Is a pen-based system just another pen or more than a pen?

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Abstract: Freehand sketch is the most critical stage in the design process. The importance of the freehand sketch is in its ability to freely represent various projections of ambiguous drawing using a convenience tool, pen-and-paper. Recently, pen-based system which developed attempted to use pen as an input device, allowing sketches to be freely drawn on computers. However, as far as the various drawing projections, such as diagram, symbol, plan, elevation, section, perspective, etc., how are they interrelated to a designer's cognitive behavior? Different media have different abilities to represent projections. What's the difference of design cognitive behavior between conventional pen-and paper and pen-based system in view of both using a pen as a design medium? This research proceeds a think-aloud protocol analysis to present an analysis and discussion. Research results show that there is a relationship of gradual embodiment, mutually complementary, going from a whole to being dissected into sections between the different projections. Moreover, pen-based system is more than a pen, it allows designer to inspect a 3-D view during the sketching stage. This gives the designer more opportunities during the sketching stage to conduct the design thinking process based on the ambiguous 2-D projections and the more concrete 3-D images, as well as more opportunities for visual feedback

Keywords. Pen-based system; sketch; drawing projections

Introduction

Sketch in the conceptual stage is the most critical in the design process. In recent years extensive studies are done on the characteristics of sketches and the designers' cognitive behavior. Studies relevant to the design aspect presented analyses and discussions on the drawings' characteristics and classifications (Faruque,1984; Robbins,1994; Fraser & Henmi,1994;Goel,1995; Herbert,1993). These studies explain how the sketches possess such qualities as convenience, freehandedness, and ability to represent ambiguity, abstraction, and imprecision (Goel, 995). Designers are accustomed to represent the ambiguous concepts or complex objects using simple, abstract drawings. These drawings are composed of many annotations or various projections, such as diagram, symbol, plan, elevation, section, perspective, etc. Faruque (1984) explained that there have different levels of abstraction in these drawings, from simpler drawings to the more complex and concrete drawings: annotations, symbols, plan, elevation, perspective, shading, and rendering. These drawing projections can be used to aid the design thinking process.

Meanwhile, Other researchers studying

sketches from the cognition aspect target the interaction between the designers and sketches in analyzing the designers' cognitive behavior. This type of research emphasizes the characteristics of visual thinking or visual reasoning and can be classified into 3 types: 1. How designers look at sketches (Goldschimidt (1991, 1992, 1994); 2. What the designer sees in a sketch (Suwa & Tversky, 1997); 3. How the designers draw and what do they draw (Van Sommer, 1984). Schon argue that designer frequently interacts with or communicates through the chosen design media in the design process. Laseau (1937) likewise pointed out that between the drawings in the sketch and the designer, there is a cycling process going on amongst the brain, hands, sketch, and eyes. Based on the dialogue between designer and the sketch, the designer will derive some visual feedback from the sketch which contains dense and ambiguous lines, and then reinterprets the sketches or experience unexpected discovery from the sketches (Schon and Wiggins, 1992; Suwa and Tversky, 1997).

In addition, introductions of new computer media brought with it the computer-aided design (CAD) systems. Earlier CAD systems emphasize on final presentation that takes place in the final stage of design. In recent years, however, in order to comprehensively assist designers to produce more stimuli for their designs in the conceptual stage, computer-aided conceptual design (CACD) was gradually explored (Lipson and Shpitalni, 1996°FGross, 1996°FVan Dijk, 1995°FElsas and Vergeest,1998 ;Won, 2000; Wong,2000). These cognitive research and related theories regarding computer media for the conceptual stage, however, focused mainly on developments of mouse-based CACD. In addition, Wong & Wong's (2000) discussion on design cognitive behaviors through comparing traditional and computer based media explained the theory that uses of different media change designers' design behaviors and visual thinking.

However, when researchers came to a real understanding of designers' behaviors during the initial sketching stage, they discovered behaviors that are fast and ambiguous yet creative, and most of the designers are still relying on the conventional media– pen-and-paper (Gross, 1996;Landay & Myer, 1995). Since these mouse-based computer media are incapable of supporting the functions of pen-and-paper during initial sketch, many researchers, like Moran (1994, 1995), Gross & Ellen (1996), and Landay (1996), turned to the research and development of pen-based systems. Their purpose was to provide the CACD system with conveniences and functions like fast expressions of images in designers' brains, ambiguity, resolution, gesture, and notions through related peripherals like stylus and tablet touch-screen displays, or combining virtual reality to simulate traditional pen-and-paper functions.

Problem Statement and Objective

The development of pen-based system has improved CAD operating interface to enable designers to complete the whole course of design in a computer environment. Currently developed pen-based systems can be classified into three categories:

1. VR or AR drafting systems which combine physical pen-and-paper as a computerized workstation. (Wellner, 1993; Moran and Chiu, 1995),

2. Systems that translate two-dimensional sketches into three- dimensional models (Igarashi, 1999; Schweikardt and Gross, 2000; Ellen, 2001).

3. Systems that function mainly as graphic recognition engines for sketches (Landay, 1996; Gross & Ellen, 1996; Plimmer & Apperley, 2002).

The main purpose for developing these systems is to simulate the characteristics of pen-and-paper, thereby achieving the cognitive design

behavior found in designers who use conventional pen-and-paper for sketches. Such characteristics include the simulated touch sensitivity of pen, coloring, and the semi-transparent tracing paper (Gross & Ellen, 1996; Pilmmer & Apperley, 2002). But of utmost importance is it allows the designer to use pen as the design medium. The motion involved in drawing out sketches can be even more freehanded and convenience. Pen-based system allows sketches with ambiguous and dense lines to be drawn out freehandedly as if using conventional pen-and-paper. It also allows doodling, which integrates various drawing projections on a sketch like diagram, symbol, and plans, elevations, sections, and perspectives to aid the design thinking process. Faruque (1984) categorized these various projections has different level of abstractions. Yet, what is the relationship between the different levels of abstraction of the drawings as proposed by Faruque (1984), and the designer's thinking process? What relationship is there between these different drawings?

While both use a pen-like device as input device, a pen-based system and conventional pen-and-paper are actually two different design media. The drawing environment for and representation of drawing projections by these media are also different. The characteristics of the projection representations by the various media will vary with the mechanisms of the media themselves, as shown in Figure 2. Especially for the computer-based media, some represent 3-D perspective projections more easily, while others are better at 2D projections like plan, elevation, or section. But freehand sketches can represent various projections freely, primarily because the drawings are made with a pen, which affords a greater degree of freedom in representing various projections. In light of the above considerations, would the differences between pen-based systems and the conventional pen-and-paper have an impact on the representation of projections? Would this then lead to differences in the design processes by designers?

Based on the questions raised here, this research will focus on the freehand sketches by two different kinds of media: conventional pen-and-paper and computerized pen-based system, and will provide in-depth analysis and discussion based on the different levels of abstraction drawings and differences in the cognitive design behaviors. Then lastly, some phenomenon will be concluded within the differences between the two media.

Figure 1. Different representation of drawing projections

Protocol analysis

Design task

A Think-Aloud Protocol Analysis is proceeds to provide in-depth analysis and discussion based on the different levels of abstraction drawings and differences in the cognitive design behaviors, target on two design media: pen-and-paper and pen-based system. The subject was an architect with 10 years professional background. He was instructed to doing the following task:

1. Warm-up session: The subject was firstly given a one-month period to get familiar with hard and software, equipment that would be utilized during the experimentation. The subject had to become accustomed to operating software, Electronic Cocktail Napkin, and hardware such as portable LCD Interactive Pen Displays without any problem. Beside, in prior to the official kick-off of the experimentation, the subject was given 30 minutes to warm up with a small design exercise.

2. Think-Aloud design session: The subject went through two design tasks, conventional free-

hand sketch (Experiment A) and pen-based system sketch (Experiment B). When Experiment A was completed, the subject was then given a week lapsing Experiment B. Each test took 90-120 minutes in total. During both experimentations, complete scenes including the produced sketches and think aloud protocol data were recorded.

Segmentation

The protocol data was firstly categorized by different levels of abstractions; each level of the dividend data was carried out for segmentation. The definition of segmentation adopt the definition of Goldschmidt's (1991), Design Moves, implicating a series of coherent or subordinate reasoning actions originated from the design essence. The beginning of a new segmentation often occurs when a designer shifts its design concepts or comparative actions such as drafting notions. An individual segmentation may contain one or more protocols.

Coding Scheme

The coding schema was proposed target on the level of abstraction, upon which to construct a process oriented coding schema. It was set delving into the relativity of the application of different design media such as conventional pen-and-paper and pen-based system versus representations of different levels of abstraction such as annotations, symbols, diagrams, plan, elevations, sections, and rendering perspectives.

Level of abstraction: Four coding ranks were divided by different abstract sketches:

Analysis and Result

Targeting to the utilized timeframe of different level of abstraction (Table 2), we can distinguish clearly that Level 1 had been mostly employed by the utilization of the SK and ECN. Nevertheless,

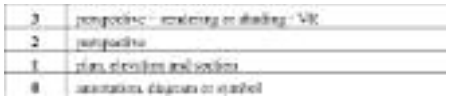

Table 1 Coding ranks of the level of abstraction

the difference between two experimentations is the time spent on different levels of abstraction (0, 1, 2, 3) by SK is far greater than the ECN. During SK design scheme, Level 1 took up 72% of the entire concept development, which comparatively only 0.9% is consumed on Layer 2. However, when designing with ECN, the overall time spent on each level during the design process is more identical. This experimentation proved that even designer used pen as primal sketch tool, different design medium can impact vastly on the usage frequency of the figure deployment.

Divergence of Timeline

From the figure 3 & 4, we can clearly see the distinct difference between the application two design media. Pen-based system took up almost

Table 2. Level of abstraction vs. timeframe

60% of time in comparison to the conventional pen-and-paper sketch. As a matter of fact, in both employed medium, the actual time taken for the experimenter to sketch were moderately similar, yet with the additional VR features Pen-Based System, designer depleted more time on viewing and examining the drawings (figure 5). Therefore, we can see that the proportion of timeframe in level 3 was largely consumptive, yet merely on reviewing the three-dimensional drawing generated by VR.

Experiment A. Conventional pen-and-paper sketch (indicate as SK)

Experiment B. Pen-based system (indicate as ECN)

Relation of different drawing projections

Meanwhile, from the two figures above (figure

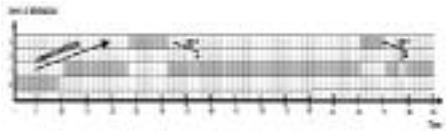

Figure 2. Pen-and-paper sketch (duration: 85 minutes)

2 & 3), we can also monitor the progressive procedure relativity, which was formed by the draw-

Figure 3. Pen-based system sketch (duration: 136 minutes)

ing projections relationship of freehand sketch (0‡1‡3). This relativity then continued carrying out at the 2nd level (plan, elevation, section) from the transferal of the 3rd level (perspective), D*. The dismantlement of overall perspective drawings into two-dimensional representations of plans/ sections/ elevations (D*) would also be recorded into the course of ECN. Moreover, almost all kinds of sketches regardless plans, sectional and elevation representations, would be additionally supported by simple diagram or annotations (figure 6). Such appearance can be concluded that the drawings with the different level of abstraction hold relationships of:

1. The gradually concretizing sequential relationship.

2. The mutually complementary relationship.

3. The relationship of going from a whole perspective-drawing to a dissected section-drawing.

However, during the ECN experiment, as the variation of level of abstraction was somewhat unsteady, the progressive procedure relativity became reasonably obscure, yet emphasized the relativity amongst different figures.

Some different phenomenon between two design media

Figure 4. Look and inspect the VR

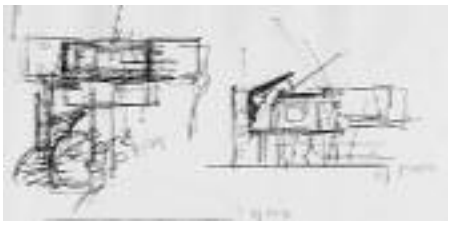

Figure 5. Plan, section (associated with diagram & annotation)

From figure 2 & 3, we can grasp of the following phenomena:

1. Different levels of abstraction have more steady variables in SK but higher variable frequency in ECN.

The timeframe in SK experiment progressed steadily from 0 to 3 in the first 1/3 of time, simple diagram or symbols gradually progressed into plans, elevation, and section representations followed by final rendering perspective completion. The concept development again returned to level 1 (plan, elevation, section) of 2 dimensional representations and steady remain until the completion of perspectives of level 3 (perspective).

However, in ECN, the design concept progression is somewhat unsteady at the beginning leaping between level 0, 1, 2 and 3. As the figures

gradually transform, the progression became more constant yet still adjusting occasionally amongst level 3, 2 and 1 (3->2->1->3->1->3->2->1->2->1) with longer retaining period for each individual figure formation.

2. Consequential progression from the level of abstraction 3->2->1 was formed in CC1 (45-85 duration) and CC2 (105-120 duration) of ECN experiment.

As the software consists of VR depiction function, level 3 of the ECN experiment was frequently presented by VR illustration. The subject had come up with the perspectives (level 2) by tracing off the 3D images generated by VR function (level 3). After inspect the drawing, they will revise it by shift to section, elevation or plan (level 1).

3. **During ECN experimentation, level 3 (VR) had appeared in early stage of the sketch design, shifting erratically amongst Level 0, 1 and 3, in contrary to the consequential progression occurs in SK experimentation.

This occurrence was a result of VR function of ECN. As the subject was able to easily transform 2D diagrams into 3D VR representations right from the beginning of the sketching stage to enable a clearer and visible milieu quality, the VR function was recurrently activated and utilized.

Conclusions and Limitations

The following conclusions can be drawn from the phenomena derived from the above analyses:

In freehand sketches, there are close relationships between the different drawings those posses varying levels of abstraction: 1. the gradually concretizing sequential relationship, 2. the mutually complementary relationship, and 3. the relationship of going from a whole perspective-drawing to a dissected section-drawing. But these relationships may change with the use of different media, which have varying degrees of difficulty in performing the task of representation.

Also, from experiment results it is seen that pen-based systems can perform freehand sketches just like conventional pen-and-paper. However, it's not just a pen but more than a pen. Due to the special functions such as VR mode, pen-based system allows designer to inspect a 3-D view during the sketching stage. This phenomenon allows the drawing and inspection of concrete image (like 3-D model) to be performed in the early sketching stage, which in the past was only possible in the later stages of the design. This gives the designer more opportunities during the sketching stage to conduct the design thinking process based on the ambiguous 2-D projections and the more concrete 3-D images, as well as more opportunities for visual feedback.

The limitation of this research is in its lack of in-depth analysis of the cognitive process applied to the drawings with varying levels of abstraction. This research only explains how the two entities mutually limit each other, but without explaining the content-oriented relationship within. More exact studies must be done to figure out the relationship between the action categories (perceptual, functional and knowledge) and the various drawing projections of different level of abstraction.

Significant and Future Studies

As pen-based systems possess the characteristics of conventional pen-and-paper, they play the critical role in representing the ambiguous nature of CAD designs and in gradually giving a

tangible form to the conventional pen-and-paper, while sewing the gap between a designer's conceptual stage and the CAD designs generated by the present-day computer-based media. The contributions from this research can be classified into:

1. Research on Sketch Recognition

This research presents detailed analyses and discussions on the levels of abstraction in the designer's drawings during conceptual stage, which may be used to help understand the precise and important visual reasoning process followed by the designer. If the designer's need to represent differently during freehand sketch is understood, then the most suitable design media can be selected and given to the designer for use as an excellent representation tool.

2. Research Methodologies on Design

When sketches become digitized information, there will be a major breakthrough in terms of research methodologies, especially for the studies of sketches. The cumbersome data processing required in the past for protocol analysis experimentation can now be recorded or dissected using computer's powerful storage and computational capabilities. From here the experimentation steps can be made more precise and efficient.

3. The Integration of Design Media Means

Because pen-based system allows designers to perform freehand sketches in a computer-based environment, the designer may integrate or combine the sketches with other computer-aided systems. This bridges the gap caused by the use of different media for initial-stage freehand sketch and for later-stage design and development. The freehand sketch not only plays the role of a communication tool for the designers, it also serves as an excellent computer based media tool to consolidate and access other design-assisting software.

Due to the cognitive behaviors displayed when using pen-based system and when using conventional pen-and-paper are different, future researches will hopefully use these derived phenomena to consolidate relevant research results, then make inferences about a theoretical model for pen-based system. Further studies can then be done to see if the computational drawing environment based on cognitive design behavior may be helpful to designer's creative behavior and how it may impact the design outcome. In addition, the hope is to take the research a step further and study how to integrate the designers' gestures with pen-based systems, providing the designers with more stimulation.

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