The Comparison Between Novice and Expert Designers' Sketching in Conceptual Design.

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In many literature reviews, we find that sketching is confirmed as an activity of generating and developing ideas. The sketching activity is also a key factor of influencing idea generation. However, the focus of conceptual design is to develop the promising new concepts. We are primarily interested in finding a creation process and thinking by analysis of sketching activity in conceptual design. The aim is to support the validation of the importance of the sketch in conceptual design and to further explore an appropriate method for improving the efficiency of ideation activities. In addition, it is important to find the distinct differences between the novice and expert sketching activities during conceptual design. Through a cognition experiment and a protocol analysis, this study investigates four elements: the total number of sketches generated, the transformation interaction (lateral thinking and vertical thinking) within the sketching, the complexity of sketches, and three types of concept generation. With this information, we can propose the ideal approach for concept generation; furthermore, providing a method for interpreting novice and expert visible sketching in conceptual design.

The comparison between novice and expert designers' sketching in conceptual design

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Abstract

In many literature reviews, we find that sketching is confirmed as an activity of generating and developing ideas. The sketching activity is also a key factor of influencing idea generation. However, the focus of conceptual design is to develop the promising new concepts. We are primarily interested in finding a creation process and thinking by analysis of sketching activity in conceptual design. The aim is to support the validation of the importance of the sketch in conceptual design and to further explore an appropriate method for improving the efficiency of ideation activities. In addition, it is important to find the distinct differences between the novice and expert sketching activities during conceptual design. Through a cognition experiment and a protocol analysis, this study investigates four elements: the total number of sketches generated, the transformation interaction (lateral thinking and vertical thinking) within the sketching, the complexity of sketches, and three types of concept generation. With this information, we can propose the ideal approach for concept generation; furthermore, providing a method for interpreting novice and expert visible sketching in conceptual design.

Keyword: design thinking, idea generation, sketching, conceptual design

1. Introduction

Design sketch is a vital part of the conceptual stage of new product development (NPD) [Cross, 1999; Lawson, 1994; Pipes, 1990]. Designers largely use freehand sketching as the main way of communicating their ideas during conceptual design.

Conceptual sketches are quickly generated and are used to frame not only the designer's early ideas, but also to try to define, understand and solve the problem. Conceptual sketches of visual representation are very different from other types of drawings used in the final stages of design development, such as rendering and mechanical drawing for a formal presentation. Contemporary studies have attempted to shed light on the elements of sketching process by various methods and techniques.

1.1 Sketching in conceptual design

During the conceptual stages of design, sketch is widely used to express ideas, sometimes referred to as the medium of reflection-in-action. Sketches are representations that allow designers to quickly and economically experiment with new ideas on paper. In addition, the sketch possesses the potential to act as both facilitator and recorder of creative acts, presenting opportunities for improved evaluation and the restating of problems [Temple, 1994].

Ferguson identifies three distinctive kinds of sketch, namely the thinking sketch, the prescriptive sketch, and the talking sketch [Ferguson, 1992]. The thinking sketch is used to focus and guide non-verbal thinking. And the prescriptive sketch is made by a designer to direct a draftsman in making a finished drawing. Finally, the talking sketch is produced through the exchanges between designers and engineers while clarifying complex and possibly confusing parts of a drawing. So, the ability of the sketch is to communicate design proposals with others.

1.2 Typology of transformation

Goel discovers and defines the act of sketching. He identifies two types of operation occurring between successive sketches in conceptual design, namely lateral transformation and vertical transformation as shown in Figure 1 [Goel, 1995]. In a lateral transformation, movement is from one idea to a slightly different idea. However, a vertical transformation is said to occur when there is a progression to a more developed and detailed sketch based on the original one.

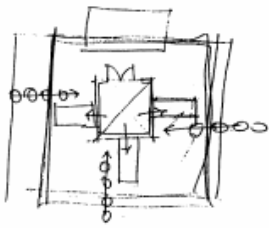
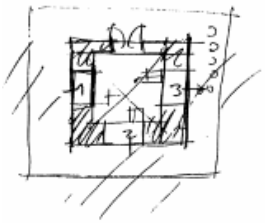
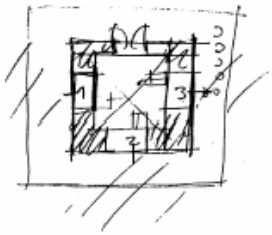
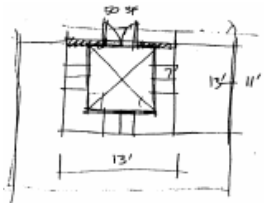
Lateral (divergent)	 **Figure A**	 **Figure B**
Vertical (convergent)	 **Figure B**	 **Figure C**

Fig.1 Lateral and vertical transformation examples [Goel, 1995]

Goel [1995] concludes that freehand sketches, by virtue of being syntactically and/or semantically dense and/or ambiguous, play an important role in the creative, explorative, open-ended phase of problem solving. He believes that the freehand sketch facilitates lateral transformations thereby preventing early fixation on design.

1.3 An 'ideal' approach

According to historical creativity and design research [Roozenburg, 1995; Cross, 1994; Pugh, 1991; Guilford, 1959], design activities in conceptual design should contain two kinds of steps: divergent and convergent (Fig. 2). [Liu & Bligh, 2003]

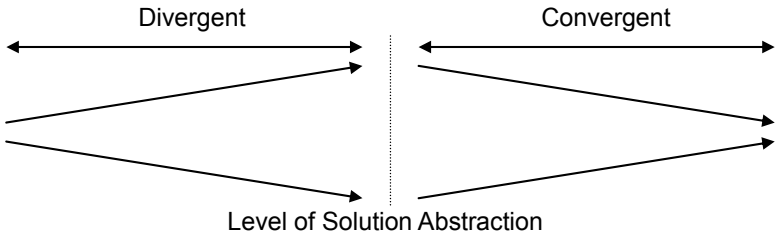


Fig. 2 The approach having a single divergent and convergent step [Liu & Bligh, 2003]

Various approaches have been suggested for supporting the initial generation of promising concepts. For instance, Cross [1994] characterizes the overall design as being convergent, but maintains that it also contains deliberate divergence for the purpose of widening the search for new ideas (Fig. 3). The breath of the search space after reaching its peak is gradually decreased as the design process continues. Also, Pugh [1991] mentions that it is essential to carry out concept generation and evaluation in a progressive and disciplined manner so as to generate progressively better designs. Figure 4 illustrates this method of divergent and convergent oscillation as the number of solutions gradually decreases. Two common features for the generation of promising concepts are found from Cross and Pugh's prescriptions: 1) the design should follow a multiple divergent and convergent approach; 2) the number of concepts is gradually decreased and only one or few solutions are left at the end of the design stage.

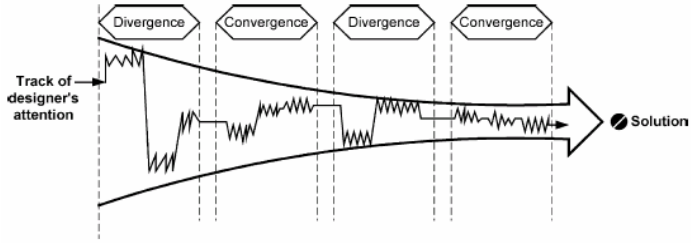


Fig. 3 The design approach characterized by Cross [Cross, 1994]

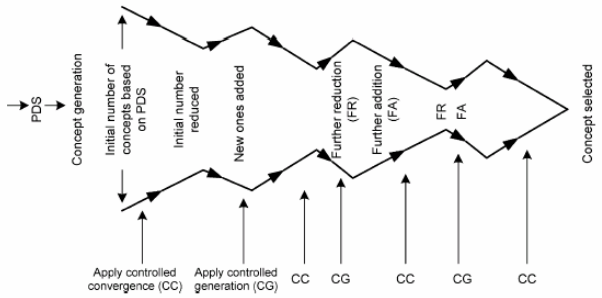


Fig. 4 Pugh's model to concept generation and selection [Pugh, 1991]

2. Method

In this study, three subjects participated in the experiment: two novice designers (A and B) and one expert designer (C). The novices each had three years of experience in product design and the expert had over nine years of experience in product design. Each of them was asked to ideate and sketch by himself for designing a computer mouse. This study was conducted by experimental method and conclusions were made through a qualitative analysis. The workplace was set in a lab with a video camera connected to a CRT terminal hidden in a neighboring observation room. The researcher remained in the observation room, recording the whole design process using videotape in a fashion as described in Purcell & Gero [1998]. The experiment was divided into two sessions, each one-hour, with a ten-minute break in between. In the first session, the subjects were allowed to freely sketch by themselves. However, in the second, they were guided by text hints.

The conditions of the first session were based on literature reviews and would be used as references for further studies. Here, all designers were asked to design a computer mouse without any given guidelines. In the second session, all designers were provided with the required specifications (wireless communication, with flash memory card, scrolling ball) and necessary attributes (easy to use, attractive, and small in size). Finally, all designers were asked to recall and report exactly what they were thinking while drawing each part of the sketch during a review session. They referred to their original sketches and the video recording to recall their thoughts while designing.

2.1 Definition: complexity of sketches

The approach adopted in this study required that the researcher identified each sketch in terms of complexity. Utilizing a method similar to that used by Goel [1995] the researchers identified the drawings

according to their generation sequence. (Fig. 5)

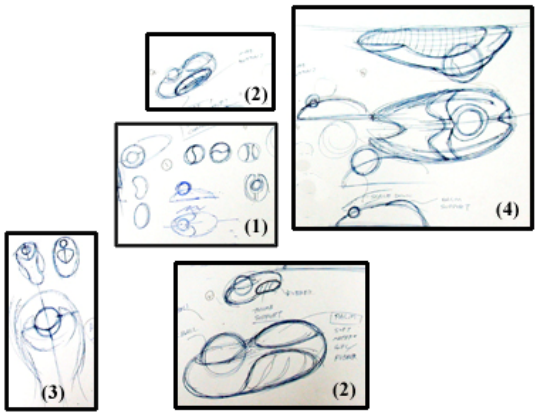


Fig. 5 Individuated sketches from Expert C's design.

Although Goel's [1995] work recognized that transformation had taken place, no measure of the degree of transformation was proposed. Such measurement would be helpful in tracking the design process and giving rank to the development of design. It may also help to measure the extent of lateral transformation, whether a small change or a complete conceptual shift. To measure the degree of transformation in the sketching process, a practical and straightforward scale was developed based on the complexity of each sketch. Typically, all designers' sketches were rated from one to five, with the simplest sketches rated as level one and the most complex ones rated as five. A more detailed definition of the complexity rating is outlined in Figure 6.

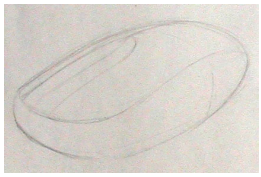
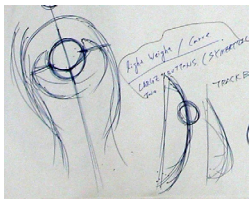
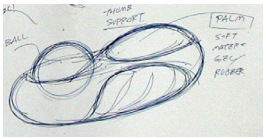
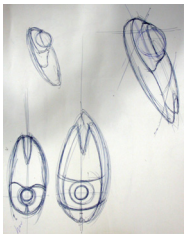
Complexity level 1	Complexity level 2	Complexity level 3	Complexity level 4	Complexity level 5
Monochrome line drawing. No shading to 3D form. No text or numerical annotations are used.	Monochrome line drawing. No shading to suggest 3D form, however the use of different thickness of line.	Monochrome, with rough shading used to give suggestion of 3D form. One or two brief annotations may appear, with not more than 6 or 7 words.	Subtle shading is heavily suggestive of 3D form. The drawing will almost certainly be annotated. Color may be used to illustrate certain parts of the concept or arrangement.	Extensive use of shading to suggest 3D form. Annotation will be used to ask questions of the idea or explain it. Detailed design and well mechanism. Color will be heavily used.
				

Fig. 6 Complexity scale of sketches

3. Results and Discussion

This section presented the results of all designers' sketching activities and design approach. The results consisted of four elements in this experiment. First, we found that the quantity of sketches produced by novices A, B and expert C over the two sessions differed. Second, we identified the occurrence of transformation interaction (lateral thinking and vertical thinking) within the produced sketches. Third, we found three types of concept generation and ideal approach. Fourth, using Goel's method, the complexity of sketches generated by both group of designers are mostly ranked in the middle complexity levels (levels 2-4). Finally, we analyzed the relationships between these four elements and obtained useful insight into the comparison of the novice and expert designers' sketching in conceptual design.

3.1 The number of sketches

As part of the study, the number of sketches produced by each designer in each session was tabulated. The results showed that the numbers of both novices' sketches decreased gradually over the two sessions. Moreover, novice A first produced 9 sketches and then 3, while novice B first produced 15 sketches and then 8 in the first and second session respectively (Fig. 7). It was worth noting however that as the quantity decreased, the detail and the complexity of both novices' sketches increased. During both sessions, the content of the drawings gradually included annotations and multi-angle descriptions. Furthermore, both novices described and drew the outline of scenario images in the second session.

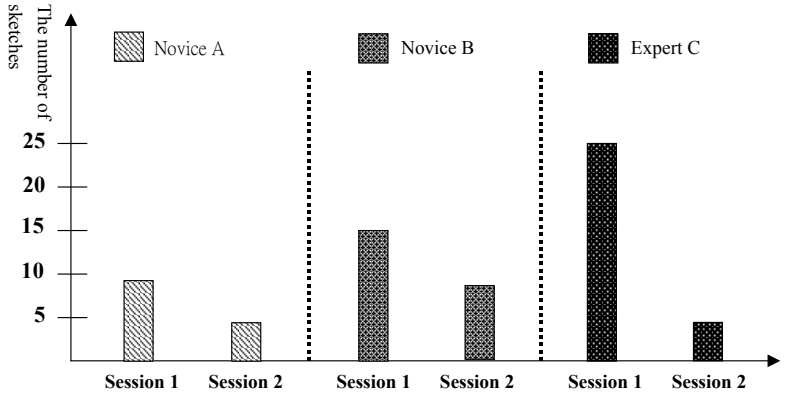


Fig. 7 Number of sketches for Novice A, B and Expert C

Expert C's number of sketches illustrated the same trend as the two novices. Expert Cs' sketches produced 25 sketches and then 4 in the first and second session respectively (Fig. 5). But, we found that expert C produced in the first session more than two novices did. Besides, for expert C, the ratio of decreasing is shaper than two novices in the number.

3.2 Transformation activity—lateral and vertical thinking

As part of the study, each designer's successive sketches were classified by whether they employed a lateral or a vertical transformation. Session by session, the ratios of each designer's sketching activity in terms of adapting lateral and vertical transformations over the observation period was calculated. Figure 8 showed the respective results from novice A, B and expert C's transformation strategies. Through this figure, it could be seen how each designer adopted a lateral or a vertical transformation in their design. Referred to Figure 7 for the quantity of sketches produced in each session by the designers.

Novice A exhibited a balance between lateral and vertical transformations (i.e. 50: 50%) in the first and second session. Novice B showed a notable bias towards vertical thinking over each of the two sessions. Expert C produced a good number of sketches in the first session. He started with a good balance between lateral and vertical transformations (i.e. 50: 50%). However, during session 2, he displayed a tendency to produce vertical work. Overall, we found three transformation activities during the two sessions respectively: novice A's work displayed a 50: 50% transformation; novice B's work showed a dominant tendency towards vertical activity and expert C's work displayed a 50: 50% transformation start with alternate switching a vertical mode.

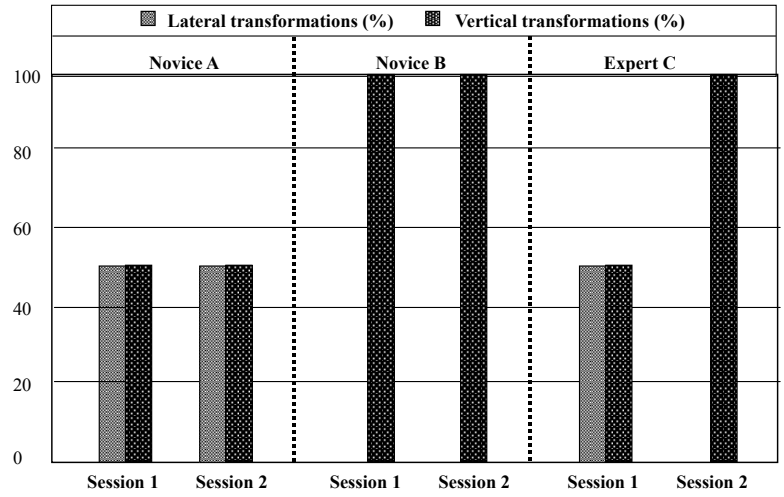


Fig. 8 Lateral and vertical transformations for Novice A, B and Expert C.

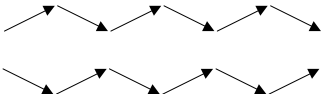
The overall result may be more helpful within the context analyzing each designer's thinking process. Overall, this figure illustrated that novice B displayed a dominant vertical bias while novice A and expert C were 50:50% between lateral and vertical transformations.

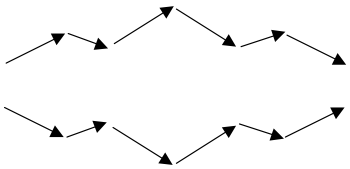
3.3 Activities for divergence and convergence

3.3.1 Types of concept generation

In many cases, transforming solutions from one abstract solution level to the next more detailed level is a synthesizing step in itself. This is because when one abstract solution is converted into a more detailed solution, alternative possibilities surface. There are two kinds of steps: divergent and convergent design approaches to concept generation [Liu & Bligh, 2003]. From this study, three types of concept generation are developed to be a practical and straightforward solution search mode to trace designers' approach for concept generation. Typically, each designer's concept generation can be classified into one of three types. We name three types of concept generation as oscillating-parallel search, linear search and expanding-contracting search. A more detailed definition for each type of concept generation is outlined in Table 1.

Table 1 Three types of concept generation

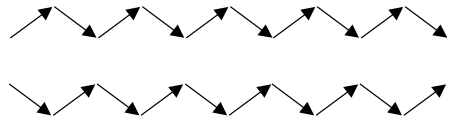
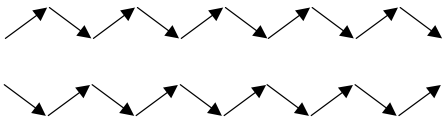
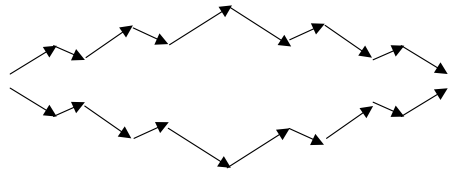
Three types of concept generation		
Oscillating-Parallel Search		The progressive manner is to carry out divergent and convergent activities in each level of solution search. This contains a number of concepts to be generated at each solution level (divergent step), immediately followed by a screening of these concepts (convergent step). But the breath of the search space is always the same as or bigger than the design process continues.
Linear Search		From start to end, the progressive manner is dominated as a convergent process. And to explore more detail or accurate function, form, usability and ergonomics on the same concept solution

Expanding-Contracting Search		This progressive manner is illustrated as an iterative, repeated divergent and convergent process with the number of solutions gradually decreasing. The breath of the search space after reaching its peak gradually decreases as the design process continues.

3.3.2 The approach for concept generation

This study analyzed the approach for concept generation by classification presentation in this study. This study found that each designer's approach was very different for generating concept during the two sessions illustrated in Table 2. Novice A adopted an oscillating-parallel approach and novice B adopted a linear approach during two sessions. Novice A couldn't narrow down solutions by screening, but with a divergent and convergent activity. Besides, novice B adopted a single convergent step and restricted his new designs with start. Comparatively, expert C adopted two kinds of approaches during these two sessions. These approaches were expanding-contracting search and linear search respectively. However, the expert's approaches for concept generation showed a learning curve.

Table 2 Novice A, B and expert C's approaches for concept generation

The approach for concept generation		
	Session 1	Session 2
Novice A		
Novice B		
Expert C		

3.4 The complexity of sketches

This study analyzed the complexity of sketches using Goel's method [Goel, 1995]. Generally speaking, the complexity of each designer's sketching activities was ranked at a middle range of complexity (levels 2-4). However, each sketch illustrated an increase in complexity (Fig. 8). Additionally, this study also found that all of two novices' sketches contained little details and annotations (low complexity) in the first session. In the second session, however, their sketches contained phrases describing the content of each sketch. Comparatively, the expert's sketches during these two sessions utilized details and annotations.

Based on the quantity of the sketches and the complexity of each sketch, the results exhibited a negative relationship between these two elements. Furthermore, the number of sketches and lateral thinking had an overall positive relationship. Moreover, we found that the complexity of expert C's sketches were higher than the two novices' during each of the two sessions.

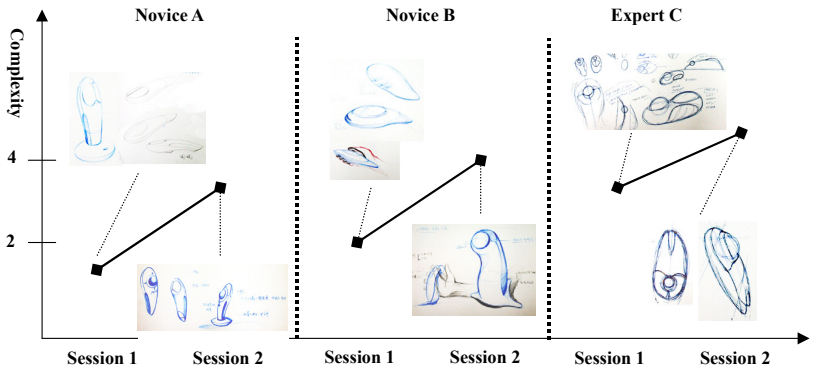


Fig. 10 Novice A, B and Expert C's sketch complexity activities

4. Conclusions and future studies

We have got the progressive findings from the study of the sketch in industrial design process [Chen, You & Lee, 2003] to this study. In 2003, Chen, You & Lee employ three elements: the total number of sketches generated, the transformation interaction and the complexity of sketches to interpret the sketching activity in conceptual design. Up to now, in this pilot study, we further explore the differences between the novice and expert visible sketching and find three approaches for concept generation.

In this pilot study, first, application of freehand sketch and cognition process adopted between experts and novices have been preliminarily probed. Potential feasibility of freehand sketch applied in concept development is once again evidenced. Second, the complexity of expert's sketch is higher than novice's and expert has a good balanced transformation activity for concept generation. Third, expert's solution space is bigger obviously than novices. Expert owns a good ability on problem-defining and product specification. On the contrary, novices can't configure out their ideas clearly during concept generation. Moreover, we find that the factor "experience" seems to influence this difference from recalling data. Fourth, this study discusses a possible "ideal" approach for the development of concepts, in which a process of repeated divergent and convergent, is used. Two novices and one expert adopt different approach for concept generation. But expert's strategy is an ideal and optimizing approach for concept generation as Cross and Pugh [Cross, 1994; Pugh, 1991] described. It is worth noticing and exploring that novices how transform themselves into experts and engage themselves into the design field. Finally, this pilot study provides effective metrics to interpret and trace designers' sketching activities. Also, this study may be expanded to utilize a setting where greater amounts of noise and more information are incorporated.

Metric one: The quantity of sketches

The quantity of sketches is means to evaluate the fluency of a designer's ideation. The more the sketch, the higer the fluency; vice versa. This metric of the quantity of sketches is the same as Torrance proposed to evaluate the creativity in 1965.

Metric two: The model between vertical thinking and lateral thinking

It focuses on the clarification of design problem. We found that the more the lateral thinking, the more space of vagueness to research. On the contrastly; the more the vertical thinking, the less space to research it. But it shows a designer understand the design problem well or not. This metric is the same as the flexibility that Torrance proposed in 1965.

Metric three: the complexity of sketches

It refers to an understanding of design object and design specification. The higer the complexity, the higer the understanding; vice versa. The metric of the complexity of sketches is the same as theelaboration that Torrance proposed in 1965.

Metric forth: The approach for concept generation

These approaches are classified into three kinds of search: oscillating-parallel search, expanding-contracting search and linear search respectively. In this pilot study, we find that novice and expert adopted different approach for concept generation respectively. It shows that the thinking model of ideation is very important.The above-mentioned are the effective metrics and methods to evaluate and trace the designers' sketching behaviors in conceptual design.

Freehand sketch media influence cognitively sketching modes of expert and novice designers. Based on this pilot study, future studies will be proposed to delve into the difference of conventional media and computer media between novices and experts in conceptual stage. Purcell and Gero (Purcell and Gero, 1998) also suggest that ambiguous and unorganized sketches be considered pivotal elements that affect design creativity. Yet, correlation between creativity and sketching analysis system is not covered in this study and is yet to be explored in some future studies.

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