Computer Graphics and Architecture: State of the Art and Outlook for the Future

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Introduction

During the three decades since Ivan Sutherland introduced the Sketchpad system [7], there has been an outpouring of computer graphics systems for use in architecture [3, 5]. In response to this development, most of the major architectural firms around the world have embraced the idea that computer literacy is mandatory for success. We would argue, however, that most of these recent developments have failed to tap the potential of the computer as a design tool. Instead, computers have been relegated largely to the status of drafting instruments, so that the "D" in CAD stands for drafting rather than design. It is important that future architectural design systems consider design as a continuous process rather than an eventual outcome.

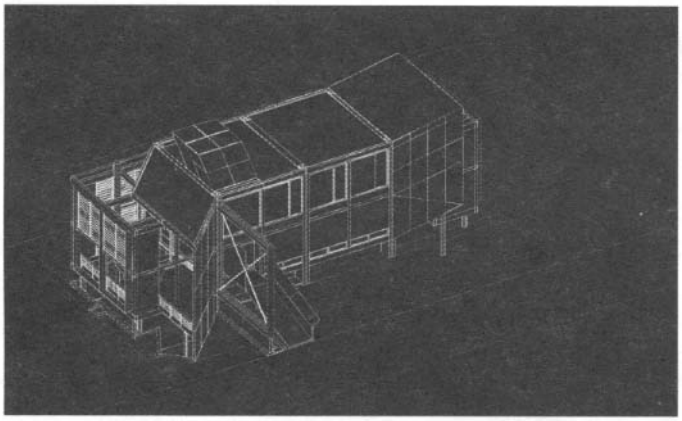

Figure 1: Hidden line axonometric view of the Tenerife House. Designed by Ann Pendleton-Jullian; modeled by Jack de Valpine and Ben Black, VISARC Inc., Boston, MA. ***See page 99 for image in full color.***

The advent of computer graphics technology has had an impact on the architectural profession. Computer graphics has revolutionized the drafting process, enabling the rapid entry and modification of designs (see Figure 1). In addition, modeling and rendering systems have proven to be invaluable aids in the visualization process, allowing designers to walk through their designs with photorealistic imagery (see Figure 2) [6, 2, 3]. Computer graphics systems have also demonstrated utility for capturing engineering information, greatly simplifying the analysis and construction of proposed designs. However, it is important to consider that all of these tasks occur near the *conclusion* of a larger design process. In fact, most of the artistic and intellectual challenges of an architectural design have already been resolved by the time the designer sits down in front of a computer. In seeking insight into the design process, it is generally of little use to revisit the various computer archives and backups. Instead, it is best to explore the reams of sketches and crude balsa models that fill the trash cans of any architectural studio.

In architecture, as in most other fields, the initial success of computerization has been in areas where it frees humans from tedious and mundane tasks. This includes the redrawing of floor plans after minor modifications, the generation of largely redundant, yet subtly different engineering drawings and the generation of perspective renderings.

We believe that there is a largely untapped potential for computer graphics as a tool in the earlier phases of the design process. In this essay, we argue that computer graphics might play a larger role via applications that aid and amplify the creative process.

Nature of the Architectural Design Process and Traditional Media

Architectural design is an iterative, visual process -- one that involves thinking and exploring in pictorial or symbolic representations. Steven Coons described the creative and complex activity of design as follows:

> *"It is typical of the design process that such iterations -- from concept, through analysis, evaluation of the analysis, decision to modify the concept, and finally to a new concept — form loops that are traversed again and again, until eventually the designer judges the design adequate to satisfy some scale or scales of value judgment." [1]*

Throughout the design process, designers employ a range of representational media and conventions to explore, assess and refine their ideas. Initially, these representations may be small diagrammatic sketches intended to stimulate the imagination, test initial thoughts and concepts and generate a series of alternatives. As a design concept is selected for clarification and development, the representations that designers employ to study the idea also become more definitive and refined until the proposal is crystallized and presented for evaluation and implementation [4].

In the generative and developmental stages of the design process, the representations are distinctly speculative in nature. Thoughts come to mind as designers view a drawing or model in progress, which can alter their perceptions and suggest new possibilities. The emerging representation allows them to explore avenues that could not be foreseen, and ideas are generated along the way. Once executed, each representation depicts a separate reality that can be seen, evaluated and

Figure 2: Tenerife House renderings at different times of day. Designed by Ann Pendleton-Jullian; modeled and rendered by Jack de Valpine and Ben Black, VISARC Inc., Boston, MA. ***See page 99 for image in full color.***

redefined, or transformed. Even if eventually discarded, each representation will have stimulated the mind's eye and set in motion the formation of further concepts. Therefore, speculative drawings or models are different in spirit and purpose from the definitive presentation media that architects use to accurately represent and communicate a fully formed design to others. While the technique and degree of finish of exploratory representations may vary with the nature of the problems and the individual designer's way of working, the mode of representation is always open-ended, informal and personal. While not intended for public display, these artifacts can provide valuable insights into an individual's creative process.

Speculative representations are essential to the creative process. Images rarely exist in the mind fully formed down to the last detail, waiting only to be transferred to a sheet of paper. An image develops over time and undergoes a number of transformations as the designer probes the idea it represents and searches for congruence between the image in the mind's eye and the one being constructed. In short, the role of the media is to allow immediate capture of ideas for examination and revision, and to provide a record of the exploration process for later review.

Computer-Aided Design Systems

The classical tools of architectural design include a wide range of media. Among these are pencil and paper, cardboard and rubber cement and clay and wire. All of these media have a common set of properties. Each is pliant, flexible and forgiving. By their nature they encourage exploration and iteration.

In contrast, the representations used in computer-aided design systems tend to be rigid and precise. The focus of CAD systems is the accurate specification of geometric relationships. At the very core of all CAD systems resides the notion of specifying coordinates for every design element. Furthermore, these coordinates are specified relative to some arbitrary center of the universe called an origin. Both of these notions involve rather serious overheads and force the designer to adopt an unnatural point-of-view.

In the words of Robert McKim:

"...not all visualization materials are well-suited to exploring and recording ideas. Materials that involve the visualizer in difficult techniques, for instance, will absorb energy and divert attention away from thinking. Time-consuming techniques also impede rapid ideation, since ideas frequently come more quickly than they can be recorded. Frustration with an unwieldy material can block a train of thought or be reflected directly in a diminished quality of thinking." [4]

During the design process, many drawings and models are often necessary to reveal the best choice or direction to pursue. They encourage designers to look at alternative strategies in a fluent and flexible manner and not close in on a solution too fast. A central aspect of these tools is that they are speculative in nature and thus subject to interpretation. In contrast, computer models can be inhibiting, which often leads to a premature closure of the design process.

We interviewed several graduate students in the architectural design studios at MIT for this article. When asked whether they had built computer models of their projects to supplement the piles of sketches and models on their desks, a frequent response was that it was too early to make such a commitment. What is it about CAD systems that force such a level of finality?

First, in the area of user interfaces, designers have to go to the computer rather than the computer coming to the designer.

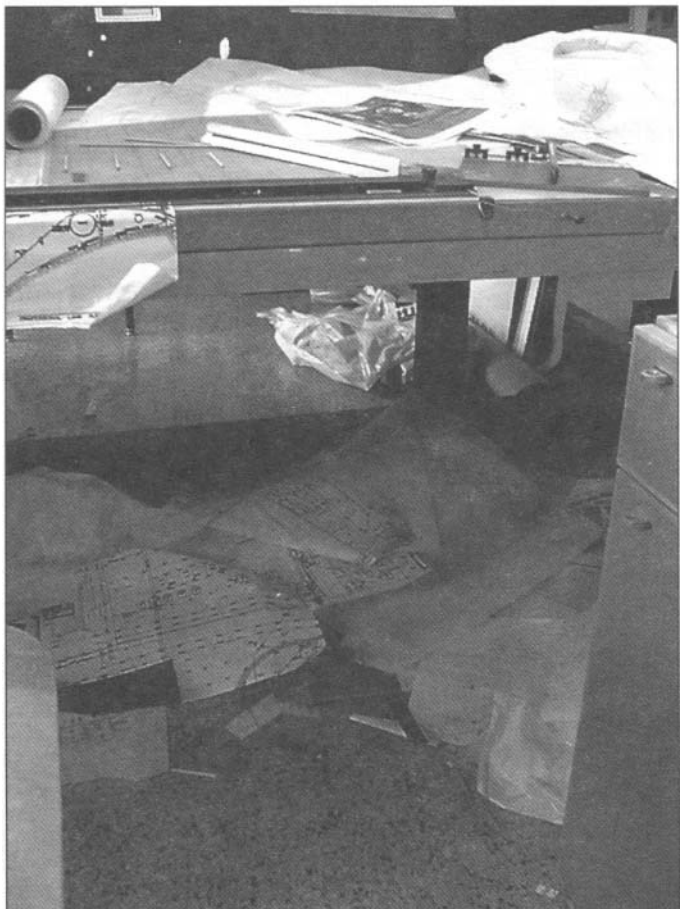

Figure 3: Typical view of a designer's archive. **See page 100 for image in full color.**

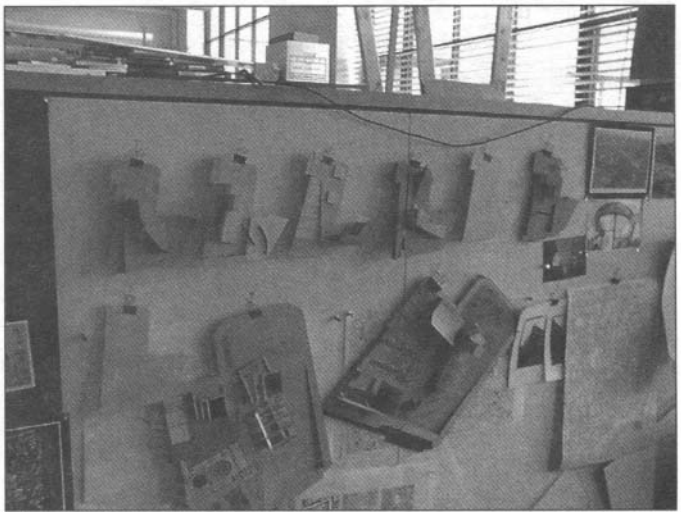

Figure 4: A collection of representations. **See page 100 for image in full color.**

Architects that are successful in their use of CAD tools are distinguished by their ability to change modes rapidly between these domains. Second, in the realm of presentation, computers present design ideas with a "hard" edge. In this case "hard" means a focus on quantitative rather than qualitative notions.

Fundamentally, today's computer graphics systems do not represent environments the way that architects conceive them. In typical architectural CAD systems the focus is on specifying the space defining elements, such as walls, rather than the space contained within them. In addition, architects find it difficult to give up both the tactile qualities of a physical model and choices of the representations.

At first glance many of these problems appear solvable. For example, through the use of parametric design approaches, one could imagine that the focus on coordinates could be diminished. However, the mere acceptance of a parameter-driven functional model requires a level of finality unlike any of the traditional design mediums used in architecture.

While computer graphics techniques have aided in the design and analysis of many structures, this is generally through very specific and disjoint programs, each requiring special preparation of data and each being applied after the conceptual design is complete. The architectural profession has yet to be presented with integrated design software that provides the opportunity to go from conceptual design to working drawings and specifications without many intermediate translations of representation.

Most architectural design systems are multi-modal. In fact, efficient CAD users rarely use the supposedly intuitive user interface that is ostensibly presented by the system. Instead they use cryptic keystroke and menu accelerators. Unfortunately all of this is done under the guise of providing a design environment with more features and flexibility. At what point do features become clutter? A pencil has relatively few features other than the hardness of its lead, the sharpness of its point and the orientation and pressure with which it is presented to the paper. Despite all of their menu options, there are few computer-aided systems with comparable flexibility.

Outlook for the Future

What is it about the medium of pencil and paper that allows for exploration of ideas, and how might this attribute be captured in a real computer-aided design system?

Sketching communicates ideas rapidly through approximate visual images with low overhead, no need for precision or specialized knowledge. Furthermore, due to its low overhead, the processes of iteration and revision are encouraged. In contrast, most 3D computer modeling systems are good at generating arbitrary views of precise 3D models and exploring designs at a variety of scales -- ranging from a bird's-eye view to that of a person within the described space.

One example prototype of a next-generation design tool is the SKETCH system developed by Zeleznik et al at Brown University [8]. SKETCH attempts to combine the advantages of free-form drawing with a 3D modeling system's ability to generate arbitrary views in order to create an environment for rapidly conceptualizing and editing of approximate 3D scenes. To achieve this, SKETCH uses simple non-photorealistic rendering and a purely gestural interface based on simplified line drawings of primitives that allows all operations to be specified within the 3D world. Figure 5 shows an example of output from the system.

In order to satisfy the needs of architectural designers, it is important that we, as computer graphics system designers, embrace the traditional tools of the architect. In addition to creating computer graphics tools based on imprecise modes of representation and interaction, another intriguing possibility is to combine such representations with traditional representations. For example, designers sometimes digitize physical models into 3D modeling systems for the purpose of refinement and construction documentation. It would be interesting if designers could digitize drawings/models early in the design process and then have computer graphics systems that support novel interactions with these representations. In this way, architects could combine the advantages of traditional tools with those of computer graphics systems.

If pencil sketching is the natural medium for exploration, then pencil sketches should be the starting points of the computer-aided design process. Tools should be developed to manipulate sketches directly, providing capabilities that are difficult to attain on paper, such as unconstrained zooming in and out of the sketched design. Future systems should also support iteration by providing output of preliminary work that can be easily erased and drawn over and once again read back into the system. Ideally through a series of iterations and manipulation, the design system could deduce and modify geometric relationships implicitly. Future CAD systems should support the generation of rapid prototypes. For instance a system might generate cutouts for paper folded models.

Designing on the computer with today's CAD systems is often like following a recipe,

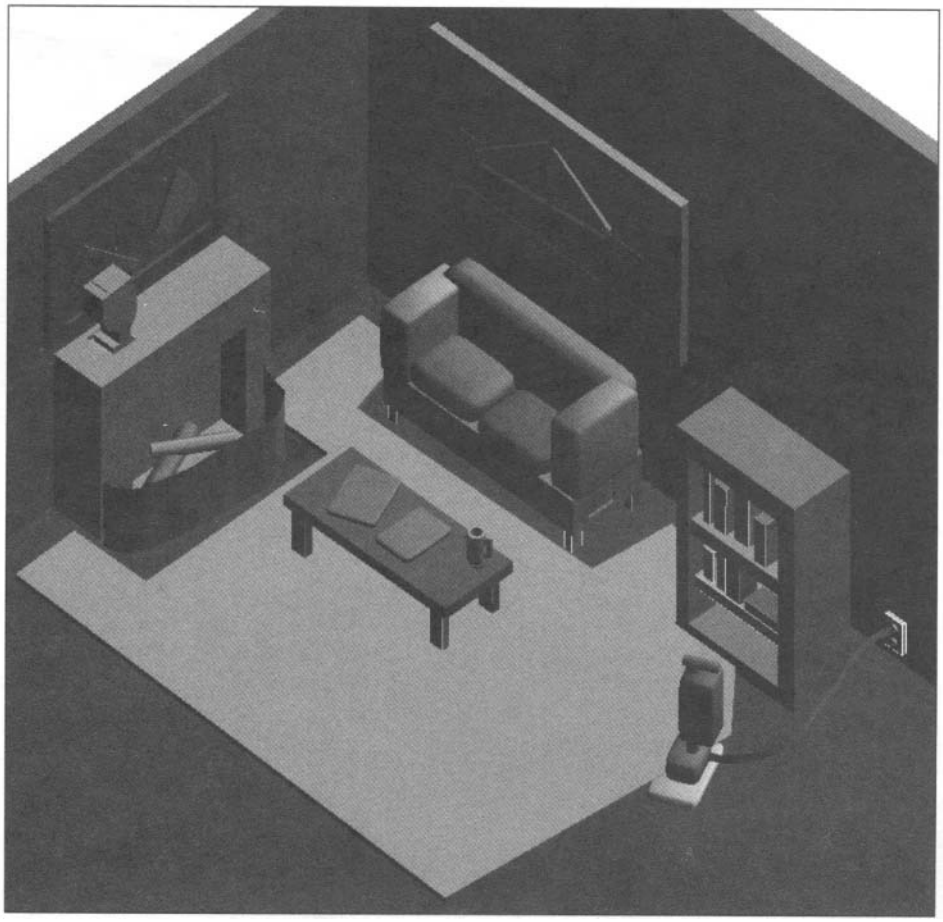

Figure 5: Sample image from the SKETCH system. ***See page 100 for image in full color.***

as designers are forced to limit themselves only to preconceived images and miss opportunities for discovery along the way. While a prior image is necessary to initiate a computer model, it can be a hindrance if we do not see that evolving image as something we can interact with and modify as we design.

The place of computer graphics in architectural design is not yet fixed, which may be a good thing. We need to develop tools that fit the approach that architects actually use when they design buildings; specifically, we should aim to create tools that allow architects to bring computers into the design process much earlier than they do now. In a sense, computers ought to be like many other design media, in that they should be flexible and practical enough to use at many different stages of design. If the next generation of CAD systems can attain this exploratory nature, we may well realize the possibility for inspiration and invention that computer graphics has long promised.

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Figure 1: "The Shape of Things to Come," by Andries van Dam. See pages 42-44.

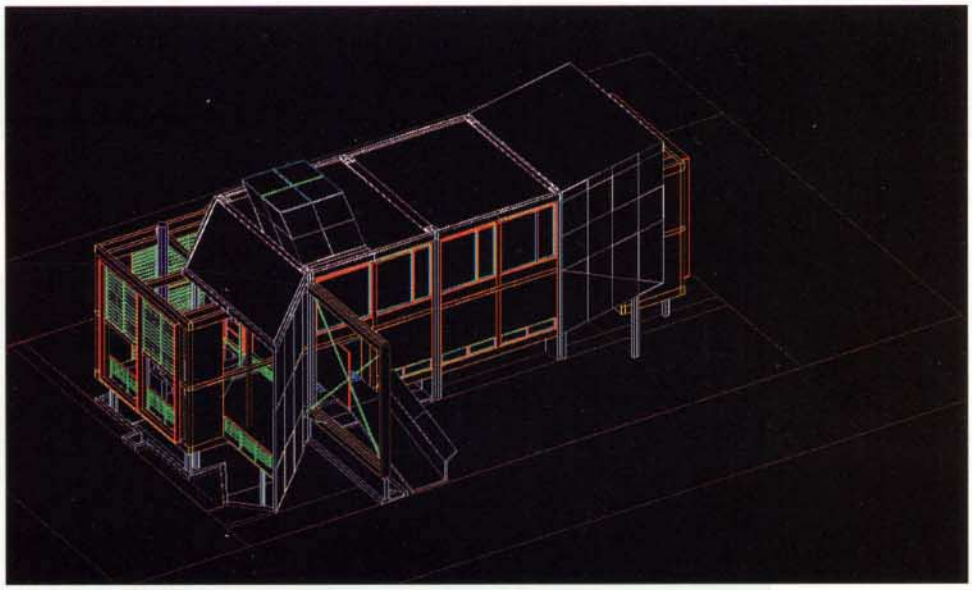

Figure 1: "Computer Graphics and Architecture: State of the Art and Outlook for the Future," by Julie Dorsey and Leonard McMillan. See pages 45-48.

Figure 2: "Computer Graphics and Architecture: State of the Art and Outlook for the Future," by Julie Dorsey and Leonard McMillan. See pages 45-48.

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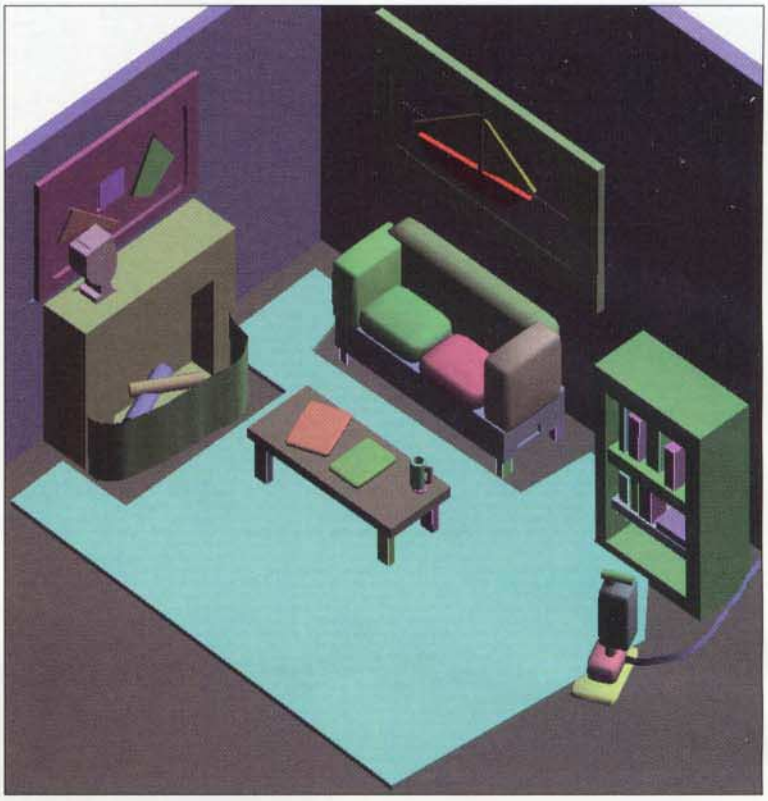

Figure 5: "Computer Graphics and Architecture: State of the Art and Outlook for the Future," by Julie Dorsey and Leonard McMillan. See pages 45-48.

Figure 4: "Computer Graphics and Architecture: State of the Art and Outlook for the Future," by Julie Dorsey and Leonard McMillan. See pages 45-48.