1. Introduction

It is commonly believed that idea sketches play key roles in a design process.[1] And the design process consists of a series of goal-directed problem solving activities, which are relied upon insufficient information. In order to generate some sketches, we deal with various design information.

Research on the visualization of conceptual thinking is expected to build the bases for design practice and for the development of computer tools to support sketch-based design.

In relation to this, it is now widely recognized that design problems are ill-defined, ill-structured, or wicked’[2] An ill-defined problem is one in which the requirements, as given, do not contain sufficient information to enable the designer to devise any ways and means of meeting those requirements simply with the given information alone. Lawson suggested that design is a process which must lead to a prescriptive rather than descriptive conclusion and in a situation in which there will be no one recognizable correct or even optimal answer.[3]

On the other hand, Nigel Cross described that the central concern of design is ‘the conception and realization of new things’, and through modeling as a design language the concept is embodied into an object. In addition, Bruce Archer argued in his paper (‘design as a principle’) that a
model is a representation of something in design. After some reviews of previous suggestions, we have recognized that design is a prescriptive problem solving activity to realize its concept under insufficient design information.

In terms of design practice, it is important to understand the communication between the designer and the persons concerned with the design project. We agreed and gave attention to Nigel Cross's standpoint that the designer's use of models and 'codes' that rely on graphic image – i.e., drawings, diagrams and sketches that are aids to internal thinking as well as aids to communicating ideas and instructions to others.

2) How can we extract idea sketches using the graphic tablet?
3) Does the type of design information make any significant differences of influences on graphic thinking?  
   a) idea sketches with verbal and/or visual information  
   b) idea sketches with concrete and/or abstract information

2. Idea Sketches as a Graphic Thinking

Graphic thinking is a basic tool to solve problems or thinking creatively in design. Especially, an idea sketch is a typical example of the graphic thinking. We have recognized that the essential concern of design is 'the conception and its realization, and there are a number of idea sketches which are media to connect those two things and explore ideas simultaneously.

Sketches are direct and representative because they have a great amount of information, which include the showing relationships and describing a wide range of subtleties. According to Arnheim, the power of visual language lies in its spontaneous evidence.

Lawson suggested that visual thinking is a form of thinking that uses the products of vision - seeing, imaging, and drawing. Verbal thinking and visual perception have a close relation each other. When thinking becomes externalized in the form of a sketched image, the graphic images are produced.

As shown in Figure (1), there are three types of images; graphic, perceptual, and mental images. When we start to do idea sketch, we just draw an image on the paper, which is a graphic image. As pointed out by Paul Laseau, depending on our experience, interests, and what we are trying to do, we will see certain things take and/or leave something in the sketch, which is a perceptual image. Next, we form a mental image to further reference and give them orientation from this perceptual one. When this mental image is transferred to paper once more, it goes through yet another changes for the design development [4].
Mental images derive from optical percepts, but they are not identical copies of them.[5] They differ from the optical percepts recorded by the eyes by their reduced intensity. They are fugitive, easily wiped off the slate of memory and, therefore, they offer a freedom not granted to optical percepts, especially in their dealing with space. Mental images can handle visual objects as thought they were weightless. A sketch is a reflection of the guiding mental image; but it is not identical with it. There is iteration when it is needed for the project.

We are communicating with sketches at the stage of conceptual design. The process of graphic thinking can be seen as a conversation with ourselves. The communication process involves the sketched image on the paper and the human body (the eye, the brain, and the hand). (Table 1) From this apparently closed network, new ideas are generated. The potential of graphic thinking lies in the continuous cycling of information-laden image from paper to eye to brain to hand and back to the paper. Theoretically, the more often the information is passed around the loop, the more opportunities for change.[6]

<table>
<thead>
<tr>
<th>Table 1. Graphic thinking process &amp; human body</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Image on paper/graphic tablet</td>
</tr>
<tr>
<td>Perceptual image</td>
</tr>
<tr>
<td>Mental image</td>
</tr>
<tr>
<td>Image on paper/graphic tablet</td>
</tr>
</tbody>
</table>

Graphic thinking is regarded as an externalized thinking. Graphic thinking as a visual thinking can open up channels of communication with us. Laseau argued that the sketches generated are important because they show how we are thinking about a problem, not just what think about it.[7] In this sense, it can be said that a sketch contains its design thinking.

Arnheim discussed that the creative process of designing, being an activity of the mind, cannot be directly observed. The sketches, done for the eyes and directed by them, make some of the design plans visible. For communication within designer (private level) and with other person concerned (public level), the sketches are used very useful. However, the level of representation is not always concrete and perceptual ones during the sketching under a given goal.

On the other hand, Paul Stevenson Oles has illustrated the scope of visual communication as a field whose boundaries are identified by the opposing extremes of four differentials: abstract-concrete, private-public, conceptual-representational, and diagrammatic-perceptual.[8]

Figure 2. Dimensions of Graphic Thinking

We draw a variation of Oles’ diagram which shows various types of graphics.(Figure 2) Conceptual and abstract graphics are found in the private realm of the designer’s thinking process; these form a graphic shorthand that supports the rapid pace of design speculation and enables the juggling of an extensive set of variables. Concrete and representational graphics are found mostly in the public
realm, where the specific results of design decisions must be clearly illustrated. There has been some use of diagrammatic graphics in the abstract, conceptual processes and the application of perceptual graphics such as perspectives to concrete, representational tasks.

Therefore, during the Graphic thinking process, the design ideas are transferred from abstract realm to concrete one, and from conceptual realm to perceptual one. Also they are real presentation for communication between private realm and public one. In all these realms there can be some iteration as a feedback and its continuity. Graphic thinking takes advantages of the power of visual perception by making visual images external and explicit. By putting them on paper or graphic tablet, we give visual images objectivity outside our brain, an existence of their own over time.

3. Computer and Sketches

3.1 Computer Aided Sketching System

In creating a sketch, designers are making an explicit representation of their ideas.[9] In order to refer in further reasoning about the problem, it needs to be changed the sketch into digital data. So, it is necessary to substitute the Graphic Tablet for the Pen & Paper in order to generating some sketches in the computing environment. All data are stored in computer system to refer them later, and reused for another purpose. It is helpful to make the designers free from the irksome tasks of managing the data and increase the creative thinking time.

As shown in Figure(2), we examined the three dimensions in graphic thinking; conceptual / perceptual, abstract/ concrete, and private / public. At conceptual realm, designers deal the abstract information, which is mostly represented in verbal information. At concrete and perceptual realm, they deal visual information.

Once the verbal and visual information is inputted into the computer system, it is changed into digital data for the computing process. There are a lot of powerful CAD systems to assist designers to create representations of their final designs, but a few tools exist for supporting designers' sketches.

In relation with this, it needs to discuss a Computer Aided Sketching System (which we call simply CASS), as a computerization of sketching works has lots of advantages due to the digitalization. Nevertheless it should have palettes of widgets that are always available. It should not hamper their creativities. Sometimes this could be a flaw of the interfaces. Designers spend lots of scrolling times around their images, as it does not fit on the screen, due to limited screen space.

But when this CASS is operated with a database system and linked with network, designers' sketches can be handled more efficiently. Undoubtedly, it is possible that communicate within designer himself or with its persons concerned through network.

3.2 Graphic Tablet for extracting idea sketches

We have examined the graphic tablet as a drawing device.

A graphic tablet is a device with a flat surface. Movement of a finger or a stylus on the tablet's surface controls the cursor on the computer screen.[10] We paid attention to two different types of graphic tablets. One type typically called Digitizing Tablet (Digitizer), works through the use of a special stylus. This stylus produces signals indicating coordinate values for cursor positioning on the separated monitor. Another type of graphic tablet is a LCD monitor-based tablet (LCD Tablet), which realizes the potential of a draw-on monitor.

There are several principles by which graphic tablets operate. Compared to the LCD Tablet, the input in the Digitizer is separated from the system response. The user has to watch the screen while touching the tablet. But drawing pictures with the LCD Tablet is exactly same to drawing with a pencil on paper.
Table 2. Comparison of sketching devices

<table>
<thead>
<tr>
<th></th>
<th>LCD tablet</th>
<th>Digitizer</th>
<th>Pen &amp; Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control-Display relationship</td>
<td>(coincident)</td>
<td>(separated)</td>
<td>(coincident)</td>
</tr>
<tr>
<td>Reusability, duplication</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Modifying the size of the picture plane</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Active Area</td>
<td>(limited)</td>
<td>(limited)</td>
<td>(unlimited)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+/-0.5mm</td>
<td>+/-0.25mm</td>
<td>+</td>
</tr>
<tr>
<td>Character data entry</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Examples: * Advantages, – Disadvantages

The LCD Tablet shows more natural WYSIWYG[11] work, while the Digitizing Tablets can employ absolute or relative cursor positioning. In terms of ergonomics, the positioning on the LCD Tablet is more accurate and faster than the Digitizer. As an onscreen tool, the LCD Tablet emulates pencils, brushes, pens, chalk and other artists' media, and pressure sensitivity is vital to proper expression. The pen that is pressure-sensitive and has a built-in eraser lets you work naturally and intuitively.

The characteristics of these sketching devices are briefly summarized in Table (2).

1) Major differences between the LCD Tablets, the Digitizer, and the Pen & Paper are followings: Control-Display relationship of the LCD Tablet is coincidental and natural, Digitizer separate.
2) Data of the LCD Tablets and Digitizing Tablet can be reusable, data of Pen & Paper cannot.
3) Active area of the LCD Tablet and the Digitizer is relatively limited, the Pen & Paper unlimited.

4. Experiments
4.1. Hypothesis

We formed the following specific hypotheses to address the questions poses at the instruction.

Hypothesis 1: There are no considerable differences between verbal and visual information for design.

This is based on the belief that most of sketches as a visual thinking entails the transformation process from mental to perceptual dimension.(Figure 1) Although we are sketching with verbal information only, we can draw some sketches according to the perceptual image and mental image.

Hypothesis 2: There are no considerable differences between abstract and concrete information for design.

Design is a goal directed, prescriptive works. Even though they had started the sketches from abstract concept, they should produce a concrete model finally. We examine the difference between abstract and concrete information.

![Figure 3. Test Types](image)

4.2. Design and its Procedure

The focus of these experiments is to examine the graphic thinking process.

For the experiments we varied the design information;

a) Type A: abstract verbal information
b) Type B: abstract verbal and visual information
c) Type C: concrete verbal information
d) Type D: concrete verbal and visual information

Subjects are randomly divided into 4 groups according to the 4 Test Types (A–D). (Figure 3)

Following the directions, subjects are asked to draw 10
sketches.

4.3 Experiment Measures

1) Project: We set up a design project, 'the handy perfume bottle for Generation X', for this experiment.

2) Tasks: subjects are randomly divided into 4 groups, which have the four different design tasks to draw their ideas. The number of subjects in Group A, B, C, and D, are respectively 45, 47, 43 and 42. We ask to draw 10 thumbnail sketches under the given design information. The size of the picture plane is 90 X 100mm. (Figure 4)

3) Subject: 177 subjects were participated for the experiments. All subjects were under graduate students majored in Industrial Design, (freshmen 19%, sophomore 22%, junior 33%, and senior 26%)

4) Direction for the test: According to their Test Type, the subjects are asked to draw the idea sketch under the specific design information. After completion of their sketches, they are asked to write a brief explanation of the design features and the elapsed time taken.

a) Following the design concept in the right box, develop your conceptual idea into real world sketches.

b) Please draw your idea sketch (one sketch in each picture plane)

c) After completion of your sketches, write a brief explanation of the design features.

5. Discussion

From the comparison of drawing devices, the LCD Tablet is possible to substitute for traditional Pen & Paper. Although the LCD Tablet has partially drawbacks in accuracy, it has lots of advantages due to be an application in digital environment. Undoubtedly the LCD Tablet is better than the Digitizing Tablet for the CASS (Computer Aided Sketching System) as a sketching device.

From the experiments, there are not wide differences of the means of four Test Types. 'The Scores of Originality' is marked under the theory of 'The Originality Test of Line Drawing'. [12] In order to confirm the more elaborate differences of the data, we analyze them by T-Test. (Figure 5)

Our analysis has provided the following insight into the graphic thinking process from the experiment.
1) For the Tests of the difference of between verbal information (Type A) and visual information (Type B), we analyzed the Originality Scores by T-Test. The F-statistic for testing whether the variances from the two groups are equal is 1.10 with a p-value of 0.7488. Because the p-value is large, one would conclude that the two variances are not unequal, continuing with a pooled t-test for the two means. The value of the pooled t is 0.4455, and the p-value is 0.6570. Clearly, the two means are not different. Between Test Type C and D, there are no differences as well. (Table 4)

6. Conclusion

The purpose of this paper was to explore the visual thinking process of design sketches in early conceptual design processes. Conducting protocol analysis, we empirically examined the cognitive processes of an idea sketch. Based upon previous reviews and analyses, we extract some results as followings:

Firstly, idea sketches have been continuously changed their dimensions through graphic thinking process between the graphic, the perceptual, and the mental images.

Secondly, we have confirmed that the LCD Tablet is proper input device for the Computer Aided Sketching System (CASS).

Thirdly, our findings show that there are no significant differences of the responses at the stage of conceptual design when design thoughts occur in response to verbal/visual information and abstract/concrete one in these

<table>
<thead>
<tr>
<th>Table 3. T-TEST 1 (Verbal/ Visual Information)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable: Idea_Sketch</td>
</tr>
<tr>
<td>Test Type</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

For H0: Variances are equal, $F' = 1.10$  DF = (46,44)  Prob>|F'| = 0.7488

<table>
<thead>
<tr>
<th>Table 4. T-TEST 2 (Abstract/ Concrete Information)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable: Idea_Sketch</td>
</tr>
<tr>
<td>Test Type</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>C</td>
</tr>
</tbody>
</table>

For H0: Variances are equal, $F' = 1.19$  DF = (42,44)  Prob>|F'| = 0.5777
experiments.

Although, we have not yet identified what the causes and conditions are, these findings support the graphic thinking process, and these results are helpful to reinforce the bases for design practice. In order to generalize these results, we need to apply this experiment into other process and product items. Also, In order to adapt the LCD Tablet instead of the Pen & Paper for graphic thinking, it is necessary to do more studies on the cognitive thinking process with the Tablet.

Acknowledgements

This research has funded by Korean Research Foundation in the program year 2000 (Grant Number krf-99-041-100076 13105).

References

7. ibid
8. ibid., 184
10. Woo H R. Performances Differences amongst the