The Computer as a Graphic Medium
in Conceptual Design

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The success CAD has experienced in the architectural profession demonstrates that architects have been willing to replace traditional drafting media with computers and electronic plotters for the production of working drawings. Its expanded use in the design development phase for 3D modeling and rendering further justifies CAD's usefulness as a presentation medium. The schematic design phase however, has hardly been influenced by the evolution of CAD. Most architects simply have not come to view the computer as a viable design medium. One reason for this might be the strong correspondence between architectural CAD and plan view graphics, as used in working drawings, compared to the weak correspondence between architectural CAD and plan view graphics, as used in schematic design. The role of the actual graphic medium during schematic design should not be overlooked in the development of CAD applications.

In order to produce practical CAD applications for schematic design we must explore the computer's potential as a form of expression and its role as a graphic medium. An examination of the use of traditional graphic media during schematic design will provide some clues regarding what capabilities CAD must provide and how a system should operate in order to be useful during conceptual design.

Graphic media and spatial design

The spatial environment in which an architect designs is composed of four basic geometrical elements: points, lines, planes and volumes. These elements are the fundamental building blocks of spatial design. They compose the graphic language with which the architect explores and communicates spatial order in design. The extent to which a designer is able to manipulate these elements and understand the form created by their arrangement may well determine how successful he/she is at designing rich, interesting spaces.

The task of manipulating geometrical patterns and elements for the purpose of design requires a graphic medium. The medium enables ideas to be externalized and evaluated, and hence becomes an integral part of the design process. It is the forum in which ideas are explored and discussed. The capabilities and limitations of the graphic medium used have a direct effect on the outcome of the design. In order for architectural CAD to become useful in schematic design, it must assume the role, and incorporate the characteristics of a useful conceptual design medium.

Role of graphic media

During the design process, the role of the graphic medium changes to accommodate the purpose of each design phase. For example, conceptual design drawings serve a much different purpose than working drawings. The role of the first is to record the architect's ideas, while the latter is to communicate to another person how the project is to be constructed. In choosing a graphic medium it is important to recognize its role in relationship to the design phase. A soft pencil and tracing paper may be a useful medium during schematic design, but it is not likely to be an effective working drawings medium. Each phase in the design process has its own criteria for an appropriate graphic medium, and it is essential to recognize the purpose of the design phase in selecting an appropriate medium.

During schematic design the purpose of the graphic medium is to allow the architect to generate and explore ideas. Drawings produced at this early stage of design may have little value.
for communicating ideas to another, for that is not their purpose. The architect uses whatever notations and graphic expression he/she feels appropriate to record information important to the design. McKinn [1972] defined this process as graphic ideation, and explained how it differs from the communication process that occurs later in the design process.

Graphic ideation is not to be confused with graphic communication. The former is a formative process concerned with the conceiving and nurturing of ideas; the latter is an explanatory process concerned with presenting fully formed ideas to others. Graphic ideation is visually talking to oneself; graphic communication is visually talking to others. Graphic ideation precedes graphic communication in most instances; the visual thinker must first discover and develop an idea worth communicating. Being his own audience, the graphic ideator enjoys certain freedoms denied the graphic communicator; he can sketch freehand, quickly and spontaneously, leaving out details that he already understands or that he believes might concretize his thinking prematurely; he can use whatever graphic idiom furthers his thinking, without concern that others be able to understand him.

In order for a graphic medium to be useful in schematic design it must serve as a graphic ideator. Illustration and rendered details are needed only to the extent that they enhance the thinking process. Precise drafting or rendering capabilities are not expected of a graphic medium at this stage. It must provide a flexible environment in which ideas may be quickly recorded, evaluated and changed, allowing designers to visually talk to themselves as they design. During this stage of design a useful medium should enhance the evolution and evaluation of a design.

Form of media

The most common form of graphic media used in schematic design, and the one which will be evaluated here, is the use of a two-dimensional medium such as tracing paper and pencil. This particular medium has been found to be conducive to the quick-paced design activities that occur during the creative design phase. A two-dimensional graphic medium imposes certain limitations on the designer in representing three-dimensional forms. Essentially the designer must "project" the three-dimensional form onto a two dimensional plane. The orthographic projection has become standard vocabulary for the architect in recording and communicating design intent, and is used to produce plans, sections and elevations of a building.

Although these two-dimensional projections can be thought of as a limit to the usefulness of the graphic medium, they also provide an important strength. Since the design of a building is a very complex exercise in spatial geometry, it is very helpful to break the geometry down into smaller, more comprehensible parts to design. Orthographic projections allow the architect to work out necessary program requirements in a single plane at a time. It is in the orthographic projections of plan and section that most of the spatial design work is accomplished. Alternating between plan and section, the architect creates a three-dimensional form which is only realized by superimposing these planar views.

Ultimately, however, orthographic projections will fall short of portraying the three-dimensional form of the building. This is where axonometric and perspective drawings provide clarity. The perspective is certainly the most useful of the two, since it includes the foreshortening effects that more closely approximate reality. But, of course, it is also the most difficult to produce. Quick perspective sketches can be very useful, but may also be wildly inaccurate and misleading. Constructed perspectives, on the other hand, can be very accurate and revealing. Unfortunately constructed perspectives take a long time to produce and it is usually difficult for the architect to justify such a time consuming task early in the design process.

Relationship between designer and medium

At no other time in the design process is the relationship between the designer and the medium more important than during conceptual design. This critical phase of design is characterized by an often fast-moving exploration of possible design approaches, as the designer seeks for the most fitting solution.
Conceptual design is one of the most violent and brutal activities we undertake. Ideas perish right and left. Judgment is necessarily swift and weak ideas are quickly wadded into yellow heaps and filed among the rubbish. This is the ultimate interactive design system: trace paper and fat pencil. Nietzsche [1989]

Without question pencil and flimsy have become the architect's most trusted of all graphic media during conceptual design. This unassuming medium yields to the ups and downs of the design process, and allows the architect to feel in total control of the medium and thus the design process. Relying upon the architect’s skill and training in graphic drawing, this medium quietly accommodates the thought process and enables the architect to express ideas graphically, respond to what he/she creates, and quickly change directions without being distracted by the use of the medium.

When the architect picks up a pencil and begins drawing lines on tracing paper a dialogue occurs between the architect and the drawing which fosters creativity. The lines that are drawn on flimsy not only delineate abstract ideas, but they provide the architect with something to respond to for producing new ideas. This notion of dialogue between the designer and the medium is an essential element in nurturing the creative process. If a medium can provide an element of harmony between the creator and his/her ideas, then it will aid the design process. If on the other hand, it continually distracts the designer by calling attention to itself unnecessarily, it will certainly impede the design process.

The computer as a graphic design medium

Unlocking CAD’s potential as a schematic design tool may require a change in how we view CAD’s contribution to the design process. Viewing the computer as a graphic medium is an essential element in the realization of CAD as a design tool. This concept necessarily focuses our attention on the process of design, and the needs of the designer, rather than the capabilities of the computer. In order for CAD to make a significant contribution to schematic design it must yield to the generic and idiosyncratic habits of the designer during this quick-paced, creative stage of the design process.

Graphic ideation

In schematic design, the role of the graphic medium is to serve as a tool for graphic ideation. Currently, most CAD applications are far more useful as communicators than as ideators. Drafting, modeling and rendering programs have all been developed to produce computer images or drawings that communicate design intent. And it is from this communication viewpoint that we often reason how to make CAD more useful in design.

One of the most significant problems to be faced in the development of computer-aided design systems is the present inability to incorporate rich geometric models into rich design decision making models . . . The difficulty is the degree of specificity of geometric information required to define such models. Solid models are too well defined for the early stages of design, where line drawings or graphs more appropriately describe the initial definition of space. Kalay [1987]

We should be careful not to look at the problem of CAD in design from the wrong end. Instead of trying to force applications clearly intended for communication to act as ideators, we should concentrate on what characterizes the process of ideation, and what the designer needs from a graphic medium (the computer) during this creative process. During schematic design realism isn't necessarily important, so the computer need not produce presentation-quality models. Solid or surface modeling may be too much, too soon. The ideator simply needs a tool for exploring composition and spatial form with the freedom of ambiguity and adaptation.

Neither solid or surface modeling may be the proper emphasis for computer programs during schematic design. They each require the architect to make decisions which may very well be premature at the conceptual phase. Instead, emphasis should be placed on the fluidity of the design process, incorporating line drawing capabilities without regard to object description, and leaving the interpretation of graphic information to the imagination of the designer. The designer merely needs to be able to record graphic information in three-dimensional space.

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Wire frame modeling is probably the most appropriate system for graphic ideation in 3D. Its lack of order for input makes it easier for the architect to concentrate on what is being created rather than on how to create it. The weakness of the wire frame model is its inability to be rendered, but in order for a modeler to operate as an ideator, it need not be capable of rendering.

**Drawing format**

If there is one major improvement which could be made to our trusted design system of pencil and flimsy it would probably be the ability to expand this system into the third dimension. Imagine, for example, that a designer could alternate between plan and section, as we typically do, tracing over existing plans and sections to create new horizontal and vertical layers, with the added ability to display all of the layers of flimsy in three-dimensional space, showing how each relates to the other spatially to create a whole.

Such a system would allow the designer to work in the familiar 2D views of plan and section to work out the formal arrangement of the building, while continually validating the spatial implications of work done in these planar views with a 3D representation. This should be the purpose of CAD in schematic design; to provide a flimsy-type format for recording ideas in plan and section, while providing the designer with that special added feature of visualizing the 3D representation of the whole.

Applying this concept to CAD means providing a working environment using plan view graphics which allows the designer to sketch in both plan and section with the ability to trace over existing plans and sections to create new layers or to refine existing layers. Additionally, there must be a means of specifying the relative elevation of layers drawn in plan as well as the location and orientation of layers drawn in section in order to construct a three-dimensional representation of the layers of sketches. In other words, there should be a very simple and clear way to draw in plan and section while keeping track of the relationship between the two. In addition to the plan and section drawing capabilities there must be a method for displaying the three-dimensional whole in perspective or axonometric form.

Since all drawing will be done in plan and section, and since no surfaces or solids will be defined or created, a very simple palette of graphic primitives will be needed; lines, polylines, rectangles, circles and text will probably suffice. Since the size and shape of objects during schematic design can be approximated, numerical information needed to enter data should be minimal. Perhaps a grid overlay in some convenient unit of measurement would provide enough reference to allow the designer to enter data that is roughly the desired size without requiring numerical input.

**User interface**

A challenging but essential aspect of enabling the computer to be used as a design medium is developing a user interface which allows the designer to concentrate on the design rather than on what series of commands to use to record graphic information. Communication between the user and the computer should be as simple and effortless as possible.

An important interface issue in dealing with 3D is determining how the object will be viewed in three-dimensional form. This includes, among other things, specifying the location of the viewer with respect to the object, and the point to which the viewer is looking. Either rotating the object in space, or changing the viewer’s position is a relatively simple procedure mathematically, but far more problematic for the user to describe using a keyboard or a mouse. For the designer, the ability to move about the space being designed is essential to understanding the physical relationships therein. Therefore it will be an important achievement of the program to provide a means by which movement about the object can be accomplished with relative ease.

**SKETCH-3D: A prototype conceptual design program**

In support of the concepts just discussed, a prototype program has been developed which demonstrates a limited application of a system designed to act as a graphic medium during schematic design. The program, which is called Sketch-3D, is a simple wire frame modeling program developed on a Macintosh II computer. The Macintosh was selected because of the interactive nature of its mouse-operated user interface. At the time of this writing, Sketch-3D is in the very early stages of development. Yet,
even in its incompleteness it can provide tangible evidence with which to test some of the ideas just presented.

General layout

The working environment consists of three separate windows on the monitor, a Plan Window, a Section Window and a Perspective Window (See Figure 1). All drawing is done in the Plan and Section Windows, while the Perspective Window is used only to display in 3D all of the graphics produced in plan and section. Only simple 2D line drawing capabilities are provided.

**Figure 1:** Sketch-3D displaying a model of a cube

The significance of the program is the relationship between the Plan and Section Windows and their collective relationship with the Perspective Window. Any drawing done in the Plan Window is considered to exist on some horizontal plane which can be uniquely located by a line in the Section Window. Conversely, any drawing done in the Section Window is considered to exist on some vertical plane which can be uniquely located by a line in the Plan Window. The user controls the location in one window of any graphic information recorded in the other window. Thus even though the Plan and Section Windows are both 2D drawing windows, they are used concurrently to produce a 3D wire frame model. The Perspective Window demonstrates the relationship between the Plan and Section Windows by displaying a perspective view of the whole. Figure 1 demonstrates how a model of a simple cube would be displayed in the three windows.

Plan and section windows

The two orthographic projections (the Plan Window and the Section Window) are the working windows where all interactive drawing takes place. The location and orientation of the plane on which drawing will occur in one window is represented by a cut line in the other window (a gray line with a bubble at each end). The shaded half of each bubble indicates the view direction. For example, the cut line shown in the Plan Window in Figure 1 indicates that the view in the Section Window is taken through the left side of the cube, and the bubbles at each end of the cut line indicate that the direction of the view is looking to the right (in the direction of the shaded half of the circles). With the plan cut line at this position any drawing done in the Section Window will occur on the left vertical side of the cube (See Figure 2).

**Figure 2:** The door and window drawn in the Section Window appear on the left vertical face of the cube

The cut line in the Section Window always remains horizontal and the view direction looking down, thus the view in the Plan Window will always be a true plan view. This cut line can be moved vertically by locating the cursor inside one of the two end bubbles, pressing down on the mouse button and dragging the cut line to a new location and releasing the button. This will effectively change the elevation at which any drawing done in the Plan Window will exist. Figures 3 and Figure 4 demonstrate how this works.
The cut line in the Plan Window can be set to any orientation or view direction, and each time it is moved the view in the Section Window is regenerated to reflect the new setting. It can be dragged to a new location (as described for the Section Window) or it can be set to be coincident with any existing line in the drawing. The latter is done by simply selecting an existing line with the mouse (see Figure 5). Selecting the view direction is accomplished by clicking inside one of the end bubbles on the side of the cut line that the viewer is intended to look. The side of the bubble selected will be shaded to indicate which direction is selected.

Perspective window

The Perspective Window displays a perspective view of all the graphics produced in the Plan and Section Windows. This window is continually updated as drawing takes place in the Plan and Section Windows. The Perspective Window is used only for viewing the model, and not for drawing. By default the viewing parameters are set with the look-to point at the center of the model and the look-from point directly above the model at a distance which enables the projected image to be inside the Perspective Window.

The model is considered to be stationary (as a building would be), and the designer is able to move about the model. Rotational movements about the model are accomplished by means of two scroll bars; the horizontal scroll bar is used for rotating right and left around the object, while the vertical scroll bar is used for rotating up or down with respect to the model.

The arrows in each scroll bar are used to make small incremental rotations (3.6 degrees horizontally or 1.8 degrees vertically) in the direction of the arrow, while the bar is used to make larger incremental rotations (36 degrees horizontally or 18 degrees vertically). As rotations are made, the slider box moves in the direction of the rotation from one end of the bar to the other. The length of the bar represents a full
360 degree rotation horizontally, or 180 degrees vertically. Rotations to a specific position is possible by dragging the box from its current position to the desired location.

By clicking in the vertical scroll bar below the slider box in Figure 5, the user’s position is rotated downward 18 degrees and the Perspective Window is redrawn as shown in Figure 6.

**Figure 6:** The user’s position is rotated downward 18 degrees

Two more downward rotations result in the view shown in Figure 7.

**Figure 7:** The model is redrawn after a 36 degree downward rotation of the user’s position

If the user clicks the mouse inside the right arrow on the horizontal scroll bar, the user’s position will be rotated 3.6 degrees to the right with respect to the model, and the perspective view will be redrawn as shown in Figure 8.

**Figure 8:** The user’s position is rotated 3.6 degrees to the right

By continually holding the mouse button down the user could essentially rotate all the way around the model, as the perspective view is redrawn at each incremental change. Figure 9 shows the model after several such rotations. The speed at which each of these movements can be made and redrawn is, of course, dependent upon the complexity of the model, but repetitive rotations can be done quickly enough to provide a feeling of animation.

**Figure 9:** User’s position rotated another 36 degrees

Other than simple rotations around the model as described, there is currently no method for changing the viewing parameters. It is anticipated that a vertical scroll bar on the left side of the Perspective Window could be used to change the distance between the viewer and the model.
Editing

All of the traditional editing functions such as move, copy, delete, trim and stretch will be included in Sketch-3D. Editing functions are probably more important than drawing functions in conceptual design, since the design is constantly in a state of change.

Cut plane intersections

Perhaps the most frustrating limitation of Sketch-3D is the present inability to determine where the cut plane intersects existing lines in a model. For example, in Figure 6, the cut line in the Plan Window is set to be coincident with the face of the fireplace. With this setting it would seem logical to draw a vertical line at each side of the fireplace representing the intersection of the face of the fireplace with the wall on each side. However, if the top of the fireplace had not already been input, there would be no way to determine where the two vertical lines should be drawn. One solution to this problem is to locate and tag the intersection of the cut plane with any existing lines in the model. In the case mentioned, this would identify points at the intersection of the cut plane and the horizontal lines at the top and bottom of the two walls, giving the user the information needed to draw the intersection between the fireplace and the two walls.

Clipping planes

Another issue to be addressed in the future is the question of how much information should be shown in each view. With larger projects, this could be too much information to deal with at a given time. It is anticipated that a mechanism will be provided to allow the user to determine how much information in front of and in back of the cut plane should be drawn. For example, there may be situations where the user only wants to see things that are coincident with, or in front of the cut plane, in which case all drawing information which exists behind the cut plane could be eliminated from the view.

One possibility is to provide two additional lines parallel with the cut line, one representing a forward clipping plane and the other a rear clipping plane. The user could control the relative location of these two lines with respect to the cut line, and only information between the two clipping planes would be drawn in the other window.

Drawing in perspective

One of the predominant enhancements desired by those who have used Sketch-3D is the ability to draw in the Perspective Window. There are many occasions while drawing in plan and section, when there is a strong temptation to reach over into the Perspective Window and connect the endpoints of two lines, or draw a line which is more clearly expressed in perspective than plan or section.

Drawing in perspective is difficult to program because of the problem of ambiguity. The location of a point picked in the window is known in regards to window X and Y coordinates, but to transform the point to world coordinates, a window Z ordinate (depth) must be known. The existing logic of cut lines, used in Sketch-3D, could be expanded to resolve this ambiguity in perspective drawing. By projecting points selected in the Perspective Window to the plane represented by the cut line in the reference window, the Z ordinate of the point selected could be determined and transformed to world coordinates.

Input / output

In addition to data files and plot files, output from Sketch-3D must eventually include data which can be used by other applications. Conceptual design work on the computer should be considered part of a sequence of events in the evolution of data from schematic design to working drawings. The data produced by a conceptual design program, such as Sketch-3D, should be transportable to other programs which allow the user to refine the information as the design moves through the design process.

Conclusions

Computer Aided Design will continue to advance to meet the needs of the architectural profession, but there remains room for improvement in developing tools for conceptual design. A considerable gap remains between traditional schematic design activities and the potentially
powerful environment the computer offers. CAD programs can only become useful to the architect for schematic design if the hardware and software feel like an extension of the architect's hand, in much the same way as any traditional schematic design medium. CAD programs must focus on graphic ideation in order to aid the architect in the creative thought process, and thus become an integral part of design.

References