ELSEVIER

Automation in Construction 10 (2001) 319–325

AUTOMATION IN CONSTRUCTION

www.elsevier.com/locate/autcon

The comparison between visual thinking using computer and conventional media in the concept generation stages of design

P.-H. Won

Graduate Institute of Applied Arts, National Chiao Tung University, Hsinchu, 30050, Taiwan

Abstract

The computer, the new media, reaches out and influences the behavior of design as it does almost every facet of life. In recent years, much research into the development of computer-aided design has looked at the concept generation stage of the design process. Most of these applied studies have focused on the testing of computer systems. On the other hand, there are also many studies on the visual thinking and cognitive behavior of designers while sketching or drawing in the stage of concept generation. From the synthesis of the two aforementioned disciplines, we can find that there exists a point of deficiency. That is, the cognitive research about designers using computers as sketching media is absent. It is this area that is discussed in the current paper. The fundamental analytic data of this research is the visual process chronicled from the sketching of subjects. The analytic data is the verbal data from the questions that the subjects are asked after sketching. The data is analyzed using three coding schemes. The cognitive appearance while designers generating concepts with computers or conventional media are propounded and discussed in this research. © 2001 Published by Elsevier Science B.V.

Keywords: Concept generation; Sketch; Visual thinking; Computer-aided design

1. Introduction

Design has been discussed widely. Some scholars pose that there are several stages to analyze a design process; analysis, concept generation, preliminary design and detail design [1–3]. The concept generation stage, which is the so-called black-box [3,4] belongs to the beginning of the design process. While there are some methodological studies about this aspect, such as the synectics method [5] and the brainstorming method [6], many researchers have posed the importance of sketching or drawing at the concept generation. Drawing is obligative for designers and usually the only modeling way to form their thinking [7] and sketching is ubiquitous [8].

Among research about sketching, most studies have investigated visual thinking. The relation between drawing and thinking is clarified and pointed out that drawing is the fastest and the most effective way to visualize the thinking of designers [9]. Visual thinking is separated into three behaviors; seeing, imaging and drawing [10]. A series of researches divide the design process into 'moves' and 'arguments' [8,11–14]. Arguments within moves can be of two types, 'seeing as' (SA) and 'seeing that' (ST). On the other hand, protocols of designers are analyzed and argued that design is composed of the serial, 'seeing–moving–seeing' [15].

As a new theme, computer-aided design has had a large impact on traditional design. New areas have

0926-5805/01/$ - see front matter © 2001 Published by Elsevier Science B.V.
PII: S0926-5805(00)00048-0

opened up, such as shape grammars [16–18], knowledge-based systems [19], expert systems [20] and database system design [21,22].

Within most research, the applications of computer-aided design have mainly been restricted to the latter stages of the design process. But, in recent years, the concept generation stage of computer-aided design has seen increased attention. A kind of shape modeling computer system is developed for industrial designers [23]. One interactive computer system is introduced for displacement features of shape of products [24]. These researches all break the standpoint that computer-aided design cannot match the design sketching [25].

The major background to this research is two inferior disciplines — computer-aided design and visual thinking while sketching. The stage of concept generation is the problem statement.

The computer system called the 'displacement features function' [24] is a typical example of research into computer-aided conceptual design at present. This system can indeed support industrial designers in designing displacement features of sculptured product surfaces in the stage of concept generation. But the important visual thinking of sketching is only briefly touched. After positive responses to this kind of application research, research into the cognitive thinking of designers should be pursued. This is one major source of the problem statement of the current research. In addition, in a series of papers, the role sketching plays is discussed within the design process [8,11–14]. The design process is divided into two types — 'moves' and 'arguments', sketching can be directly related to moves. Arguments within moves can be of two types — ST and SA which are directly related to sketching activities. This research program has a critical attitude toward visual thinking within designer's sketching. At present, while computer-aided design is flourishing, researches dealing only with sketching using conventional media, pens and papers, seem somewhat deficient. This is the other major source of this paper's problem statement.

The absence of discussion about cognition of designers in the field of computer-aided design and the deficiency of using computers as sketching media while generating concepts poses a number of questions in the field of cognition or visual thinking.

The major question of this research is: when designers use the computer as the sketching media in the stage of concept generation, will cognition and visual thinking be the same as when using conventional media? If there are differences in behavior between the two kinds of media, what kind of differences will there be? The minor question is: if designers use these two kinds of sketching media in the concept generation stage, will there be design performance differences? In other words, the author would like to understand the phenomena of cognitive visual thinking of designers and representations of designs or drawings while sketching with two kinds of media in the stage of concept generation.

2. Methodology and steps

The research is consisted of three parts. In part one, a hypothesis is suggested; while designers generate concepts using computer or conventional media, their cognitive visual thinking will be different. In part two, two experiments are conducted. One designer as subject A is asked to generate concepts with conventional media, such as pens, rulers and papers. The purpose of conducting the first experiment is to know the cognitive visual thinking of designers in the stage of concept generation in the traditional way. Likewise, the other designer as subject B is asked to do the same task as subject A, but using computer as the media. The purpose of the second experiment is the same as the first one, only in a computer-aided way. After these two experiments are completed, the third part of the method is the analysis of the results from those experiments. The major analytical source is the visual data from experiments, and the supporting data is the verbal data of the questions that subjects were asked after the experiments. Before the experiments, the warm-up experiments should be accomplished to prove that the chosen subjects are suitable for the experiments.

2.1. Hypothesis

The major objective of this research is to find out the cognitive phenomena of designers while generating concepts using two different tools as computers and conventional media. The hypothesis raised is

that when designers use computer to generate concepts, some visual cycle such as the S–I–D will appear more frequently for the stronger visual feedback of computer.

2.2. Experiments

2.2.1. Experiment one: conventional media

This experiment is with respect to the behavior that designers generate sketches while using conventional media in the concept generation stage. It is done according to the traditional sketching method, not concerning about computers. The objective is to discuss the cognitive behavior of designers generating concepts in this traditional way.

1. Subject A: An industrial designer who has perfect ability of generating concepts and using conventional media, and has been educated with more than 3 years of industrial design.
2. Topic: the shelf, which has simple elements, is easy to handle and allows much space for design.
3. Tools: papers, pens and rulers. Two types of transformations can be identified in the drawing [2]. There are lateral transformations where there is movement from one idea to a different one, and vertical transformations where one idea is transformed to a more detailed one. Most lateral transformations occur in the preliminary design phase. Based on this argument [2], the subjects are asked to generate lateral ideas during these two experiments.
4. Process: subject A is asked to generate 5–7 lateral idea sketches fitted the demand of the experiment. Besides, each idea should be preliminary shading.
5. Time: One hour for Subject A to generate idea sketches. Before the subject starts to generate, the demand of the experiment is described to Subject A, and he is allowed to think for 30 min. In the other half an hour after the concept generation phase, Subject A is asked some specific questions about his sketches for the supporting data of analysis. The total time taken is 2 h.
6. Recording Process: During the experiment, Subject A is recorded by video recorder. A digital camera is used to catch visual image per minute. After the experiment, Subject A is asked some specific questions about his sketches.

After experiment one, the cognitive behavior of the designer while using conventional media generating concepts is studied. After the experiment is conducted in the traditional way, the experiment in the computer-aided way in the same degree should also be discussed.

2.2.2. Experiment two: computer media

This experiment is about the behavior that designers generate sketches while using computer media in the concept generation stage. It is done according to the new computer-aided sketching method, not concerned with the conventional media. The objective here is to discuss the cognitive behavior of designers generating concepts in the computer-aided aspect.

1. Subject B: An industrial designer who has perfect ability of generating concepts and using computer, and has been educated with more than 3 years of industrial design.
2. Topic: The same as Experiment one.
3. Tools: Hardware (Pentium II 300 computer, 19 inch monitor, keyboard and mouse), Software (Pro-Engineering)
4. Process: The same as Experiment one.
5. Time: The same as Experiment one.
6. Recording Process: The same as Experiment one.

2.3. Analysis

The major analytical data of this research is the visual data recorded from experiments one and two,

Table 1
Three coding schema

Coding scheme	Clarification	Source
S–I–D	S: seeing I: imaging D: drawing	Mckim [10]
SA–ST	SA: seeing as ST: seeing that	Godschmidt [8,11–14]
T–D	T: total D: detail	the author's deduction

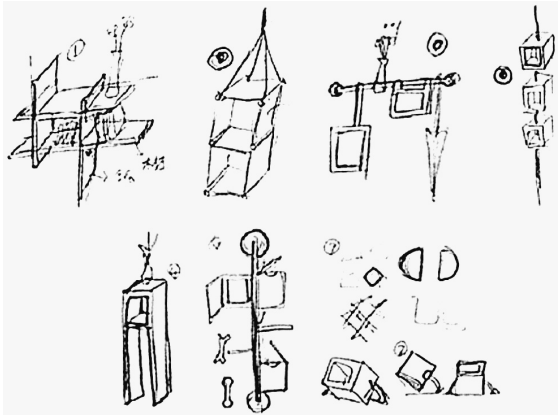

Fig. 1. Seven wireframe sketches generated by Subject A.

and the supporting data is the specific questions which are asked after the concept generation phase. This is the research dealing with visual process but not with verbal process. The reason why the visual process is chosen for the analytical data is that it is a tough task to ask the designer to generate concepts with computer. If the designer is asked to think aloud while doing this tough task, the result of the experiment will be easily disturbed. For this reason, visual data is decided to be used as the analytical data. In addition, because of the difficulty of getting visual data, a photo is taken with a digital camera every minute. And the entire process of the experiment is recorded by video recorder in order to prove that the visual data is valid.

Additionally, some absent aspects would exist for the mere consideration of visual data as analytical source. Verbal data is, therefore, used to aid visual data. The verbal data is from the specific questions that are asked by the author after the sketching phase.

The author uses three kinds of coding schemes (Table 1) to analyze the major visual data and supporting verbal data. Two schemes come from the background review, which include the cycle of S–I–D [17] and two types of arguments – SA and ST [6–10]. The other is the deduction about 'total' and 'detail' of sketches from the author. 'S–I–D' represents 'seeing–imaging–moving', 'SA–ST' represents 'seeing as–seeing that' while 'T–D' represents 'total–detail'.

During the process of generating concepts, Subject A generates 7 wireframe sketches (Fig. 1) for the first 23 min and uses the remaining time to make preliminary shading with conventional media. In the author's opinion and the discussion with Subject A herself, the behavior about shading has little relation about visual thinking, so the coding data of experiment one is the first 23 min. Besides, Subject A generates 5 wireframe sketches (Fig. 2) in 60 minutes by the computer. But for the auto-shading property of Pro-Engineering (the experimental software),

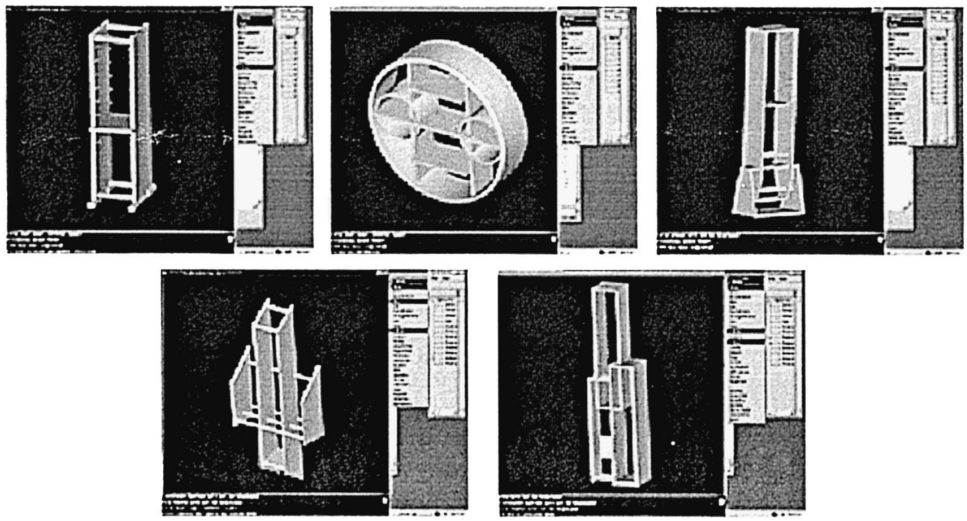

Fig. 2. Five wireframe sketches generated by Subject B.

Subject A has not used the remaining time to shade. Not only for the contraction of the coding data of Subject A, but to avoid the unfamiliarity and tiredness of Subject B, the author chooses the 23rd to 52nd minutes for 3rd and 4th sketches to be that of Subject B.

3. Cognitive phenomena of visual thinking

This section contains both the recording and coding results of two experiments and some sketches of two subjects during the phase of concept generation. The author uses three coding schemes to analyze the major visual data in the sketching process of two subjects. The relation between the coding result of two subjects and the time can be produced as a table.

Figs. 3–5 represent the relation between the coding result and the time of subject A and B who generate concepts with conventional and computer media. From the representation of these three figures, we can clearly see the shifting times and amounts of cognitive behavior of the two subjects. With the convenience of pens and papers, subject A can generate a rough sketch in a short time. With the immediate visualized feedback of computer however, subject B would generate a more concrete sketch in a longer time.

Firstly, in Fig. 3, regarding the aspect of S–I–D, subject A spends more time 'drawing' than 'seeing' and 'imaging' (Fig. 3a) while subject B spends more time 'imaging' and 'drawing' than 'seeing' (Fig. 3b).

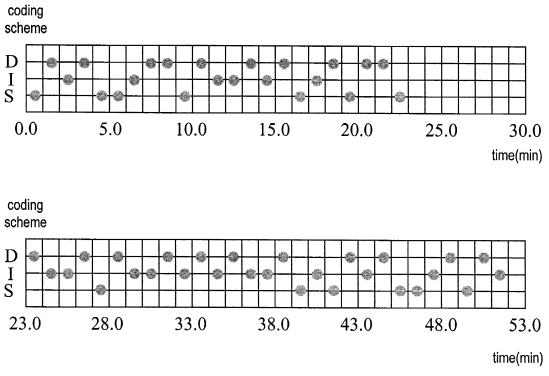

Fig. 3. The result of first coding schema — 'S–I–D'. (a) S–I–D coding result vs. time of subject A. (b) S–I–D coding result vs. time of subject B.

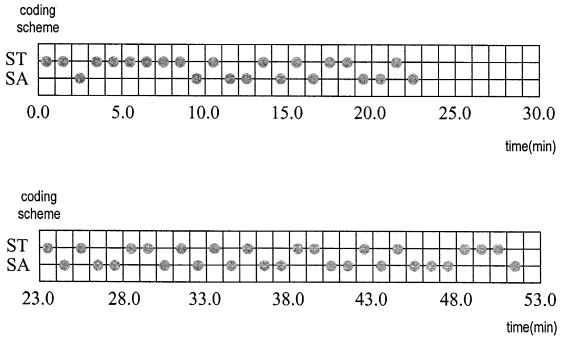

Fig. 4. The result of second coding schema — 'SA–ST'. (a) SA–ST coding result vs. time of subject A. (b) SA–ST Coding result vs. time of subject B.

Secondly, in Fig. 4, regarding the aspect of 'seeing as-seeing that' (SA–ST), subject A spends more time ST than SA, and the standing time of SA is rarely long (Fig. 4a). Subject B spends almost the same time SA as ST, but the standing time of SA is longer than that of subject A (Fig. 4b).

Thirdly, in Fig. 5, regarding the aspect of 'total–detail', subject A spends more time on the concentration of 'total' than 'detail' (Fig. 5a), likewise the standing time of attention on 'detail' is usually not long. Subject B spends almost the same time on the concentration of 'total' as 'detail' (Fig. 5b), but the dissimilarity is that the standing time to 'detail' is more than that of 'total'.

The author, thus, interprets that the visual cognitive behavior of the designer when he/she uses conventional media is a stable process. And the

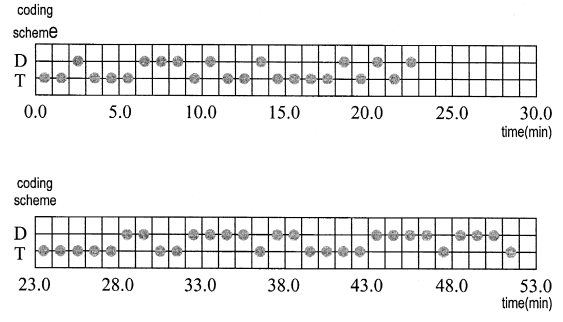

Fig. 5. The result of third coding schema — 'T–D'. (a) T–D coding result vs. time of subject A. (b) T–D coding result vs. time of subject B.

behavior of seeing, seeing-that and concentration on detail here are more important than imaging, seeing-as and detail. Moreover, the visual cognitive behavior of the designer when he/she uses computer is a more changeable process, and the visual thinking of imaging, seeing as and concentration on detail here are more important than others.

The dissimilarity of visual cognitive behavior of two subjects comes from the different media they use to generate concepts. Not only would the cognitive behavior be different, but also the representation of sketch or drawing would have some specific phenomena for the characteristics of two media. The particular description will be discussed in Section 4.

4. Conclusions

From the result of the analysis of visual and verbal data of experiments, the author derives some cognitive phenomena of designers while he/she generates concepts with computer or conventional media.

When a designer uses conventional media as tools to generate concepts or ideas, his/her cognitive behavior is simpler than he/she who uses computer. First of all, after the designer has been told the principles of the design case, he/she begins to generate some ideas in his/her mind. This period of process should be 'stimulus' and then 'thinking'. Afterward, the designer will use pens, drawing or sketching on the paper, and this phase is referred to 'drawing'. During the process while the designer draws, he/she will see the representation of sketches on the paper, and sometimes when the designer concentrates on some specific figural properties of this kind of 'seeing' behavior, he/she will see the image as something else. The shift of 'seeing' and 'seing as' will stimulate the designer to generate some 'imaging' in his/her mind. Sometimes, the focus of the designer will shift from the 'total' to the 'detail' of the sketch, but the shifting time does not last long. The cycle of these cognitive behaviors will not stop until the task about generating sketch is well done.

On the other hand, when a designer uses the computer media to generate concepts or ideas, his/her cognitive behavior is much more complex than the traditional method. Firstly, after the designer has been told the principles of the design case, he/she begins to generate some ideas in his/her mind. This period of process should be 'stimulus' and then 'thinking'. The forepart is just the same as in the traditional way. Then the designer will use the keyboard and mouse to draw or sketch on the monitor, and this phase is referred to as 'drawing'. Among the movements of drawing, the designer will gaze the figural properties of sketches on the monitor, and he/she will easily see the representation as some kind of image for the intensive visualization of computer. The shift of 'seeing' and SA will stimulate the designer to generate some 'imaging' in his/her mind in the same way as with the traditional method, but stronger and more frequent. Likewise, the attention of the designer will shift from the 'total' to the 'detail' of the sketch, but the shifting time is much more frequent and stands longer than in the traditional way. The cycle of these cognitive behaviors will also continue until the task about generating sketch is well done.

Besides, from the representation of the visual result of experiments, there are some appearances of sketches or drawings. Firstly, on the aspect for the amount of generating concepts, the designer can generate more concepts when he/she uses conventional media than computer. The reason is the deficiency of present computer systems. Secondly, for the representation of preliminary sketches or drawings, the stroke representing the traditional way is rough while that of the computer-aided way is concrete. That is because of the characteristic of these two different media. Thirdly, on the aspect for shading of sketches or drawings, the designer can easily use the computer system (Pro-Engineering) to generate image with immediate shading, and that is the shortcut of the conventional media such as pens and papers. For the immediate visualized feedback of computer, the designer can easily be influenced to form some imaging in his/her mind. However, that is the critical point of a computer system when the designer uses it as a tool to generate concepts. Furthermore, the significant point is just the reason why the visual thinking of cognition of the designer will be different while he/she uses a computer to generate ideas in the stage of concept generation.

References

[1] N. Cross, Engineering design methods, Strategies for Product Design,1989, Chichester.
[2] V. Goel, Sketches of Thought, MIT Press, Cambridge, MA, 1995.
[3] J.C. Jones, Design Methods (1970).
[4] P.G. Rowe, Design Thinking (1987) 43–46.
[5] W.J.J. Gordon, Synetics: The development of Creative Capacity (1961).
[6] A.F. Osborn, Applied Imagination (1963).
[7] J. Lansdown, Computers and Visualization of Design Ideas: Possibilities and Promises, caad'87 futures, Elsevier, 1987, pp. 77–80.
[8] G. Goldschmidt, The dialectics of sketching, Creativity Res. J. 4 (1991) 123–143.
[9] B. Archer, Lecture delivered at Manchester Regional Centre for Science and Technology, 1976.
[10] R.H. Mckim, Experiences in Visual Thinking, Stanford, Wadsworth, 1980.
[11] G. Goldschmidt, Problem representation versus domain of solution in architectural design teaching, J. Archit. Plann. Res. 6 (3) (1989) 204–215.
[12] G. Goldschmidt, Serial sketching: visual problem solving in designing, Cybemetics Syst.: Int. J. 23 (1992) 191–219.
[13] G. Goldschmidt, On visual design thinking: the vis kids of architecture, Design Stud. 15 (1994) 158–174.
[14] G. Goldschmidt, Visual displays for design: imagery, analogy and databases of visual images, Visual Databases in Architecture: Recent Advances in Design and Decision-making (1995) 53–76.
[15] D.A. Schon, G. Wiggins, Kinds of seeing and their structures in designing, Design Stud. 13 (1992) 135–156.
[16] U. Flemming, More than the sum of parts: the grammar of Queen Anne Houses, Environ. Planning B 4 (1987) 323–350.
[17] G. Stiny, Introduction to shape and shape grammars, Environ. Planning B 7 (1980) 343–351.
[18] G. Stiny, W.J. Mitchell, The Palladian grammar, Environ. Planning B 5 (1978) 5–18.
[19] Y.-T. Liu, Schematic-designer: a knowledge-based CAD system for schematic design in architecture, Design Stud. 12 (3) (1991) 151–167.
[20] T. Jindo, K. Hirasago, M. Nagamachi, Development of a design support system for office chairs using 3-D graphics, Int. J. Ind. Ergon. 15 (1995) 49–62.
[21] L. Candy, E. Edmonds, Creative design of the Lotus bicycle: implications for knowledge support systems research, Design Stud. 17 (1) (1996) 71–90.
[22] W. Muller, G. Pasman, Typology and the organization of design knowledge, Design Stud. 17 (2) (1996) 111–130.
[23] C.G.C. van Dijk, New insights in computer-aided design, Design Stud. 16 (1) (1995) 62–80.
[24] P.A. Elsas, J.S.M. Vergeest, New functionality for computer-aided conceptual design: the displacement feature, Design Stud. 19 (1998) 81–102.
[25] M.J. Tovey, Drawing and CAD in industrial design, Design Stud. 10 (1) (1989) 24–38.