An Insight into the Freedom of Using a Pen: Pen-based System and Pen-and-paper

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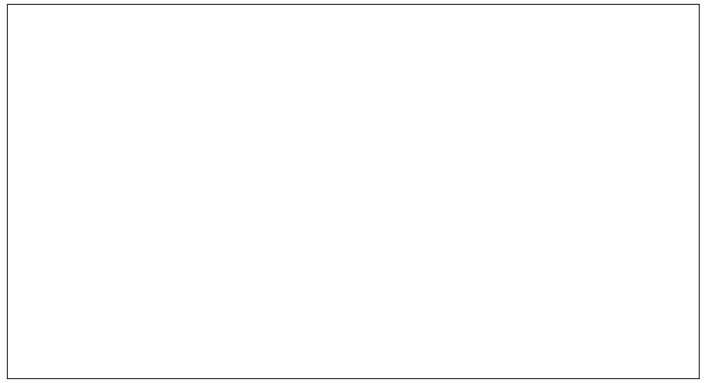
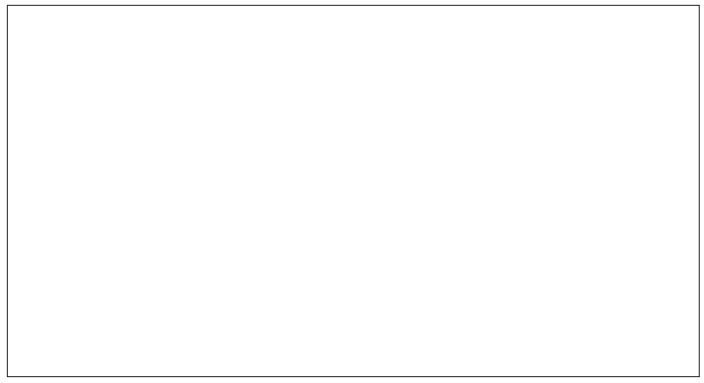
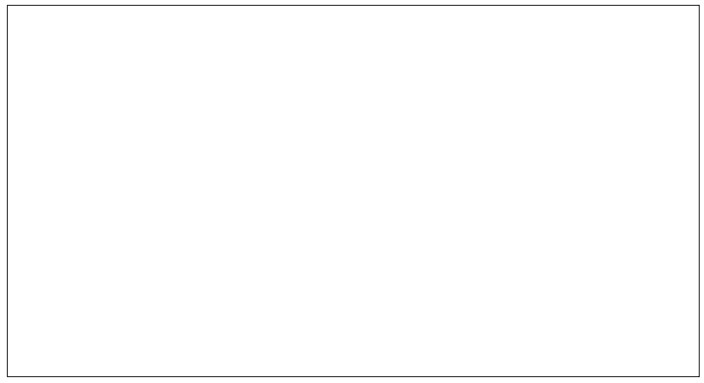
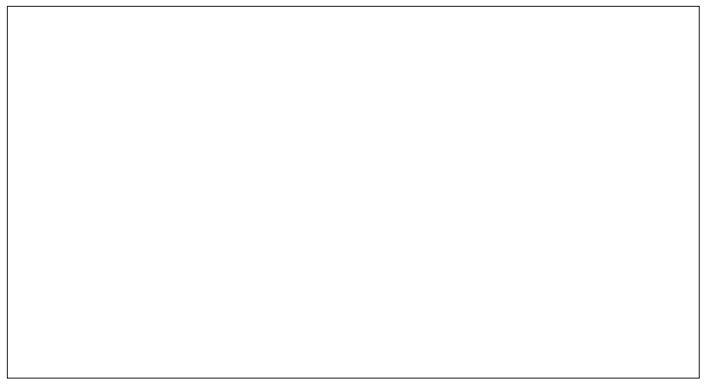
Abstract

In earlier researches on freehand sketching, the cognitive behavior of designers was studied. In recent years, some researchers began to look into this area from the design media aspect. The pen-based system, developed by Gross, Landay and other researchers, used the pen as an input device, allowing sketches to be freely drawn in a computer environment. The importance of the freehand sketch lies in its ability to freely represent various drawing projections using ambiguous sketches. However, as for the various drawing projections, such as diagrams, symbols, plans, elevations, sections, perspectives, etc., how are they interrelated to a designer's thinking process and the cognitive behavior? Different media have different abilities to represent different projections. Would they affect the designer's design thinking as well? Targeting different media, i.e., conventional freehand sketches vs. the computer pen-based system, this research uses case studies and think-aloud protocol analysis to present an analysis and discussion. Research results show that there is a relationship of gradual embodiment that is mutually complementary, going from a whole perspective to being the dissected into sections between the different projections. In addition, these projections restrict the designer's various design thinking processes, while the use of different media may somewhat change the actual design thinking of the designer









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1 Introduction

The conceptual stage is the most critical stage in the design process. In recent years, extensive studies have been done on the characteristics of sketches resulting from this stage 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 the ability to represent ambiguity. Thus, they are an excellent tool used by designers to express their ideas outwardly. Designers are accustomed to representing ambiguous concepts and complex objects using simple, abstract drawings. These drawings are composed of many annotations or various projections, such as diagrams, symbols, plans, elevations, sections, perspectives, etc. However these drawings are not the complete and concrete drawings found in the final designs, so they possess such qualities as abstraction, ambiguity, and imprecision (Goel 1995). Faruque (1984) used examples to explain the different levels of abstraction in these drawings, from simpler drawings to the more complex: annotations, symbols, plans, elevations, and perspectives, shading, and rendering (Fig. 1). These drawing projections can be used to aid the design thinking process.

Figure 1. Level of abstraction (after Faruque, 1984)

Other researchers studying sketches from the cognition aspect target in on the interaction between the designers and their sketches while analyzing the designers' cognitive behavior. This type of research emphasizes the characteristics of visual thinking or visual reasoning and can be classified into three 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 argues that the designer frequently interacts with or communicates through the chosen design media in the design process. Laseau (1987) likewise pointed out that between the drawings in the sketch and the designer, there is a cycling process going on among the brain, hands, sketch, and eyes. Based on the dialogue between designer and sketch, the designer will derive some visual feedback from the sketch, which contains dense and ambiguous lines, and then reinterprets the sketch or experiences an unexpected discovery from the sketch (Schon & Wiggins 1992; Suwa & Tversky 1997).

In addition, the new computer medium came up with the Computer-Aided Design (CAD) systems. Utilization of CAD is different from traditional methods; therefore, certain impacts and influences are expected to happen to design behaviors. Earlier CAD systems emphasized the 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 developed (Lipson & Shpitalni 1996; Gross 1996; Van Dijk 1995; Elsas & Vergeest 1998; Won 2000; Wong 2000). These cognitive research and related theories regarding the computer medium for the conceptual stage, however, focused mainly on the development of mouse-based CACD. For example, the shape molding system, Fast Shape Designer (FSD) developed by Van Dijk (1995), was a drawing system capable of transforming two-dimensional sketches into three-dimensional models. The Displacement Feature Function (DFF) proposed by Elsas and Vergeest (1998) utilizing interactive windows and real-time visual feedback was another example. In addition, Wong and Wong's (2000) discussion on design cognitive behaviors through comparing traditional and computer based media explained the theory that uses of different media change the designers' design behaviors and visual thinking.

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

2 Problem Statement and Objective

The pen-based system has improved the CAD operating

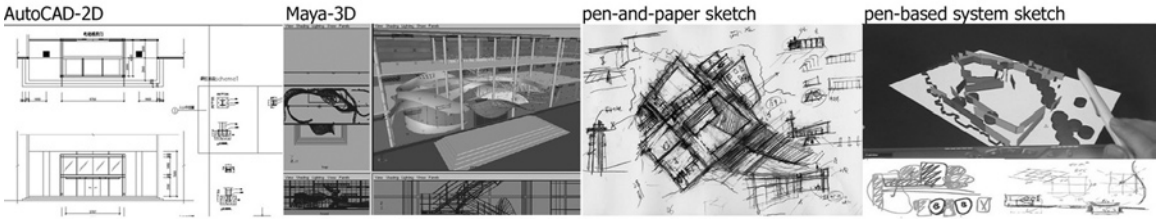

Figure 2. Different representation

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. Projection drafting systems that combine physical pen-and-paper to aid in group communications (Wellner 1993; Moran & Chiu 1995).
2. Systems that translate two-dimensional sketches into three-dimensional models (Igarashi 1999; Schweikardt & Gross 2000; Do 2001).
3. Systems that function mainly as graphic recognition engines for sketches (Landay 1996; Gross & Do 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 sketching. Such characteristics include the simulated touch sensitivity of a pen, of coloring, and of semi-transparent tracing paper (Gross & Do 1996; Pilmmer & Apperley 2002). However, the most important feature is that it allows the designer to use the pen as the design medium. The motion involved in drawing out sketches can be even more freehanded and convenient. Pen-based systems allows sketches with ambiguous and dense lines to be drawn freehanded as if using conventional pen and paper. It also allows doodling, which integrates various drawing projections on a sketch - such as diagrams, symbols, plans, elevations, sections, and perspectives - to aid the design thinking process. Faruque (1984) categorized these various projections into different levels of abstraction. Yet, what is the relationship between the different levels of abstraction during the process of drawing, as proposed by Faruque (1984), and the designer's thinking process? What relationship is there between these different approaches to drawing?

While both use a pen-like device as an input tool, a pen-based system and conventional pen-and-paper are actually two different types of design media. The drawing environment for and the 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 2-D projections, such as plans, elevations, and sections. However, 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 freehand sketches by two different kinds of media: conventional pen-and-paper and a 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. Lastly, some aspects regarding the differences between the two media will be discussed.

3 Case studies

As undeterminable and divergence issues often arise alongside with proposed research fundamentals and its experimental methodology, in addition to the ambiguity of predetermined analytical criteria versus the achievable objectives, the lack of understanding of design cognition has repeatedly become the primal obstructions of experimental actualization. Hence, in order to further integrate the systemization and feasibility of the cognitive experimental scheme conscientiously and thoroughly, the research was commenced by case studies with initial attempts of analyzing and categorizing the possibilities of preliminary and phenomena occurrences as the essence of experimental hypothesis and analytical configuration.

3.1 Procedures

The procedures were carried out with the specific topic "Tied-up Sketch," targeting on the experimentations on sixth, seventh, or eighth grade architecture students to come up with freehand sketches and answer some questions. The design processes are described in detail as below.

The subjects began with freehand sketch to initiate each of their design concepts; the task was to be accomplished within a given time or preset extensions. The key was that the design concept must be completed. The subjects were then to answer five questions. The topics of the design task comprised aspects on functionality and criterion within similar scopes of very simple design. All design tasks were limited to certain degree of representation (Table 1), and each type of representation was

categorized into 4 representative figures of level of abstraction (Faruque 1984), from simple to complex:

A. Only use annotation, diagram or symbol
B. Only use plan, elevation and section
C. Only use perspective
D. Only use perspective + rendering or shading

	Design topic	Representation (drawing projections)	Time (min)
A.	Personal working space	Only use annotation, diagram or symbol	10-15
B.	An observatory	Only use plan, elevation, section	10-15
C.	Bus stop	Only use perspective	10-15
D.	Lavabo near the beach	Only use perspective + rendering or shading	10-15

Table 1

Questions-

1. What would you think about the perfection of your concept? (%)
2. What did you think about when you are drawing? (e.g. Spatial relationship, form, functions etc.)
3. What is the limitation of this way of presentation?
4. What do you want to draw next step?
5. Do you feel have to change the drawing projections?

3.2 Discussion and Findings

Sketches of the case studies

A: Only use annotation, diagram or symbol

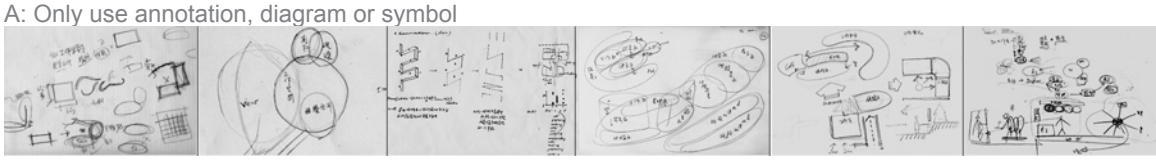

Figure 3

B. Only use plan, elevation and section

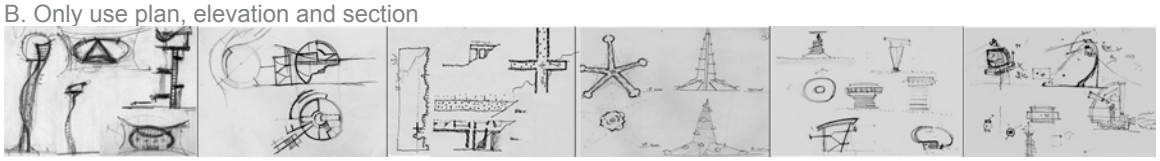

Figure 4

C. Only use perspective

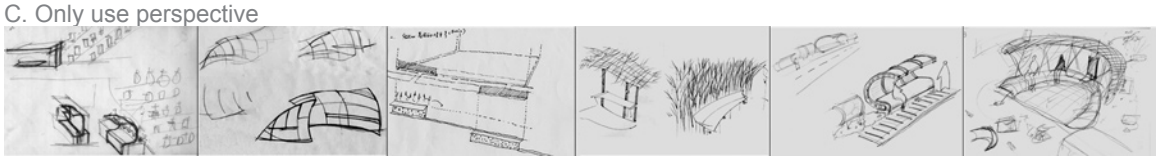

Figure 5

D. Only use perspective + rendering or shading

Figure 6

From subject's interpretations, the sketches in aspect of design factors and considerations were then concluded and classified into visual features including shapes, sizes, textures; spatial relativity as well as relations to spaces and environments and spatial configurations; functionality design and design concepts. Suwa's (1998) theory was consequently used to guideline these factors into three levels of action categories:
Perceptual level --- visual feature, spatial relation, organization
Functional level --- function
Conceptual level --- concept

As table 2 shows, we can find out that there are some relationships among levels of abstraction and action categories:
1. When using annotation, diagram or symbol, most designers (5 persons) considers spatial relation.
2. When using plan, elevation and section, most designers (6 persons) consider design function, design concept, and also consider environment relationship (5 persons).
3. When using perspective, most designers (6 persons) consider design function, and also consider shape and environment relationship (5 persons).
4. When using perspective + rendering or shading, most designers (6 persons) consider design function and shape. Secondly, they consider the texture and environment relationship (5 persons).

At the same time, it is also evidently obvious that the more precise and visual the drawings are (e.g. perspectives), the more design factors were put into consideration. Simple-formed drawing projection such as diagrams had only led the subjects to focus on the factors of spatial relationship and conceivably on functionality aspects. However, with slightly more complex perspectives, the subjects were able to focus not only on functionalities, but also form, environmental relation and textures. When applied upon different action categories, we could capture that: when sketches were done in projections of plan, elevation or section representations, and more considerations in accordance to Conceptual category. In category of Functional, projections of plan, elevation, section, perspective and rendering greatly involve in the relatively considerations. Visual features, spatial relation and configurations are the three sub-categories of Perceptual categories. In this category, diagram, symbol and annotation are mostly considering the spatial relation (5). Moreover, projections such as plan, elevation, section and perspective representations acquire supplemental and powerful visual features (5) and spatial relations (5). The perspective with rendering also creates more visual features especially textures consideration (5).

Meanwhile, different drawing projections could create relativities amongst its individual procedures and reciprocal, as the following procedure:
1. When using annotation, diagram or symbol, next step hope to draw plan (5 persons).
2. When using plan, elevation and section, next step hope to draw perspective (5 persons).
3. When using perspective, next step hope to rendering (4 persons).
4. When using perspective + rendering or shading, next step hope to draw section (5 persons) and also need annotation, diagram or symbol to assist. (4 persons).

From the above consequential relativities, we can easily comprehend how these sketches from four different levels of abstractions interact with one another. The design concept steadily developed into more concrete systems from initial abstractions; and so on the drawing sketches represent the

Table 2

	perceptual						functional	conceptual	next step					
	visual feature			spatial relation					different projections					
			texture		environment	layout	function	concept	Symbol, Annotation, diagram	plan	elevation	section	perspective	rendering
Annotation Diagram, symbol	0	1	1	**5**	2	3	4	1	----	**5**	2	2	2	0
Plan Elevation, Section	**5**	2	2	1	**5**	1	**6**	**6**	2	----	----	----	**5**	1
	5	1	3	2	**5**	0	**6**	4	3	3	4	3	---	4
Rendering	**6**	1	**5**	1	**5**	0	**6**	3	4	4	3	**5**	---	---

The Numeral is the amount of the designers

gradually concretizing sequential relationship. Moreover, when designers have rendered the perspectives, they sometimes hope to continue designing by taking advantage of the deployment of other abstract concepts. From the drawing it is shown that most designers would hope to use section representations to consolidate the overall design physique, whereas some also use simple diagram or texts to support their concepts. (From the Sketches of the case studies, textual descriptions and simple diagrams were drawn next to the main design body to represent the less crucial fundaments of the design.) These approaches show that different projections of drawing 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.

As a result, the hypothesis of relativity between different levels of abstraction and design attempts can be concluded as follows: Different levels of abstraction such as texts/ symbols/ diagram, plans/ sectional/ elevation, perspectives and renderings will lead to the different design action categories, Perceptual, Functional, and Conceptual. Meanwhile, there is a relationship of gradual concretizing sequential, mutually complementary, and going from a whole perspective-drawing to a dissected section-drawing between the different projections.

4 Protocol analysis

4.1 Procedures

The experiment is proceeded by constructing a Think-Aloud Analysis to prove the preliminary hypothesis from the first part of case studies and to enable further analytical progress. The subject was an architect with 10 years professional experience. Warm-up session: The subject was first given a one-month period to get familiar with hardware 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. Besides, prior to the official kick-off of the experimentation, the subject was given 30 minutes to warm up with a small design exercise.

Think-Aloud design session: the subject went through two design tasks, conventional freehand sketch (Experiment A) and pen-based system sketch (Experiment B). When Experiment A was completed, the subject was then given a week long 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.

4.2 Coding Scheme

Segmentation

The protocol data was first 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 the proposed target on the level of abstraction, upon which to construct a process oriented coding schema. It was set on the basis of the analytical structure developed from the first part of Case Study, delving into the relativity of the application of different design medium such as conventional sketches 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:

Table 3

3	perspective + rendering or shading / VR
2	perspective
1	plan, elevation and section
0	annotation, diagram or symbol

4.3 Analysis and Result

A. Conventional pen-and-paper sketch (indicate as SK)
Duration: 85 Minutes

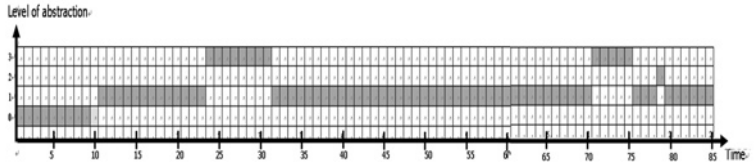

Figure 7

B. Pen-based system (indicate as ECN)
Duration: 136 Minutes

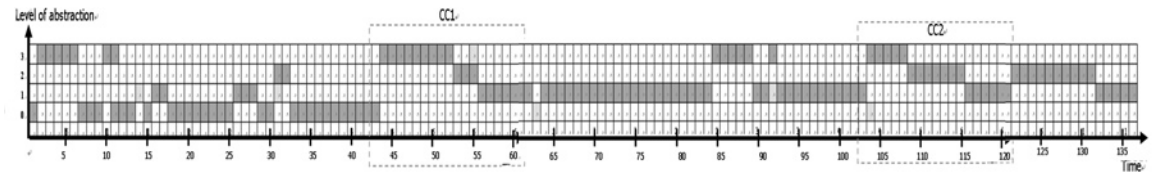

Figure 8

Divergence of Timeline

From the above two figures, we can clearly see the distinct difference between the application of the two design mediums. The Pen-Based System took almost 60% of the time to complete as that of the conventional pen-and paper sketch. As a matter of fact, in both mediums, the actual times taken for the experimenter to complete the sketches were relatively similar, yet with the additional VR features Pen-Based System (Figure 9), the designer spent more time on viewing and examining the drawings. From Figures 7 and 8, we can see that the proportion of time taken was largely consumptive, spent merely reviewing the 3-D drawing generated by VR.

Hypothesis Verification

From the two Figures (7 & 8), we can also monitor the progressive procedure relativity, which was formed by the drawing projection's relationship to the freehand sketch (0-->1-->3). This relativity then continued at the 2nd level (plan, elevation, and section) from the transferal of the 3rd level (perspective). The dismantlement of overall perspective drawings into two-dimensional representations of plans/sections/elevations would also be recorded during the course of using ECN. Moreover, almost all kinds of sketches, whether plans, sectionals or elevation representations, would be additionally supported by simple diagrams or annotations (Figure 10). Such a result had perceptibly verified the three hypotheses from the previous case study. However, during the ECN experiment, as the variations of the levels of abstraction were somewhat unsteady, the progressive procedure relativity became somewhat obscure, yet emphasized the relativity amongst different figures.

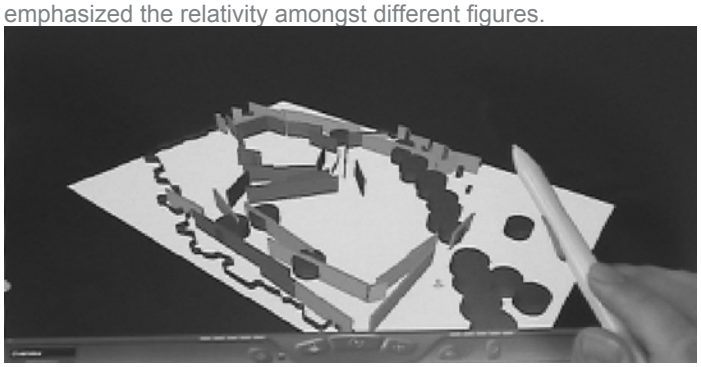

Figure 9. Look and inspect the VR

From figures 7 and 8, we can determine the following phenomena:

1. Different levels of abstraction have steadier variables in an SK (conventional pen-and-paper sketch) but a higher variable frequency in ECN.
The timeframe in the SK experiment progressed steadily from 0 to 3 in the first third of the overall time, simple diagrams or symbols gradually progressed into plans, elevations, and sectional representations followed by the completion of the final rendering perspective. The concept development again returned to level 1 (plan, elevation, and section) of two dimensional representations and remained steady until the completion of the perspectives of level 3 (perspective).
However, in ECN, the design concept progression is somewhat unsteady at the beginning, bouncing between levels 0, 1, 2 and 3. As the figures gradually transform, the progression became more constant yet still adjusting occasionally amongst levels 3, 2 and 1 (3-->2-->1-->3-->1-->3-->2-->1-->2-->1) with a 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 minutes) and CC2 (105-120 minutes) of the ECN experiment.
As the software consists of a VR depiction function, level 3 of the ECN experiment was frequently presented by a VR illustration. The subject had come up with the perspectives (level 2) by tracing the 3-D images generated by the VR function (level 3). After inspecting the drawing, they revised it by shifting to section, elevation or plan (level 1).

3. During ECN experimentation, level 3 (VR) had appeared in the early stages of the sketch design, shifting erratically amongst Levels 0, 1 and 3, in contrast to the consequential progression that was occurring in the SK experimentation.
This occurrence was a result of the VR function of ECN. As the subject was able to easily transform 2-D diagrams into 3-D VR representations right from the beginning of the sketching stage, enabling a clearer and more visible milieu quality, the VR

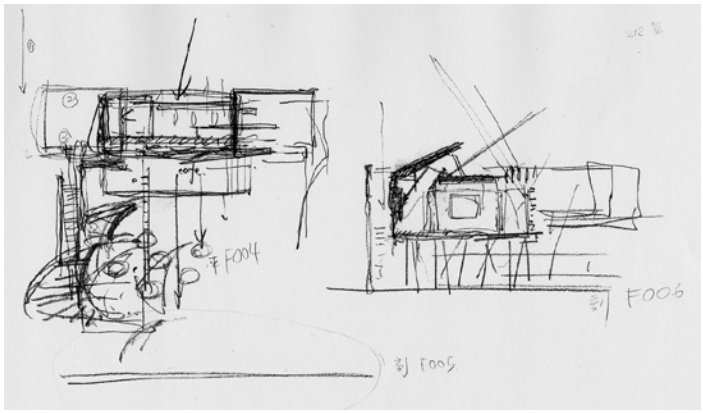

Figure 10. Plan, section (associated with diagram & annotation)

function was recurrently activated and utilized.

From Table 4, we can distinguish clearly that Level 1 had been mostly employed by the utilization of the SK and ECN. Nevertheless, the difference between the two experimentations in the time spent on different levels of abstraction (0, 1, 2, 3) is far greater in SK than in the ECN. During the SK design scheme, Level 1 took up 72% of the entire conceptual development period, while only 0.9% is used in Level 2. However, when designing with ECN, the overall time spent on each level during the design process is closer to being the same. This experiment proved that even when a designer uses a pen as the primary sketching tool, different design mediums can impact greatly on the usage frequency of the figure deployment.

5 Conclusions and Limitation

The following conclusions can be drawn from the above analysis: In freehand sketches, there are close relationships between the different drawings that possess 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. However, these relationships may change with the use of different media, which present varying degrees of difficulty in performing the task of representation. From case studies, it is also known that the various projections restrict the designer's design thinking in different action categories (perceptual, functional and knowledge). Therefore, the utilization of various projections and the varying frequencies of their occurrence will lead to differences in design thinking during the design process.

In addition, from experiment results it is seen that pen-based systems can perform freehand sketches just as well as conventional pen-and-paper. However, due to the former's special functions, such as VR mode, pen-based systems allow a designer to inspect a 3-D view during the sketching stage. This characteristic allows the drawing and inspection of concrete images (e.g. 3-D models) 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 carry out the design thinking process based on ambiguous 2-D projections and more concrete 3-D images, as well as offering 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. From the case studies only a preliminary conclusion was drawn about the relationship between the action categories (perceptual, functional and conceptual) and the various drawing projections. More exact studies must be done using protocol analysis. This research only explains how the two entities mutually limit each other, without explaining the content-oriented relationship within.

6 Significance and Future Studies

As pen-based systems possess the characteristics of conventional pen-and-paper, they play a critical role in representing the ambiguous nature of CAD design and are gradually giving a tangible form to the conventional pen-and-paper method, while linking the gap between the designer's conceptual stage and the CAD designs generated by the present-day computer-based media.

1. Research on Sketch Recognition

This research presents detailed analyses and discussions on the levels of abstraction in the designer's drawings during the 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 sketching is understood, then the most suitable design media can be selected and given to the designer for use as an excDot representation tool.

2. Research Methodologies on Design

When sketches become digitized information, there will be a major breakthrough in terms of research methodologies,

Table 3

Level of abstraction	SK (drawing time/total time)	ECN (drawing time/total time)
3	796 /5078 = 0.15	1543 /8141 = 0.19 **** (inspect)**
2	47 /5078 = 0.009	1324 /8141 = 0.16
1	3667/5078 = 0.72	3452 /8141 = 0.42
0	568s/5078 = 0.11	1822 /8141 = 0.22

especially for the study of sketches. The cumbersome data processing required in the past for protocol analysis experimentation can now be recorded or dissected using the 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 systems allow 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 made by the use of different media for initial-stage freehand sketching and for later-stage design and development. The freehand sketch not only plays the role of a communication tool for the designer, it also serves as an excellent computer based media tool for consolidating and accessing other design-assisting software.

As the cognitive behaviors displayed when using the pen-based system and when using conventional pen-and-paper are different, future researches will, one hopes, use these derived phenomena to consolidate relevant research results, and then make inferences about a theoretical model for an improved 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 a 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' personal idiosyncrasies into the pen-based systems, thereby providing the designers with more stimulation.

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