

DRAWING ANALOGIES:
finding visual references by sketching

by

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A B S T R A C T

In creative and conceptual designing, architects often look to books, magazines, and other collections of images to find forms they can adopt and adapt in designs. On line visual collections are becoming available but typically they are indexed only with descriptive key words. We argue that in addition to key word indexing, which supports retrieval of images based on design concepts or issues, a more directly visual, graphical reminding scheme based on sketches can help designers recall interesting references from various domains. We describe Drawing Analogies, a shape based reminding program that uses hand drawn sketches to index and query visual databases.

1. INTRODUCTION

1.1 Sketching is basic to conceptual design.

Architectural designers are trained to use traditional paper and pencil media when developing conceptual designs. Beginning with the simple sketch, the doodle, and the proverbial cocktail napkin diagram, designers develop ideas graphically through the medium of freehand soft line drawings on tracing paper. Sketching activities include finding, adapting and combining new forms with previously learned shapes and structures, for example from precedents, design studio experiences, and case studies.

Designers sketch to explore design solutions, to record their ideas, or to illustrate them and communicate them with others. The act of drawing is important not only as a vehicle for communication; it actually helps designers see and understand the forms they work with (Edwards 1979).

Recent books on the functions of drawing in architecture (e.g. Fraser and Henmi 1994; Herbert 1993; Lawson 1994; Robbins 1994) remind us that though CAD is used for making and editing mechanical working drawings and for producing renderings and animations for clients, drawing is still the medium of choice for creative design and design development. Despite software that helps designers produce cleaner and more precisely drafted drawings, few designers feel computer tools actually help in developing designs. It may be that CAD software is too structured for conceptual design thinking, which uses freehand sketching as its primary mode of development. Drawing-thinking with a pencil-remains an essential design skill.

1.2 Architects use analogies and metaphor in creative design

The use of 'references'-images of natural and artificial forms from rocks and flowers to

boats and buildings-is frequently discussed in accounts of architectural designing. Architectural design primers (e.g. (Laseau 1980)), stories of the masters (e.g. Guiton 1987)), and studies of design process (e.g. (Broadbent 1973)) all discuss the use of references as visual analogs and metaphors. This suggests that on-line libraries containing images of a variety of reference forms can be useful for architectural design.

Hypermedia databases of architectural images have been developed for teaching in architecture history and for general use, for example ArchWAIS, a WAIS client application (Choi 1994) , Architectural Courseware, which uses Mosaic (Tector and Thornhill 1994), DOORS (Design Oriented On-line Resource System) (Sklar in press), SPIRO (Slide Library Image Database at UC Berkeley, <http://www.mip.berkeley.edu>) and the Great Buildings Collection (Matthews 1994) which is built in HyperCard. Items in these databases are connected via hard coded links (e.g. connecting a building with others by the same architect, or the plan of a building with photographs and other drawings). The databases are indexed with text that describes the images, giving information such as name, date, place, and architect for each image. This enables the designer to search using queries formed by Boolean expressions on keyword contents (e.g. 'architect = Scarpa AND place = Venice'). We would extend the use of these and other image collections by providing sketch based indexing, thereby enabling designers to pose queries using a sketch or diagram instead of keywords.

1.3 Organization of the paper

The remainder of the paper is organized as follows:

Section 2 comprises a scenario that suggests how a designer might consult and employ visual references in her design process. Following the scenario we comment briefly on the activities involved.

Section 3 discusses the use of visual analogy, metaphor, and shape borrowing in architectural design. We take examples from introductory texts for architects, studies of the masters, and accounts of design process and method.

Section 4 presents our Drawing Analogies program, a system for managing visual references, which is embedded in a computational design environment that supports hand drawn sketching.

Section 5 concludes with a discussion and outlines directions for further work.

2. VISUAL REFERENCES IN DESIGN-A SCENARIO

2.1 Scenario: finding and using visual references in design

Imagine an architect engaged to design a library of natural history. She is an experienced designer and sophisticated in layout arrangement, and for years she has kept a journal containing sketches, notes, and clippings from magazines and design folios. We join her in the early stages of design as she seeks inspiration for her building form. Often she finds ideas in her journal for the physical shape of the building and incorporates them into her design. As we join her, she has proposed a basic scheme for the building's spatial arrangement as a bubble diagram on her tracing paper (see figure 1). In her diagram, four bubbles surround a central object depicting the four major functional spaces in the library program. The adult's section, children's reading room, reference area, and staff office are all connected with a central service lobby with the patron's entrance and service entrance on opposite sides.

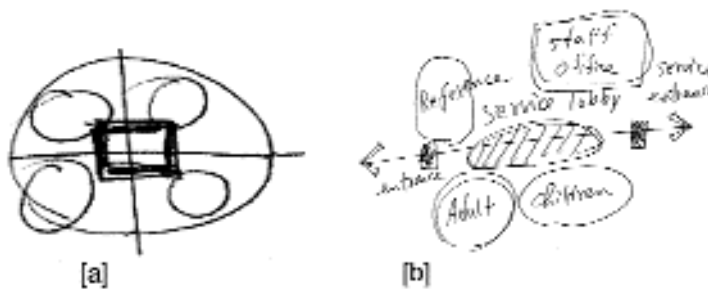


Figure 1: Designer's basic scheme for spatial arrangement;

[a] minimal bubble diagram;

[b] developed version with functions labeled and some size and positional information.

Now she wants to arrange the elements of her scheme in an interesting way so that the building's shape will recall the natural history theme. To find appropriate and compelling shapes she flips through her journal to find forms similar to her current drawing. The objective of her search is to find appropriate shapes that can accommodate both the functions of the library program and the spatial arrangements she has already developed. Believing that form should follow function, she searches for shapes that are similar to her drawing, to guide the translation of bubbles into building form. She decides if she finds any shape interesting or similar in shape to her bubble diagram, she will draw it on her tracing paper and make notes so later she can use those drawings for her current design project or include them in her journal for future use. She also decides the shapes

should come from the design theme-natural history. So she browses her journal to find shapes of natural objects. Also, some notes in her journal point her to books on plants and animals. She copies what she finds in her journal and books (figure 2) to her drawing as a reference for design (figure 3).

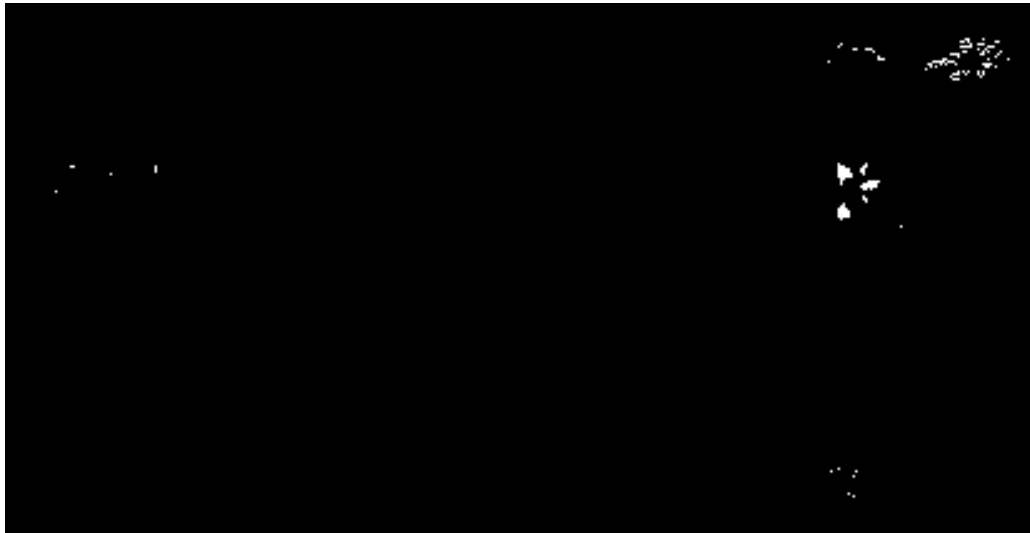


Figure 2. Forms found in a handbook of the natural world.
(Drawings by author, after (Gibbons 1984), and (Webb 1948))

After finding an interesting form in her journal, she makes a diagram to record her thoughts about the object's shape (figure 3b). She might also look in her books for the original picture (figure 3c).

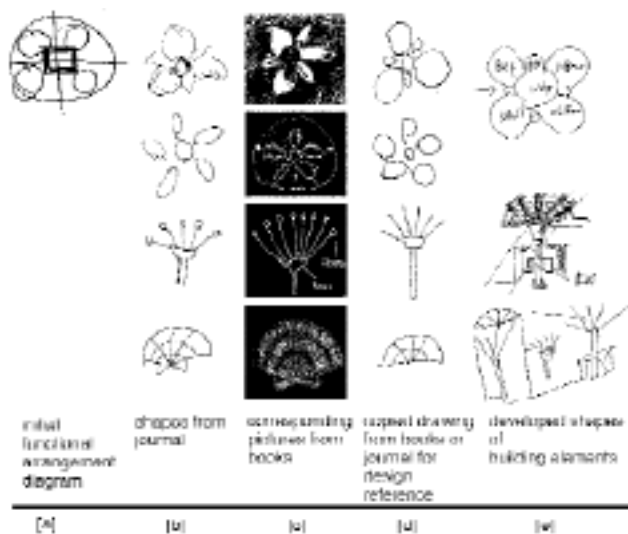


Figure 3. Graphic representations used in design development.

After finding the photograph she flips through the rest of the book looking for other interesting forms (figure 2). For example, she might copy some plant and shell shapes to her tracing paper and add annotations on how she might use the shapes in her design. She considers using flower petals or round seashell forms for her floor plan because both have shapes surrounding a central object. Or she might find an arrangement of plant

forms suitable for her atrium column and skylight structure (flower stalks rising from a central point of the stem end to create an umbrella effect), or a fan shaped sea shell for her arched window (figure 3e).

Our designer's journal also contains magazine clippings and drawings of architectural precedents-buildings she has found interesting in the past. While browsing her journal perhaps she finds a building whose form seems relevant (it may be a library, a church, or an office building) and she uses tracing paper to copy it into her design drawing. Then she might ask herself, 'how about extending this form to fit the children's reading room?' She gradually traces over the drawing, adjusting the shape to fit the functional program (Figure 4).



Figure 4. Tracing a magazine clipping into the design drawing (design clipping by author after Kallmann, McKinnell & Wood's American Academy of Arts & Sciences, (Krieger 1988)).

After fitting the children's reading room into the form, she decides to flip the drawing so the entrance will be from the west side as in her functional arrangement diagram (figure 1), and she adjusts the drawing again to fit the adult's section. Then she combines her previous concepts of using the flower petal arrangement (intervals of large and small petals; figure 3) to the modified flipped floor plan. She finishes her schematic design of the building shape, arriving finally at the schematic design shown in figure 5.

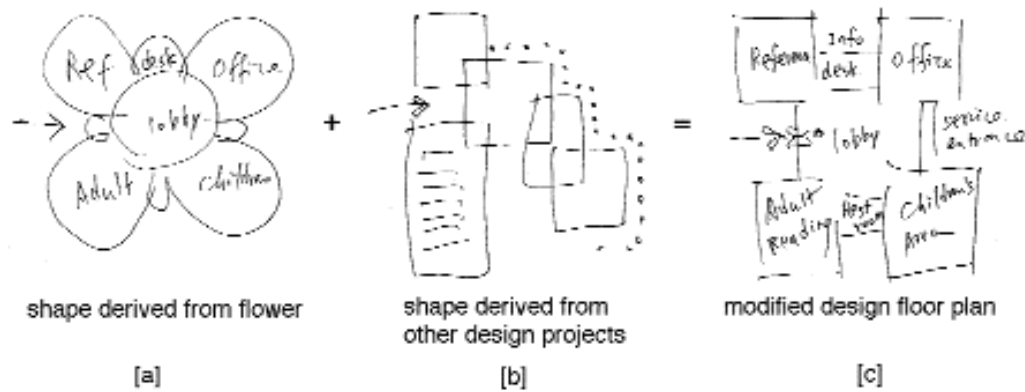


Figure 5. Combining ideas and stretching the drawing to suit the design.

2.2 Remarks on the scenario

First, our designer moves fluidly between different graphic media: the drawing board, where the actual design takes shape; a journal, or sketchbook where she stores interesting fragments of designs; tracing paper, by which she transfers items into the journal or into the design; and a collection of books, magazines, and design folios, in which she searches for, and from which she copies, interesting reference images.

Second, she uses various operations. She browses her journal and her collection of books. She selects interesting items from them and she traces and copies them into her design. She adapts the forms she finds to her design, using one part here and another there, stretching, rotating, and moving her traced references in order to make the reference 'work' with the design. And she finds ways to map her functional library program with the reference forms she adopts.

Third, our designer chooses explicitly to adopt a shape for her building associated with a concept derived from the architectural program—the natural history theme. Although this may seem contrived, designers do in fact borrow forms that are associated quite literally with the building concept, as we will see in the following section.

3. USE OF VISUAL ANALOGIES AND METAPHORS IN ARCHITECTURE

3.1 Visual references are often cited by architects and educators

Accounts of creative architectural design often mention natural and artificial objects as sources of architectural form. For example, Le Corbusier wrote, “the shell of a crab picked up on Long Island in 1946 is lying on my drawing board. It will become the roof of the chapel.” (Corbusier 1957), p 89 (see figure 6a). Le Corbusier also urged

young architects to study and draw from nature (Guiton 1987). Similarly, Wright stated that the form of his Unitarian meeting house in Madison, Wisconsin derived from the form of hands clasped in prayer (Storrer 1993) (Figure 6b).



Figure 6.

[a] Le Corbusier's Ronchamp - a crab shell;

[b] Wright's Unitarian meeting house - hands clasped in prayer.

It may be that stories such as Wright's and Le Corbusier's are merely fanciful after the fact embellishments of their designing. But whether we believe stories told by the masters about their sources of architectural form, certainly many instructional texts urge students of architecture to employ analogy and metaphor in their designing. For example, Laseau (Laseau 1980) applies Gordon's *Synectics* (Gordon 1968) to design, giving architectural examples of direct, personal, symbolic, and fantasy analogy. Capplemann and Jordan's "Foundations in Architecture" shows how students from around the world used plant and insect forms in their designs (Capplemann and Jordan 1993). Students take this advice seriously, and one often finds pictures of natural and human-made objects as inspirational images in studio workspaces and in presentations.

Finally, studies of design method and process often identify visual analogy, metaphor, and visual references as important activities in creative designing (Antoniades 1990; Lawson 1980). For example, Rowe says, "Literal analogies .. involve borrowing known or found form-giving constructs as a point of departure for structuring a design problem (Rowe 1987). Or Broadbent: "Analogic design is the most potent source of creative ideas in architecture" (page 35, (Broadbent 1973)). The history of architecture is rife with examples of borrowing forms from historical and indigenous buildings and from natural and artificial objects.

3.2 Finding visual references.

At first the process of finding references to use in a design might seem unfathomable. The designer may leaf through books, walk in the forest, visit the museum, when her eye falls fortuitously on an appealing form. She studies it, draws it in her sketchbook or at least in her mind's eye, and returns to the drawing board to incorporate the form into her emerging design.

Although we cannot account for all the ways a designer may seek and find reference forms, we propose two processes. First, designers look for forms that are similar in shape to what they have in mind, and perhaps rough sketches on the drawing board suggest or recall a shell, a rock, or an architectural precedent. Le Corbusier's crab shell roof for Ronchamp would seem to fit this category. Second, designers think of forms that are linked through some concept about the design at hand. For example, the section of Kahn's performing art center at Fort Wayne, Indiana (like many of his performing art centers) has the form of a violin in its case (Brownlee and Long 1991). Here the concept of music and the need for acoustic richness in a concert hall, seemed to play a key role in suggesting the building's form. We call these two ways of finding visual references 'shape reminding' and 'conceptual reminding'. Traditional key word indexing schemes support conceptual reminding; our Drawing Analogies project aims to augment this approach by developing a computational scheme to support shape reminding.

3.3 Adapting references to designs.

In Drawing Analogies we are chiefly interested in helping designers find references and use them graphically in their designs. But after finding a reference, how does the designer bring it to bear on the emerging design? Clearly this leads to the question of how designers employ metaphor and analogy to work a design problem. This is a larger question than we can tackle here, but other studies have focused on metaphor and analogy in design. For example, Goldschmidt (Goldschmidt in press) has made case studies of architects designing, looking particularly at logic and sequence in a series of sketches, and at the role of visual analogy and architectural precedents in guiding design. Analogical and case based reasoning are also discussed in artificial intelligence applications to engineering design. Gero and Maher have suggested using reasoning by analogy to bring in innovative solutions (Gero and Maher 1992), and this approach has been explored further by Navinchandra (Navinchandra 1991).

Yet, even without looking closely at the deeper (and fascinating) questions of analogical reasoning and design, a simple set of graphic mechanisms may go a long way in

accounting for how references are adapted and employed. We maintain that architects often just adopt the shape or physical form of a reference they find, and adapt it through graphical transformations to meet the needs of their design (see Herbert's companion paper, this volume.) For example, a designer might trace a reference form or copy it onto a layer of tracing paper, which then can be placed under or next to the design drawings. In freehand copying, the designer may change the size of the reference, or even distort the reference by scaling only part of it, or stretching it vertically or horizontally. Putting the copied reference in the context of the design (physically, as an underlay or immediately adjacent to the drawing) makes it easy to employ the borrowed form's basic lines and shape. In many instances the designer transfers only parts of the reference into the design.

3.4 At what point in designing are visual references useful?

If visual references play such an important role, when does the architect engage them in the designing? Of course, designers browse magazines and books continually as a background task not particularly directed to a specific design problem, and this background browsing may later provide interesting references. More directed use of visual references, analogy, and metaphor seems to happen during what we will call the conception activities of design (Do 1993), that is, when the designer engages mainly in exploring physical form, thinking less about the organization of the site, the architectural program, and the building system. Later, when solving functional concerns or working with the building system, we believe that the designer is more likely to access other kinds of information (for example case libraries of specific building problems or building component libraries) and less likely to browse visual collections to find interesting forms. In practice, of course, the designer moves back and forth between exploring physical form and solving organizational problems. It seems however, that different databases will be useful for different kinds of design activities.

4. DRAWING ANALOGIES-A COMPUTATIONAL ENVIRONMENT FOR CREATIVE REMINDING

Drawing Analogies is a prototype system that helps designers mark and recall interesting visual references. Retrieval is based on the similarity of the reference form's shape to a given hand drawn sketch. We have built the Drawing Analogies program in the context of a hand drawn sketching environment because visual references are likely to be of the most value during conceptual and creative designing when the designer works with freehand sketches and diagrams. We begin with a brief review of our design environment for hand drawn sketching, then discuss enhancements that support finding and managing visual references from multiple sources.

4.1 A hand drawn sketching environment

The Electronic Cocktail Napkin (Gross 1994) is a design environment for making and managing hand drawn sketches and diagrams. The designer makes marks using a digitizing tablet, a mouse, or a 'personal digital assistant' (i.e. a Newton). The program stores and attempts to recognize the hand drawn figures; it also supports graphical search, management of trace layers, and multiple users sharing the drawing surface. The use of graphical rewrite rules for recognition enables designers to program the parsing of higher-level configurations made up of an assembly of simpler elements. Figure 7 shows the Cocktail Napkin's working screen.

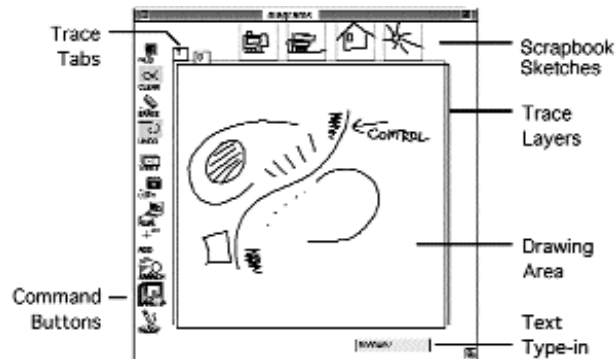


Figure 7. Electronic Cocktail Napkin working screen

4.2 Sketchbooks, query windows, and visual databases

For the Drawing Analogies program, we added a 'sketchbook' to the Cocktail Napkin program, where the designer can assemble a collection of diagrams and associate them with items in different reference databases. The designer can copy pages between drawings and the sketchbook, and a 'scratch pad' is used to make diagrams and initiate queries. Figure 8 shows relationships between the design drawing, the scratch pad, the sketchbook, and the visual reference libraries.

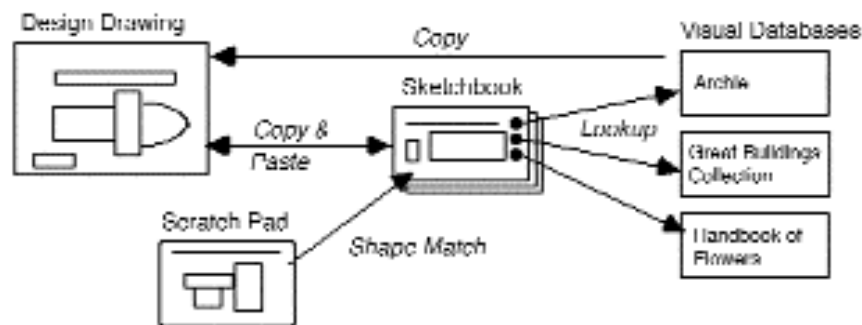


Figure 8. Parts of the Drawing Analogies system.

Drawing Analogies (written in Macintosh Common Lisp) is designed for simultaneous use with several different visual databases, which may be built in a variety of applications. For example, our current databases include Archie (Zimring and others 1994) a case based library of post occupancy evaluation data built in Macintosh Common Lisp, the Great Buildings Collection CD-ROM (Matthews 1994) built in HyperCard and a library of natural forms we built in FileMaker Pro.






The Drawing Analogies program provides two basic functions. The designer can link a sketchbook page with an item in a visual database, and the designer can query the system for visual references. To store a link, we assume the designer has found an item in one of the visual databases that she wishes to index with a sketch. She draws a sketch on the scratch pad, and copies it to her sketchbook. When she performs a 'link' command, the Drawing Analogies program associates the current item of the most recently referenced database with the current sketchbook page. The meaning of 'current item' depends on the database. For example, when a sketchbook page recalls an item in the Great Buildings Collection this may entail turning to a particular card in the HyperCard stack, opening image files, and displaying a QuickTime animation or a three-dimensional model.

To query for visual references, the designer draws a diagram on the scratch pad and executes a 'find' command. The program compares the scratch pad diagram with the diagrams on pages of the sketchbook, ranking them by their similarity with the query. The similarity measure is a weighted sum of several simpler similarity dimensions: number of elements, types of elements, and spatial relations among elements.

The element-type similarity measure compares the types of elements in each diagram. The element-count similarity measure compares the number of elements in each diagram, computing the ratio of the smaller number to the larger. The element-type-count similarity measure compares the number of elements of each type. The spatial relations similarity measure compares only the spatial relations in the two diagrams. The relations&type similarity measure compares the spatial relations and the types of their element arguments, together.

Figure 9 compares the pattern in figure 9a with several others (figures 9b, c, d, e) according to various similarity measures. For example 2/3 of the element types in figures 9a and 9b match (both include a horizontal line and a triangle), and relations match exactly (two 'directly-above' relations). The combined relations&type measure, however scores 0, because none of the matching relations relate the same element types. On the other hand, the combined type&relations measure between figure 9a and 9c scores 1/2,

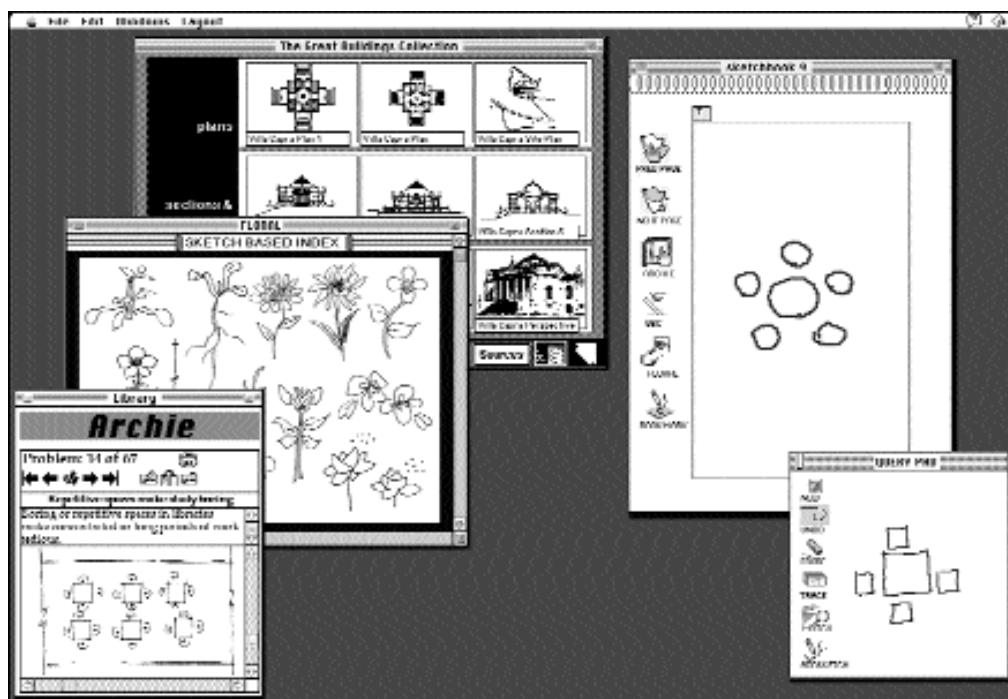
Figure 9 - Dimensions of diagram similarity: [a] compared with [b, c, d, e].

FIGURE					
ELEMENTS	triangle: box horizontal line	triangle: row of columns: horizontal line	half circle: box horizontal line	box box box	line triangle box
RELATIONS	tri d- above box box d- above line	tri d- above col col d- above line	half c- above box box d- above line	box above box box d- above box	line d- above tri tri d- above box
SIMILARITY	element type relations type & relations	2/3 1 0	2/3 1/2 1/2	1/3 1/2 0	1/3 1 0
	[a]	[b]	[c]	[d]	[e]

because one (box directly-above line) of two relations in figure 9c matches that of 9a in both relation and type.

The program finds the most similar diagram page, finds the database items associated with that page, and sends lookup calls to each of those databases that are currently running. A single query can retrieve an architectural precedent from the Great Buildings Collection, a story from Archie, and a page in our Natural Forms database. (Figure 10). Thus, the sketchbook associates items in different visual databases that have similar shapes.

Figure 10. Drawing Analogies: Query (bottom right) retrieves several database items.



4.3 Using retrieved references

Once the system has retrieved a reference, the designer can incorporate it into the design using one of two methods: taking the image itself as an underlay to the design, or working directly with the simpler diagram from the sketchbook. In the first method, the designer simply copies the reference image into the Cocktail Napkin work area, where it can be stretched, moved, and clipped using simple paint tools (no doubt a fuller set of image processing tools would be put to good use). The designer can trace over the adjusted reference, using certain parts of its form and ignoring others (figure 11).

In the second method the designer simply adopts the sketch that indexed the reference. She brings the sketch from the sketchbook into the Cocktail Napkin environment and works it into her design. The designer can edit the sketch lines, moving, deleting, stretching, and rotating them using the Cocktail Napkin's standard editing operations.

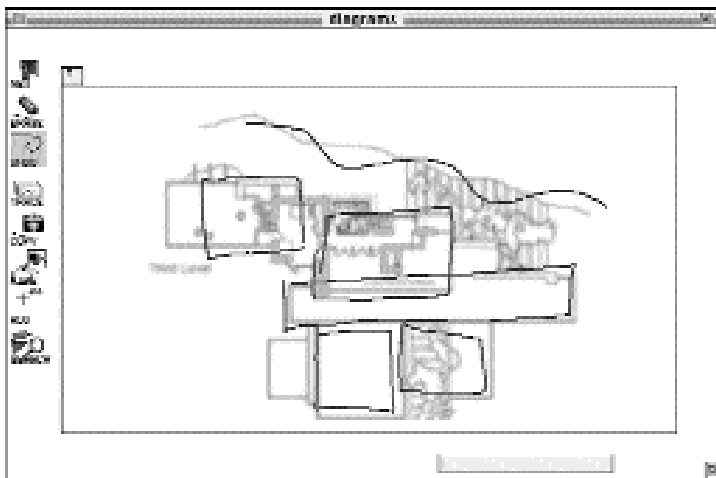


Figure 11 - Using the reference image as an underlay.

5. DISCUSSION AND FUTURE WORK

There appears to be much evidence that form borrowing, visual metaphor, and analogy play an important role in creative, conceptual designing, yet little computational support has been built for this activity. We have suggested that designers use two methods to find images in visual databases to use as form references for design: conceptual links and shape reminding. Existing keyword search systems (combined with a thesaurus) support conceptual reminding (e.g. 'performing arts' to 'music' to 'violin' would lead Kahn to the form he chose for his Fort Wayne, Indiana performing arts center). We concentrate here on shape reminding. We described Drawing Analogies, a working prototype visual reminding system. Drawing Analogies enables architects to find references

and incorporate them into designs while remaining in their design drawing environment.

We have planned three next steps for the project. First, we plan to stabilize the program and try it out in a studio setting. In the first round of studio testing we hope to tune the Drawing Analogies user interface so it is easy for novices to use, but we also hope to build up sketchbooks that index the visual collections we provide. Studio testing would also provide an opportunity to study when and why students turn to the visual collection.

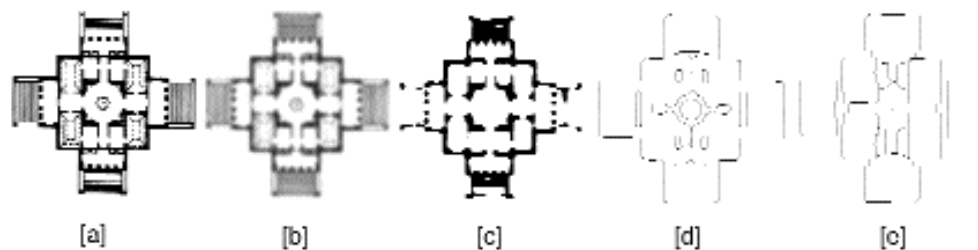


Figure 12. Image processing a scanned drawing to diagram:

- [a] original from The Great Buildings Collection matrix ;
- [b] resolution reduced to 72 dpi, apply Gaussian blur;
- [c] bitmap conversion, grays darker than 3% to black;
- [d] vectorized version, outline method with curve path option;
- [e] vectorized version, center and outline method, with noise suppression, line thinning, and straight line path option

Second, we have begun to explore the use of image processing software (the Adobe PhotoShop and Streamline programs) to convert scanned diagrams, drawings, and photographs into sketches that the Drawing Analogies program can read and compare with the designer's diagrams. Our preliminary experiments encourage us to believe that for some kinds of images (particularly diagrams and drawings) it will be possible to find and apply a sequence of image processing operations to reduce the images to a few sig-

nificant lines and shapes. Working by hand with these programs, drastically reducing resolution, fattening lines, applying Gaussian and low frequency filters, thresholding gray levels, we have been moderately successful at producing credible diagram versions of scanned images (see figure 12). In addition to relying on designers to draw the sketches in the sketchbook index, we would like to employ image processing tools to convert source images to sketches automatically or semi-automatically.

Third, we can easily expand the image collections that are accessible to the Drawing Analogies program. We have designed the interface of our Lisp program to work with any program that can respond to simple AppleEvents (a standard Macintosh interprocess communication protocol). Our current databases include one built in Lisp, one in HyperCard, and one in FileMaker Pro. We would extend the access to other image collections, including accessing architectural databases on the World Wide Web. Ideally, we would use automatic image processing techniques (as mentioned above) to compare queries with stored images on the fly. However, this is unlikely to work well enough in the near future.

Alternatively then, we can store key words (rather than direct database pointers) on the sketchbook pages to pass to existing Web search engines. The key words can be entered by the designer and associated with a diagram, or the program can build a table of key words for each sketchbook page by gathering keywords from other linked databases. By 'inducing' relevant keywords for diagrams from the database pages the designer links, we can avoid the strict keyword-sketching dichotomy, and begin to investigate how words and images can work together to access extended databases.

Finally, imagine the possibility of a world wide community sketchbook. Designers distributed across the network could share their personal sketchbooks and the associated links to various image collections. This would not only be a way to share the work of indexing large image collections, the community sketchbook could be a reference point for shared understandings in collaborative design. Although designers might have idiosyncratic ways of drawing, at the very least they would find one another's sketchbooks interesting.

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