STUDY DRAWINGS IN ARCHITECTURAL DESIGN: APPLICATIONS FOR CAD SYSTEMS

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ABSTRACT

To guide their future development, research and teaching in computer-aided design must look beyond the technical capabilities of computer systems to establish a theoretical foundation based on known processes in design. This paper suggests that such a theoretical foundation can be derived by analyzing architectural study drawings — defined as the rough drawings that architects make in the exploratory stages of design — to determine their epistemological properties. The analysis brings forward concepts from a number of disciplines related to the structure of human knowledge to identify five properties of study drawings. Based on these properties, the paper proposes strategies for application to the next generation of research and teaching in CAD systems.

INTRODUCTION

The rough drawings architects use to study design problems are far more complex than they appear. They are rooted in a tradition of 30,000 years of graphic notation and their familiar form reflects not just the nature of the tools, surfaces and circumstances of their production but a mix of human physiology, psychology and culture. Understanding these drawings — I will call them study drawings — and the working processes that produce them may be significant in determining future directions for research and teaching in computer-aided design.

Research for future CAD systems surely must continue to explore ways for computer systems to handle issues centered around design content, such as the parametric variations William J. Mitchell and others have addressed in their recent work. But in teaching and research, issues centered around process are as important as those centered around content; further steps in the design of computer-aided systems must also take up such issues as the empirically determined working processes that designers actually use in studying design problems.

At the moment, of course, these working processes of design rely on the kind of familiar pencil-and-paper drawings that litter every designer's desk; they are the graphic medium for exploring design ideas. Although they are often so rough and abstract that they may be meaningless to anyone but their author, these drawings are undoubtedly the principal graphic instruments of thought in architectural design. Such handmade drawings can provide a model
for CAD systems, not as specimens for copying into computer graphics, but as subjects for analysis to understand their epistemological properties: their part in determining the origin, nature and methods of obtaining knowledge in design. They provide an objective view of the working process of design which can guide our thinking about CAD systems.

In order to examine the properties of these drawings and suggest their application to CAD systems in design, this paper will bring forward concepts from a number of disciplines related to the structure of human knowledge as well as observations from a good many years of architectural practice and teaching. The examination will begin by comparing the main features of handmade study drawings with those of computer-generated drawings.

COMPARISON OF HANDMADE STUDY DRAWINGS AND COMPUTER DRAWINGS

Architectural designers use some kinds of drawings, including the familiar handmade study drawings, to conduct an internal dialogue aimed at solving design problems. [Figure 1] Their internal focus makes these study drawings "private", in contrast to other, more "public", drawings which are used for communicating with other people -- making contract document drawings or presenting a design proposal, for example. [Figure 2]

Computer drawings, of course, can serve these same public presentation functions. But the private -- or, rather, the "less public" -- function of computer drawings differs from that of the workaday handmade study drawings because these computer drawings are used mainly for research activities, to explore the capabilities of computer systems by investigating means for generating surfaces and volumes, studying realistic image synthesis, or displaying the permutations of a given form vocabulary, for example. There are other differences: where study drawings appear spontaneous and unconstrained and are likely to contain personal conventions made up on the spot [Figure 3], even preliminary computer drawings, when they are used for design exploration, appear to be so intentional, so firm and determined that they may mislead or even intimidate some viewers. [Figures 4, 7] And where study drawings are graphically rough, informal and often ambiguous -- sketched on thin paper, at the margins of larger drawings [Figure 5], on
paper scraps, envelopes [Figure 6] or place mats -- computer drawings, limited either to the screened or plotted image, appear to be formally precise and unambiguous. [Figure 7]

This comparison of the main features of study drawings and computer-generated drawings -- familiar to every designer or user of computer graphics -- gives us a base from which to examine the properties of study drawings as a graphic medium and their implications for CAD systems.

PROPERTIES OF STUDY DRAWINGS

Five properties of study drawings affect the origin, nature and methods of obtaining knowledge in design: study drawings embody a hidden structure, they act as a means for information gain, use graphic conventions, provide both continuity and change, and they work as graphic metaphors. Each of these five properties has direct or indirect implications for the design of CAD systems.

1. Hidden Structure

The spontaneous and unconstrained appearance of study drawings in comparison to computer drawings is deceptive. Every handmade study drawing as well as every computer drawing has a hidden structure which not only embodies a significant amount of pre-formed information, but also cuts the drawing off from the conditions that first gave rise to the design problem. Concepts from contemporary philosophy, linguistics and neurobiology demonstrate that this pre-structuring and separation of design work from primary reality are not superficial, but fundamental. They come from the processes of perception and cognition, from the nature and origin of knowledge itself, and they affect every medium. Our examination of the properties of the familiar study drawings as a basis for the future development of computer drawings must begin, therefore, with a fundamental first property: HIDDEN STRUCTURE: Study drawings always represent a set of hidden structural relations that entail irreversible losses of information about the design problem they are intended to solve. After looking first at study drawings as a model, we will see that hidden structure is even more pronounced in computer drawings.

In study drawings, the forming of structures begins even before the drawings themselves begin, with the abstraction -- that is, the selection and organization -- of data that make up the initial program statement and the description of the physical and cultural context for the project. And this organization is not neutral — Sheldon Nodelman's article on the application of structural analysis to art makes the point as follows: "The decision to objectify one or another aspect of the phenomena ...immediately polarizes the totality and in effect pre-imposes a particular structure upon it before the analysis proper has begun." But the effect of abstraction does more than arrange data. No structure can accept all of a collection of data, so selecting and organizing must lose some of the data which do not fit in the putative structure. Even the first study drawings, then, are separated from the gritty world of primary reality by information losses due to desktop, or external, structuring of pre-design information.

Information losses are not limited to the desktop, however; internal
processes of perception and cognition also incur a loss of information as the inescapable price of forming structures. Gunther Stent states the principle from neurobiology:

"...neurobiological insights into the visual pathway show that information about the world enters the mind not as raw data but as highly abstract structures which are the result of a preconscious set of step-by-step transformations of the sensory input. Each transformation step involves the selective destruction of information according to a program which pre-exists in the brain."

In sum, we must infer that information is lost through patterning at any level of any mental activity, internal or external, from the simplest act of perception to the creation of the broadest conceptual structures.

So the first study drawings for a design project are by no means as naive as their rough appearance suggests: their content reflects previously-made irreversible decisions entailing losses of information about the reality of the problem, losses which are multiplied as structures are formed at each new level of development. Later, we will see that there are ways to make up for these losses of information.

These information losses from the formation of structures are compounded in CAD systems because of the computer's additional layers of hardware and software. How can future development offset these losses? One immediate strategy is to avoid unnecessary prestructuring by keeping CAD systems close to the known working processes of design, say, by providing multiple open-ended branching options throughout the work for the designer's active participation in the evolving solution of the design problem rather than, for example, prompting for all the input at the start of a program as a basis for automatic processing toward a programmed solution, as is often done in drafting programs. Another strategy is to use the depth of CAD systems data storage, say, by gathering, holding and forwarding more basic data about program and context and more alternative interpretations of that data than are possible in manual design. For example, digitized photographs could provide better access than hand-measured drawings to specific detailed information for remodeling an existing building. Such a strategy of conserving a greater quantity of primary data offers a kind of compensation for the subsequent loss of content due to the computer's presence as an additional factor in the working process.

It appears, then, that work in any graphic design medium, especially including CAD systems, implies losses of information about the primary reality of the problem and these losses are incurred at each step in the creation of a complex hierarchical structure. But is this to say that making more study drawings means emptying the design of its information?

2. Gaining Information

In practice, of course, we find that designs get fuller rather than emptier of content as the work goes on. It is true that the primary data lost in pre-design abstraction and forming structures cannot be regained, but these losses are more than made up by new information drawn from our experience. Allowing for this replacement leads us to the statement of a second property
of study drawings to use as a basis for thinking about CAD systems:

**GAINING INFORMATION**: Study drawings provide a graphic means to add information from our cognitive experience to the solution of design problems.

A graphic model for considering cognitive experience as a factor in design has been proposed by Charles Rusch of the University of Oregon. This model is directly applicable to the examination of study drawings — and CAD systems, too — because it accounts for design as a dynamic process and it shows how different kinds of experience may be brought into design by means of images.

To establish the role of images within an overall cognitive process, Rusch describes them as mental structures which carry meanings. These mental structures are formed in a schematization process involving perception, reflection, and memory. [Figure 8] The reflection part of the process serves as a locus for mixing and re-integrating the mental structures among the formal, imaginal, kinesthetic and emotional levels.

All this mixing and re-integrating produces new meanings which are held in new meaning-structures and stored within the memory as symbols. Each symbol has an inner and outward form; its inner form is the meaning of the symbol; its outward form is expressed in a dimensional medium such as paper, ink, sound, gesture, etc. So, finally, an image can be defined as that kind of symbol which has some dimensional pattern or other sensory quality to it.

Rusch points out the importance of the imaginal level as the bridge between the non-conceptual (emotional and kinesthetic) levels and the purely conceptual (formal) level, as shown in the diagram. The externalized products of the imaginal level, Rusch says, are the principal medium of design thinking.

Now, study drawings, as graphic symbols, are exactly such externalized products of cognitive images. They provide the means for adding new information to the developing design from other parts of the designer's cognitive experience. The importance of this second property of study drawings — adding information via cognitive images — lies not just in the addition itself but in the power of these images to connect the conceptual and non-conceptual aspects of experience. It is through the medium of drawn images, then, that the designer's whole experience, personal as well as professional, can be brought to bear on design problems.

For CAD systems, this view of adding information via cognitive images suggests that CAD systems should be built around a core of image-based processes. For example, selecting viewpoints for a perspective drawing or addressing an extended data base such as an energy-budget program should be done by locating positions on a drawing, not by entries from a keyboard. Emphasizing the use of images will be crucial in order to avoid
over-formalization of CAD systems; Rusch's model explains how a strictly formal, conceptual address to design issues would bypass the imaginal bridge that leads to the emotional and kinesthetic parts of the designer's experience.

1. Graphic Conventions

Analysis of the first two properties of study drawings shows how design information is first structured, with consequent losses, and how these losses are compensated for by the creation of new structures drawn from the designer's experience by means of images. We turn now to the examination of a third property of study drawings in order to extend our understanding of CAD systems: GRAPHIC CONVENTIONS. Study drawings use rudimentary graphic conventions as a basis for changing from a private to a public audience and for indexing stored images.

The introductory section of this paper noted the contrast between the formality of CAD drawings and the apparent informality of study drawings: typical study drawings serve mostly an internally focused, private purpose, with little use of conventional graphic symbols and only the rudiments of graphic conventions. But why should such private, informal drawings use any conventions at all?

Study drawings typically do embody some basic graphic conventions for two reasons, one turning outward and one inward. In the outward direction, private study drawings often need to surface briefly as semi-public drawings. For example, a core of architectural graphic conventions makes it possible for a designer to talk to someone else about even a very rough study drawing with only a brief preface such as "this is a section through the auditorium." And — still in the outward direction — this core of drawing conventions within study drawings provides a basis for their eventual metamorphosis into the more conventional public presentation drawings and the still more conventional contract documents. But their outward, private-to-public reason for using conventions is less significant than their other, inward, reason: conventions in study drawings appear to be the key to the symbolic code for access to images stored in the designer's memory. It is likely that the storage of design-related images is structured and indexed according to these conventions because architectural education and practice are conducted largely through the use of such conventionalized images and each use predisposes every next use. Introspection suggests that architects can experience and remember forms and spaces without using graphic conventions, but any recall for recording, analysis or application of these experiences appears always to use some form of graphic convention.

For CAD systems, the outwardly-directed use of graphic conventions for communication with others is perfectly straightforward and needs no further comment here. But looking inward, at the use of conventions for coding images, computer graphics has already demonstrated its capability for generating new kinds of "operational" conventions, such as icons, "layers," color-coding, various forms of cursors, etc. Given the power of conventions for coding, structuring and indexing images in the designer's mind, these and other new conventions deserve extended study, not just to integrate them into the working processes of design, but to account for their effect on thinking with the aid of computer-generated graphics.

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In CAD systems as well as study drawings, then, graphic conventions are more than handy rules for drafting: in their role as image-based codes for access to the designer’s experience they channel the flow of the working processes in design. And the relative infancy of development in computer graphics for design presents unique opportunities for inventing new conventions as well as for adapting them from familiar uses.

4. Continuity and Change

In addition to the three properties that are related to hidden structure, gaining information and graphic conventions, study drawings exhibit a fourth and still more complex property that raises issues for the development of CAD systems. **CONTINUITY AND CHANGE: Study drawings provide both continuity and change in a dynamic working process for studying design problems.** The discussion of continuity and change will start by analyzing the dynamics of the working process and then move to find implications for CAD systems by considering design graphics and the design workplace.

The dynamic character of the working process comes from its cyclic action. Study drawings form the outer arc of an iterative loop in the process; perceptual and cognitive processes form the other, inner arc of the loop. Looking first at the inner arc: development of a design comes through changes in the designer’s cognitive experience — in the mental structures which represent his or her understanding of the design problem. These mental structures, as described in Rusch’s model of cognition, grow in number and complexity with the evolving design solution. However, the designer’s capacity to carry mental structures is limited; psychologist George Miller has shown that “There seems to be some limitation ... in the design of our nervous system ... that keeps channel capacities in this general range [of about seven categories],” and that the simultaneous presentation of a larger number of unrelated categories must either be brought together into about seven chunks or much of the information about them will be lost. As mental imaginal structures reach high levels of complexity, then, it becomes necessary to rely on a supplemental storage system in order to carry imaginal overloads; a graphic supplemental memory which permits us to catch, save and build on those increments of new information which are introduced from memory or perception. Study drawings or computer graphic displays, the outer arcs of the working process, provide this supplemental storage.

But storage is too static a term. Keeping pace with the dynamic imaginal processes in an evolving design means that the supplemental storage system must change quickly. Introspection suggests that the cognitive part of the design activity goes faster than the drawing does and that an uninterrupted flow of design work is more effective than an interrupted or impeded one. Speed is needed in study drawings, then, not in order to save what could be only a trivial number of minutes for some other work, but to keep up, to capture as much as possible from the cognitive image as it encodes new aspects of the evolving design solution.

How can graphic media and processes keep pace with design thinking? An analysis of the familiar pencil-and-paper study drawings for an answer to this question holds a number of suggestions for application to CAD systems.

Several techniques derived from the study of graphics and visual perception
can affect the speed of making architectural study drawings and, hence, the efficiency of the working process: minimizing unnecessary conventions, cutting down on detail, accepting rough drawings as "finished" and keeping drawings as small as possible — all economize drawing time. Experienced designers keep study drawings small, partly to avoid undue precision and partly for speed. Past drawing time is a concern for CAD systems, too; "rough" drawings with either mouse or stylus are much too slow if they require arm movements and separate start-stop operations for each line segment. Future systems should achieve speeds approaching rough hand-made drawings — or provide interface with them — and stress the faster and smaller finger/hand movements over hand/arm movements.

Small drawings are a good idea for CAD systems as well as for study drawings not just because a small drawing is faster to make graphically, but also because studies in the psychology of perception suggest that small drawings — subtending a visual cone of only a few degrees — can be perceived more efficiently than a large drawing: a small drawing, held as a whole in the eye's focus of attention keeps the drawing-cognition loop short by concentrating on an image held as a whole in the retinal fovea, where vision is most acute, rather than searching through a larger visual field. The intuitive response to the need for speed and small size accounts for the ubiquitous graphic aside which designers make at the margins of larger drawings to study some particular part of the primary drawing without losing sight of its nearby context. [Figures 9, 10] Future CAD systems should recognize this intuitive need for instant access to a graphic aside mode.

The design of CAD systems can recognize another intuitively organized part of the working process which reflects the need for fast changes and quick access: the workplace.

In the workplace for the pencil-and-paper model of the working process, "completed" study drawings and other visual references are kept available in a changing array, casually pinned up, overlayed and scattered about in apparent confusion. [Figure 11] The workplace is not as confused as it seems, however, because it actually provides a short-term annex of spatially-indexed stored images to back up the active role of the study drawings. The designer's memory map of various drawings in the workplace allows a directed search of the visual field to anticipate reaching its target and to recapture a needed element almost instantly as it reaches the center of visual attention." CAD systems must provide equally immediate and uninterrupted access to displays with wide fields of view [Figure 12]. Even very fast serial displays on a single monitor are no substitute because of the loss of kinesthetic and perceptual continuity which are essential
features of a highly evolved system of human perception and cognition.

The use of broad, shallow arrangements and databases is typical of the workplace for architectural design, as pointed out by Douglas Stoker and Nicholas Weingarten. Many spatially-indexed arrangements encourage personal variations: some designers — including both Le Corbusier and Kahn — have used sketchbooks for their work, combining working medium, memory annex and archive in a single highly idiosyncratic format. Since the example of study drawings shows that these deceptively casual and often unconscious arrangements of the workplace and its accessories become significant elements in the working process of design, it seems clear that CAD systems should be flexible enough to permit personal imprinting of formats, displays and operations. And CAD systems should be designed to continue their good start in complementing broad formats and databases through programs that provide access to expert systems and deep databases on special topics.

5. Drawings as Metaphors

The fourth property of study drawings — embodying continuity and change in the working process of design — leads to a fifth property of study drawings which treats continuity and change at an epistemological level: DRAWINGS AS METAPHRORS: Study drawings act as graphic metaphors for the extension from the known to the unknown in design problems. Graphic metaphors, as their name suggests, work something like verbal metaphors. Roughly speaking, we can compare verbal and graphic forms of metaphor to find an internal structure for study drawings and state its implications for CAD systems.

Verbal metaphors act by using the name of one thing for the name of something else — calling a child a "kid", for example. Each of the three kinds of verbal metaphor has an approximate graphic equivalent in study drawings, but not all of them have equivalents in CAD systems. The first kind of verbal metaphor — such as the "kid" metaphor — works by direct substitution of words. A graphic equivalent is the substitution of lines for edges in a drawing, simply a useful but not very provocative graphic convention, clearly shared by both study drawings and CAD systems.

The second kind of verbal metaphor is the comparison, or analog metaphor. Saying "he is as big as a house", compares the metaphor's referents, [name] and [house], according to a specified criterion: size; it does not suggest new similarities, like weatherproofness or color, or other kinds of interaction. An architectural example of a graphic comparison metaphor is a measured floor plan of an existing building: after assuming a few conventions, there is a direct one-to-one matching between graphic elements and parts of a real object, compared according to a given scale. Another example of a comparison metaphor is a study section that holds supposed spatial relationships in a graphic order that might be realized in a building. [Figure 13] Such drawings provide a home base, or context, for the goings and comings of other, smaller drawings that are used to explore problems selected for special attention (these exploration drawings are discussed in detail below). So the study drawing version of the comparison metaphor is the "context" drawing, a roughly drawn scaled plan, section, elevation or axonometric drawing that
shows a view of the project as a whole.

For CAD systems, the basic context drawing function appears manageable with current technology: graphics for CAD systems routinely include overall displays of a current design solution. But a strategy for future development would be to make context drawings in CAD systems go beyond the static limitations of hand-made drawings to include dynamic interconnection of the various context drawings so that editions to any one drawing could be reflected in the others. Such a complex, multiply interactive system could significantly change not just the working process but the actual content of design. Another strategy for CAD development is suggested by the fact that current computer graphics imply more precision and intention than the hypothetical nature of context drawings actually possesses; new CAD graphics need to avoid this misleading precision, actually to search for more ambiguous forms of graphic expression. This search for ambiguity is will be discussed in more detail below.

The third and most complex kind of metaphor is the symbolic transformation: it produces new areas of similarity by inviting interaction between components, going beyond both substitution and comparison. Using anthropologist Stephen Tyler's example:

"To say of someone 'He's an old dog' not only says something about the person of whom doggishness is predicated, it also says something about doggishness, that in certain circumstances it can be predicated of humans as well as of dogs. These circumstances 'extend' the meaning of 'dog'. Every metaphor has a dual function: it illuminates or emphasizes something about the argument to which it is extended, and that extension to that argument illuminates and emphasizes something about the original argument."[2]

The point is that the symbolic metaphor is not a passive index, but an active instrument for extending old knowledge into the new and unfamiliar, for interconnecting the known with the unknown. The graphic correlate of this metaphor is another kind of study drawing, the exploration drawing. These drawings are usually small, roughly made drawings that are used to study problems selected for special attention. [Figure 14] As outlined above, context and exploration drawings work together in solving design problems: for each exploration study, the information that describes the selected problem is abstracted from its context, coded into an exploration drawing, manipulated by overlay or redrawing to resolve or develop the problem and returned to be reintegrated into the next edition of the context drawing. The need for ambiguity is even more urgent for exploration drawings, as graphic versions of the symbolic transformation metaphor, than it is for context drawings. The "old dog" example shows that the effectiveness of this type of verbal metaphor depends on its having, among other attributes, a degree of ambiguity that allows for a range of interpretation of its meaning. Douglas Hofstadter has called such ambiguous verbal expressions "symbols with halos."[3] But how does ambiguity work in graphic metaphors?

Even though the eventual purpose of all study drawings, including exploration
drawings, is to reduce ambiguity of the whole design proposal, the initial statement of the exploration drawing must be ambiguous enough to admit new information from the designer's cognitive experience and to represent graphically the searching, hypothetical nature of the inquiry. Ambiguity is created at the inception of the exploration drawing and then resolved in its transformation through re-structuring in the cognitive system.

Graphical ambiguity does not imply unskilful drawing; indeed it takes the courage of long experience to make appropriately ambiguous drawings. [Figure 15] Exploration drawings are ambiguous partly because the designer just decides to think of them that way and partly because of their graphic characteristics, typically shown in freehand lines with uneven width and density, irregular figure and apparently casual position and scale relations.

Can CAD systems make fuzzy lines? Should new menus include more spray-can icons? It seems pointless for CAD systems to copy the graphic character of handmade exploration drawings when this character may actually be only an evolutionary accident, or a by-product of the pencil-and-paper medium. Ambiguity is a very difficult issue, even in linguistics, where it is still a focus of hot debate. Deliberately creating ambiguity to specification in a new medium — and a digital medium at that — may be an impossibly abstract assignment. What form ambiguity can take in CAD systems is the deepest question to appear in this discussion. I believe this question lies beyond extrapolation from our current body of experience, so I can only suggest indirect strategies for thinking about graphic ambiguity for CAD systems. A first strategy would be to allow ambiguity to evolve: it is possible that sufficient graphic ambiguity will, if not suppressed, simply follow from applying the other strategies derived from this analysis of study drawings. And a second strategy would be to keep subsequent development of CAD systems open to new findings from research on study drawings themselves as well as on artificial intelligence, semiotics and linguistics, for further insights into cognition and meaning. In any case, CAD systems must incorporate the metaphorical functions of architectural study drawings: they form the core of thinking processes in design.

CONCLUSION

Through these five properties — having to do with hidden structure, information gain, graphic conventions, continuity and change, and drawings as metaphors — study drawings give expressive form to a seamless graphic and mental working process. Analysis of these properties — and their related working processes — allows research and teaching in computer-aided design to look beyond the technical capabilities of computer systems for a theoretical foundation to guide new development. The theoretical foundation outlined in this paper is only a beginning; other views of the properties of study drawings and other, more experienced views of computer systems than mine are needed. But this foundation provides both an agenda of issues for the development of CAD systems and a preliminary source of information on how CAD systems must work with human physiological, perceptual and cognitive systems. Only by taking account of these human systems can design continue to evolve as a human activity satisfying human needs.
ILLUSTRATIONS

1. Lasane, Paul: private drawing; from Graphic Thinking for Architects, 1960, Reprinted by permission of Van Nostrand Reinhold Co., Inc.


3. Author: demonstration drawing, University of Oregon, 1986


6. Author: sketch for competition entry, 1985

7. Student drawing, University of Oregon, 1987

8. Rusch, Charles: diagram from Understanding Awareness (see Reference #1), as adapted by the author.


11. Student work sheet, University of Oregon, Photo by author, 1986


15. Le Corbusier: study drawing, Ibid.

REFERENCES


