if they can be demonstrated to be characteristic of expert designers generally.

1. Introduction

This paper is concerned with the sketching behavior of novice and expert designers in the early stages of the design process. Sketching produces visual/graphical design depictions and designers interact with these depictions by interpreting them, where interpretation is the mapping between design depictions and their performance requirements (Coyne et al., 1990). This interaction between self-produced visual

depictions and the cognitive processes involved in interpreting them we would argue constitutes a visual reasoning process.

The results of previous research on the role of sketching in design give some indication that visual reasoning processes could be involved. Schon and Wiggins, (1992) argue that sketching plays an essential role in the conceptual design process by evoking unexpected discoveries and through a process of reinterpretation. Designers do not necessarily interpret design sketches with the same meanings, but reinterpret them with new meanings. Goldschmidt (1991) calls this reinterpretation process a "seeing-as" activity, while Goel (1995) calls it "lateral transformation". However, both unexpected discoveries and reinterpretation can be defined as a class of perceptual actions dependent on design depictions and functional actions (Suwa et al., 1998a), that is as the result of a visual reasoning process. Suwa, et al (1999) examined whether there is any significant causality between the occurrence of goals and unexpected discoveries based on sketches. Their findings significantly imply that the occurrence of goals is paralleled by the occurrence of unexpected discoveries. Unexpected discoveries, in their study, are defined by the perceptual actions that refer to the discovery of implicit spaces, features and their relations. Again this can be seen as another form of visual reasoning.

The results of this research therefore point towards the importance of what appear to be visual reasoning processes in the early phases of design. The aim of this paper is to further extend this work by a detailed comparison of the reasoning processes of an expert and a novice architectural designer that take place while they engage in sketching. If visual reasoning is an essential part of the design process then expert performance should exhibit such processes and differences between experts and novices should highlight the particular visual reasoning processes that are the basis for expert performance.

2. Protocol Analysis Codes

Protocol analysis methods can be divided into two categories: the process-oriented approach and the content-oriented approach (Dorst and Dijkhuis, 1995). The retrospective protocol analysis method and the associated coding scheme used in this study are based on the content-oriented approach used by Suwa and Tversky (1996). Subsequently Suwa et al. (1998a and 1998b) further developed this coding scheme to identify four categories (and associated sub-categories) of cognitive processes or actions that a designer engages in while sketching. These are referred to as physical, perceptual, functional and conceptual actions, each of which is described in detail in the following sections. Detailed information on procedures of protocol parsing and coding using this method can be found in Suwa et al. (1998a and 1998b). The expert used in the experiment was

an architect with 25 years of experience while the novice was a second year architecture student. The results of the analysis should therefore be treated with some caution and regarded as indicative of possible directions for future research. However it must also be pointed out that the data derived from each protocol is very rich and detailed and consequently carries more weight than if only a small number of simple measures were taken for each of the participants. Because this experiment must be considered as a preliminary examination of visual reasoning in design, we have confined our analyses to examining the patterns in the percentages associated with the different types of cognitive actions.

2.1. CODING OF PHYSICAL ACTIONS

Physical actions refer to three main groups of actions: the physical act of drawing (D-actions, which has six sub-categories); movements made by the designer in relation to design depictions (M-actions, which has six sub-categories) and paying attention to previously drawn elements (L-actions, no sub-categories). The details of the sub-categories for the D- and M-actions are shown in Table 1.

TABLE 1. Codes of D-actions and M-actions in the category of physical actions

D-actions: drawing actions	*M-actions: moves*
Dc: create a new depiction	Moa: motion over an area
Drf: revise an old depiction	Mod: motion over a depiction
Dts: trace over the sketch	Mrf: move attending to relations or features
Dtd: trace over the sketch on a different sheet	Ma: move a sketch against the sheet beneath
Dsy: depict a symbol	Mut: motion to use tools
Dwo: write words	Mge: hand gestures

2.2. CODING OF PERCEPTUAL ACTIONS

Perceptual actions (P-actions) also are divided into three main categories: actions related to implicit spaces (divided into two sub-categories), to the visual features of elements (divided into three sub-categories) and to spatial relations (also divided into three sub-categories). Details of each of the categories and sub-categories are shown in Table 2.

TABLE 2. Codes of P-actions

P-actions:perceptual actions related to implicit	*P-actions:perceptual actions related to features*	*P-actions:perceptual actions related to*

spaces		*relations*
Psg: discover a space as a ground	Pfn: attend to the feature of a new depiction	Prn: create or attend to a new relation
Posg: discover an old space as a ground	Pof: attend to an old feature of a depiction	Prp: discover a spatial or organizational relation
	Pfp: discover a new feature of a new depiction	Por: mention or revisit a relation

2.3. CODING OF FUNCTIONAL ACTIONS

Functional actions (F-actions) refer to associations of particular visuo-spatial features in sketches with meanings, functions or abstract concepts. Functional actions are divided into three main categories: actions related to new functions (with three sub-categories), to revisited functions (two sub-categories) and actions related to of a previous concept in a new setting. Details of the different categories and sub-categories are shown in Table 3.

TABLE 3. Codes of F-actions

F-actions:Functional actions related to new functions	*F-actions:Functional actions related to revisited functions*	*F-actions:Functional actions related to implementation*
Fn: associate a new depiction, feature or relation with a new function	Fo: continuing or revisited thought of a function	Fi: implementation of a previous concept in a new setting
Frei: reinterpretation of a function	Fop: revisited thought independent of depictions	
Fnp: conceiving of a new meaning independent of depictions		

2.4. CODING OF CONCEPTUAL ACTIONS

Conceptual actions refer to preferential or aesthetic evaluations (E-actions), the set-up of goals (G-actions), and the retrieval of knowledge or past similar cases (K-actions) (Suwa et al., 1998b). In this group, we only examine the G-actions and in particular the sub-category of these actions related to introducing new functions (G1-actions) and the further four sub-categories related to introducing new functions. Table 4 provides

the details of the four sub-categories of G-actions and the four sub-categories associated with G1-actions.

TABLE 4. Codes of G-actions

G-actions: Goals	*Subcategories of G1 type goals:*
G1: goals to introduce new functions	G1.1: based on the initial requirements
G2: goals to resolve problematic conflicts	G1.2: directed by the use of explicit knowledge or past cases (strategies)
G3: goals to apply introduced functions or arrangements in the current context	G1.3: extended from a previous goal
G4: repeated goals from a previous segment	G1.4: not supported by knowledge, given requirements or a previous goal

3. Differences Between Novice And Expert Designers

The design protocol of the expert was divided into 340 segments containing 2,651 actions while the novice's protocol had 115 segments and 961 actions. Considering that the same amount of time was given to both participants, this indicates that the expert's design protocol was much richer and denser than the novices. It contains almost 3 times as many segments and 2.8 times as many actions as in the novice's protocol. During the design process, the expert produced 13 pages of sketches including 7 different design alternatives, while the novice produced 4 pages including 2 design alternatives. Figures 1 and 2 show samples of the sketches produced by both the novice and the expert. We do not analyze the sketches themselves in this paper; they are presented simply to ground the following work. The major distinction in their sketches is the greater intensity in the expression of design ideas as seen in the expert's design alternatives.

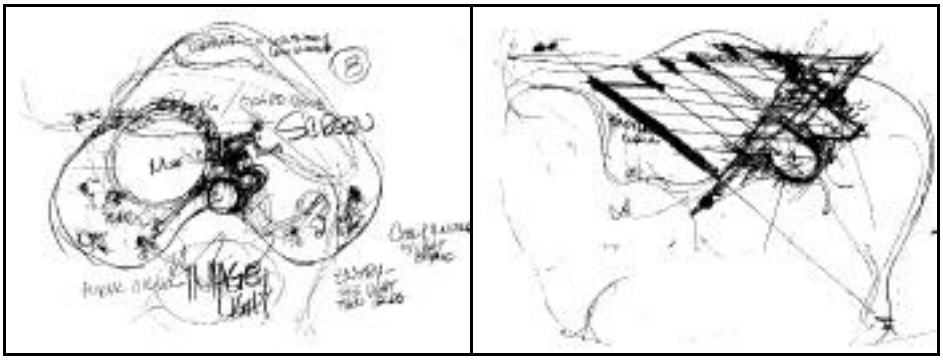

Figure 1. Samples from the sketches of the expert

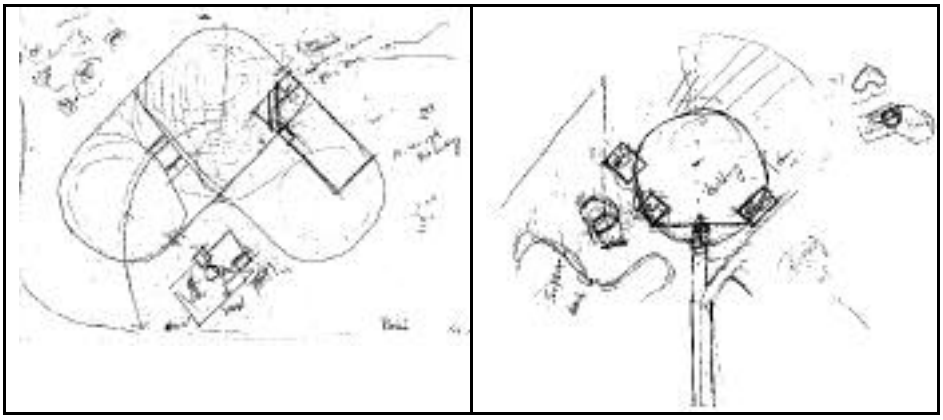

Figure 2. Samples from the sketches of the novice

Based on these general results and given that the actions referred to are cognitive actions carried out in relation to or concurrent with sketching activities that produce visual depictions, it would appear that what characterises this architectural designer's expert performance is a very large amount of visual reasoning. An indication of whether particular types of visual reasoning account for the difference can be obtained by an analysis of each of the categories of cognitive actions outlined above.

Table 5 presents the results for the expert and novice for the major categories of cognitive action.

TABLE 5. Action categories.

ACTIONS	Expert (%)	Novice (%)
Physical	39	47
Perceptual	23	24
Functional	29	21
Conceptual (Goals)	9	8

The major differences at this level of analysis are in the physical and functional action categories. It is also apparent that physical actions occur most frequently in both protocols and that, apart from the difference between the expert and novice in terms of functional actions, both the perceptual and functional categories occur with similar frequencies and that conceptual goals occur relatively infrequently and with equal frequency. Although the percentage of perceptual actions does not differ, if the sub-categories are examined differences between the expert and the novice become apparent. Because the goals category of conceptual actions occurs at such a low level, no further analysis of this category is possible. The following analyses examine these differences at the sub-category level.

3.1.PHYSICAL ACTIONS

The category of physical actions can be sub-divided into drawing actions, looking at previous depictions and making movements in relation to a previous depiction. Table 6 presents the percentage of each of these sub-categories for the expert and the novice. It is apparent that the largest difference between the expert and the novice is for the drawing category with the novice producing a higher percentage of drawings than the expert.

TABLE 6. Sub-categories of physical actions

PHYSICAL ACTIONS	**Expert (%)**	**Novice (%)**
Drawing	15	25
Looking	22	19
Moves	2	3

Table 7 presents a re-arranged version of the sub-categories within the drawing actions category. It is apparent the major difference in drawing actions lies in both creating a new depiction and in modifying an existing depiction. The novice produces more new depictions and these are associated with new symbols, such as arrows, lines, and objects having special meaning. The expert modifies existing depictions more often than does the novice particularly in terms of revising an existing depiction. The novice as a result does not revise and manipulate the design depiction as much as the expert.

TABLE 7. Drawing actions

DRAWING ACTIONS	**Expert (%)**	**Novice (%)**
Depicting	55	62
Drawings (Dc)	42	42
Symbols (Dsy)	13	20
Modifying	31	24
Revising (Drf)	12	5
Overtracing (Dts)	12	16
Copying (Dtd)	7	3
Writing (Dwo)	14	15

3.2. PERCEPTUAL ACTIONS

Perceptual actions can be categorized into three main groups: implicit spaces, features, and relations. As shown in Table 8, the major differences between the expert and the novice in perceptual actions lies in discovering implicit spaces (13 versus 36%) and the emphasis given to

perception of the relations between the depicted elements (67 versus 40%).

TABLE 8. Perceptual Actions.

PERCEPTUAL ACTIONS	**Expert (%)**	**Novice (%)**
Implicit spaces	13	36
Discovery of a new space as a ground (Psg)	5	13
Discovery of an old space as a ground (Posg)	8	23
Features	20	24
Attention to the feature of a new depiction (Pfn)	8	12
Discovery of a feature of a new depiction (Pfp)	6	6
Attention to an old feature of a depiction (Pof)	6	6
Relations	67	40
Discovery of a spatial or organizational relation (Prp)	17	10
Creation of or attention to a relation (Prn)	29	20
Revisit or mention of a relation (Por)	21	10

In terms of the sub-categories associated with implicit spaces, both "discovery of a new space as a ground", which is a class of unexpected discovery, and "discovery of an old space as a ground" are more frequent for the novice compared to the expert designer. This indicates that the novice's attention focuses on discovery of implicit spaces more than the expert does. For the sub-categories of the relations category, higher percentages are associated with the expert in terms of creation of a relation, revisiting a relation, and discovery of a relation. Revisiting a relation has one of the highest rates for the expert, whilst it is one of the actions having the lowest rates for the novice.

3.3. FUNCTIONAL ACTIONS

Functional actions can be categorized into three main groups: revisited functions, new functions, and implementations. As shown in Table 9, the major difference in functional actions is in the rates of "revisited functions" and the "implementation of functions". The difference in revisited functions is associated with a higher percentage of continual or revisited functions for the expert and this difference is quite substantial, however, the rate of "implementation of previous concepts in a new setting" is higher in the novice.

TABLE 9. Functional actions.

FUNCTIONAL ACTIONS	Expert (%)	Novice (%)
Revisited functions	46	34
Continual or revisited thought of a function (Fo)	45	33
Continual or revisited thought independent of depictions (Fop)	1	1
New functions	40	47
Associate a new depiction, feature or relation with a function (Fn)	29	34
Reinterpretation of a function (Frei)	10	11
Conceiving of a new meaning independent of depictions (Fnp)	1	2
Implementations	15	23
Implementation of a previous concept in a new setting (Fi)	15	23

These results indicate that the expert's functional actions focus on continuously revisiting functions of design depictions, however, the novice's functional actions focus on new functions and implementations in a new setting.

4. Discussion

The results of these analyses can be summarised in the following way.

- The expert engages in much more cognitive activity while sketching, that is visual reasoning, than the novice indicating at this broad level that visual reasoning is associated with expert performance.

- The expert modifies existing depictions by revising and manipulating them while the novice draws more new depictions in the form of symbols such as arrows and lines or symbols with special meaning. This difference in drawing activity can also be interpreted as indicating a difference in visual reasoning. Revising and manipulating existing depictions is clearly associated with a focussed visual reasoning process while drawing symbols of the type produced by the novice would appear to be a much lower level of visual reasoning.

- The expert discovers new or revisits old spatial or organisational relations while the novice discovers more implicit spaces. Here again the activity of the expert would appear to be consistent with a highly organised visual reasoning process that develops spatial and organisational relations. This contrasts with the novice’s discovery of implicit spaces which is more static as it is simply associated with a specific perceptual change grounded in a particular depiction.

· This pattern of the expert engaging in more focussed and progressive visual reasoning is also apparent in relation to functional actions. The expert continues to think about and revisit existing functions while the novice has a higher rate of implementation of a function.

It would therefore appear that focussed and progressive visual reasoning while sketching is a characteristic of the performance of an expert architectural designer. However we would like to emphasise that as interesting as these results are, they must be treated as preliminary because they are based on one novice and one expert. Replication of the experiment is clearly necessary both in terms of collecting data from more novices and expert architectural designers and extending the experiments to include other design disciplines. The interest of these results however remains – expert designers may engage in a specific sub-set of visual reasoning activities more frequently and these activities are highly focussed and progressive. If this pattern can be established more generally it will have clear implications for design education and practice. Particular emphasis, for example, could be given to ways of teaching that could enhance these types of visual reasoning processes. This could potentially result in more effective practising designers and consequently be of benefit to society through better design outcomes.

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