

Inferring Design Intentions from Sketches

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INFERRING DESIGN INTENTIONS FROM SKETCHES

an investigation of freehand drawing conventions in design

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Abstract. Designers draw to explore ideas and solutions. We look at empirical studies of the use of drawing in design, including our own work on the connection between graphic symbols and specific design concerns. We describe an empirical study on sketching for designing an architect's office. We found that designers use different drawing conventions when thinking about different design concerns. We are implementing a freehand drawing program to recognize these drawing conventions and to deliver appropriate knowledge based support for the task at hand.

1. Introduction -- Why Study Drawing?

The goal of many intelligent computer aided design systems, and in particular knowledge based systems, is to provide advice in the form of critiques, relevant cases or examples, and the results of simulations. How might these systems decide what advice to provide the designer, and when to provide it? Specifically, can intelligent design systems determine appropriate advice to give designers by looking at their drawing? The drawing conventions that designers share in designing may be a good indication of what contexts and concerns they are interested in at the time. If so, this raises the question: what drawing conventions should a computer understand?

We are interested in finding how contexts and intentions are embedded in design drawings. The inference of context and intention from a design drawing will help elucidate the relationship of design drawing to design thinking, and enable the development of digital sketching environments that invoke knowledge-based design tools at the appropriate time.

Drawing plays an important role in design education. For example, design educator Lockard argues that the act of freehand drawing allows our mind to "see, comprehend and respond" to information (Lockard, 1973). Laseau in *Graphic Thinking* argues that conceptual drawings are drawn to present points of concern and to provoke further design decisions (Laseau, 1980).

Designers use drawings to develop their designs. Designers often work by making sketches or transcribing drawings from their design team colleagues for further development (Graves, 1977). They use drawings to represent "movement, access, sound, view, function, and time" (Fraser & Henmi, 1994) (p 110). Lawson describes that the designers "find it hard to think without a pencil in their hand" (Lawson, 1994) (p 141). Herbert argues that drawings are "the designer's principal means of thinking" (p 1) (Herbert, 1993). He further argues that designer "must interact with the drawing" (p 121) .

Designers use the terms of 'diagrams', 'sketch' and 'schematic drawing' somewhat interchangeably. Here we use the term drawing and sketches to refer to the drawings designers make during early design process. In the following sections, following a brief discussion of relevant research on protocol analysis, we focus on the experiment on extracting design intentions from freehand design drawing. We describe our experiment setup and the experiment results. We conclude with a brief discussion of computational approaches to support the use of freehand drawings in design.

2. Protocol Analysis of Design

Protocol analysis studies have been used to study design problem solving. These research involved the collection of both verbal and visual data. In one of the first design process protocol studies, Eastman observed designers sketching to improve a bathroom layout to argue that designers' words and drawings correlate with the problems they find and solve (Eastman, 1968).

Akin's *Psychology of Design* (Akin, 1986) followed Newell and Simon's information processing model (Newell & Simon, 1972). He studied architects sketching and recall to analyze the chunking of design actions and attention shifts. His study revealed several chunks: the wall and window segments, steps, and furniture of similar size that have close spatial relations.

A more recent chunking study done by Suwa and Tversky (Suwa & Tversky, 1996) video taped architects designing an art museum. From the verbal post-design review protocols, they argued that seeing different types of information in sketches drives the refinement of design ideas. They further classified the information in the protocols into different categories such as spaces, things, views, lights and circulation.

Akin and Lin designed a two-part experiment (Akin & Lin, 1995) that asked subjects to do two tasks: (1) to reproduce a drawing from a printed transcript, and (2) to predict verbal data from a video of the design drawing

process with the sound track suppressed. They concluded that the verbal transcripts and drawings are complementary.

Schön analyzed protocols of architects' sketches in an attempt to infer their design reasoning (Schön, 1985; Schön & Wiggins, 1992). He described design sketching protocols to illustrate the idea of "reflection-in-action." He argued that designers first "see" then "move" the design objects.

Goldschmidt's design protocol studies, like Akin, examined drawing as well as verbalization. She viewed sketching as an operation of design moves and arguments that results in the gradual transformation of images. Sketching, she argued, is a systematic dialectic between the "seeing as" and "seeing that" reasoning modalities. Her studies showed that the act of sketching is a vehicle for design thinking.

All the above studies described the association of thinking, verbal protocols with design drawing. However, none identified the graphic symbols designers use in design. They mainly looked at the verbal descriptions of design problems and solutions, the state shift or chunking of the thinking.

Our empirical study, *What's in a diagram that a computer should understand* (Do, 1995), however, focused on identifying the association of the drawing marks with the design thinking. The experiment used diagrams and stories from a case based design aid Archie (Domeshek & Kolodner, 1992; Zimring, et al. 1995) as test material for sixty-two designers. We identified several drawing conventions designers used when diagramming different design concerns. We found that 1) designers only use a small set of symbols in their drawings and arrange them in conventional and consistent ways (figure 1 shows the lexicon of symbols they used), 2) designers exhibit different view preference for different concepts (e.g., plans or sections) to illustrate different sorts of problems (e.g., spatial arrangement versus getting light into a building), 3) keywords from the stories are often used as labels in diagrams, and vice versa, and 4) designers mostly agree with each others' diagrams.

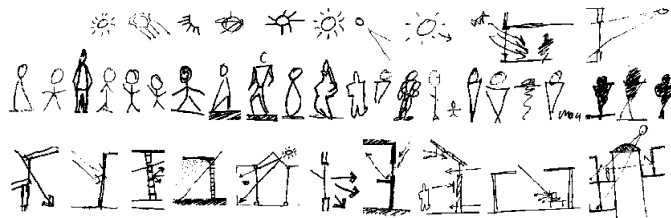


Figure 1. Designers used conventional symbols and configurations for architectural concepts in diagrams. A symbol for sun is usually represented by a circle and light rays.

A figure person consists a circle and a shape underneath. Lighting concerns are illustrated by light rays that penetrate building envelope.

However, this study only involved diagramming from descriptions instead of real design tasks. The next question is, do designers use the same drawing

conventions when thinking about different concerns when they design? In order to answer this question, we conducted a new experiment.

3. The Design Experiment -- How Do Sketches Convey Design Ideas?

This new experiment focuses on identifying the association of the drawing marks with the design thinking. We set up the tasks to find out what drawings designers make when dealing with different concerns. For example, when designers think about lighting, what symbols will they use and in what spatial configurations? Do they follow the same conventions as we found from the previous empirical study?

3.1. THE EXPERIMENT

The test material was a design brief that included four tasks in a sequence. Each task asks participating designers to focus on a particular issue. The time spent by participants ranged from thirty minutes to one and a half hour. One design instructor and two undergraduate senior design students participated. The process of designing was recorded in the video tape while an observer took notes on designer's remarks and drawing actions.

We used office space design as an example domain to set up experiments for finding the symbols sets for the design tasks involving lighting, space arrangement, visual access and dimensioning. The design program was:

"to design an office for an architecture firm in a 70 ft. by 25 ft. one story warehouse, providing workspace for architects, CAD operators, contract draftsmen, a secretary and student interns. The office will be designed to have space for work groups, a meeting room, a small kitchenette, a bathroom, and a chief architect's private office, a general affairs section, storage space, printing and plotting area."

After reading the design program, designers were asked to start with a new sheet of tracing paper for each task and to focus on four different concerns in conceptual, schematic design: spatial arrangement, lighting, visibility and privacy, and fitting a special piece of furniture into the design.

The first task (1) asked the designers to pay particular attention on the zoning of the spatial arrangement for the office, considering where to put the lobby, chief architect's office, meeting room and the different work group spaces, etc. The second task (2) asked the designers to focus on lighting for the meeting and working area. The third task (3) asked for consideration of visibility and privacy between different spaces. Finally, task (4) was a special request for fitting a large meeting table into a conference room and a minimal footage requirement for designers' work space.

3.2. EXPERIMENT RESULTS: DESIGN CONTEXT & DRAWING CONVENTIONS

Our previous study (Do, 1995) reported that designers share and can understand others' drawing conventions in diagramming architectural concepts. The goal of this new design experiment was to verify if these conventions appear when designing. We identified several drawing conventions that correspond to different design concerns, e.g. bubble diagrams for spatial arrangements, and a sun symbol and light rays for natural lighting concerns. These findings match our previous results. We describe below our five major findings from the current experiment.

3.2.1. *Designers share drawing conventions: symbols & their configurations*

We found from the experiment and the post-experiment questionnaires that designers use drawing symbols in their design. Participating designers chose primitives from a limited universe of geometric shapes and symbols in their drawings, and composed them in highly conventional ways. They used predominantly lines, ovals and blobs, rectangles, and hatching. Ovals and rectangles were drawn with varying size and aspect ratios. We call these drawing elements, such as lines, arrows, and geometric shapes, primitives.

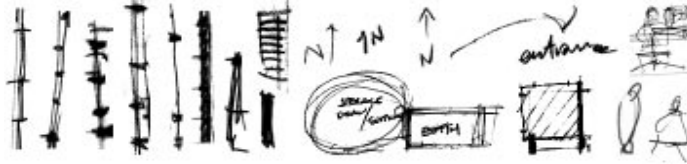


Figure 2. Primitives (drawing elements) used in drawing included arrows, lines, hatches and simple geometric shapes. Symbols (architectural objects) such as walls, windows and stairs are formed by combination of primitives.

When drawn individually, primitives do not imply much architectural meaning. When primitives are combined together, they form symbols to represent architectural objects such as walls and windows or to simulate natural phenomena such as sun and human figures. For example, a symbol for North was composed with an arrow and a letter N; lines were composed to indicate walls and windows; and circle with lines or a blob was drawn to indicate a person (see Figure 2).

3.2.2. *Lighting concerns are portrayed in sectional view with light rays*

From the experiment we found that different design concepts tend to correlate sectional or plan representations. The experiment asked designers to focus on separate issues such as zoning, lighting, visibility and dimensioning. As in our previous study of diagram making, participating designers seem to share a preference for using plan or section to illustrate certain architectural concepts. For example, they chose a plan view to

illustrate relationships between different spaces and zones for layout design and sectional views to illustrate lighting conditions. Figure 3 shows that a lighting issue included a sectional view, a representation of light from a sun passing through the building envelope. These representations were made using conventional symbols for the sun, light rays, windows and walls; some drawings also included symbols for persons and computer screens.

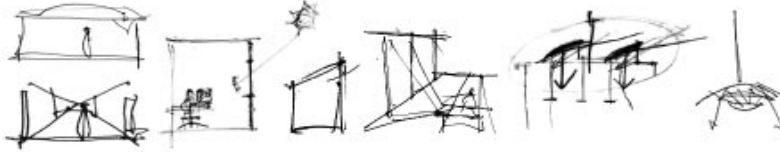


Figure 3. Drawings illustrate lighting by using light lines that penetrate building envelope from windows and roof. The changed direction arrows indicate reflecting light in an interior lighting fixture design (right) and from a roof skylight (second to right).

3.2.3. Attention and focus can be identified through labels and overtracing

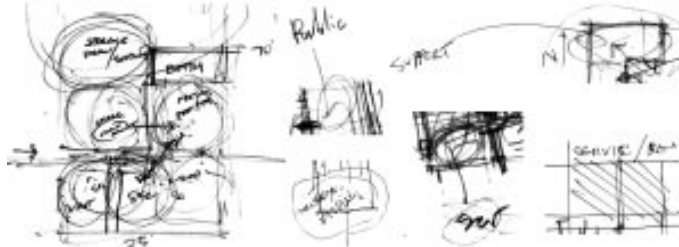


Figure 4. [a] a bubble diagram for layout and zoning, [b, c, d, e] designers used overtracing (circle) to select a space, they put labels inside the shapes, or drew lines out to indicate space use, [f] hatching is another way to emphasize a certain area and distinguish among other spaces

We found that plan drawings have more text labels than sections. The data also revealed that participants frequently included key words from the design concepts as labels in their drawings. Labels of functional space were mostly written inside a containing shape (oval, blob, or rectangle), occasionally put beside the shape with an arrow or line from the label pointing to the shape it identifies (see Figure 4). From video protocols we found that designers constantly engaged in overtracing, in which the designer's pen repeatedly outlines a particular shape or area of the drawing. This overtracing, or redrawing serves as an act of selection, to draw attention to the element, to refine a shape, to add detail to the drawing, or to explain to the observer. Designers also used hatching to distinguish a particular space from others.

3.2.4. Dimensional reasoning through figure calculations

When thinking about allocating objects or spaces with a required dimensions, designers wrote down numbers beside the drawing to reason about scale and

calculate about dimensions. For example, task 4 called for a work space of at least 800 square feet, and the conference room to accommodate a 4' by 10' table. Figure 5 shows a design drawing with annotated numbers for calculation made by one of the participating designers. Below we show his design reasoning process:

*The designer first drew an outline of the site (25 * 70) and then reasoned about the depth of the work space. He wrote down "800", then 4*8 while looking at the number 25 on the side of the site. After written down 4*8, designer put down 32' alone the side and drew a rectangle of that size. The designer murmured and calculated that 70-32=38 and deducted 1 for partitions, arriving at 37.*

*He then drew dimensional marks with 10' intervals along the length of the site (three 10's and a 7'). Then he checked to see if the table can fit into the conference room. First he wrote down the dimension of the table (4*10),, calculated and wrote down the answer 40, and doubled it (80) for buffer space.*

*He then wrote down 200 to be the dimension for the conference room. He drew a rectangle that occupied two 10' sections, and half of the width, wrote down the dimension for the conference room (20*10) inside the newly made rectangle. He overtraced the rectangle to see if it would be large enough. Then he left some corridor space and drew a smaller rectangle on the left side, wrote down 10*15 and said "this should be big enough for another office space".*

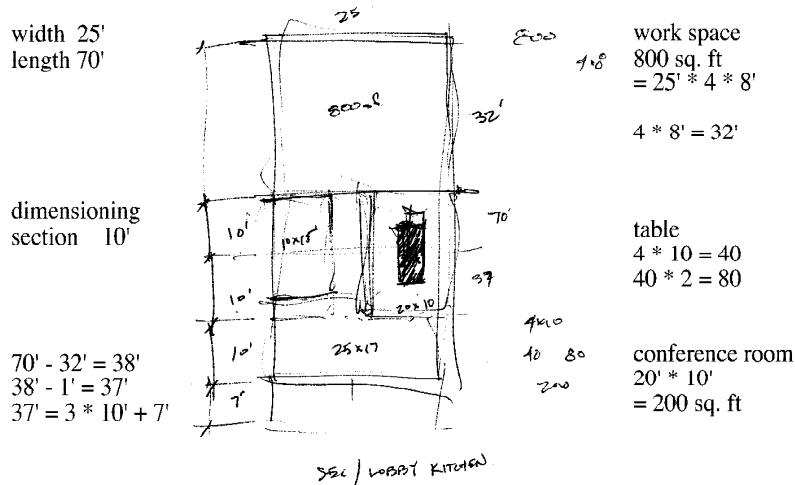


Figure 5. Process of calculating of space requirements and dimensioning: 1) mark the width and length of the site, 2) calculate to make room of 800 sq. ft. for work space, 3) calculate the left over space, divided by 10' intervals, 4) check dimension of table (4*10) to fit inside the conference room, calculate the space.

3.2.5. Designers drew furniture in space and to put themselves in context

We found designers drew simple shapes into space to represent furniture, and to put themselves in the right context to think about design. For example, the

top row of Figure 6 shows variations of a conference table. Two designers drew chairs (small rectangles or dots) surrounding the table and one drew a larger rectangle surrounding the table to see (test) if the space is big enough. One designer further drew a door and windows along the wall, service counters and a white board for the room. The bottom row (figure 6) shows different furniture placed in space for a lobby and office space.

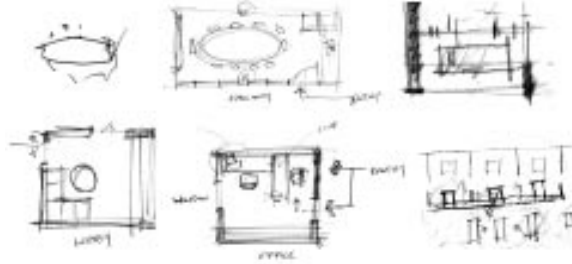


Figure 6. Symbols give clues for context. Top row: different designer's symbols for the conference space. Bottom row: lobby, office and cubicles

4. Discussion & Future Work -- Sketches & Computing

4.1. DISCUSSION

Designers might use conventional representations of symbols because of their architectural training. Books about visual thinking teach students to use symbols for presentation. For example, in *A Primer of Visual Literacy*, Dondis states that "dots, lines, and shapes," as well as "direction, tone, color, texture, scale, dimension and movement" are components of visual media (Dondis, 1973). Similarly Laseau in *Graphic Thinking* suggests diagrams are composed of "identities," "relations," and "modifiers" (Laseau, 1980). He drew several geometric shapes, circles, squares, blobs and crosses to illustrate possible "elementary symbols." He indicates that these symbols can be supplemented or replaced by numbers, letters, or other symbols. Lines and arrows are used to suggest relationships, a sequence of events, movement and process. Modifiers use size, tone to create emphasis. It is not surprising that designers use drawing conventions when designing.

4.2. FUTURE EXPERIMENTS

We plan to repeat the experiment with additional design instructors as well as practicing architects. It would also be interesting to conduct experiments from different schools and geographical districts. We have engaged video and verbal protocols in the experiment and collected drawings designers made. However, the sequence of drawing and the process of overtracing can not be easily extracted from the final static drawing. It would be more informative if we could display the sequence in which the drawing was made.

A stop frame from the video can never get as clear, and high resolution as a paper drawing. A digital drawing device that could record and play back the drawing sequence would therefore be useful. In short, it may be valuable to automate the experiment apparatus by using a computer based drawing environment to record, collect and analyze data.

4.3. DRAWINGS AS AN INTERFACE TO DESIGN INFORMATION SYSTEMS

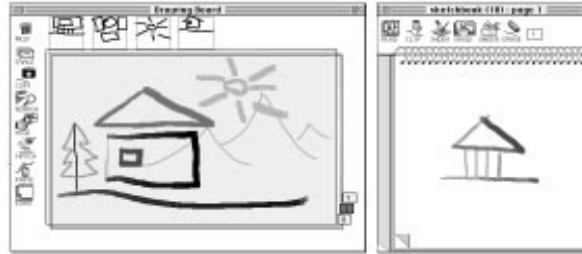


Figure 7. The Electronic Cocktail Napkin -- [a] drawing area, [b] sketchbook for storing interesting sketches.

We are investigating how to program a computer to recognize these design symbols and to infer intended design contexts. We are currently working on a freehand sketching program called the Electronic Cocktail Napkin that recognizes hand drawn diagrams and communicate these to other knowledge based systems. The Cocktail Napkin program (Gross, 1994; Gross, 1996; Gross & Do, 1996; <http://wallstreet.colorado.edu/Napkin>) aims to support casual drawing. Designers employ a digitizing tablet and a cordless pen, or a mouse or a personal digital assistant for their design drawing. Designers can diagram and sketch freely on the drawing surface, and can customize the program to recognize personal defined symbols by combining drawing elements together.

The program also supports multiple trace layers, a sketchbook and drawing pin ups (Figure 7). We have built several prototype systems for querying design information databases and interactive simulations using hand drawn diagrams (Gross, et al. 1994). We are currently implementing a "Right Tool at the Right Time" manager (Do, 1996) that will activate different design tools based on the task at hand. For example, if a drawing contains sight lines, wall lines and a plan person symbol, then the 'context' is plan view, the 'intention' is visual perception, and so the right-tool-right-time manager will call up a visual analysis program.

We have suggested that designers share a small universe of symbols and configurations when thinking about different design concerns. Therefore we can infer design intentions and context from these drawing conventions. Detecting context from drawing is proving to be an interesting and complex problem. We are conducting further empirical studies to understand design

drawing conventions, their associated tasks and relevant design tools. We have suggested how an "intention recognizer" in an integrated freehand sketching environment might support delivering the right tools at the right time. We have already connected various design tools with the drawing environment. We are incorporating additional design tools into the system, automating tool activation, and improving the context detection mechanism.

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