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Drawing and Design Intentions -- An Investigation of Freehand Drawing Conventions in Design

Ellen Yi-Luen Do1,2, Mark D. Gross1, Craig Zimring2

1 Sundance Lab for Computing, University of Colorado, Boulder, CO 80309-0314

2 College of Architecture, Georgia Institute of Technology, Atlanta, GA 30332-0155

Email: ellendo@acm.org

Abstract. Designers use drawings to explore alternatives and to test their ideas employing different symbols and configurations for different design concerns, or tasks. We argue that designer's attention to, and interest in, these various tasks can be determined by examining the drawing symbols and spatial arrangements. We have conducted several empirical studies on design and drawing to determine whether, and to what extent, it is possible to infer, interpret, or even guess what a designer was thinking about by looking at the drawings she has made.

Keywords. design thinking, design intentions, freehand drawing conventions, protocol analysis, design context

I. Introduction

Before reading further, please examine Figure 1 and consider what the drawings suggest.

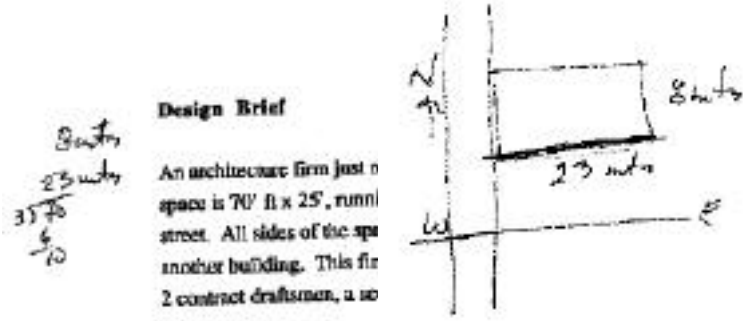

Figure 1. Scribble interpretation of a design program (left) and the drawing made as a consequence (right).

Figure 1 left is cropped from the corner of a piece of paper that presents an architectural program. An architect's handwritten annotations appeared by the side of the program to convert the dimensions into the metric system. Figure 1 right is a drawing this designer made to illustrate and record basic site information (direction, dimension, street). The first four sentences of the program read as follows:

"An architecture firm just rented a one story warehouse to be its new office space. The space is 70' ft x 25', running East-West the long way. The west side entrance faces a main street. All sides of the space may have openings except the south side, which connects to another building."

Now examine Figure 2 below and identify the chairs and tables.

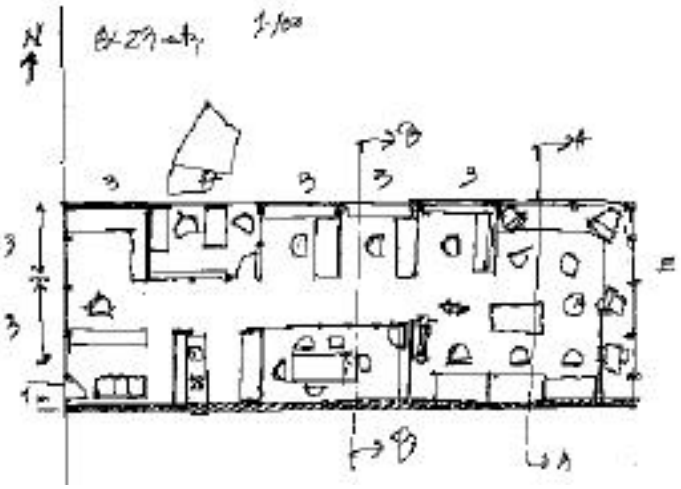

Figure 2. A design drawing of an architect's office.

For architects and designers who are reading this paper, it should be fairly easy to identify all the chairs and the tables. One may further identify objects such as the couch, conference table, the sink and stovetop, the computer monitors, and the dimensions of individual workspaces. Some may be able (and eager) to generate two sectional drawings from this floor plan that look similar to Sections A-A and B-B in Figure 3. How can we understand the drawings even though there was little text annotation? We contend that the reason why architects can 'read' these drawings is that they understand the symbol conventions contained in the drawing.

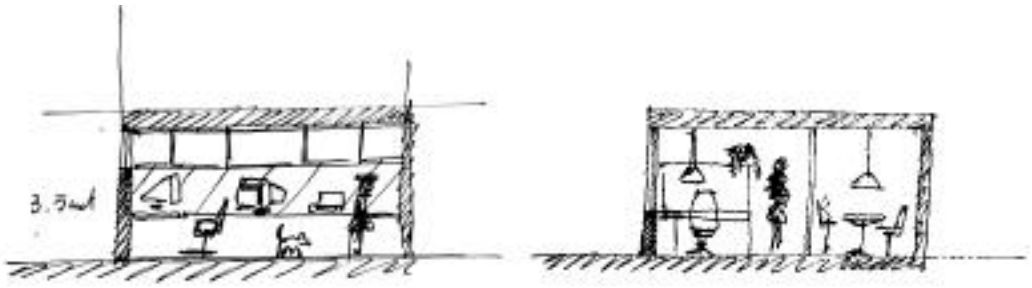

Figure 3. Sections A-A and B-B for the floor plan of Figure 2.

We are interested in finding how drawings reveal contexts and intentions of design. Understanding the inference of context and intention from a design drawing will help elucidate the relationship of design drawing to design thinking, and it will enable the development of digital sketching environments that invoke knowledge-based design tools at the appropriate time. This paper reports on our empirical studies on drawings and our findings. The rest of the paper is organized into four sections. Section II reviews related work in cognitive science and protocol analysis studies of design. Section III describes the experiments and the profiles of participating designers. Section IV reports summaries and analyses of the four case studies. Section V concludes with a discussion of the findings and an outline of future research directions.

II. Background

Studies of diagrammatic reasoning and design drawings have been of great interest to cognitive scientists and design theorists in recent years. They argue that design drawing is important because it is an external representation that helps in solving problems and generating ideas. We ask two questions here: 1) What is the role of freehand sketching and diagramming in design? 2) How can one study the reasoning processes of designers so as to further

our understanding of sketching in design? To answer these questions, we briefly review cognitive science and protocol analysis studies of the relationship between drawing and design thinking.

Cognitive Studies of Drawings

One of the earliest studies, Larkin and Simon's "Why a Picture is (Sometimes) Worth Ten Thousand Words" argues that a diagram is a representation created to externalize and visualize problems . Chandrasekaran, Narayanan, and Iwasaki, in their review paper on the "Diagrammatic Representations" observe that there is an emerging consensus that diagrams function as an aid in the organization of cognitive activity. An overview of the related literature in experimental psychology is provided by Blackwell's "Diagrams about Thoughts about Thoughts about Diagrams" , which views a diagram as a notation (e.g.,) that provides information and intention clues in a visual form. Suwa and Tversky report that architectural drawing is important in that it reveals a designer's thinking graphically and facilitates problem solving and creative effort . They argue from their retrospective reports of design process that drawings provide visual cues for revision and refinement of ideas. They also classify the information in the verbal protocols into different categories such as spaces, things, shapes, views, lights and circulation.

Fish, in "How Sketches Work" argues that sketches are representations of "visual thought" that help facilitate perception and translation of ideas . Van Sommer's "Drawing and Cognition" describes experimental studies of graphic production processes and argues that the act of drawing is a "graphic engine or a production system" (p. 245) that helps people generate concepts. Goel's "Sketches of Thought" argues that drawings are 'external symbol systems' to represent real world artifacts that can be manipulated and reasoned with .

Protocol Analysis of Design Activity

Cross and Dorst suggested that protocol analysis is a useful research technique for analyzing design activity . 'Think-aloud' protocols have been used to study problem-solving activity from verbal reports . Eastman's "Analysis of Intuitive Design Processes" views design as problem behavior, following the 'information process model' of Newell and Simon . His study portrays design process as identifying problems and testing alternative solutions. Akin's "Psychology of Design" follows this view of information processing and analyzes the chunking of design actions and attention shifts . In a recent study, Akin and Lin observed that novel design decisions usually occurred when the designer was in a "triple mode period": drawing, thinking, and examining. They also concluded that the transcripts and drawings echo and complement each other.

Schön analyzes design protocols and argues that design reasoning is a thinking pattern with the use of design rules and a process of "reflection-in-action" . He argues that designers "see" and then "move" design objects. Goldschmidt further argues that design reasoning consists of "seeing as" and "seeing that" modalities . She views sketching as an operation of design moves and arguments, an "oscillation of arguments" that brings about a gradual transformation of images . Ullman, Wood and Craig argue that the importance of drawing in a design process is that each marking action is an external representation of a chunk of information . They argue that the "marks-on-paper contain different types of information."

New Empirical Study of Design Drawing Conventions is needed

All the above cognitive studies and protocol analyses agree that design drawing is associated with design thinking and can be interpreted through verbal descriptions. They discuss several important issues about design drawings: first, that designers use freehand drawings when thinking about design concerns; second, that design reasoning is related to design drawing; and third, that different types of information are embedded in design drawings. This implies that a design drawing may employ different symbols to represent different types of information. However, none of the studies examine the graphics symbols designers use in design. They mainly look at the verbal descriptions of design problems and solutions, or the state shift or chunking of the thinking. The study we describe

in the following section is designed 1) to verify the relationship between design drawing symbols and design intention, 2) to identify the universe of drawing symbols that designers use and 3) to demonstrate the feasibility of making drawing convention computable.

III. Experiment Design & Participants' Profiles

This section describes the experiment sequences, test materials and participating designers' profiles.

Two undergraduate design students and two architectural instructors participated in the design drawing experiment. The test material given to the participants was a program that called for the design of an architect's office followed by a sequence of four tasks, in which each task asked the participants to focus on a particular concern. The four concerns are 1) spatial arrangement, 2) lighting, 3) visibility and privacy, and 4) fitting a special piece of furniture into the design.

Let's return to the design brief that was used in the design experiment to generate the drawings in Figure 1 and Figure 2. The rest of the architectural program read as follows:

"This firm currently has 1 chief architect, 3 designers, 3 CAD operators, 2 contract draftsmen, a secretary and about 1-2 student interns.

The office will be designed to have, besides the area of work groups of designers, CAD specialists and draftsperson, a meeting room, a small kitchenette, a bathroom, and a chief architect's private office, a secretary – receptionist – general affairs section, storage space, printing and plotting area, and space for student interns."

All participants filled in basic information – name, gender, occupation, professional experience, and education in the pre-experiment questionnaire. They were also asked to report on a scale from 0 to 4 how often they used freehand drawing for architectural design (0 means never, and 4 means all the time), and how often they used freehand drawing to communicate with other designers. Table 1 shows a summary of designer's profiles. A brief description of each participant is given below.

Table 1. Profile of participating designers

Name	Roger	Noi	Samuel	Mario
Nickname[§]	Functional Designer	3D Sketcher	Philosopher	Research Architect
age	21	20	28	51
experiment date	09/16//96	09/17/96	02/12/97	06/18/97
design education	3 years	4 years	5 years	13 years
professional experiences	3 internships	1 internship	1.5 - 2.5 years in 3 architecture firms, & 1 year private business	3 years in architecture firm, & 15 years consulting business
use of freehand drawing in design (0 - 4) *	3.3 (right handed)	4.0 (left handed)	3-4 (right handed)	4.0 (right handed)
use freehand drawing to communicate	3.5	4.0	3-4	4.0

use computer for design (0 - 4) *	3.0	4.0	3-4	4.0
post-experiment self report on personalized symbols and short hands for designing	window, wall, door, entry, movement, link, height, dimension	tree, plant, human	circulation, light, visibility, thick walls, thin transparent screen	solid wall, chairs, people, dogs, plants, kitchen, windows, computers, roof

* (0 never - 4 all the time)

[§] A caricature description and nickname are included associate with the designers' pseudonyms to make it easier for the readers to differentiate among designers.

Roger was a graduating senior who spent all his summers working in architectural design firms. He believed that he produced good designs by making sure his design work fulfilled "functional" aspects. Therefore, Roger is referred to as the "Functional Designer." Noi also was a graduating senior who enjoyed using freehand drawing for "everything" and was proud to have the ability to draw "3D" sketches from any drawing. Hence Noi is referred to as the "3D Sketcher." Samuel was an instructor at the architecture school. He was a philosophy major before he chose to study architecture, and he believed that everything that appears in a design should be justified. Therefore, Samuel is nicknamed the "Philosopher." Mario was a visiting scholar who had professional experience in architectural office and consulting firm. He called himself a "Research Architect."

IV. Summaries and Analysis of the Design Sessions

Functional Designer Roger– Diagram Conventions & Dimensional Reasoning

Roger used a well-defined set of drawing elements to indicate different concerns. He drew bubble diagrams (Figure 4a) when thinking about conceptual, schematic design and he drew furniture such as tables and chairs in the room to test how the space would work (Figure 4b). He drew a sun symbol with a light ray penetrating the windows into the building when working on the lighting task (Figure 4c), lines and double arrow links to indicate relationships or movement for visibility and privacy issues. He used dimensional symbols and wrote down numbers when reasoning about dimensions (Figure 4d, see also for a more complete account of the dimensional reasoning process).

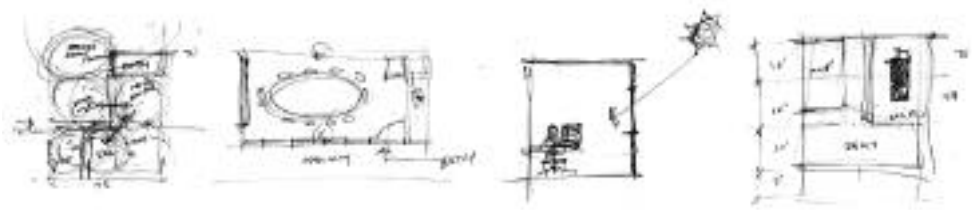

Figure 4. Roger's conventions: (a) bubble diagram, (b) furniture, (c) lighting section, (d) dimensional reasoning

3D Sketcher Noi– Lines for Partitioning, Lighting & Hatching

Noi had a tendency to make perspective, isometric "3D" drawings from of his plan or sectional drawings. He used a set of drawing conventions such as dimensions (70, 25) and directions (N, E, W, S). He used hatching and text labels to indicate space (Figure 5a) and drew simple furniture and human figures. Instead of bubble diagrams, Noi drew partition lines for the spatial layout task (Figure 5b) and he drew lines penetrating the building to illustrate lighting (Figure 5c).

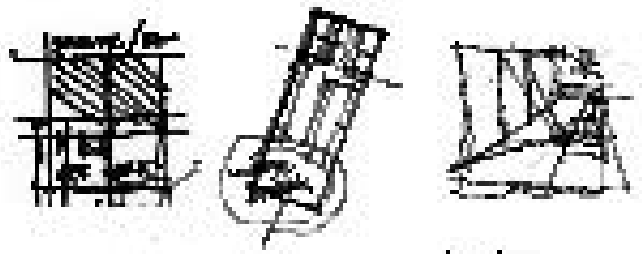

Figure 5. Noi's conventions: (a) label and hatching of space, (b) spatial partitioning lines, (c) lighting concern

Philosopher Samuel– Arrows for Lighting, Entrance and Visual Access

Samuel's design drawing was a hybrid of Roger's bubble diagram and Noi's spatial partitioning. He drew bubbles to represent different functional space (Figure 6a left). He also drew many lines to define space – labeled 'chief' (architect's office), 'meeting' room, and 'kitchen' – and called these lines walls, windows, or screens (in the verbal protocol). He drew sections with light rays to illustrate lighting (Figure 6b) and used arrows to indicate entrance, lighting and visual access (Figure 6a). Samuel also drew lines, hatching and shapes to represent windows, walls, and furniture (Figure 6c).

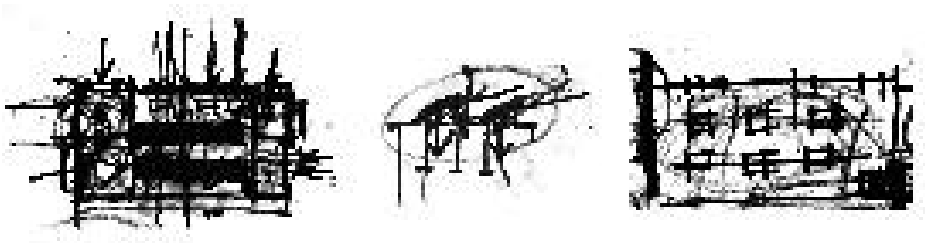

Figure 6. Samuel's conventions: (a) bubbles and partitioning of space, (b) lighting section, and (c) architecture elements: stair, tables, windows and walls

Research Architect Mario– Scale, Dimensions & How Things Work

Mario's design drawings, like others, revealed many drawing conventions. From the transcript (see Appendix A of) it seemed that Mario performed three tasks throughout the design session. (1) He started by thinking about the site (Figure 1). He proceeded to understand the dimensions and orientation, writing down numbers, using scale measurement, and writing down N, E, W. (2) He partitioned the space available to correspond to the program (Figure 7a), arranging space by drawing partition lines for walls, windows and doors (Figure 7b). (3) He checked the partitioned space by drawing in furniture such as tables and chairs, human figures, plants and dogs (Figure 2 and Figure 3). He drew the same kinds of objects in sequence (Figure 7c, 3 monitors, 3 tables and 3 chairs). He used symbols to label dimensions (Figure 7d) and wrote down numbers to calculate area and to convert between the metrics and the English systems of dimensions (Figure 1 and Figure 7e).

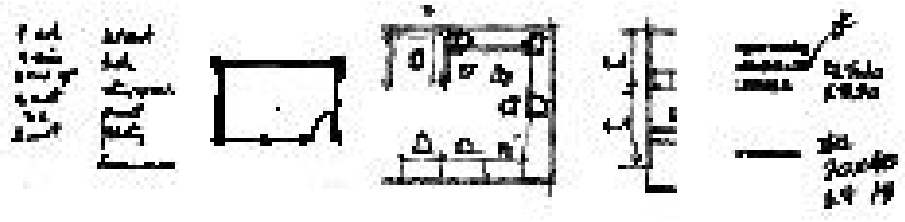

Figure 7. Mario's conventions: (a) design program as copied in writing on the trace, (b) architectural elements, door, wall and window, (c) objects drawn in sequence, 3 monitors, 3 tables and 3 chairs, (d) labeling dimensions on side, and (e) dimensional reasoning, conversion of numeric calculations

V. Summary and Conclusions

The experiment examined drawing how architects use symbols and configurations in the design process and how use differs across different design tasks. A previous study with sixty-two designers found that designers share and can understand one another's conventions in diagramming architectural concepts. The goal of the present experiment was to verify whether architects also use these conventions when designing. In the four design sessions, several drawing conventions that correspond to different design concerns were identified. For example, bubble diagrams and line partitioning are used for spatial arrangements, a sun symbol and light rays for natural lighting concerns, and numbers to calculate and reason about sizes and dimensions. This experiment was set designed to test whether designers use the same drawing conventions when they think about design concerns and when they design. We found that they did. We found the studies showed that the four participating designers shared drawing conventions not just among themselves but also with those who participated in the design diagramming experiment described in the previous study.

The design drawing experiment revealed several patterns: First, designers share drawing conventions. They consistently use symbols to represent walls, windows, furniture and human figure. Second, designers combine symbols in specific configuration to indicate design contexts. For example, conference rooms are portrayed as chairs surrounding a long table, and the direction North is indicated by letter N and an arrow. Third, designers have different drawing preferences for different design concerns. For example, visual access concerns are portrayed in plan view with arrows representing view lines, lighting issues are illustrated in sectional view using light rays that penetrate the building. Fourth, designers write down design concepts or space names as labels in their drawings. They overtrace their drawings to draw attention to specific shapes or areas. Finally, designers write down numbers to reason about scale and calculate about dimensions.

There were also some individual differences among the designers: 1) Roger, the functional designer, drew "bubble diagrams" for spatial arrangement. He was articulate and had developed a personal set of symbols for direction, furniture and dimensioning. He wrote down numbers to label dimensions and to reason about square footage. 2) Noi, the 3D sketcher, was obsessed about turning all his plan and sectional drawings into "3D" drawings. He used lines as "spatial partitions" to arrange space. 3) Samuel, the philosopher, talked a lot about what he was doing when he designed and his verbal protocols were very informative. However, his drawing symbols tended to be few and simple. He drew rectangles to represent tables, counters, printers and rooms. He used arrows to represent many concepts such as sunlight, entry, view, and circulation. His spatial layout plan was a hybrid of "spatial partitioning" and "bubble diagram." 4) Mario, the research architect, made the whole design session into a testing task by drawing furniture elements. He used a set of symbols for furniture, and structural elements such as columns and walls. He wrote down numbers to calculate and convert feet to meters. He copied down program requirements on the tracing paper unlike other designers who underlined or drew shapes to visualize space requirement given in the design program.

The four design sessions from the empirical studies described above showed evidence that different concerns and contexts can be identified through drawing conventions. In other words, in the domain of architectural design, the graphical marks that designers make are conventional and correspond to the specific tasks that they engage in as they solve a problem. For example, when thinking about natural lighting, a designer might draw a configuration consisting of a symbol for the sun and an arrow that representing a light ray in section. The presence of these symbol configurations indicates that the designer's current concern is natural lighting. In a specific drawing context (e.g., sectional view) the design concern is called an 'intention' (e.g., natural light). The question then is: can a computer recognize these symbols and configurations and hence their associated intentions. If a computer can infer design intentions from drawing conventions, then these drawing conventions can serve as a trigger to access appropriate design tools targeting the task at hand. Different design concerns can be supported by appropriate knowledge-based design tools. Therefore, the results from the design experiment suggest that a computer system would be able to infer design intentions from the drawing symbols designers use, and to use that inference to provide the designer with the right tool at the right time. A Right-Tool-Right-Time prototype system has been implemented and reported elsewhere .

Acknowledgments

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