COMPUTABILITY OF DESIGN DIAGRAMS

an empirical study of diagram conventions in design

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Abstract. Designers draw diagrams to think about architectural concepts and design concerns. We are interested in programming a computer to recognize and interpret design diagrams to deliver appropriate tools for the design task at hand. We conducted empirical studies to find out if designers share drawing conventions when designing. In this paper we first discuss reasons to investigate design diagrams. Then we describe our experiment on diagramming for designing an architect's office. The experiment results show that designers use different diagramming conventions when thinking about different design concerns. We discuss and report our efforts to implement a freehand drawing program.

1. Why do computers need to understand design diagrams?

Diagrams play an important role in design practice. Designers draw diagrams to explore ideas and solutions in the early, conceptual phases of design. They use diagrams as objects to think about design concerns (Laseau, 1980) and to record their ideas (Graves, 1977). Designers find it hard to "think without a pencil" (Lawson, 1994) and "must interact with the drawing" (Herbert, 1993).

Several design studies discussed the connection between design drawing and design thinking. They argued that design drawing and verbal protocols are related (Eastman, 1968) and complementary (Akin & Lin, 1995). Designers "see information" from drawing to refine their ideas (Suwa & Tversky, 1996); they "move" after seeing (Schön & Wiggins, 1992), and they operate between "seeing as" and "seeing that" modalities (Goldschmidt, 1991).

Many computer aided design systems have been built to support design by giving designers advice such as cases, suggestions and simulation. A problem with these systems is that in order to provide appropriate advice they must identify the design context. We argue that the diagrams designers use in the early conceptual design process is a good indication of design concerns and can be computed.

In the following sections, following a brief description of our previous diagram study, we report a new empirical study of design to discuss the implications for a computer system. Section two focuses on the experiment about extracting design intentions from freehand design diagrams. Section three describes the experiment results. Section four concludes with a brief discussion of computational approaches and future work.

2. Empirical Studies of Design Diagrams

In our earlier experiment to identify the association of drawing marks with design thinking, we conducted an empirical study with sixty-two designers (Do, 1995) using diagrams and stories from a case based design aid Archie (Domeshek & Kolodner, 1992; Kolodner, 1991; Zimring, et.al, 1995). We asked participating designers to 1) make diagrams from given stories, 2) write stories from given diagrams, 3) pair diagrams and stories together, and 4) comment on the diagram story pairs from Archie case base.

The experiment identified that 1) designers used drawing conventions when diagramming different design concerns (figure 1 shows a sample of symbols and configurations designers used for sun, person and lighting concerns), 2) designers preferred to use certain views for different design concepts, 3) keywords from the stories were often used as labels in diagrams, and vice versa, and 4) designers understand each others' diagrams. However, this study only involved diagramming from descriptions instead of real design tasks. Therefore we developed a new design experiment to find out if these findings also apply in the design process.
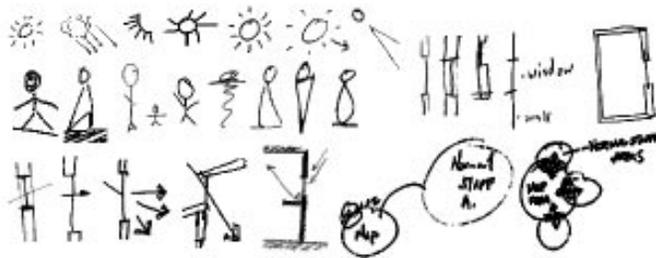

Figure 1. The lexicon of diagram symbols and configurations designers used for architectural concepts (Do, 1995). Top: symbols for architectural objects: sun, figure person and building elements such as walls and windows. Bottom: view preference: sectional views for lighting concerns and plan views for spatial layouts.

Three designers (one instructor and two students) participated in the diagramming design experiment at different dates. We gave participating designers a design program of an architect's office and video taped their design process while an observer took notes. The design program described the dimension of the site (70 ft. by 25 ft. one story warehouse) and required functions (work space for designing, CAD operations, drafting, meeting room, kitchenette, bathroom, etc.). The experiment has four tasks; each tasks called for a different focus. After reading the design program, designers were asked to do conceptual design starting with a new sheet of tracing paper and to focus on four different concerns for each task: (1) spatial layout for zoning of different work spaces, (2) lighting concerns, (3) visual access and privacy issues, and (4) fitting a large meeting table (4 ft by 10 ft) into a conference room and a minimal area requirement (800 square feet) for the designers' work space.

3. Mapping Drawing Conventions and Design Contexts

From the design experiment we verified that designers share drawing conventions not only when diagramming architectural concepts but also in their design process. Below we briefly describe three major findings that have influenced our current computational implementation.

3.1. DESIGNERS USE GRAPHIC SYMBOLS AND TEXT LABELING WHEN DESIGNING

We found from the experiment that designers arranged graphic shapes and symbols to compose architectural objects. Designers also used text labeling to identify architectural concepts (figure 2). They used simple geometric shapes such as circles and lines in their drawings, and composed them in conventional ways (e.g. parallel lines for walls and windows, an arrow and a letter N for North). We also found that key words from design concepts are included their drawings. For example, labels of functional spaces were written inside a containing shape (ovals, rectangles); an entrance was represented with a label and an pointing arrow.

Figure 2. Designers share drawing conventions: They used lines, arrows, hatches and simple geometric shapes to compose symbols for architectural objects such as walls, windows and stairs. Words are used to indicate directions and functional spaces.

3.2. VIEW PREFERENCES FOR DIFFERENT ARCHITECTURAL CONCEPTS

Designers showed a preference for using different orthographic views (plan or section) when diagramming different design concepts for the experiment tasks: layout planning, lighting, visual access, and dimensioning. Participating designers drew plan views to illustrate spatial relations between spaces (figure 3a) and sectional views to illustrate lighting concerns (figure 3b, c , d). Another phenomenon worth noting is that designers used circling or overtracing to draw attention to an element, to refine a shape, or to explain to the observer (figure 3a, d).
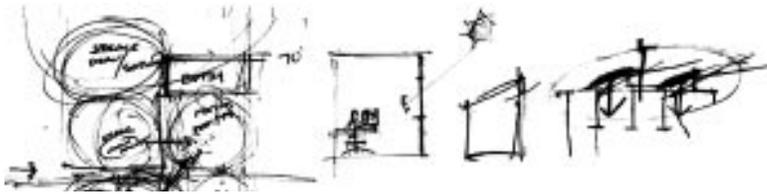

Figure 3. Designers revealed view preference for illustrating different architectural concepts. [a] plan view for spatial layout, [b, c, d] sectional view showing lighting by lines that penetrate the building envelope from windows and roof. Overtracing and circling showed a designer's attention to space [a] and concerns of reflecting light [d].

3.3. DESIGN CONTEXTS ILLUSTRATED BY DIMENSIONAL REASONING & FURNITURE

We found from the experiment that designers used symbols of architectural objects such as furniture and dimensioning figures to put themselves in mind of design concerns. When thinking about allocating objects or spaces with a required dimension, designers wrote down numbers beside the drawing to reason about size and calculate dimensions. For example, task 4 called for a work space of at least 800 square feet, and a conference room to accommodate a 4' by 10' table. One participating designer annotated his design drawing with numbers for calculation (figure 4a).
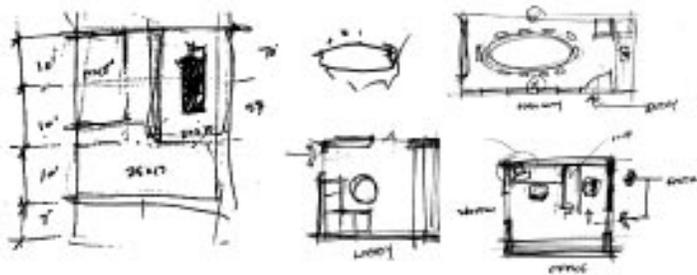

Figure 4. Designers wrote numbers for dimensions and drew furniture in their drawings to put themselves in the design context. [a] drawing documented a design process of calculating space requirements and dimensioning. [b, c, d, e] Symbols give clues for context. [b, c] conference space. [d, e] lobby and office space

When thinking about different functional spaces, designers drew simple shapes into the spaces to represent furniture, fixing in their minds the context to think about design. For example, when thinking about the placement of a conference table, designers drew chairs (small rectangles or dots) surrounding the table to see and test if the space is big enough (figure 4a, b). One designer also drew a door and windows along the wall, service counters, and white board (figure 4c). Similarly, designers drew symbols for furniture such as tables, chairs, and sofa in a lobby and office space (figure 3d, e).

4. DISCUSSION AND FUTURE WORK

Recognition and interpretation of design context is an interesting and complex problem. Our empirical studies showed that designers share a universe of conventional symbols and configurations when thinking about different design concerns. Therefore we can program a computer to recognize these conventions and use them to infer design context and intentions. We are conducting further empirical studies to understand more about design drawing conventions, their associated tasks and relevant design tools.

We are currently working on a freehand sketching program called the Electronic Cocktail Napkin (http://wallstreet.colorado.edu/Napkin) that recognizes and interprets hand drawn diagrams into relational propositions and communicates these to other knowledge based systems (Gross, 1996; Gross & Do, 1996). We are using this program to build a "Right Tool at the Right Time" manager (Do, 1996) that will activate different design tools based on the task at hand. The Napkin program uses a simple low level recognizer based on a 3x3 grid to identify low level glyphs, and employs rules built interactively by end users to parse configurations of low level glyphs to higher level configurations. Designers can train their personal language of diagram symbols and configurations by showing examples to the Napkin program. The right-tool-right-time manager uses Napkin's recognition abilities and sends requests to different programs. For example, when the designer is drawing bubble diagrams, the right-tool-right-time manager may infer that the designer is working on 'functional configuration' and call up a floor plan with similar layout from a case base or a slide library.

In sum, we have conducted empirical studies that show that designers share drawing conventions when designing. We have suggested that an "intention recognizer" in an integrated freehand sketching environment could support delivering the right tools at the right time. We have already connected various design tools with the drawing environment and are incorporating additional design tools into the system, automating tool activation, and improving the context detection mechanism.

Acknowledgments

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