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SKETCHES AS AFFORDANCES OF MEANINGS IN THE DESIGN PROCESS

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Abstract. This paper utilized protocol analysis to explore further the roles of the sketches as the affordances of functional issues while designing. We found that statistically significant amounts of the drawing, looking, moving, and perceiving actions have meaning attached to them. In our limited number of subjects, the expert produced more meaningful actions than the novice. Finally, designers can generate more meanings from sketches when revising them than when depicting them.

1. Introduction

Sketches made by designers during the design process play multiple roles for both designers and the design process (Purcell and Gero, 1998). They serve as an external memory to augment the limitation of human cognitive abilities, as the medium that designers use to communicate with themselves and others, and as the triggers that enable designers to reason about a design problem (Goldschmidt, 1991; Schön and Wiggins, 1992; Goldschmidt, 1994; Gero and McNeill, 1998; Kavakli, et al., 1999; Suwa, et al, 2000).

It has been increasingly recognized that a perception-based view of images and drawings related to the design process is not sufficient to describe all the aspects of the design process. There is a kind of thinking process that directly relates to sketches and visual perceptions. The increasing importance of this kind of thinking process comes from our improved understanding of the roles of sketches and their relationship to design.

The essential relationship between sketches and the design process was highlighted by Schön (1983). The kinds of seeing and their functions in designing and the relationship between seeing and the appreciative system are related to the meanings and functions attached to the sketches themselves. The dialectics of sketches between figural reinterpretation and emergence and non-figural functional references in the design process was proposed by Goldschmidt

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(1991). The dichotomy between analytic and synthetic thinking was proposed to argue that visual thinking is not only equivalent to vision, but a production of thought via visual imagery (Goldschmidt, 1994). Consequently, designing is considered essentially, by many, to be a visual reasoning process.

Visual reasoning is the cognitive process that links abstract, concept knowledge and perceptually-based knowledge (Tversky, 1999). In cognitive psychology, it is referred to as the drawing of inferences from visual representations to abstract knowledge. In the same vein, sketches or drawings are different from images in that they reflect conceptualizations of the thinking process (Tversky, 1999). Through research on children's drawings, sketching maps, and geometric design, Tversky proposed that segmentation and order of drawings could reveal some underlying conceptual structure.

In the design research community, the interactions between different cognitive levels – physical, perceptual, functional, and conceptual levels – have been addressed (Suwa, et al., 1998). Sketches are described as visual cues for association of functional issues, and as physical settings in which functional thoughts are constructed on the fly in a situated way (Suwa, et al., 1998). In the same sense, the design process has been categorized as combinations between sensor-driven processes and goal-driven information-processing processes to point out the important connections between these four cognitive levels (Tang and Gero, 2000). These researchers found that there was no pure goal-driven process. All the episodes of the conceptual design process were related to visual perceptions or physical actions, such as drawings and seeing. This supports the idea that visual reasoning plays a more important role than had been expected in the design process, given that visual reasoning means conceptual reasoning with physical and perceptual drawing actions.

2. Methods

The experimental method and settings in this study are the same as that in Suwa and Tversky's paper (1997). The encoded results in this study are partly from our cooperation with Dr Suwa and partly from our independent encoding with comparison to his results.

2.1 RETROSPECTIVE PROTOCOL

The methodology of this paper is retrospective protocol analysis. It has been utilized to examine the cognitive aspects of the design processes mainly because of the claimed minimization of interference with the act of designing. The procedure of this method is that participating designers first design, and then retrospectively report the design process with the aid of the videotapes that records their design sessions.

The audio report was transcribed into a verbal protocol, and was then parsed into segments and categorized using an encoding scheme. Utterances, sketches, and video images are the material that this study used to determine the encoded protocol.

2.2 SEGMENTATION

The definition of segments in this study is that "one segment accounts for a designer's single intention, and therefore consists of pieces of information that appear to have occurred simultaneously in the designer's mind". The parsed protocol may be viewed as organized information processing streams, documenting different types of information and intentions. The segmentation are carried out by two encoders individually.

2.3 THE CODING SCHEME

The structure of our coding scheme was originally established by Suwa and Tversky (1997) and further modified by Suwa, Gero, and Purcell (2000). It consists of two distinguishable groups of actions. Lower level cognitive actions are the physical and perceptual levels that interact with the external world, including actions for drawing, looking, and recognizing graphical features and spatial relationships. Higher level cognitive actions are the functional and conceptual levels that interact with the designer's internal world, including actions for functional reference, goalsetting, making decisions, and utilizing designers' knowledge.

Consequently, this coding scheme represents the design process in terms of four levels that have inter-linked and inter-related relationships. *Physical* refers to the instances that have direct relevance to the external world, comprising drawing, looking, and moving actions. *Perceptual* concerns the instances of attending to visuo-spatial features/relationship in an automatic perceptual mechanism. *Functional* relates to the instances of functional references mapped between visuo-spatial features/relationship and abstract concepts, including meanings and functions. *Conceptual* represents the instances that process abstract concepts and the instances that process physical and perceptual actions. An instance in a level is called an action that has different meanings to an action in cognitive psychology. For example, there are three types of actions in the physical level: drawing, looking, and moving, so a drawing action in the physical level occurs when a designer draws a line to mean a public road in the design process.

A design session is transformed into a series of consecutive segments. Each segment has four types of cognitive levels, and each level may contains actions that are identified in the utterances, sketches, and video images. All the actions in a segment have dependencies but not chronological sequence.

2.4 THE DESIGN BRIEF AND SUBJECTS

The experimental task is to design a museum building on a given heart-shaped site. The participants are required to fulfill a functional list, including a sculpture garden, a pond, a green area, parking lots, and a museum building that contains entrance(s), ticket office(s), a cafeteria, a gift shop, and exhibition rooms for about 100 paintings. The participants have 45 minutes to finish the design (Suwa and Tversky, 1997).

In this study, we analyzed the cognitive processes of a novice and an expert designer. The novice is a second year architectural student; the expert is a practising architect with more than 25 years experience.

3. The Physical and Perceptual Actions with Meaningful Intentions

3.1 SKETCHES AND UNDERLYING CONCEPTUALIZATIONS

It has been proposed that the design process is a conversational and iterative process between the designer’s ideas and their sketches. The sketches serve as instantiations of ideas and the inspirations of new ideas. (Goldschmidt, 1991; Goldschmidt, 1994; Suwa and Tversky, 1997; Purcell and Gero, 1998). Moreover, they can help designers to reason about non-visual elements by designers’ attaching meanings to visual depictions. The functional references and design knowledge are articulated with sketches to advance the design (Suwa, et al., 1998; Verstijnen, et al., 1998). Tversky has proposed that drawing are representations of reality, and they can provide insights into conceptualizations (Tversky, 1999). It is claimed that the representations, segmentations, and orders of depictions reveal the organization and components of the underlying conceptual elements. Drawings are thus clues to conceptualizations of mental domains, and studying the segmentations and orders of sketches in design should provide insights into the operations and schema of conceptual modules.

Inspired by these ideas, this study asks the question: How many sketches in a design process have attached meanings? Some sketches produced in the design process are regarded as externalized memory to aid human memory, having non-visual elements. However, some sketches do not stand for any specific meanings. Instead, they are designers’ incubators of inspiration through arbitrary doodling and graffiti.

3.2 HOW WE IDENTIFY MEANINGFUL ACTIONS

Utilizing the structure of our coding scheme, we examine the relationship between lower level cognitive actions and function-referencing action to understand the relationship between actions and the corresponding meanings that are attached to them. The relationship may reveal the connections between visual processing and information processing, namely the visual reasoning process.

The four actions we examine are drawing actions (D-actions), looking actions (L-actions), moving actions (M-actions), and perceiving actions (P-actions). *D-action* refers to making different kinds of depictions, such as lines, circles, arrows, and etc. *L-action* refers to looking at existing depictions that are drawn in previous segments. *M-action* refers to other actions in the physical level. *P-action* refers to attending to visual features and visuo-spatial relationship through D-action(s) and L-action(s).

The method by which we identified a meaningful action was by checking whether an action had either direct or indirect attachments of functional references in a segment. A direct meaningful D-action means that a designer knows the functional reference of a depiction when he/she draws a depiction. We can identify it from video images or transcripts. For example, in a segment a designer reported "*First, I tried to place the building over here, so you enter here, you see all the things and finally come to the building.*", and, at the same time in the video, we saw that he drew a square inside a big circle. At this segment, we can tell that this designer attached a functional reference to the square, and thus this D-action, drawing a square, is meaningful or function-referencing as it occurs. In contrast, an indirect functional reference is one where a designer attaches meanings to a D-action through L-action or P-action. In the former case, the L-action has a direct meaning and the D-action has an indirect meaning. In the latter case, the P-action has a direct meaning and the D-action has an indirect meaning.

In terms of L-actions, a direct functional reference is related to the depiction that is revisited by this L-action. If that revisited depiction is meaningful, the corresponding L-action is meaningful as well. An indirect functional reference for L-action is when a designer attached meanings to a P-action that depends on L-action(s); all such actions are regarded as meaningful: one direct meaning for P-action and indirect meanings for L-action(s).

In terms of M-actions, indirect functional references result from their being included in a meaningful P-action. In terms of P-actions, the functional references result from either a direct functional reference of itself or an indirect functional reference through other P-actions. The latter one occurs when a P-action is included in a meaningful P-action, so the former one has indirect meaning and the latter has direct meaning.

3.3 HOW MANY THE SKETCHES ARE MEANINGFUL

Table 1 presents the results of meaningful and non-meaningful actions of both designers for the four types of actions. The results indicate that more than half of the actions are meaningful, and this situation is true in all the sub-categories of the lower cognitive activities and for both designers.

TABLE 1. The distributions of meaningful and non-meaningful actions in the novice and the expert in terms of four sub-categories of lower cognitive activities

	Novice			Expert		
	With meaning	Without meaning	Total number	With meaning	Without meaning	Total number
Drawing action	169	99	266	310	108	418
Looking action	167	61	228	427	164	591
Moving action	5	11	16	29	15	44
Perceptual action	89	132	221	369	258	627

The Chi-square tests of the differences between meaningful and non-meaningful actions are conducted to examine their significance. Table 2 shows the result of the novice's design process, and indicates a statistical significance of the difference with a 99% confidence level.

TABLE 2. The Chi-square test of meaningful and non-meaningful actions in the novice's design process

	Novice's Actions				
	D	L	M	P	Total
Meaningful attachment	169	167	5	89	430
Non-meaningful attachment	99	61	11	132	303
Chi-square test statistics	$\chi^2 = 57.91 > \chi^2(3) = 11.345$ (p-value < 0.01)				

Similarly, Table 3 shows the result of the expert's design process, and indicates a statistical significance of the difference with a 99% confidence level.

The results show that the lower cognitive activities in the design processes are quantitatively dominated by functional references. Designers draw, revise, move, and perceive in a meaningful way. However, there are limitations regarding this result. First, the number of subjects is not sufficient to generalize the result. Second, the significance of the non-meaningful actions in terms of inspirations or creativity is not known.

TABLE 3. The Chi-square test of meaningful and non-meaningful actions in the expert's design process

	Expert's Actions				
	D	L	M	P	Total
Meaningful attachment	310	427	29	369	1135
Non-meaningful attachment	108	164	15	258	545
Chi-square test statistics	$\chi^2 = 36 > \chi^2(3) = 11.345$ (p-value < 0.01)				

3.3 COMPARISON BETWEEN THE EXPERT AND THE NOVICE

The chi-square tests of the differences between the novice and the expert are conducted to examine how differently the novice and the expert use their external actions in terms of attached meanings. Table 4 shows the difference in the D-actions between the expert and the novice, and indicates a statistical significance of the difference with a 99% confidence level. The last column shows how differences of the meaning-attached actions are from the normal distribution. In Table 4 we can see that the expert created more meaningful D-actions than the novice.

TABLE 4. The Chi-square test of the difference between meaningful and non-meaningful drawing actions in the novice and the expert.

	With meaning attached	Without meaning attached	Difference from the expected value
Novice's drawing action	63%	37%	- 18.5
Expert's drawing action	74%	26%	+ 18.5
Chi-square test result	$\chi^2 = 9.98 > \chi^2 (1) = 6.63$ (p-value < 0.01)		

Table 5 shows the difference in the L-actions between the expert and the novice, and indicates that there is no statistically significant difference. It also shows that the expert created a similar percentage of meaningful L-actions as the novice.

TABLE 5. The Chi-square test of the difference between meaningful and non-meaningful looking actions in the novice and the expert.

	With meaning attached	Without meaning attached	Difference from the expected value
Novice's looking action	73%	27%	+ 1.6
Expert's looking action	72%	28%	- 1.6
Chi-square test result	$\chi^2 = 0.08 < \chi^2 (1) = 3.84$ (p-value > 0.05)		

Table 6 shows the difference in the M-actions between the expert and the novice, and indicates a statistical significance of the difference with a 95% confidence level. From the difference from the expected value, we can see that the expert created more meaningful M-actions than the novice.

TABLE 6. The Chi-square test of the difference between meaningful and non-meaningful moving actions in the novice and the expert.

	With meaning attached	Without meaning attached	Difference from the expected value
Novice's moving action	31%	69%	- 4.1
Expert's moving action	66%	34%	+ 4.1
Chi-square test result	$\chi^2 = 5.74 > \chi^2(1) = 3.84$ (p-value < 0.05)		

Table 7 shows the difference in the P-actions between the expert and the novice, and indicates a statistical significance of the difference with a 99% confidence level. From the difference from the expected value, we can see that the expert created more meaningful P-actions than the novice.

TABLE 7. The Chi-square test of the difference between meaningful and non-meaningful perceiving actions in the novice and the expert.

	With meaning attached	Without meaning attached	Difference from the expected value
Novice's perceiving	31%	69%	- 30.4
Expert's perceiving	66%	34%	+ 30.4
Chi-square test result	$\chi^2 = 22.54 > \chi^2(1) = 3.84$ (p-value < 0.01)		

In conclusion, the expert created more meaning-attached lower level cognitive actions than the novice in terms of drawing, moving, and perceiving actions. In looking actions, the expert and the novice created similar percentages of meaningful actions.

4. Affordances

Norman (1998) refers to affordances as the perceived and actual properties of the things by which we can determine how things are used. Every object can be used for more functions than that of its designed purposes. This section reports on the characteristics of affordances in the designers' sketches that imply more functional references than initially given when created by designers.

4.1 THE NUMBER OF ATTACHED-FUNCTIONS IN ACTIONS

In our experimental data, most of the physical and perceptual actions have intended meaning attached when initially created, Table 1. Given that a D-action is isolated from other actions, there may be only one functional reference attached to it since one depiction without interpretation could have only one meaning. However, in our empirical data, a D-action might have more than one meaning attached to it when we included other related actions and observed them as a whole. Two examples are given as follows.

When the designer produced a new function-referencing depiction for a gallery next to an existing depiction, a pathway, he also perceived a spatial relationship. It was perceived between the new depiction, a gallery, and the old one, a pathway. In the same segment, he then attached a functional reference to the spatial relationship, saying that "this can create another world experience". Consequently, the new D-action had two functional references, one direct attachment and one indirect inheritance from the spatial relationship. The depiction has the meanings of a gallery and another world experience. In the second example, when reviewing his drawings, the designer introduced new functional issues into the existing depiction. It was a re-definition or re-phrasing of a function through L-action. In both cases, the D-action afforded more than one meaning.

We calculated the number of meanings attached to D-action, L-action, and P-action to verify our assumption of sketches as affordances in the design process. All these three kinds of actions need sketches as a medium to proceed, and sketches assist the function-referencing process.

The way we calculated this is based on single segments. For D-action, the number of functional references is determined by its own functional reference, and the functional references given by spatial relationships that depend on this D-action. For L-action, the number of functional references is determined by the functional reference of the targeted depiction of L-action, and that of the spatial relationships that depend on this L-action. For P-action, the number is determined by its own functional reference, and that of other spatial relationships that depend on this P-action.

In actions that have no function attached at all are excluded from this analysis. On average, there were more attached meanings to L-action and P-action than that to D-action for both the novice and the expert, Table 8. Although it is difficult to determine how different they are from drawing, we can still propose that revising depictions, L-action, and perceiving spatial relationship, P-action, help designers to handle and generate more functional issues.

Based on these results, we propose that a depiction has more than one meaning graphically and semantically after being created. It carries groups of meanings and relationships. Designers utilize this characteristic to generate different concepts and to reason about functional issues through sketches. Consequently, sketches become affordances of meanings in the design process.

TABLE 8. The mean, minimum, and maximum of the number of attached meaning of drawing, looking, and perceiving actions in the novice and the expert.

	Novice			Expert		
	D	L	P	D	L	P
Mean	1.156	1.359	1.188	1.350	1.756	1.419
Minimum	1	1	1	1	1	1
Maximum	3	3	3	4	4	4

This expert had a maximum of four attached functions in D-, L-, and P-actions, being one more than the novice. Although we need more data to conclude more generally, in terms of this case study it could be proposed that this expert had a better ability to attach functional issues than this novice.

4.2 UNDERSTANDING THE DESIGN PROCESS THROUGH SKETCHES

Given the sketches as affordances of meanings, an examination of sketches should provide clues to increase our understanding of the design process. The depictions in a design process could be shown as a series of physical drawing elements that increase with time. Replacing these elements by the functional meanings attached to them could create a series of conceptual elements. This could reveal the high-level thinking process in designing. The train of conceptual elements may be similar to Chan’s work that divided the design process in terms of problem solving (Chan, 1990). From it, we can see the order of the conceptual issues that have been used in an episode of designing, and how designers move in both problem and solution spaces.

In one sense, the design process could be regarded as information processing, and in another sense it could be regarded as reflection-in-action or conversations between designers and their design media. This study proposes a way to transfer the design process into an information process of functional issues through graphical elements. The design process is regarded as the hybrid process between seeing-moving-seeing and information processing and the oscillation between physical/perceptual actions and functions.

5. Conclusions

This paper proposed sketches as affordances of meanings in the design process. We analyzed protocol data of a novice and an expert to examine the roles of sketches using a cognitive content coding scheme.

First, we found that most of the drawing, looking, perceiving actions in our data were meaningful when they were initially created. There are statistically significant differences between those with and without attached functions. Second, the expert created more statistically significant meaningful actions than the novice in terms of drawing, moving, and perceiving actions. Third, we found perceiving and looking actions have more attached functions than drawing. We proposed that the depictions could afford more meanings when revised by designers.

Although we have only a very limited number of subjects, the results preliminarily show that sketches play important roles in the design process from various perspectives. They serve in the design process as the carrier of functional issues to help designers to generate more ideas and realize those ideas. Consequently, when we ask what architectural experts and novices perceive in their design sketches, functional issues may play equal or even more important roles than spatial relationships. The design process here is regarded as a visual spatial "reasoning" process in which spatial relationship and functional issues blend together to advance the design.

Finally, we had a very limited number of subjects, and therefore the results in this paper should be regarded as that in a case study. In calculating the number of functional references, we did not differentiate between the references attached during the creation of depictions and those of discoveries. This distinction may be explored in a future study to understand the differences between generation and interpretation of functional references.

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