

Drawing as a means to design reasoning

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*Artificial Intelligence in Design '96 Workshop on Visual
Representation, Reasoning
and Interaction in Design, Palo Alto, CA.*

1996

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Drawing as a Means to Design Reasoning

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We investigate the functions of drawing in design and how, based on these functions, a computational sketching environment might support design reasoning. Design, like all problem solving activities, involves reasoning—making decisions, expressing ideas, verifying and evaluating proposals, and ultimately, taking action. For designers, drawing is a vehicle for design reasoning, and therefore the spontaneous marks made on paper during sketching form a partial record of the designer’s thinking. Most designers sketch early design ideas with a pencil on paper: sketching is still the quickest and most direct means to produce visual representations of ideas. The ambiguity of free hand sketching allows multiple interpretations and thus stimulates the production of more design alternatives. The linked acts of drawing and looking invite designers to recognize new interpretations of the alternatives they propose. By drawing and looking, designers find visual analogies, remember relevant examples, and discover new shapes based on previously unrecognized geometric configurations in their sketches.

1. Thinking with a pencil

Visual representations such as freehand sketches and concept diagrams seem to play a significant role in design problem solving. Design reasoning is accompanied by, and we might say, embedded in, the act of drawing. Sketching on paper and pencil supports ambiguity, imprecision, and incremental formalization of ideas as well as rapid exploration of alternatives.

The Importance of Drawing

Many studies have emphasized the importance of drawing and visual thinking in design. For example, sketches are viewed as central to architectural design and serve as “reference” to be used, transformed, or engaged in a later composition (Graves 1977). They record a sequence of design moves (Goldschmidt 1991) that reflect a systematic dialectic between two modes of reasoning: “seeing as” and “seeing that”. Stated simply, the designer engages in a “graphical conversation with the materials of design”(Schon 1992) or “having a conversation with the drawing” (Lawson 1994).

Research on design thinking also argues that drawings support the design process. For example, drawings are “the designer’s principal means of thinking” (Herbert 1993), that serve to “direct, order, clarify and record ideas” (Robbins 1994), or to inquire about shapes and ideas of buildings and spaces (Rowe 1987).

Artificial Intelligence in Design 96

Workshop on Visual Representation, Reasoning and Interaction in Design, June 1996, Stanford University

In “Drawing and Cognition” van Sommers studies the mechanics of drawing and drawing preferences (van Sommers 1984), examining how people use speed, pressure, and line weight to convey semantic information. In “Sketches of Thought”, Goel (Goel 1994) argues that the traditional ‘computational theory of mind’ (proposed by Fodor and others) does not account for what designers do, and that the representation of sketching supports design cognition in ways that more finite and precise representations cannot. Larkin and Simon’s “Why a diagram is (sometimes) worth 10,000 words” compares symbolic representations with diagrammatic ones, and identifies several reasons why diagrams can be advantageous for certain kinds of cognitive tasks (Larkin and Simon 1987). Suwa and Tversky (Suwa and Tversky 1996) have conducted a study of designers sketching to solve a simple art museum problem. They looked at the relation between concepts (as identified by ‘chunks’ in verbal post-design review protocols) and graphical acts of sketching.

There seems to be agreement that drawing plays an important role in supporting design reasoning. However, little work to date has examined this connection in close detail. It may turn out to be difficult. On the one hand, design seems to employ a range of quite different reasoning activities, and on the other hand, designers employ a range of quite different drawing acts. Nevertheless, the time may be ripe to develop a mapping between design reasoning and the drawing acts that designers use to carry them out. We propose the following as a sketch of how this mapping might look. We view design as a cognitive activity that involves attention, perception, memory and processing through the act of drawing.

As shown in table 1, we propose to look at various activities of designing, drawing, and interpreting. We do not mean to suggest that the items listed in a column are exhaustive or exclusive, or even necessarily exactly the right categories. And, it may turn out that despite our facile categorization, the acts of drawing, interpreting, and design are not so easily separable. Eventually we would like to understand the relations between these activities, showing how the lower-level activities of drawing and interpreting serve the activities of design, and how the goals of design might direct the drawing and interpreting activities. However, at this stage, an attempt to draw links between these columns will just create a complicated net; therefore we leave it as list of items.

Table 1. Parallel activities in Design, Interpreting and Drawing.

Design	Interpreting	Drawing
reference analogy abstraction refinement evaluation search	attention focus recognition restructure filtering recall context	overtracing speed pressure erase shape specification shape generalization symbols hatching

In sum, the act of drawing seems to support several kinds of cognitive activities that are important in design. It seems these activities are mainly carried out by drawing and interpreting the drawing.

2. Design Activities

Since Asimow's examination of design process, "Introduction to Design" (Asimow 1962), many studies of design process (Markus 1969; Roozenburg and Cross 1991) have focused on two dimensions. One dimension corresponds to a staged process model with phases such as primary and detail design. The other dimension corresponds to problem solving processes such as analysis, synthesis and evaluation. We argue elsewhere (Do 1996a) that different stages of design require different kinds of visual representations. Thus, the symbols and strokes in a design drawing provide not only geometric information (Do 1995; Herbert 1993) but also clues about the stage of design and the designers' intentions about spatial and functional concerns. However, here we draw attention to specific acts of design reasoning: attention -- focusing and selection, perception -- filtering, recognition, processing -- refinement, evaluation, and memory -- finding references and drawing analogies.

Here we discuss three major activities in design: finding references, drawing analogies and making evaluations.

Finding References

In design of all types, but especially in architectural design, designers depend heavily on reference to previous similar designs, that is, cases or precedents. Sometimes relevant cases are found by similarity of building type or by materials or construction type. Often, designers refer to similar buildings based on their physical shape, spatial configuration or form. For example, a designer thinking about using a helical shape for a building (or part of a building) might study Wright's Guggenheim museum, because Wright used a helix as the main internal organizing shape for the building. A designer thinking about arranging four spaces surrounding a central hall might study Palladio's Villa Rotunda for its four way symmetry.

Analogy

A special case of finding references through drawing is visual analogy. Though verbal analogies of various kinds have been much studied in cognitive science, relatively little effort has been made thus far to understand visual analogy, especially its uses in design. As with finding references by shape similarity within the design domain, drawing seems to play a key role in various aspects of this cross-domain analogical reasoning. In the first place, drawing seems to stimulate the reminding process, helping the designers think of visual analogies from other domains. After an analogy is retrieved from memory, drawing seems also to play a role in mapping the analogy to the design domain, in adapting the analogy, and in testing whether it is ultimately appropriate for use.

Abstraction

Often a designer will begin bottom-up, making highly specific decisions in order to quickly develop an "object to think with". Later in the design process, the designer will re-examine these specific decisions, and develop a higher-

level abstraction in their place. For example, in designing a school, the designer might develop a specific configuration of walls and public space to make a public meeting area for students outside classrooms. The configuration might be specific to a particular place in the building, but later in the designing the architect might abstract the elements and spatial relations inherent in that configuration, in order to make similar meeting areas throughout the building.

Refinement

On the other hand, a designer will often work top down, beginning with abstract concepts and gradually specifying, or refining the abstractions into specific configurations. For example, an architect might begin by including in a design a “public entrance”, then gradually refine that concept by making specific decisions about its parts and their relations.

Evaluation

Design involves a continual evaluation of alternatives at every step against performance goals, even while the goals themselves may change during the designing. Drawing facilitates this evaluation, especially when the evaluation involves dimensional or shape criteria. For example in early design, an architect often sketches furniture arrangements, not so much to design the actual arrangement of furniture, but to test whether the size and shape of the room has the capacity to support at least one plausible layout. To evaluate the relative privacy of spaces in a building design, and the feeling of containment that a plan gives its users, a designer will often draw sight lines, testing what a user can see from a given location in the building.

3. Drawing and Interpreting

We consider together two major activities that support design as we have discussed it: 1) drawing and redrawing, and 2) seeing and interpreting.

We have observed architectural designers in action, in teaching design and in architectural practice. They rely heavily on several drawing techniques. First, designers constantly draw repetitive traces to identify aspects of concerns, to bring focus to the drawn shapes, to recognize ‘emergent’ shapes in the drawing and to specify shape modification. This redrawing and overtracing can happen on a same piece of paper or on different trace layers. Second, a designer may use a different tone or make marks on the drawing on top of old marks to extract a form from the ambiguous noise. Or, the designer may draw and overtrace to simplify an idea to an abstract form where no specific shape features are given. Designers also use hatching to add shadows for shape and give it three dimensional depth, to emphasize a particular area, or to assign different character to that particular shape. Third, designers often use symbols to interpret their design or place their design in context for analysis and evaluation. Often we found a lighting analysis drawing consists a symbol of sun and light rays, visual perception of a space with sight lines, and investigation about circulation path, or spatial relations between different spaces depicted by lines or arrows of force.

The symbols that designers use in drawing indicates the issues they are thinking about. We found the act of redrawing and recognition worth noting.

Drawing: Redrawing and overtracing

Designer's working sketches (for example figure 1) are characterized by overtracing, in which the designer's pen repeatedly outlines a particular shape or area of the drawing. This overtracing, or redrawing, seems to serve several functions: (1) selection, or drawing attention to the element; (2) shape emergence, attending to one or another shape interpretation; and (3) shape refinement, or adding detail to an abstract or roughed out shape.



Figure 1. Drawing techniques that indicate ambiguity and imprecision: overtracing, shading, and blob-like shapes. (Initial sketch by architect Ping Xu for a gallery and meeting place).

(1) Focus and selection. The act of redrawing keeps the designer's mind focused on the element in question, causing the designer to think about the element, and its relations with other parts of the design. This repeated redrawing of a part of the figure serves the same cognitive function as "selection" in a computational environment. Whereas in a computational environment, the drawing program can display the element in a different color or blink it, on paper it is easiest for the designer to continually overtrace, to draw attention to the element.

(2) Emergence and shape interpretation. Overtracing often selects certain boundaries of a shape combination, and disregards others. For example, in figure 1, the designer began by drawing two intersecting shapes, and then overtraced an outline that selects certain segments from each of the shapes, darkening a new outline, and leaving certain parts of the original shapes untouched.

(3) Shape refinement. A third function overtracing fulfills is the refinement or specifying of particular shapes. In figure 1, the designer has begun with a crude rough blob shaped figure, and through the act of overtracing, has added more detailed shape information to the figure.

Interpreting: Recognition, Replacement, Refinement and Transformation

An important skill in design is replacing an abstract form by a more specific set of details, or alternatively, replacing a set of detailed elements with a more abstract overall form. For example the darkest marks on figure 1 can be replaced by three major shapes, as shown in figure 2.



Figure 2. Abstract figure drawn from figure 1.

Restructuring

Ilse Verstijnen (Verstijnen and others 1996) argues that the main need for sketching in design stems from the ability of sketching to aid the designer in problem restructuring, or, what the design research community has called, “emergent shapes.” Certainly, being able to parse, or re-interpret an initial sketch in various ways is an important visual skill, one that plays an important role in design. For example, the skill of seeing “emergent shapes” involves grouping component lines in a sketch in different ways than they were initially conceived and drawn (figure 3).

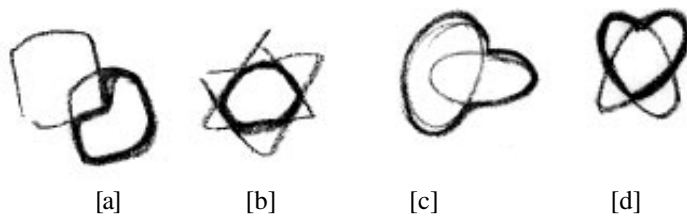


Figure 3. Discovery of emergent shapes, [a]. parts of original shape, [b]. new shape found from 2 overlapping triangles, [c]. new outline profile of combination of two shapes, [d]. new shape made by taking segments from different original parts.

Updating the Drawing -- Maintaining constraints and spatial relationships

Designers keep in mind inherent or intended behavioral characteristics of the design elements they manipulate, and the act of drawing and the drawings themselves reflect the designer’s understanding of this behavior. For example, when changing the positions or dimensions of a room in a floorplan, a designer will continually redraw adjacent rooms and walls in order to maintain certain desired relationships. Or, when changing the positions of columns and beams, a designer will move related elements to maintain the constraints of structural stability. So the designer constantly updates the drawing to maintain the constraints and relationships that are inherent and desired in the drawing.

4. Conclusion: the implications for Computer Aided Design

What “intelligent” paper should do to support design drawing

Given these observations about design reasoning and the various ways that drawing seems to support it, we come to the question of whether artificially intelligent computational design media—‘intelligent paper’—can support design better, and if so, how? We believe that AI based sketching programs can indeed provide an enhanced environment for design. We have constructed several prototypes on top of our freehand drawing program, the Electronic Cocktail Napkin (Gross 1996; Gross and Do 1996) to explore how this might play out.

Reorganization & Restructuring

One prototype supports recognition of emergent shapes. Our drawing program keeps all the point information of a shape. The program finds intersection points when two shapes overlap or are closely placed together. We break the shapes at these intersections into shape segments, and examine possible combinations that make new recognizable shapes. However, this ability introduces new and potentially difficult representation issues (Soufi and Edmonds 1995). We can exhaust all possible new shapes, but how shall we decide which ones the designer might like to see?

Graphic rewrite rules

Currently the Napkin program provides the designer the ability to define personalized graphic symbols, combined from different shapes. The user defines these symbols by sketching examples and interacting with a dialog box to adjust the rewrite rule. We plan to let the user specify substitution rules by drawing 'before' and 'after' pictures.

Analogy

We are also exploring analogical transfer of spatial relations. For example, following Evans' (Evans 1968) Analogy program, we have constructed a module that solves simple geometric analogy problems (Figure A is to Figure B as Figure C is to what?) Our simple analogy transfer (figure 4) does two things: 1) pattern recognition, identifying objects from drawing, 2) description processing, including finding rules for transformation, comparing and checking parts that have been transformed between figures. (Do 1996b)

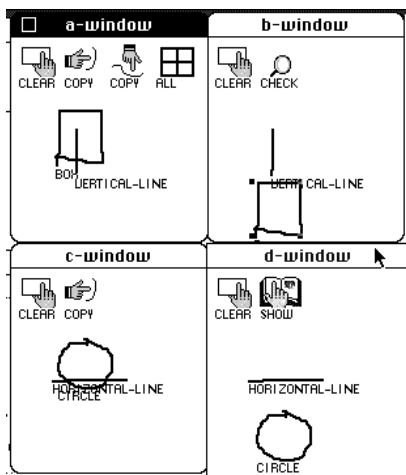


Figure 4. Movement of box from A to B is mapped to circle in C to D.

Filtering to abstract a drawing

Many sketches are made up of many little lines, and the art of reading the sketch is to filter out the important ones. We have experimented with various filtering schemes, to reduce the number of lines in a complex sketch to a smaller number of potentially important ones. (Gross and Do 1995)

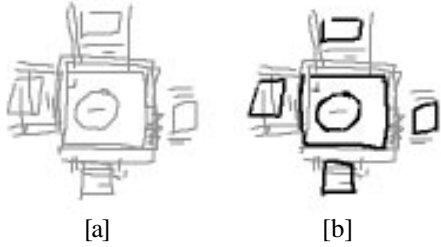


Figure 5. Free hand drawing of plan of Palladio's Villa Capra [a] as drawn, [b] filtered for geometric shapes.

Maintaining constraints

We have implemented a scheme whereby the drawing program first recognizes, then maintains spatial relations in the sketch. We noted above that a drawback of paper is that the designer must maintain the spatial relations and constraints to reflect desired or required design behavior. Our Stretch-A-Sketch prototype shows how 'intelligent paper' might automatically keep track of these relations and ensure that the drawing reflects them (Gross 1994).



Figure 6. Stretch-A-Sketch maintains relations in the diagram. (a) diagram as first drawn; (b) after resizing a room; (c) partially rectified drawing.

Evaluation and testing

We have built several prototypes in which the drawing environment is linked to an interactive simulation. In each of these programs, the designer sketches an initial design; the design is then carried over into a simulation environment, and the designer can test and evaluate its performance. For example, figure 7 shows the integration of sketching into a viewshed analysis program. In future work we would like to integrate the simulation components more tightly with the sketching (Gross and Do 1996).

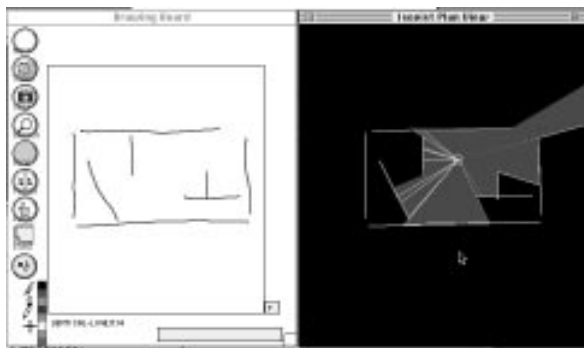


Figure 7. A drawing of floorplan activates a viewshed analysis program (IsoVist).

Finding references based on shape and configuration similarities

We have developed several systems that enable a designer to locate design information by making sketches and diagrams. For example, we have linked our sketching program to a case library of designs, to a visual database, to Netscape, and to other databases. In each of these schemes, the program retrieves items from the database based on similarity of shape and configuration features (Do and Gross 1995; Gross and others 1994).

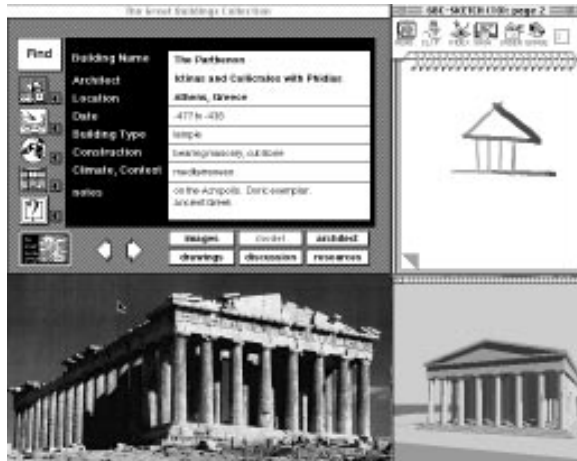


Figure 8. A diagram retrieves pictures and information about the Parthenon from a visual database (The Great Buildings Collection.).

We have suggested that design activities involve drawing and interpreting of the drawing. These activities are closely interlinked and inseparable. We have attempted to show how we might support some cognitive processes in design such as recognition, finding references and evaluation with our freehand sketching environment.

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