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SPACE-FORM. COMPUTER-AIDED DESIGN FOR ARCHITECTURE

Max J. Smith, et al

Utah University

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Max J. Smith
Stephen L. Macdonald
C. Stephen Carr

Robert Wehrli
Edward F. Smith
Jay A. Schadel
David A. Luther

SPACE-FORM

Computer-Aided Design for Architecture

September 1968

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University of Utah
Salt Lake City, Utah

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INTRODUCTION

Design and Construction Transformation

Dramatic changes have taken place in the construction industry in recent years. Fewer than one hundred years ago, construction was accomplished through a designer-craftsman joint effort. The designer did some drawings, which by today's standard would be considered little more than preliminary drawings describing the appearance and the approximate materials. The craftsman would then employ his own knowledge and skills to further enhance the intent of the drawings. The craftsman in this case was often aesthetically oriented and knew detailing better than most designers. Law suits were practically nonexistant except for major failures in which buildings collapsed or whole elevator and stair systems might have been forgotten.

Less than thirty years ago craftsmen were rapidly disappearing and building was becoming a process shared between the designer and the contractor, in which only occasional contact was made with the craftsman directly. Buildings were becoming much more complex as was the communication of concepts through drawings and specifications.

Today the desire for more sophisticated buildings and the emergence of technology have had an increasing effect on the cost of buildings. The technology alone involves many special engineering and testing professions. Responsibility also runs high. For example, the architect is now subject to so many law suits for errors and/or omissions that he now feels compelled to carry insurance against such errors. The frightening prospect of having to be responsible for the safety of people within the building for periods extending over twenty years is so appalling that few people have been willing to undertake such responsibility. This ruling has been recently changed to provide a statute of limitations, yet the need is still abundantly clear for more reliability.

Looking toward the future, accelerated communication inevitably means rapid change requiring more and more reliability in design techniques, and more speed both in design and construction. It now takes almost as long to design an object as it does to build it. In the case of national defense, the urgency of certain projects is often critical for an entire defense effort, yet months or years may be expended in the design of harbor facilities, ships, planes, defense bases, supply facilities, mobile equipment, satellites, and hundreds of other items which could spell the difference between success or failure of defense

movement. There is little question but what a properly coordinated design system coupled with structural and mechanical capabilities would speed these operations immensely. However, for the benefit of man himself, speed alone is not an adequate solution.

Man's needs run deep with psychological reactions which have been with us since history began, and do not manifest themselves through tools alone. He requires a way of interacting with his tools in order to discover a more meaningful environment in which he may fulfill his desires and aspirations. The proposed Space-Form design sysem is such a means of interaction. It is the opinion of the writers that many of man's desires and aspirations never materialize because no easy way of studying the environment has yet existed without resorting to actual construction. In other words, the tools and the language of the tools has not permitted sufficient communication and interaction with the designer and his clients to convince them of the worth of more than one or two possible alternatives. It is the aim of this project to not only speed the process of design and construction, but to give architects and other designers a full measure of man-machine interaction. It is a further object of this project to free the designer of tasks which are better done by the machine and allow his major efforts to be devoted to concepts beneficial to man.

The authors believe that total man-machine interaction where man does that which he does well and the machine does that which it does well is the answer to the common fear of machine-made decisions. The machine can make decisions only as well as the man has programmed it to make them. To link man and machine in a creative team is the main goal of this research effort. Since the very essence of creativity lies in the surprises and reactions which man encounters, we feel that man must interact with the machine especially on those levels which affect the behavior of man. Space-Form is particularly oriented to frequent interaction. In fact it is essential that all decisions which influence man's environment be made by the designer.

Space-Form Computer-Aided Design for Architects

The original idea for the use of space-forms as a pre-programmed way of design came from Dr. David Evans in 1967, Dr. Larry Roberts, and Dr. Ivan Southerland who did some block space-form work several years earlier, but only by specifying coordinate corners. With punched card input they constructed a primitive castle from programmed blocks and pyramids. This was then rotated into various views with hidden lines removed and photographed on the Cathode Ray Tube. The problems of removing hidden lines in those days was very costly in machine time because every line in the design had to be related to every other line in the design before the machine could determine whether a surface described by two or more lines obscured any other line.

Much of Space-Form is dependent upon effective hidden line removal. Concurrant work being carried on at this University by John Warnock is, therefore, quite important to us; for he is developing a halftone display which effectively resolves the hidden line problem. Hardware, developed by Alan Erdahl, will reduce the time required for halftone display to a few seconds. John Warnock is also working with color halftone photographs.

We wish to thank the balance of our staff listed separately below the authors for their constructive criticism of our ideas as they were discussed in the light of their application to architectural design. It was generally felt that all items of construction, no matter how small, were three-dimensional in nature and could therefore be dealt with as space-forms. Some forms such as changing land surfaces present special problems. However, if one thinks of a land surface in the same way as he would build a topographic model, then it can be dealt with simply as a single form, or multiple layers of space-forms. Other items such as piping and wiring are so specialized they may require additional manipulating capability before they can be properly incorporated into the designs. There is no problem about shaping a vinyl-coated copper wire, or a galvanized pipe or even a fitting, but we have not addressed ourselves to the problem of threading automatically these forms through other space-forms such as studs and beams to their destination.

Once the space-forms are fully implemented on the computer graphic system, the next step will involve a rigorous testing program using real problems and architects and engineers. We view this as a time of considerable change as well as a period of debugging. The total system might include:

1. The Space-Form design system.

2. Data storage and retrieval system.

3. Structural design system.

4. Quantity and cost analysis system.

5. Various building systems--such as mechanical, electrical,etc.

6. Survey input system.

7. Numerical control output for models or components.

Obviously many of the above may not originate with this research effort, but will be interfaced to the Space-Form system which is the core of our research. However, included in our effort will be a compact console design some of which will be stock parts and some of which will be specially designed. We hope that any office will be able to afford one as well as the high or low speed connection to a central computer.

One last point should be made clear. It is not the intent of this research to develop a system which will produce working documents and specifications in the traditional sense, although all that information will be available and may be essential during the transition to new ways of building. The ultimate system would work something like this: When the design is complete it will be stored on tape at the central computer. The contractor would purchase a console similar to the architect's and would on receipt of the design name and number be able to call up the same design by rotation, sectioning, zooming, scanning, and all the other capabilities that were available to the architect. He would then order plots or specs from the center as needed for his purpose, as well as use the quantity and cost data for bidding and ordering. Any change orders would be recorded and altered in the design, and the center would automatically alert the contractor of any change which applied to his job and at the same time request a change in price. This could be approved or rejected at the architect's console by the owner and architect with a transfer message by teletype back to the contractor. Needless to say, all bookkeeping for both contractor and architect would be done on their respective consoles.

The following descriptive maneuvers are presently being programmed and debugged. They are far from complete, but do represent the needs as we see them at present. We have termed this an interim report until all aspects of the needs are programmed or altered. Any extension of the Space-Form concepts will be added to this report as Addenda under separate authorship.

1 THE SPACE-FORM CONCEPT

The chief aim of this paper is to describe a process of design which involves the digital computer as the basic tool of the designer. Strongly implied in this process is the development of techniques which allow for a free-flowing interchange of information between man and machine. This "real time conversation" is essential to merging the attributes of the machine (memory, accuracy, speed) with those of man (decision making ability, imagination, curiosity, intuition, invention) into a strong team. A cathode-ray tube (CRT) display and a stylus with tablet replace the drawing board and pencil. A typewriter keyboard and other peripheral devices will assist in the communication. The proposal is to use a selected set of geometric primitives as building blocks. These three-dimensional primitives will be referred to as basic space-forms, and are the means through which the designer will represent real world conditions.

There are several reasons why space-forms are to be used as graphical computer input rather than free sketching. The most significant derives from the two-dimensional nature of the CRT display. When perspective drawings are made on a flat surface such as paper or a CRT display, they represent three-dimensional objects in two dimensions as seen from a single vantage point. Since a part of the

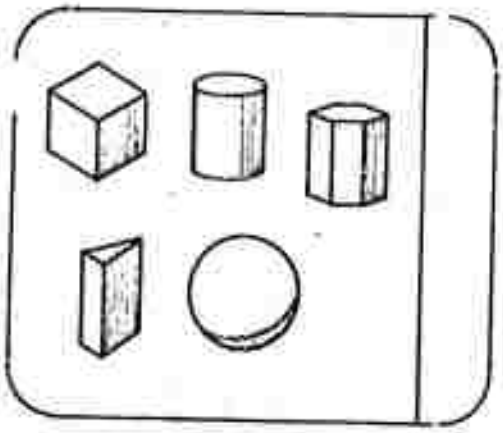
object is hidden, the two-dimensional picture contains less information than the object itself. In fact, an infinite number of solid objects can be constructed having exactly the same two-dimensional projections. Man applies judgment based upon past experience to make the most probable interpretation. The computer can be programmed to select the most probable instance; but this type of heuristic programming, while of great interest, is very involved and peripheral to research on a computer-based design system which involves a strong man-machine relationship. The objects which represent the final result of the design process all occupy space--they have volume, and this suggests that primitive or basic drawing elements should be three-dimensional in nature instead of volumeless lines and points. Thus, one may wish to think of the space-forms as the stuff with which one draws. If thought of as building blocks of any size and scale, one can easily imagine building up an object, and to do so in a manner which can only be interpreted in one way by the computer. The basic space-forms are the simplest three-dimensional shapes the computer will know.

The designer must be capable of developing his design in a reasonably short time within the limits of the system, and should not be burdened with maintaining mathematical descriptions of the geometric relationships and topology of the schemes he is developing. It is important that the machine

maintain this description for "real time" interaction. In order for this to happen, the mathematical model must be simple and compact. This is another reason why space-forms are used to communicate graphically with the computer.

1.1 The Basic Space-Forms

The basic space-forms which will be used are: the cube, the cylinder, the hexagonal rod, the triangular rod and the sphere. Each of these basic forms can be thought of as notions. For example, the cube represents the notion of "cubeness" and as such has no other property than that of cubeness.



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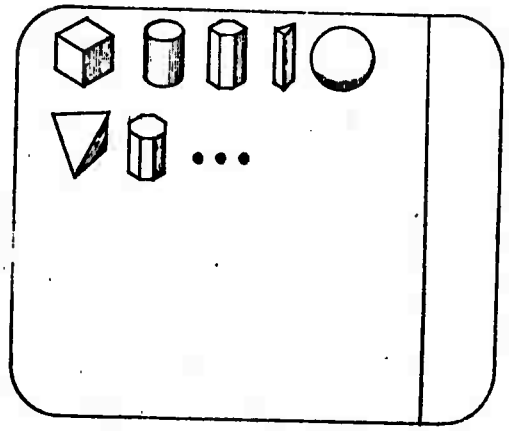
1.2 Space-Form Index

The basic space-forms will be displayed in an index which would be a part of the larger design system data structure. Also included in this index could be any other space-forms which the designer wished to include. For example, the designer may wish to use a tetrahedron and an octagonal rod in addition to the space-forms mentioned above. Ultimately this index would be built-up by each individual designer and would include the forms which he personally prefers to work with. This does not imply that he would be limited to the exclusive use of these forms, for he is free to reshape any of the forms at any given time. He



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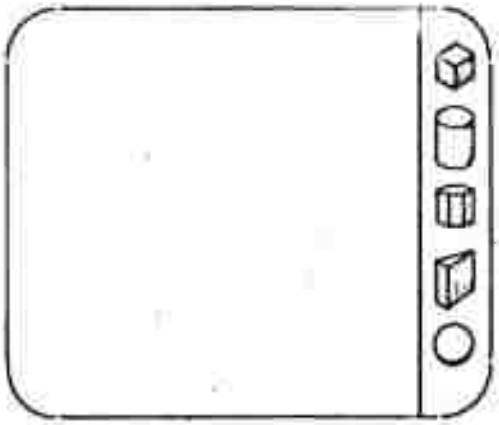
may do this without destroying the original form since the shaping routines are carried out upon copies, and not on the original, which remains in the index. The designer will also be capable of removing a form which he no longer wishes to use.

1.3 Space-Form Key

The designer, upon initiating a design, would select from the space-form index displayed on the CRT those forms which he wished to use in the problem at hand. After selection of a given form has been made by pointing to it with the stylus, a copy of this form would appear in the space-form key which would occupy a portion of the display face. That portion of the display to the left of the key would be the working surface. After the desired space-forms have been selected and the appropriate command given, the index would be removed from the working surface and the designer would be left with only the key containing the selected basic forms, and the clean working surface.



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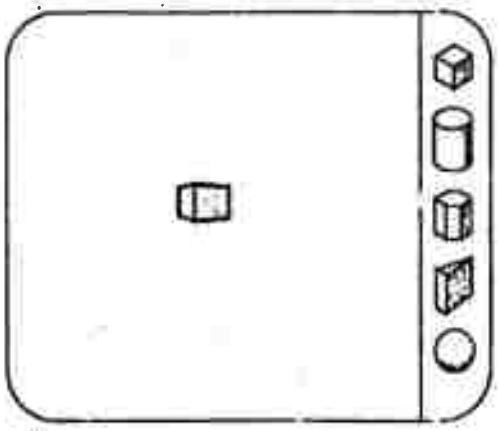
The act of calling-up or signaling one of these basic space-forms onto the working surface would be accomplished by attaching the stylus to any part of the form and moving to the desired position. At this point the designer is dealing with a specific instance of the basic notion, which still exists in the key. When stylus contact is



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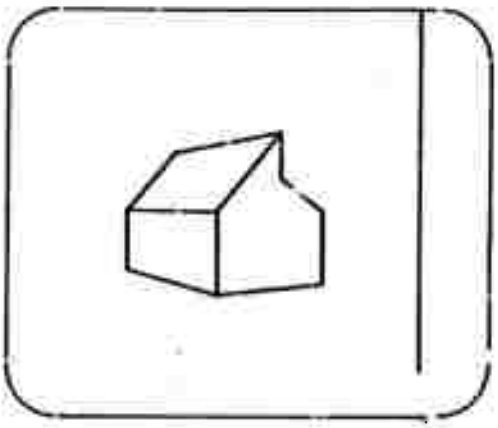
broken, the instance will remain in place. The designer is now free to bring other instances of basic notions to the working surface, and may begin "building up" his design. If he wishes, however, to change the size or shape of a single form; he may do so. A detailed description of how each basic space-form can be shaped follows in Sections 3.1 and 3.2.

1.4 Transformed Space Forms

After a basic space-form has been changed in any way by shaping, it is called a transformed space-form. These space-forms can be retained for future use by the designer if he wishes. This is accomplished by giving a command to "store" at which point the machine would place the description of the form in the supporting data structure. A transformed space-form derived from a basic cube could be found by displaying the space-form index, touching the cube with the stylus and giving the appropriate command to get to the next level. At this point all of the transformed space-forms deriving from a cube would be displayed.



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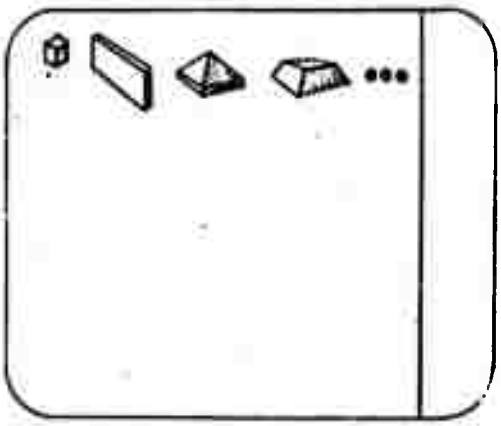

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Another class of transformed space-forms comes from the grouping of basic space-forms without any shaping having taken place. When two or more forms are grouped and named they can be stored in the same manner as above. Any combination of grouping and shaping is possible, but storage can become a problem where groups may be

composed of more than one basic space-form. In this case it will be necessary to add to the basic index a "composite" command to allow for easy access to stored forms made up of more than one basic space-form. Some complex forms can be developed through revolving basic or transformed space-forms about certain axes. This class of transformed space-forms will be discussed further in Section 3.25.

1.5 Object Images

Space-forms shaped and combined to closely represent real world objects eventually can be made to simulate the actual object. This is accomplished by assigning attributes to the transformed space-forms, such as material, color, etc. Once these assignments are made, the machine will present the object image to the viewer as near as possible to the way it would actually look. For example, one may assign to a group of space-forms the properties of concrete. This would be accomplished by pointing with the stylus to each space-form and typing "concrete." The object would now "behave" as though made of concrete; that is, the physical weight of the object in concrete would figure dominantly in a structures analysis program, and its heat loss and heat gain would figure strongly in an analysis of a mechanical system. One can go on assigning attributes such as "monolithic" at which point the lines between the space-

#7

forms would disappear, and certain texture conceived of and named by the designer could be applied.

The object image, then, is an advanced state of the space-form--when the space-form actually begins to take on the visual and non-visual characteristics of the object in the real world.

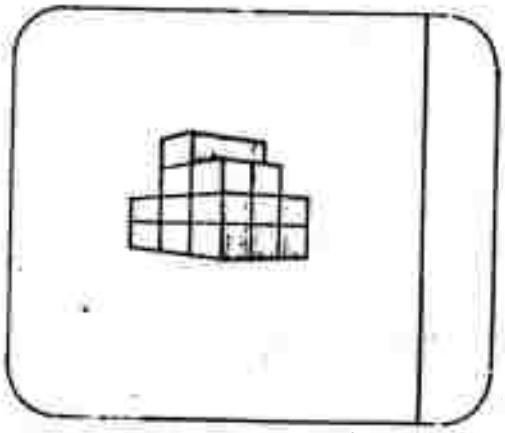
2. SOME CHARACTERISTICS OF SPACE-FORMS

Initially all space-forms are made of unassigned material, and while in this state they can be either opaque or transparent--depending upon the needs of the designer. Space-forms can also be assigned the physical properties of materials, and in this state would appear visually to be made of the material specified. Each of these three states will now be discussed in greater detail.

2.1 Three States of Space-Forms

2.11 Opaque

If the characteristic of opaqueness were not given to the space-forms, all edges would be seen. It is felt that even in design schemes of minimum complexity it would be confusing if all edges defining the space-forms were allowed to remain in the picture. Therefore, edges that would normally be hidden if the space-forms were solid will not be seen in this state, and to see hidden portions of the design will require rotation or sectioning (which will be discussed later). It is felt that this opaque space-form will serve the needs of the designer most of the time.



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It is recognized that the problem of removing hidden lines is a big one. However, a concurrant project at the University of Utah is solving this problem. *

2.12 Transparent

In certain special cases such as some types of structural frame design or space analysis, it may be desirable to see all edges of

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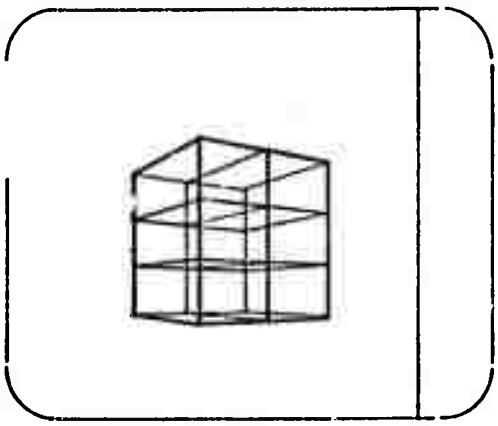
*John Warnock, Hidden Line Algorithm for Half-Tone

individual or group space-forms. This would permit the designer to deal with a three-dimensional linear space frame as a network of lines. These lines could then be used to represent the various structural members at their centroids or edges until such time as it seemed desirable to convert these to real beams, columns, etc. A symbolic non-specific rectangular or triangular equivalent might be introduced as the first step to converting to real materials. This would give the designer a chance to study relative sizes physically before converting to a specific material.



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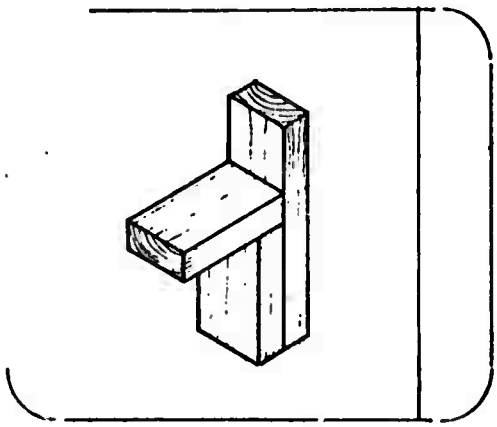
Again, in the planning of indoor-outdoor spaces it may be desirable to view certain space-forms as if they were transparent, but with edges defined. This certainly would be true in the early phases of design of a modular building with many penetrations such as terraces, courts etc. Since opacity is the usual case, transparency needs to be invoked by stylus selection and typed command. or mode switch.

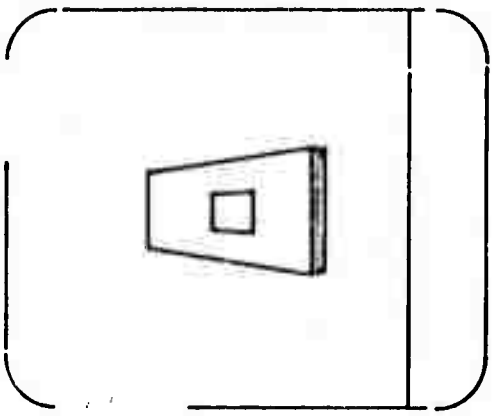
2.13 Material

As mentioned in Section 1.5, space-forms can be made to accurately reflect the real world by assigning to them the properties of specific materials. This advanced state of the space-form is essential for simulating the performance of the design solution. The manner of designating materials was covered in Section 1.5, and will not be treated at length here. However, it may be helpful to discuss one other material assignment which can be made by the designer. This assignment which the designer can make is that of "air." He makes this assignment in the same manner as that of concrete or any other material. The result



#10

of such an assignment can be clearly seen in the illustration (#12) of an opening in a wall. It does not really appear as an opening until the space-form representing it is assigned as "air." This is visually similar but not the same as "transparency." A transparent space-form can still be assigned a specific material. Once a space-form is given a specific material by command, it can be changed without reversing the last command or deleting and replacing with a new space-form. The designer may wish to change materials after having specified one. A later specification will replace an earlier one.



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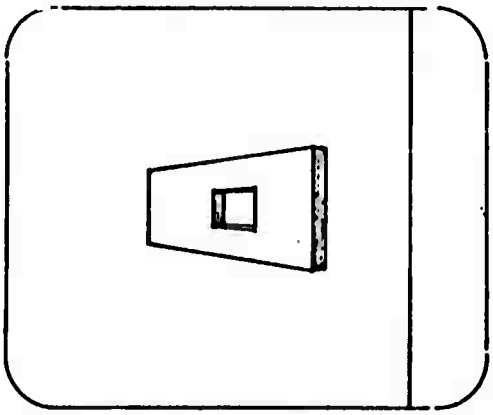

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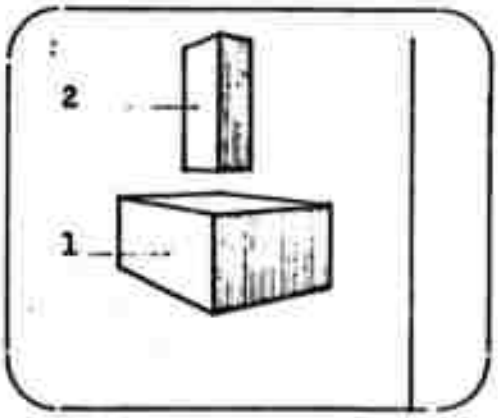
2.2 Interpenetration of Space-Forms

At the outset the space-forms may only serve to define a certain volume of space. This is their intended basic nature and purpose. It is further felt that at all levels of design, space-forms should be allowed to interpenetrate one another. As a general rule the portion of the space-form penetrating another space-form should be subtracted from that space-form. Thus, as space-form two penetrates space-form one (as in illustration #14) that portion of two (labeled 3 in the illustration) would be subtracted from form one. As space-form two is progressively withdrawn, space-form one fills in behind the retracting form until both forms regain their original and separate identities.



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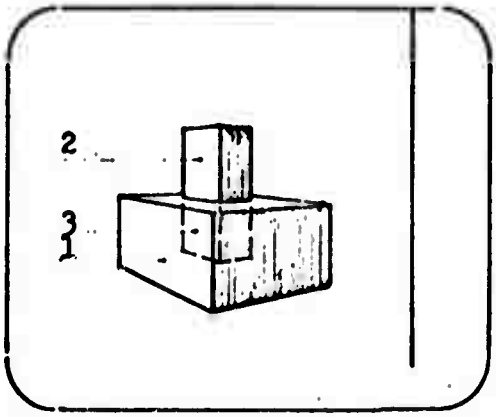
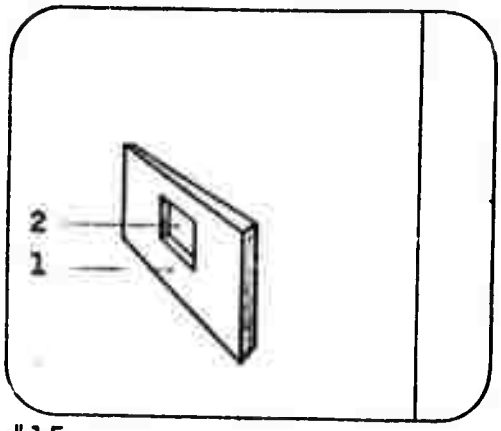
It will be extremely important to the architectural designer to be able to penetrate one form with another. An example may serve to clarify this. The simple case of placing a space-form representing an opening in a wall will be a common enough problem.



in architectural design. The window could be located in many places in the wall, and some positions would be more suitable (or appropriate) than others. The process of designing this wall would include the designer's searching for the "best" position for the window. If he can penetrate form one with form two and freely move form two about within form one, this process of searching is easily accomplished. If, however, the designer is not able to penetrate one form with another, he must build up the wall and window assembly out of five space-forms, and the size of each must be predetermined. Any change of position, however, slight, means a corresponding change in every other form. In that case the design process of searching for the "best" position is extremely complex.



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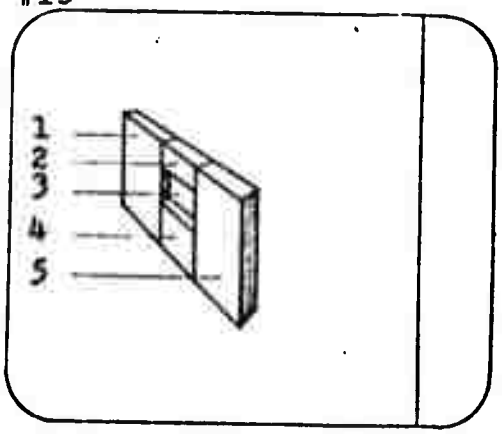
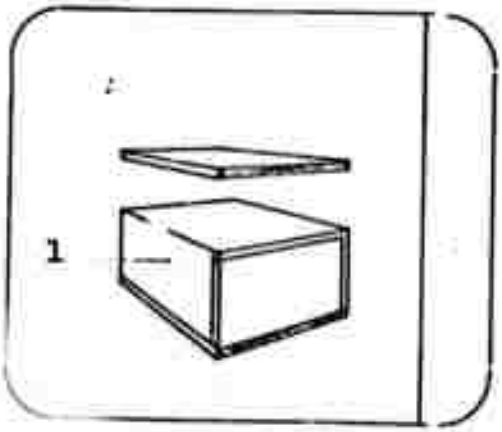
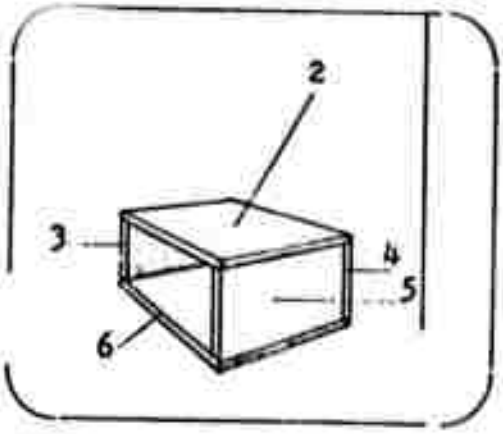


#16

By allowing space-forms to interpenetrate, it is possible to develope the same combination of forms in different ways. This may at first appear unnecessarily complicated, but good reasons exist for being able to achieve the same result through different means. The designer may begin, as shown in illustration #17 with a total volume of a room. He may then add within this first space-form representing walls, floor, and ceiling. As the illustration shows, this combination of forms is made up of three walls, a floor, and a ceiling, but there is also the remainder of the original space-form. In other words there are six space-forms making up this "room."

The designer could have arrived at the same solution by simply connecting the three wall forms to the floor form and ceiling form. In this case he has essentially the same "room," but it is made up of only five forms.



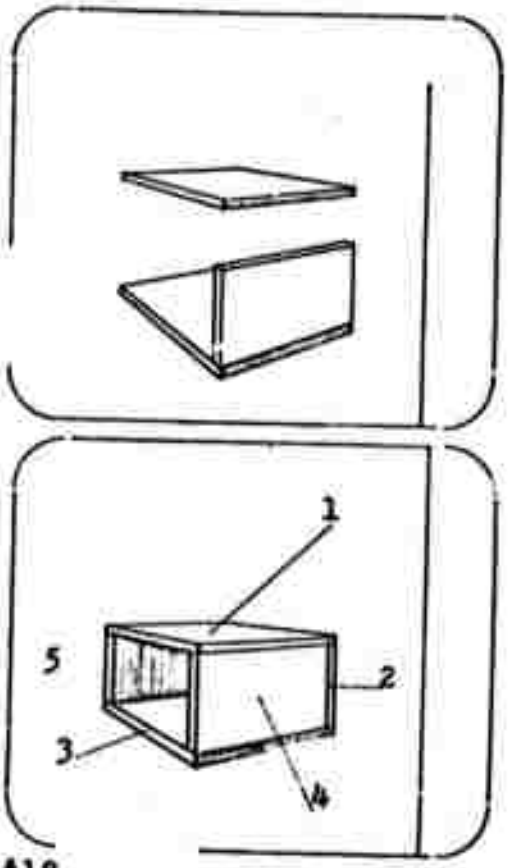


#17

In a third case, the designer may wish to penetrate a large space-form with one just smaller until the leftover space is enough to represent the walls, floor and ceiling. The "room" has been made with only two forms, yet is not quite the same since there are now no joints between walls, roof, and floor.

In an attempt to make the illustration more clear, the first and third situation were drawn incorrectly. Actually one would not be able to see into these "rooms" as shown until space-form five in illustration and space-form two in illustration were assigned as "air." This assignment could be easily and quickly made by the designer as outlined above.

It is felt that the designer should have the choice of working in each of these ways to produce similar results. In organizing and planning a design solution, it would be useful to be able to represent rooms or spaces by proportionally sized space-forms without concerning oneself with such things as walls, floors, and ceilings, and to place these at a later time as in the first example. In another instance a designer may wish to begin by immediately dealing with the walls which surround a given space--perhaps when the scope of the design is smaller and the enclosed space is not so strictly specified. The case for the third manner of dealing with space-forms has been established in the example of placing a window in a wall. Probably many details of construction will be most conveniently designed in the latter manner.



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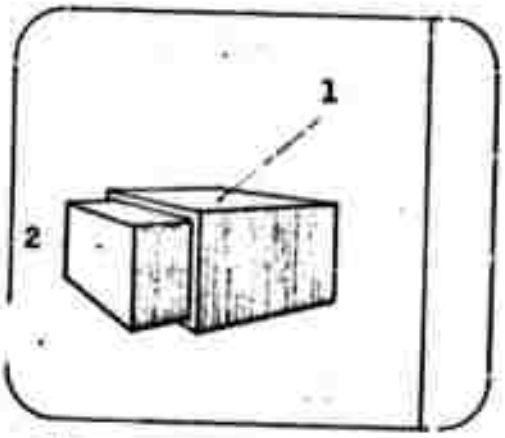
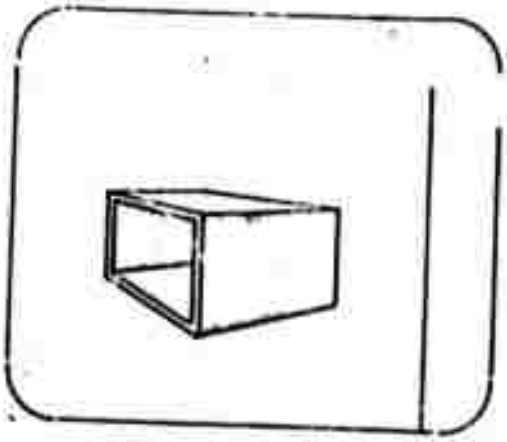




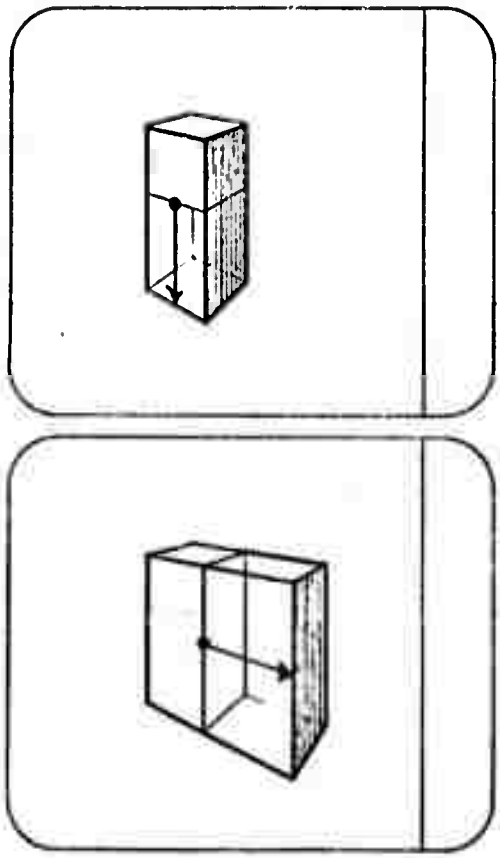
3. SPACE-FORM MANIPULATIONS

3.1 Shaping without Curves

The shaping routines which are described in this section consist of stylus maneuvers which vary with attachment points and the direction in which the stylus is moved. Curved surfaces can and do result in some cases, but are still closely related to the geometry of the basic space-form. Further development of curved surfaces will be discussed in the next section.

3.11 Expand-Contract

The method of expanding or contracting any of the basic space-forms is quite straightforward. In the case of the cube, it involves attaching to one of the edges defining a side, top, or bottom of the form and moving in or out normal to the surface to be moved. An entire surface will move with the stylus as shown in the illustrations, and it will be constrained to remain parallel to its original position. This can be done to any surface of the cube, and allows the designer to develop an infinite number of rectilinear shapes. The cylinder and rod shapes can be expanded or contracted in much the same manner as the cube. By attaching the stylus to a top or bottom edge and moving in either direction parallel to the longitudinal axis, the shape can be made taller or shorter. When the stylus is attached to the apparent edge defining the outer surface in or out at an angle roughly normal to the longitudinal axis or one of the faces, the shape can be made thinner or fatter.



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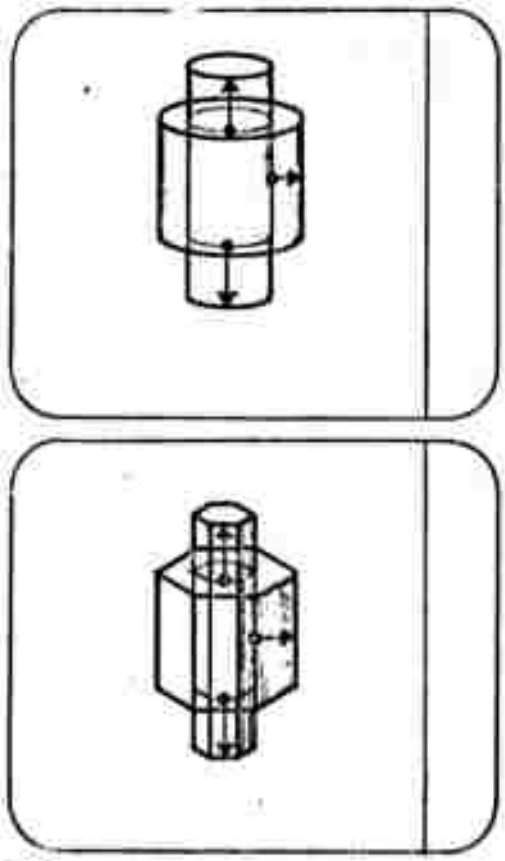
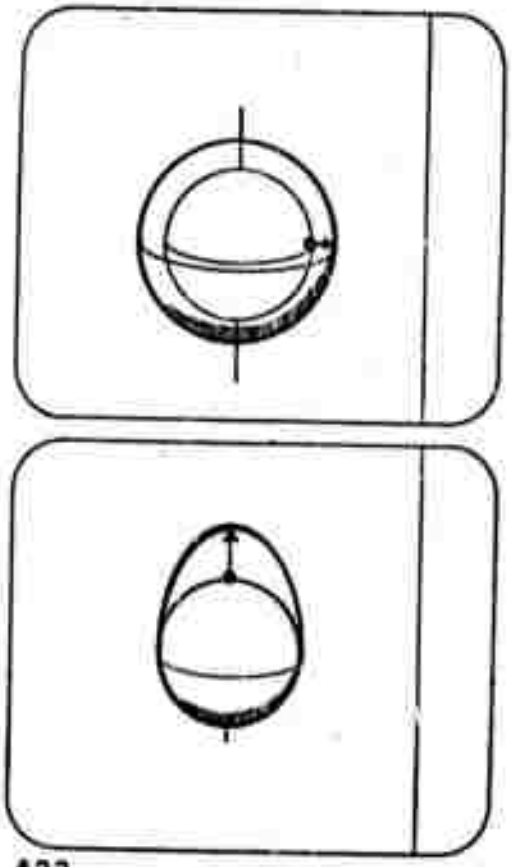


#21

The sphere is shaped by attaching the stylus to an apparent edge and moving either in or out. A faint line at the equator and a north-south axis would help the designer orient himself so that he could move the stylus roughly normal to the axis or parallel to the axis. A move normal to the axis would expand or contract the basic sphere. A move parallel to the axis would expand or contract one-half of the sphere elliptically. The ellipse would be tangent and "faired" to the other half of the sphere. When both halves are shaped, a basically elliptical form results where both the major or minor axis of each end, but not both axis, may vary if the resulting shape is not symmetrical.

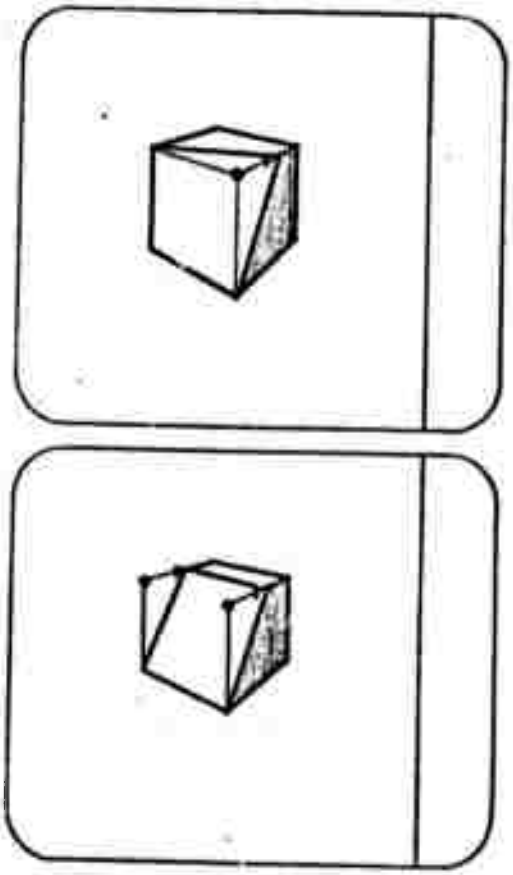


#22

3.12 Movement from a Corner along an Edge

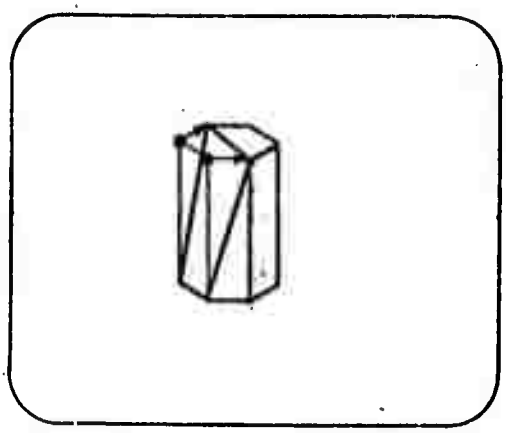
Further shaping can be done to some of the forms by moving from a corner along an edge. In the case of the cube, the designer can pull a side with him as illustrated. This results in a warped surface where three corners remain fixed and the fourth moves. By moving from opposite corners in the same direction, one can develop the fairly complex form of the hyperbolic paraboloid. And by moving in the same direction from two adjacent corners on a single face, one can produce a basic cube shape with a sloping side or face.

Shaping the rod forms in the same manner is possible. By attaching the stylus to a corner of a hexagonal rod form and moving along an edge, a warped



#23

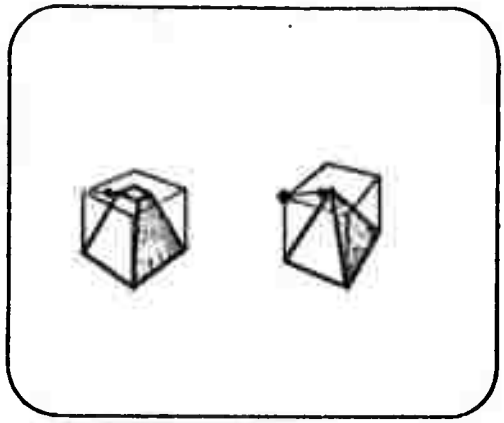
surface results, and moving along two edges as illustrated allows even more freedom in developing additional shapes.



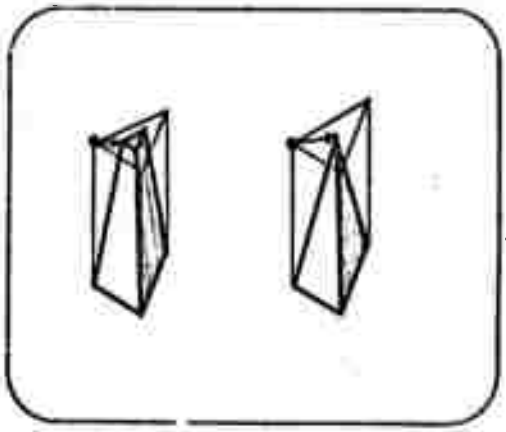
#24

3.13 Movement away from a Corner

A pyramidal or partial pyramidal form can be made of a cube by attaching the stylus to a corner and then moving toward the center of a surface of the cube. All sides would move toward the center as shown in the illustration. The designer could stop anywhere short of a perfect pyramid, creating a basically trapezoidal form. The center of each surface of the cube would be indicated by a bright dot allowing the designer a reference point to work to. If the stylus continues past the center, a pyramid then a sloped axis results.



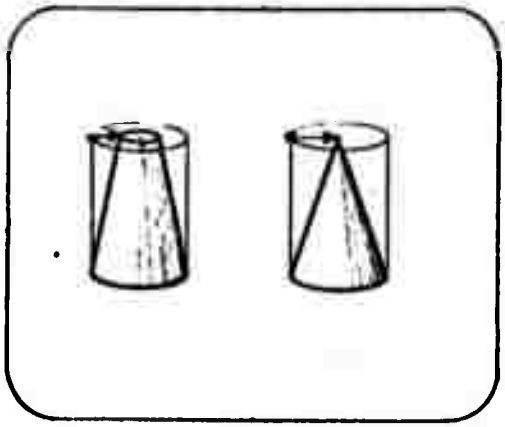
The rod forms similarly can be shaped to hexagonal pyramids or triangular pyramids. Again, the designer can stop anywhere short of the center which would be indicated by a bright dot. With all pyramidal forms, once they have been brought to the center, they can be drawn off axis in any direction and to any degree desired.



#25

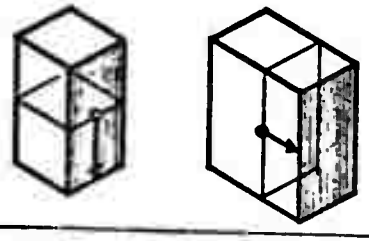
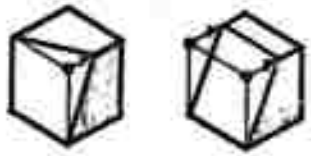
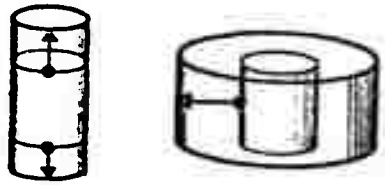
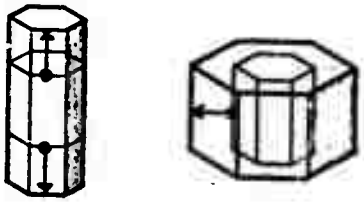
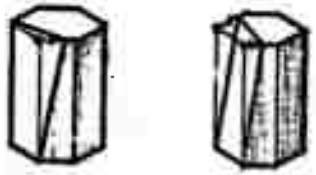
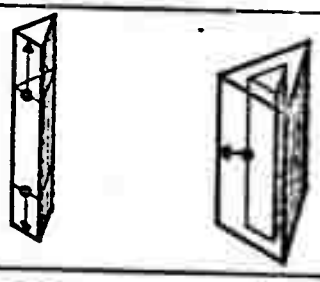
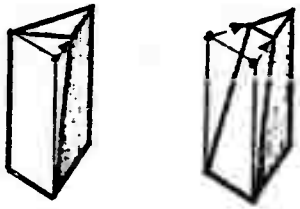
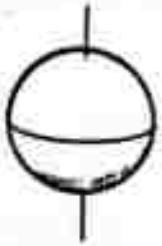
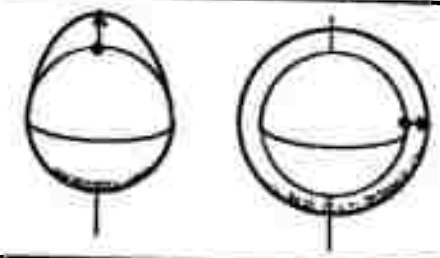
3.14 Movement away from an Edge

By attaching the stylus to a top or bottom edge of a cylinder and moving toward the center of the surface (indicating a bright dot) a partial or complete cone can be developed. This cone can also be drawn off center if the designer wishes.



#26

A chart of all the shaping maneuvers discussed in this section follows.

BASIC FORM	EXPAND - CONTRACT	MOVEMENT AWAY FROM CORNER OR EDGE	MOVEMENT FROM CORNER ALONG EDGE
			
			
			
			
			

3.2 Shaping with Curves

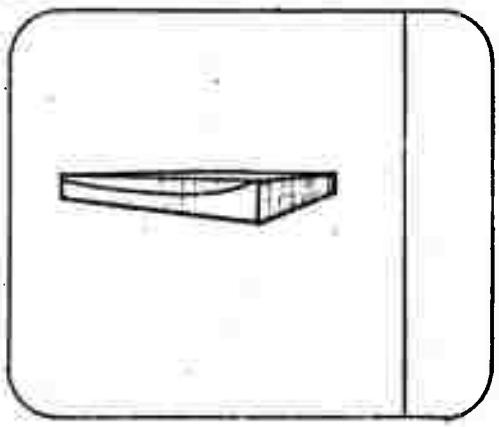
There is a need for the designer to be able to deal with more complex curvilinear surfaces than is possible within the limits of the basic shaping routines described in the previous section. Some furniture design, for example, must presently be carried out through the use of full-scale mock-ups because drafting methods are inadequate in indicating just what is happening in the design. In addition to problems of furniture design, and design of other complex curvilinear objects; the architectural designer is frequently faced with the problems of understanding and representing topographical information. This information can be graphically represented as a complex curved surface.

3.21 Boundary Curves

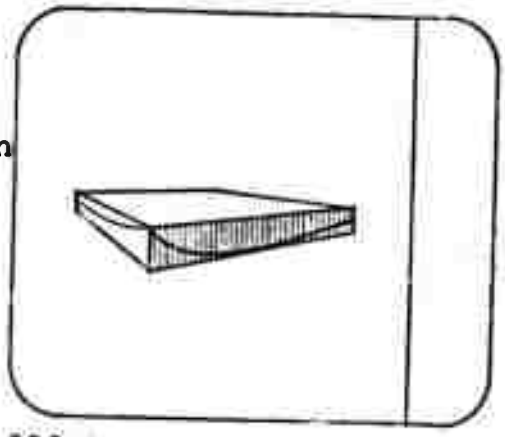
The designer should approach the curve problem three-dimensionally, i.e., in terms of surfaces. These surfaces are to be developed upon one of the primitive space-forms previously described. It is not possible, in this system, to create a surface which does not begin from a space-form. This will help define for the machine where the surface is located in three-space.

The designer may begin to develop a desired surface by drawing with the stylus a profile of the surface he wants. If this is drawn on the principal face (defined as that face which is most in view) of the space-form, the machine can locate the curve in three-space. It is necessary for the machine to "recognize" the curve or series of curves, and "fit" segments of curves from its library which most closely approximate that which has

#27



been drawn. The designer must now rotate the space-form until another face becomes the principal face. This rotational capability is essential and will be discussed in Section 3.31. He may now draw the profile of the second boundary curve of the surface. In like manner each of the four boundary curves would be specified. Upon having completely specified the fourth boundary curve, the machine can generate the surface. The surface formed is defined by the four boundary curves and may be thought of as the surface of least energy--a perfectly elastic surface --bounded by the four curves. These surfaces are similar to those discussed by Steven A. Coons in his paper "Surfaces for Computer-Aided Design of Space-Forms."*



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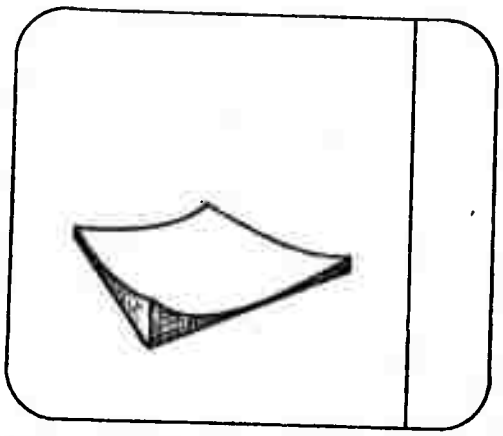
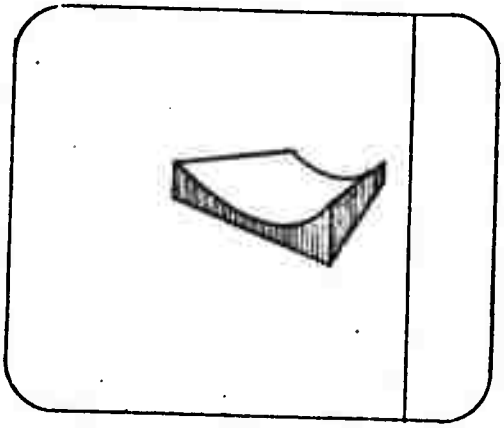


#29

If the designer does not wish to draw the curves, but rather has in mind specific mathematically defined curves, he may specify these curves through the typewriter keyboard. Stylus commands are still essential to indicate beginning and end points and/or points through which curves pass such as in a circular curve which requires two points and a radius or three points. In order to use mathematical curves, the designer must know the control factors of the curve.

3.22 Cutting with Curved Lines

After having specified only one boundary curve, the designer may give an "execute" command and the desired curve can be made to slice through the space-form, in a direction normal to the principal face, in the manner shown. In this case it may be helpful to think of the curve as a thin blade which is moved through the space-form.



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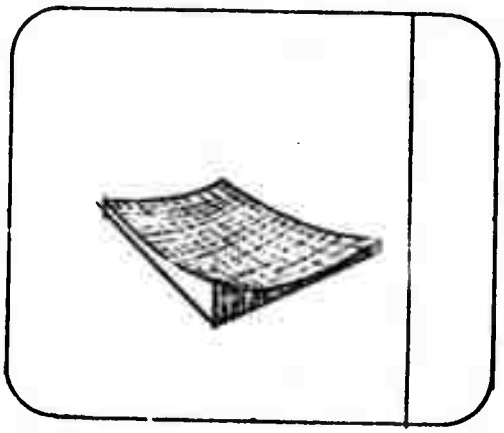
*Steven A. Coons, Surfaces for Computer-Aided Design of Space Forms. (Cambridge, Massachusetts Institute of Technology, 1967).

This is a special case of the above shaping routine. In both the general case and the special case, two surfaces are created--one the negative of the other. The designer may use both if he wishes or he may "erase" one by indicating with his stylus the one to be erased and giving the appropriate command. Prior to erasing he may also store either one he wishes for later use.

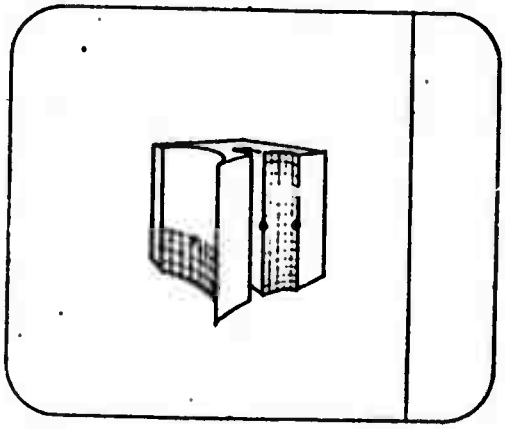
3.23 Surface Net

Since it is difficult to visualize the complexity of an extended surface, it is suggested that it be ruled into a grid of connected patches. The designer can select the scale of this surface net so that the rulings could be much closer together for a rapidly changing surface than for a slowly changing surface.



#31

The designer can control the net through a sequence of commands. The initial command requires the designer to indicate with the stylus the point where the net is to begin, then he must type "net" and the spacing between nodes on the net (such 5'-0", 10'-0", etc.); he must then indicate with the stylus the points where the net is to terminate. This step completes the command, and the machine will generate the net uniformly as specified. If the net is to completely cover a given surface, the designer need only indicate the beginning and end, for the net will generate in the other two directions until a sharp (not curved) change in surface is sensed.

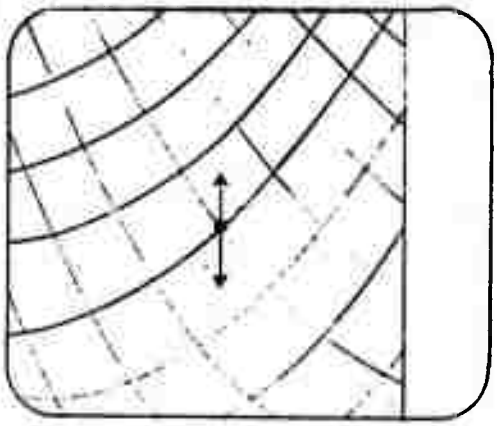


#32

The spacing between rulings on the grid can be specified to any degree of sophistication desired. For example, the designer may wish the rulings to increase or decrease logarithmically, or by some other factor. The rulings can even be varied in two directions.

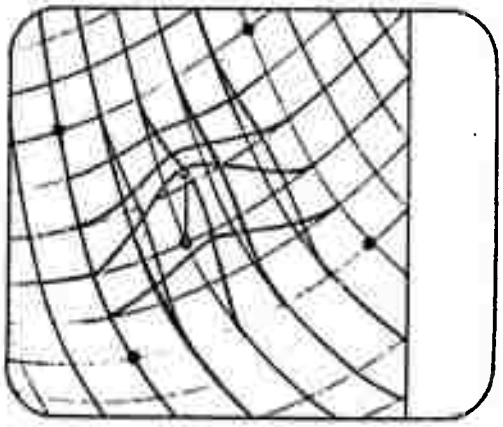
3.24 Shaping the Surface within the Boundary Curves

It is possible that the surface formed by a perfectly elastic membrane stretched between the boundary curves will not be the surface needed. Therefore, the designer may further shape the surface, after the general case has been generated by attaching the stylus to any one of the nodes created by the rulings and moving it up or down. In this manner, the entire surface can be further shaped.



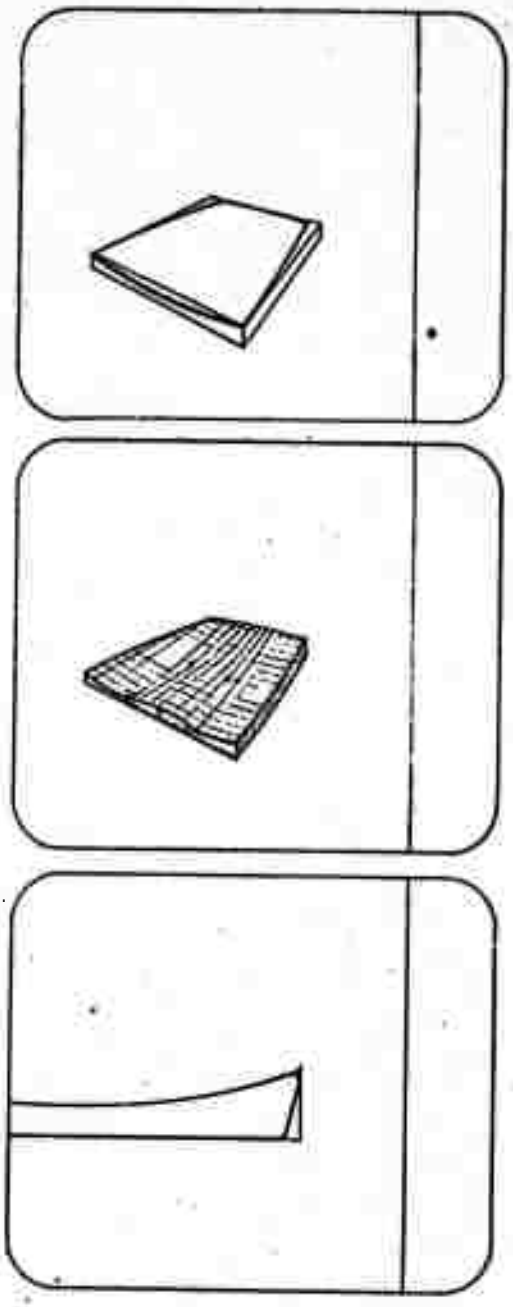
#33

On a given surface it must be defined to what extent a single manipulation will affect the entire surface. Unless otherwise specified, it is suggested that the effect be limited to one node, and that the nature of the curved "patch" being changed be rounded on its crest and be "faired" into the overall surface. If the designer wishes, however, to change the boundary curve; he should be capable of doing so at any given time by redrawing it. This may, of course, affect the entire surface which would be automatically regenerated. When several spaceforms, each with a shaped surface, are brought together to form a much larger surface, the designer should be able to adjust these to one another to create an overall "faired" form. This adjustment could be made automatically at the designer's command. A typical development of a design might require the designer to begin shaping in a very general way, the object he is designing. Once having arrived at a general shape he believes appropriate, he can go on refining his design by examining it in its most minute details:



#34

Thus, in the example shown, the designer begins by shaping the general form of a chair seat by drawing the boundary curves. After this is accomplished, he may further shape the surface within the boundary curves. Now he may wish to give attention to the edges, which may require him to enlarge the scale and possibly examine at various sections. These edges can be defined in the same manner as the first example given in this section. If the designer wishes now to re-define the overall shape, he may do so by re-drawing boundary curves, and all surfaces would adjust to this change. This entire process would be much like carving the object out of a homogenious material with tools over which the designer can exercise complete control. Each time a decision is made and a surface is generated, the designer is not faced with an irrevocable situation, for he can freely return to any previous state. In this case the information which defines the chair seat could be fed through punched-tape to a numerically-controlled milling machine which would produce the seat from a specified material.



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3.25 Topography

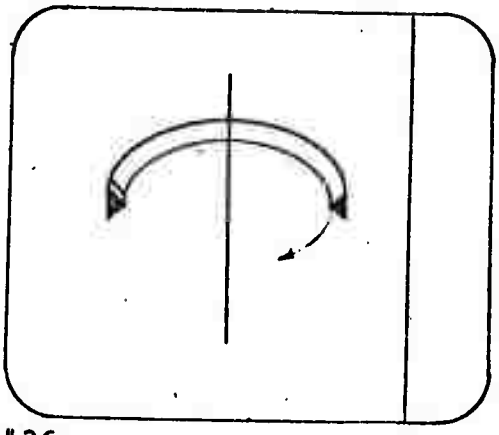
An example of where the designer may need to develop a very large curvilinear surface would be in dealing with terrain or topography. The larger landscape--perhaps regional--may be composed of many separately developed surfaces as discussed previously. The smaller segment could be dealt with in the following manner. It would first be necessary for the designer to shape a basic space-form to a point where its depth is at least equal to the difference

between the highest and lowest points in the piece of topography to be examined. He may then call for a network surface to be placed upon this space-form. The scale of this net would be indicative of the amount of information known about the land. Thus, if actual surveyor's readings had only been taken every five feet, the grid or ruling would also be five feet between nodes. At this point the actual site readings should be possible for the designer to give the proper command and have the surface generated by the machine. Any changes which are to be made in the existing site would be made by working with individual nodes, as with any other surface shaping. The designer should be able to go back to the original (real) surface at will.

In dealing with the surfaces discussed, it may be necessary to make sharp vertical offsets. An example of this is a road which is lower than the surrounding terrain. The problem is one of specifying the area of land or surface which is to be lower and lowering it the desired amount. The designer can in this instance use the line drawn with the stylus as a cutting plane--as in Section 3.22. After having drawn the limits of the road on both sides, he may lower the entire surface as he wishes.

3.26 Space-Forms of Revolution

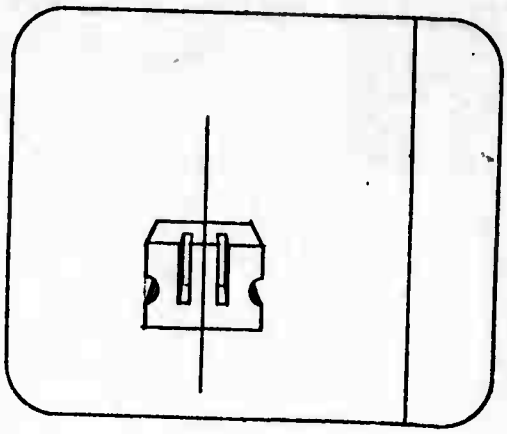
Any basic or transformed space-form can be revolved about an axis. The axis, which would appear in the key as a line would be placed by the designer relative to the space-form to be revolved. When the command is given the space-form would revolve about the axis leaving behind it the three-dimensional space-form of



#36

revolution traced by the original form. Many forms which would be difficult or impossible to get otherwise can be created in this manner.

The designer may also wish to make mirror images about a plane or a line. This he can do by placing the line or plane in the proper relationship with the element to be copied and typing "mirror image."



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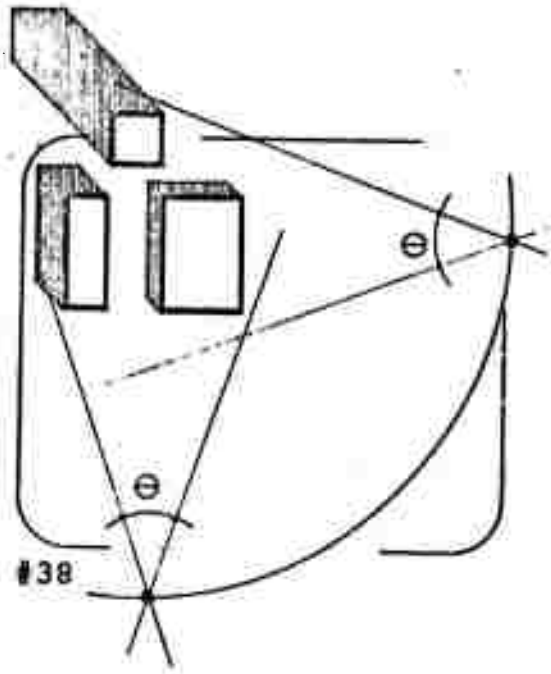
3.3 Viewing Routines

Since design generally involves the creation of real objects in a real world, every attempt should be made to re-create for the designer real world conditions at the CRT display. Central to this idea is the capability of viewing in three dimensions the object or building being designed. But a single view is not sufficient for complete understanding, and the designer will be able to rotate about three axes to any other desired view, and move (zoom) toward or away from the object or building being designed. Rotation, zooming, scanning, and panning will be discussed at length as viewing routines in this section of the paper. But it is important to note at this point that as these viewing routines are affected, the designer is faced with rapidly changing perspective views of his design. These views will change smoothly and closely simulate the experience of moving toward, around, and through the scheme. A more complete analysis of the mechanics of the "Perspective Concept" appears in the Addenda to this report.

The following discussion will center on some of the viewing routines which will be available in this design system. A 40° cone of vision has been set as the desirable viewing angle.



3.31 Rotation

The designer will want to view whatever he is designing from many different positions. He must be able to examine it in every detail. This means that he should have the ability to turn and move a smaller object, and to give the impression of moving about a larger

object. At the present time, the designer, in the process of designing, is required to draw additional views or, perhaps, to build a mock-up or model of his design in order to "see" what it looks like.

The nature of the design which the designer will develop on the CRT display will be that of a three-dimensional model. Since it is obviously impossible to move about this "model," the designer must be able to move the object being displayed. As the designer rotates the object or building on the display, the view changes. This can be represented in plan view as shown in Illustration #38. A more accurate representation would show the object rotating with the viewing position fixed, but the illustration indicates what is perhaps closer to what the viewer will feel. In other words, as he rotates the object, he will experience a sense of motion--as if he were walking around the object. The viewing points shown are not two isolated views, but are two stopping points in the walk around the object or building. When one considers a completed picture of a building with its entourage of plantings and associated site developments giving it a foreground and background, it is easy to imagine how the act of rotating this entire package would give one a convincing simulation of movement. The sense of movement one can feel while viewing a film is suggested as evidence of this.

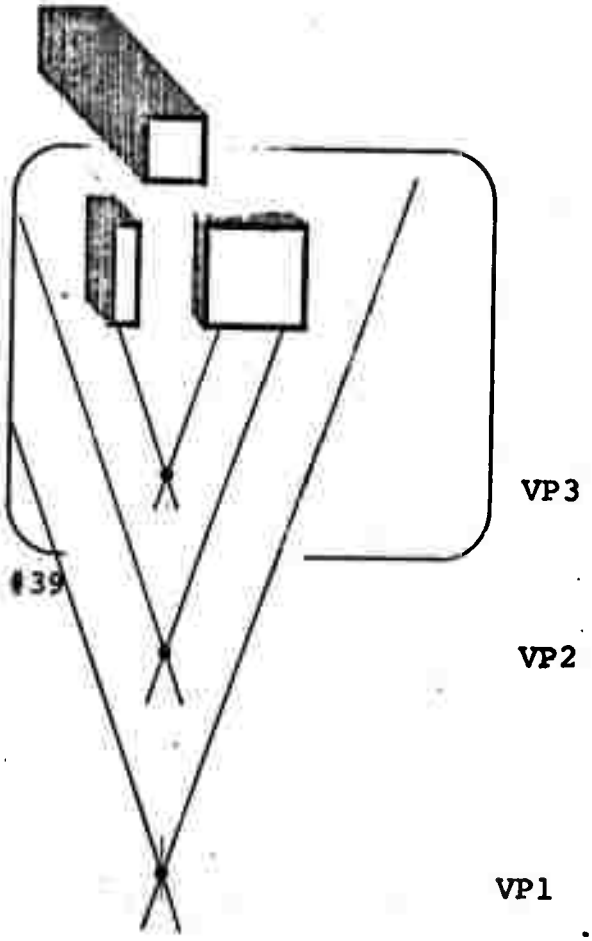
To provide maximum flexibility, the designer will be able to rotate his design in any direction. The rotation will be made smoothly to simulate movement as closely as possible. The rotational device selected should allow for exact positioning--"fine tuning."

To rotate one or more parts of the design scheme relative to the rest, the designer may touch the part or parts to be rotated with his stylus and then move the rotation device. Only the part or parts touched will rotate. Once the rotation is concluded, the machine returns to the general rotation mode, and any subsequent rotation, without touching a part with the stylus, will cause the entire design to rotate. When a face in the design comes into near elevation perspective, i.e., one point perspective; the face snaps into elevation and can be studied as a true elevation. (See Addenda)

The three-axis track-ball, and the joystick are presently being tested and evaluated as rotational devices.

3.32 Zooming

The designer may wish to examine his design more closely. He may also wish to move away to include more of the design and its surroundings on the display. This "zooming" in and out will simulate the man actually moving toward or away from the object being designed.



Together with rotational capabilities, zooming will allow the designer to thoroughly examine his design. It will, however, be necessary for the designer to select the area or part which he wishes to zoom in on. This may be accomplished by pointing with the stylus to the area which is to be the new center on the display, typing "CENTER," and then activating the zoom device. In this manner he will be able to select specific details or parts and enlarge them until they alone occupy the display surface.

It is clear that as the designer zooms away, he is less capable of seeing the smaller details or parts

of his design. In fact, many of these details become unintelligible at certain distances. It is suggested that at the point where visual clarity of any part is lost, that the part be automatically removed from the display. While zooming away, portions of the design that were not seen in the close-up view because of the 40° cone of vision come on the display. In the most natural simulation of moving away, the machine would be constantly up-dating the picture, and including parts previously out of the field of vision--in a sense those parts that are behind the observer. The same holds true for zooming toward the object when those parts previously deleted for sake of clarity are included again.

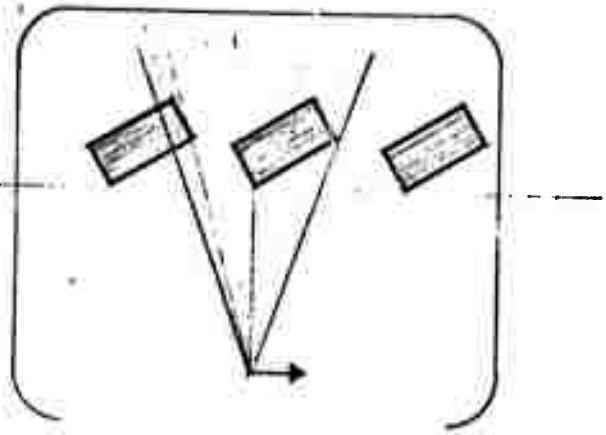
The designer may wish to move through an object or building. This should be accomplished by zooming in on a natural opening, and through it. Then, by the simultaneous use of the stylus, zooming device and rotational device, the designer could move through the object or building, examining whatever he wished. This simulated "trip" would be as real a trip through the building or object as possible. The stylus in this instance would be used as a pointer to select the new center of the display after the use of the zooming device. The act of moving through a building would probably be limited to evaluating the results of the design rather than the actual designing of the spaces. Actual design would be more conveniently done by cutting sections since this allows the designer the opportunity to view the area being designed without restraints imposed by the geometry of the space itself. It is felt that to make the system react as naturally as possible, one should not be allowed to do unnatural

things--such as moving indiscriminately through walls, windows, etc. In every way possible, the display world will be made to reflect the real world.

By pointing to a given part with the stylus and then zooming in or out, the part can be moved in or out relative to the larger design. This can be very useful in placing parts within a three-dimensional frame of reference. Any number of parts can be grouped in this manner and zoomed in or out relative to the other parts. Of the devices being considered to activate and control the zooming operation, the footpedal seems most promising, although it may be desirable to combine zooming, and Enlarging-Reducing in one instrument under different mode buttons.

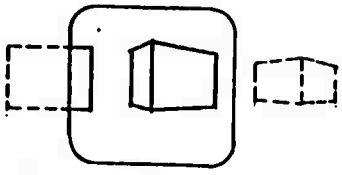
3.33 Scanning

When viewing an object or building at an enlarged scale, it may not be possible to get the entire picture on the display. The designer in this case may wish to scan the surface to see another area of interest. He should be able to do this without changing the scale at which he is viewing. The process of scanning could be compared to moving the viewing point in a straight line without changing the viewing distance--as shown in Illustrations #40,#41. Each view would be shown in perspective, and would closely simulate one's walking or driving by the object or building.



#40

The scanning operation could best be controlled through the trackball; but since this device is also used for rotation, it would be necessary to have a mode switch which was easily accessible. Panning, which will be discussed next, could also be controlled through the trackball. The three mode switches could

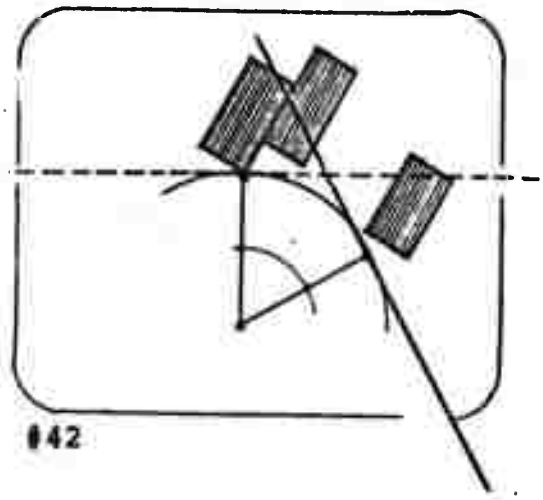


#41

be placed directly in front of the track-ball allowing the designer to quickly and easily rotate, scan, or pan.

3.34 Panning

The designer will often want to view the object or building he is designing from a single vantage point. If the object or building is large, he may direct his attention to various parts without actually changing his position relative to it--much as one looks at a very tall building. This is defined as panning. The viewing distance changes, but the only movement simulated is that of the head of the viewer. This will be an invaluable tool to the designer--especially in viewing interiors of designs --such as rooms, courtyards, etc. The means of controlling the panning operation could be the track-ball in the panning mode as explained in section 3.33.



#42

3.35 Enlarging-Reducing

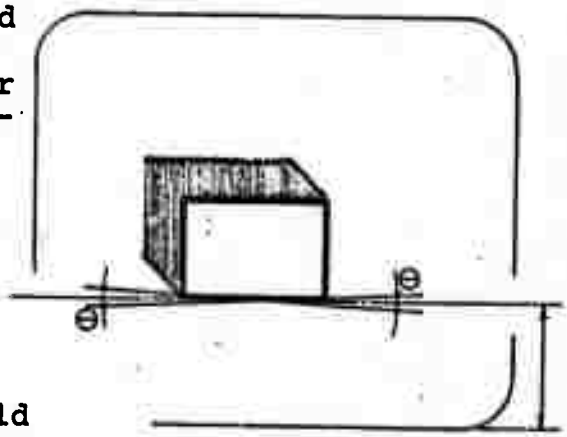
Often the designer may simply want to enlarge or reduce a given view of the design scheme. The enlargement may be for purposes of giving an undistorted view of the design scheme to someone who is standing further than the prescribed distance from the display. Also for purposes of plotting-out given perspective views, the designer may wish to enlarge in order to experience this view before plotting. In object design the designer may be dealing with some minute element such as a circuit chip which he would like to enlarge more than full scale. Zooming is limited to showing things only up to full scale. Enlargement gives the designer the ability to go beyond this.

Enlargement and reduction should be accomplished through the same device as the zooming operation. A mode switch would be necessary and should be located on the device.

3.36 Orienting

Even with the capability of Rotating, Zooming, Scanning, Panning, and Enlarging-Reducing, the designer may have difficulty in orienting himself to what he is seeing on the display. A few tools designed to assist him in this area will be discussed next. They are: positioning stops, coordinate systems, and edge extensions.

The designer may wish to have views which closely approximate orthagonal views of the object or building he is designing. These would not be true orthagonal views since everything displayed is shown in perspective, but would be that view displayed when a given plane of the object or building is parallel to the display screen. To assist the designer in stopping his rotation on that view, the machine would be programmed to "adjust" to that exact view. In order for the machine to take over and make this adjustment, the designer must come close to stopping on the desired view. These stops can be easily programmed for each elevation and plan view of a basically rectilinear design. For non-cubic schemes the task of recognizing what the designer may wish to regard as elevations would be difficult for the machine, and it may be necessary for the designer to set these stops himself. This could be accomplished by rotating the object or building to the desired views and pushing an elevation button--much like a typist would set tabs on a typewriter. For the duration of the design, the elevation



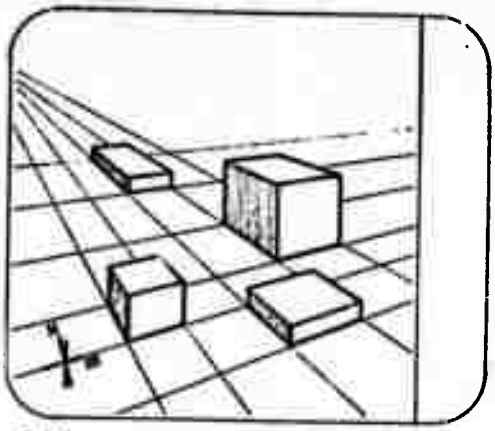
#43

stops would continue to work until released by a "release elevation" command.

In all cases where the designer is moving elements about and placing them with respect to other elements, he must communicate somehow what he is doing or wishes to do. Much of this communication can be made through simply moving elements with the stylus and actually placing them where and how they are to be. The designer is assisted in this by being able to rotate and view from any vantage point. Some situations, however, may be more difficult to control; and the designer will need to communicate more verbally what he wishes to do. Thus, if one element or space-form is to have one surface exactly coplanar with another, the designer may indicate this by pointing with the stylus to one surface type "coplanar" and touch the other surface. The first element touched would move and become coplanar with the others. He may further wish one edge to be colinear with another. This would be executed in a similar manner as above. In this manner elements can be made exactly perpendicular, parallel, colinear, coplanar, etc., with any other element. Specific angles between elements can also be indicated by touching one element first, typing the angle and touching the other element. Space-forms with the same dimensions could be close-packed in a similar manner. In each case the designer is orienting one thing with something else in some specific way. By having this wide range of communication, both visual and verbal, with the machine; it is felt that the designer can effectively and easily develop his designs.

As a further assistance to the designer, coordinate systems of various types would be available. A simple

set of coordinate axes for which the designer types in the labels of the separate axes would provide sufficient orientation to the designer for many situations. In the case of object design these axes could be labeled top, bottom, front, side, back, as the designer wished; or for the architect, North, South, East, West. The coordinate system, fully labeled, would then move with the object or building through all rotations and other maneuvers. Directional indicators for such specialized purposes as indicating prevailing wind direction or sun direction can be displayed. Since these parameters change with time, the designer could query the machine to give these directions and velocities or intensities for a specific time. Dynamic simulation of these and other patterns affecting the design could be displayed as a function of time. Thus, the designer could watch changing sun patterns on his building for a twenty-four hour period while at the console for ten minutes.



#44

A very specialized grid system can be developed by the designer as a further means of orienting himself. The grid results from the extension of the edges of space-forms or elements of the design at the point where they join the ground plane. This would assist the architectural designer as a planning grid, and would help any user to organize parts or elements relative to one another. A basic command to "extend edges" would result in the extension of all edges touching the ground plane, or the designer could selectively extend a single edge by touching it with the stylus and typing "extend edge." In this manner any edge of any space-form can be extended.

3.4 Grouping

At some point in the process of designing, the designer will need to deal with the object or building being designed in the context of its most minute parts. Thus, the architectural designer developing a window would be involved with the generation from basic space-forms of each part which composes the jamb, sill, and head, and their consequent placement in relation to one another.* The window thus designed is now placed in the next larger context which might, in this case, be the wall. At this point the designer probably would no longer want to deal with the smallest parts, but may wish to deal with each jamb and the head and the sill as single items. He could then "adjust" the window to a desired size without affecting the already designed details. He may then wish to deal with the window as a single item, and position it in the wall. Implicit in all of the above manuevers is a rapid means of grouping parts so that they may act as sets.

3.41 Natural Groups

The displayed size of the element or part being designed can help determine whether or not the designer can effectively work on it. For example, if the designer is trying to increase the length of a window by moving the sill down; but is viewing the building in its city context, it would be difficult or impossible for him to attach the stylus to the sill and move it the desired distance. His natural reaction would be to zoom in closer until he could see what he was doing. In this sense the designer

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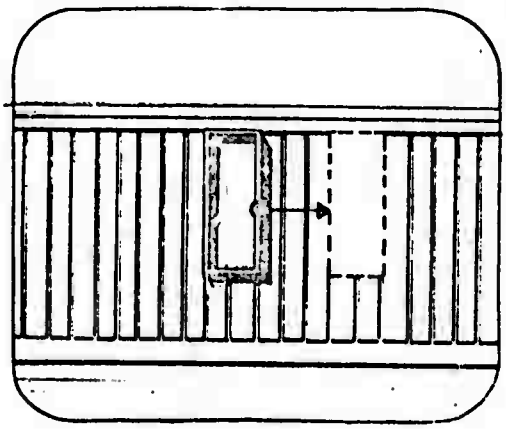
* He would also have the option of using stock manufactured window sections which would be stored for his use.

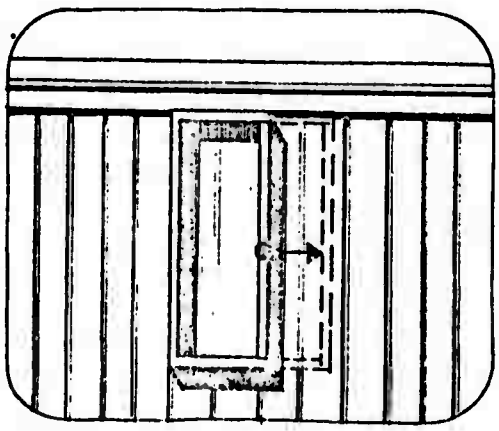
can really only work upon what he can see clearly. The displayed size of a given group of parts will help us determine what parts will "hang together" and act as a group or set at a given point. The groups referred to here consist of a number of parts which act together to perform a specific function. These are called natural groups. Thus, all of the parts of a window logically group together to form a window. And the window together with other windows, doors, and other parts logically group to make up a wall. An example of an unnatural group is two windows. The manner of creating unnatural groups will be discussed in the next section.

The rule for making or breaking natural groups can be stated thus: The major whole element on the display is the only element that can be manipulated by parts. By tracing back through the window design, the application of this rule can be seen.



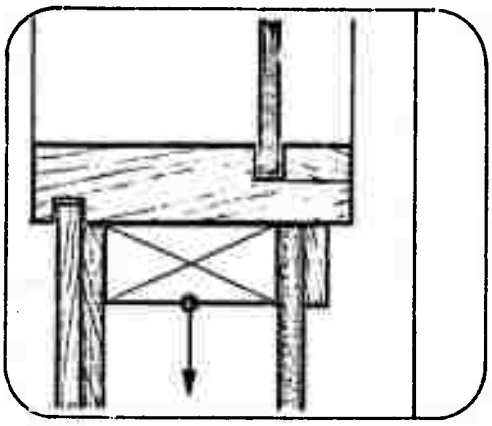
#45

At the level where the designer is concerned with the positioning of the window in the wall he obviously wishes the entire window and all of its parts to act as a whole. Since he is interested in the window's position in the wall, he would be looking at the entire wall or a major portion of it in order to be able to position the window relative to the other parts of the wall. By the before stated rule, the window is a subgroup within the wall and can be moved as a set. In other words, the wall is the major whole element shown on the display, and the window is a part. If the designer now wished to focus his attention on the window, he would enlarge the image on the screen until it is the major whole element on the screen. He could now move any of these major components of the window. Finally, he may



#46

wish to redesign the sill. For this purpose, he must both enlarge the picture to show the sill as the major whole element on the display and cut a section (Sectioning will be discussed in Section 3.54.) in order to see all of its parts.



#47

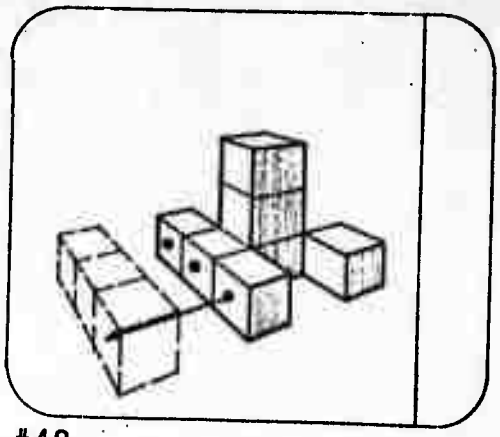
It is obvious that, as the designer includes more and more of the element being designed on the screen, he becomes more concerned with the larger scale problem and its relationships than with small details. Thus, the designer may move from the design of the parts which make up the window sill to the eventual placement of the building within its larger context in which the building is a sub-group of a plaza development, or perhaps the community as a whole. Natural groups are, then, made and broken by the application of the rule stated above as imposed by the designer as he selects parts and enlarges and shrinks them on the display--thus changing their context.

3.42 Unnatural Groups

Many elements in a design do not logically fall into the same group as do the elements which make up a given window or door assembly. Still, the designer may wish to deal with combinations of these elements as sets or groups.

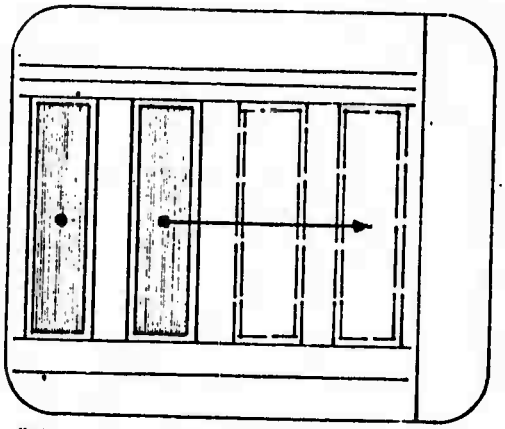
The manner of grouping these elements is quite straightforward and consists of pointing with the stylus to those elements to be included and then performing whatever operation one wishes to upon the group. This newly formed group exists for the duration of the single operation only, unless the designer types "group" after having pointed to each part. He may further label the group thus formed. For example, a series of living units may be pointed to and then formed into a group by typing

"group, neighborhood cluster." This labeling can be useful when storing sets or groups for future use where retrieval is important. In order for storage to be effected, the designer must type the command "store." He also has the option to designate where a given group or part is to be stored. This will be discussed further in section 4. All groups other than those mentioned above will, however, only exist for the one maneuver, after which they are freed. To further assist the designer in designating a group a given space-form or part pointed out with the stylus would be designated by a bright dot at the point of stylus connection. These dots would remain on each element until the elements are freed from the group.



#48

After a group is designated, the designer may carry out any operation he wishes on the group. Thus, he may, as in Illustration #48 move the newly formed group independently of the main group, and place them where he wishes. The architectural designer may wish to group two windows and move them as a set. After pointing to each window with the stylus, he may attach the stylus to any part of either window and move the set, and no matter how or where they are moved; they will retain the same relationship with one another. Other operations can be performed such as selecting various space-forms to be removed from the display and erasing them as a group. Erasing, storing, and other manipulations will be further discussed in section 4.1. Local rotation of a group or set can also be effected. In short, nearly every operation which can be performed upon a single space-form can be performed upon groups of space-forms.



#49

3.5 Additional Manipulations

To further assist the designer in his work at the console the following routines have been developed. They include deleting, copying, storing, sectioning and sizing.

3.51 Deleting

Any given space-form can be deleted from the display whenever the designer wishes by pointing to the form with the stylus and either typing "delete" or making a scrubbing motion on the space-form with the stylus. Words in strings of text can also be deleted in the same manner, and entire lines can be deleted by typing "delete line."

The designer can selectively delete many forms from the display by pointing with the stylus to each one. After a form has been pointed to, the form will be designated by a bright dot. In this manner, several forms can be pointed out, and all erased at the same moment.

3.52 Copying

Any transformed space-form or group of space-forms can be copied and used elsewhere by the designer. There is no limit to the number of copies that can be taken from a given space-form. This is accomplished by pointing to the element to be copied and typing "copy." If the element to be copied is composed of many transformed space-forms that form a natural group then the designer would only have to point once if the element was seen in the proper frame of reference as defined in Section 3.41. If, however, the designer wished to copy an element

whose space-forms did not form a natural group then he would have to point to each part before typing "copy."

Once the designer has indicated that a given element is to be copied, he may attach the stylus to the object image of the element and move it to the area where he wishes to use it. The original will remain in place and the copy will follow the stylus. If the designer wishes to store a copy of the element for future use he may indicate the element with the stylus and type "copy-store."

3.53 Storing

A very important aspect of the ADS will be the designer's capability of storing important graphic information as well as textual information. For example, the designer in the future will have the graphical representations of many manufactured items. These products would be represented three-dimensionally just as elements which have been built-up by the designer himself out of space-forms. They will be object images as described in Section 1.5, and as such would exhibit all of the material attributes of the actual item. In a typical architectural application, the designer would simply reach out the product he wished to use from a vast catalogue in the computer memory, copy it (as specified in the preceding section), and place it in his design scheme. Along with the graphical representation (object image) of the item would be stored textual information including availability, price, and other pertinent data which the manufacturer wished to include. It is quite possible that the manufacturers will be responsible for building-up and maintaining this catalogue.

Just as the manufacturer can store his product for instant use by the designer at the console, so can the designer store any of his own designs which he may wish to use again. An architectural designer may store "patches" of typical wall, floor, and roof constructions which he has devised, for example. These may then be used in designing new buildings by simply selecting the given system from storage and graphically indicating where and to what extent it is to be used. Changes can be made upon this copy--altering it to exactly fit the new design. The designer may also store whatever textual specifications he wishes. There are no limits imposed upon the designer by the system--he may store as many different ideas or elements as he wishes.

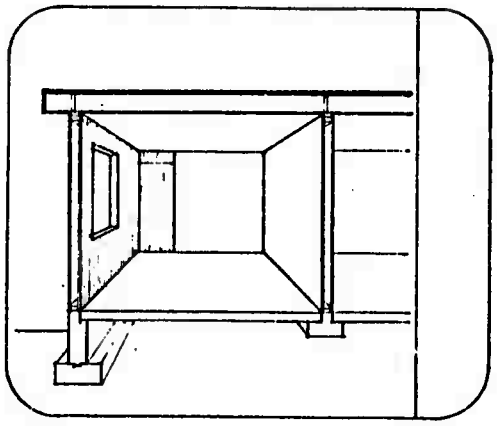
As alluded to in the previous section, the act of storing some element which is presently displayed involves copying the element and then giving the command to store. This command could be given via a button on the console or by typing. The designer may specify where he wishes the element to be stored, and at the same time may name the element to assist in its retrieval at some future date.

3.54 Sectioning

In order for the designer to have greater flexibility in designing, it will be important for him to be able to quickly and easily cut sections. This will allow him to view portions of the design scheme which are otherwise hidden to him. Sectioning can be thought of as passing a cutting plane completely through an object or building. This cutting plane can also be used as a device with which to shape space-forms. A sectional zoom allows the designer even greater flexibility. A discussion of how sectioning routines function follows.

3.541 The Section Line and Cut

The section line is drawn by the designer with the stylus on the face of the display. This line positions the cutting plane at any angle drawn in the x-y plane of the display. The cutting plane is always positioned normal to the surface of the display in the other dimension. Once the object to be sectioned has been positioned, the designer must type "SEC" (to distinguish for the machine the section line to be drawn from lines drawn in other commands, such as in translation) then draw the section line. He may then rotate the object or building 90° right or left. If he rotates right he will view the portion to the right of the plane in section and vice versa.



#50

To restore the two parts cut by the section plane to their original state, the designer must rotate back the 90°, or he may simply type a predetermined command to restore sections.

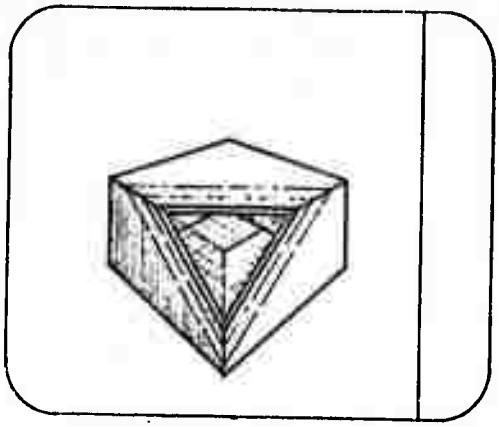
3.542 Shaping with the Sectional Cutting Plane

The cutting plane can be used as a device with which to shape spaceforms. By following the same procedure as used in cutting a regular section, but making a scrubbing motion over the portion he wishes to delete, the designer can effectively "lose" that part and remove it from the display. In this manner, the designer can use the cutting-erasing maneuver in "carving" out a new form.

3.543 Sectional Zoom

As discussed in Section 3.32, the designer can zoom in on a building or object until it is so close that he gets a micro view of a portion of the enclosing surface. But he

cannot zoom through the object or building except where natural openings occur. The sectional zoom will not allow the designer to zoom through the object or building either, but will allow him to zoom a sectional plane through. This plane will always be parallel to the surface of the display and will move through the object or building at the speed dictated by the designer through the zoom device. By use of capability, the designer will be able to dynamically view the relationships between parts which make up the object or building. For example, a very slow sectional zoom through a complex building or series of buildings would allow one an excellent opportunity to evaluate and correct conflicts between various systems that compose the building. The designer may stop at any given view and enlarge it to fill the display, or he may relocate the center of interest on the display as discussed in Section 3.32 and enlarge a given detail to fill the screen.



#51

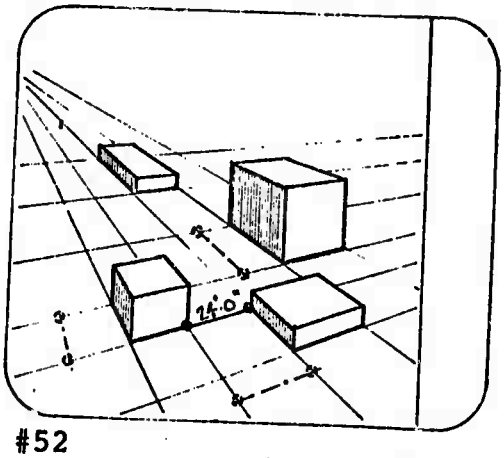
The sectional zoom would be controlled through the zoom device. A mode switch would be necessary to distinguish from the regular zoom.

3.55 Sizing

At some point in the design process, the designer will want to give exact size to the design solution. He can, if he wishes, deal only with relative proportions for some time; and in the case of large scale projects in regional planning, etc., this may be the best way to solve many problems. Still, at some point size will have to be imposed upon the design scheme. How to accomplish this is one of the problems to be discussed next. Once size has been brought in, the designer

will often want to know the specific sizes of various elements within the design scheme. What the designer must do to get this information will also be discussed.

The designer begins a sizing routine by first typing the command size (or pushing a SIZE button). He then attaches the stylus to some point on the element he wishes to size, and draws the stylus toward another point. As he moves the stylus, he draws with him a line which remains firmly attached to the initial point. This line acts much like a rubber band under tension--one end fixed at the attachment point and the other fixed at the stylus. Thus, the line remains straight and moves with the stylus until the stylus attaches it to the point to be dimensioned to. If size has not already been imposed upon the design scheme, no numbers appear. At this point the designer types in the dimension and its units. By doing this, the designer automatically sizes every other part of the scheme. For, the sizes of all other elements will be directly related to the size of the initially dimensioned element--being in some proportion to this element. The designer may now query the machine about any other element and receive an answer. The answer would be given in the same units initially typed.



#52

The procedure for querying the machine regarding dimensions is similar to that outlined above. The designer still gives the command "size," attaches the stylus, draws the dimension line to whatever point he wishes, and is then given a number which is the dimension asked for, and is displayed along the dimension line. In this manner, he can ask for and receive any

dimension he wishes. If he wishes to change any dimension, he may type in the new dimension and the form will adjust to the new dimension.

It would be helpful, after initial sizing, to have the relative dimensioning of all other elements appear on the display for approval. This would eliminate the need for initial inquiry about each element. The dimension would disappear after the designer either approves it or changes the form--perhaps by typing in the correct dimension, and having the machine adjust the form to comply.

Whenever the designer wishes to plot-out what is currently displayed, he may do so by giving a "plot-out" command. This command must also include the scale at which the plot-out is to be made.

3.6 Communicating with the Machine

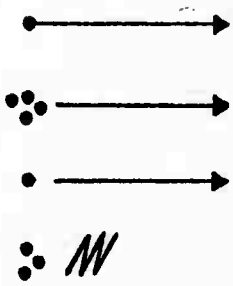
The designer will be constantly communicating with the machine, and much of this communication will be in the form of commands issued through the stylus in his hand. Other commands will be possible through special devices which allow him to rotate, scan, pan, and zoom, etc. There are, however, still other communications which the designer will want to make which are very difficult, if not impossible, by these means. Ideally, the designer should be capable of speaking and explaining his wishes to the machine. Since this is not as yet possible, he must work through an interpretive device which most closely approaches this conversational mode. At the present time, this is probably the alpha-numeric keyboard. Through this device, the designer can type questions and issue commands. Equally important is the fact that he will be able to outline for the machine certain tasks which the machine can do for him. His success in communicating a program to the machine to have it do a particular task will depend more on his understanding the task than on his mastery of programming technique; but, undoubtedly over a period of time, he will acquire and develop special programming skills.

Since a large portion of the communication between man and machine will be made through the keyboard, it is important that it be done as spontaneously as possible. Thus, as the designer needs to give a short command while designing, it seems unlikely that he will want to put the stylus down and turn to a keyboard to type. For this reason it is

suggested that a five-fingered chorded keyset such as the one developed by Douglas Englebart* at SRI be used. Apparently it takes little training to become proficient in its use, and it does allow the designer to continue working with the stylus as he communicates with the machine through the keyset. Any of the many commands which the designer can give by other means should also be possible with the keyset. For larger blocks of information, such as long notes, specifications and programs, the designer will undoubtedly prefer a standard keyboard. Both the keyset and the standard typewriter keyboard should be available. All communication will be displayed on the screen as it is typed. The machine's answer or acknowledgment should also be displayed. Basic text editing capabilities which will allow the designer to develop specifications should also be provided.

Summary of Commands

Some communications are possible with the stylus alone. Thus, we find the designer can attach the stylus to a space-form and shape it in a specific way as discussed in Section 3. He may point to a specific space-form or element and translate it with the stylus. Group translations can be made similarly. One or more parts can be deleted from the display by simply pointing with the stylus and making a scrubbing motion.



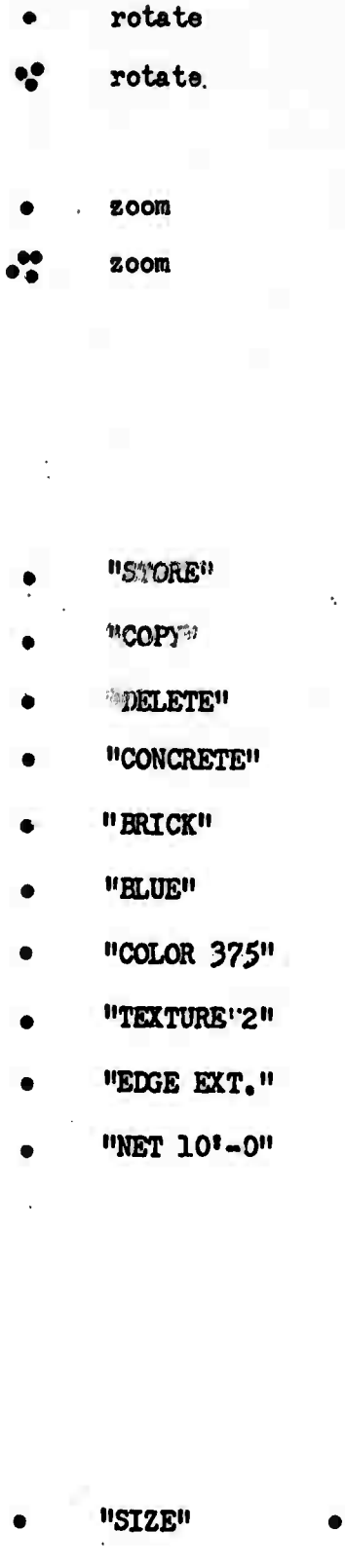
The designer can use special devices to communicate such things as zooming, panning, scanning, and rotating. He can also enlarge

* D. C. Engelbart, Augmenting Human Intellect: A Conceptual Framework. (Menlo Park, Calif., Stanford Research Institute, 1962.

or shrink the displayed picture in this manner. A single space-form or element on the display can be rotated independent of the other elements displayed by pointing to it with the stylus and activating the rotation device. Selected groups of space-forms can be rotated by pointing to each one before rotating. Single elements or groups can be zoomed independently by first pointing to them with the stylus and activating the zoom device. This results in the element or group moving forward or backward relative to the rest.

By adding the alpha-numeric keyboard to the stylus and special devices, the communications team is complete. The range of material which can be communicated widens considerably at this point. Many commands will require the designer to point with his stylus first and then type a command. For example, he can point to a given element and type "store," or "copy," or "delete," etc. He may point to an element and type a specific material or attribute, which will cause the element to exhibit this property. By pointing to a given edge of a space-form and typing "edge extension" the edge will extend as a line--giving the designer a special grid line to work with. Further assistance in the way of grids and nets can be commanded by indicating the point of origin of the net and the scale, i.e., ten feet node to node.

Some commands require the designer to use the stylus more than once. This allows him to say that one element is like another in some way. For example, he may point to one space-form and type "size" and point to another space-form.



This will cause the first form to "adjust" to the same size as the second form. By pointing to one surface and typing "coplanar" and pointing to another surface the two surfaces will become coplanar. One form can be made to close pack with another by a similar command.

"COPLANAR"

"COLINEAR"

"CLOSE PACK"

The curve command discussed in Section 3.21 requires the designer to type "curve" and then draw the approximate curve with the stylus. The section cut requires a similar command.

Many commands, simple and involved, can be composed through the use of the three means of communication--the stylus, the special devices, and the alpha-numeric keyboard. The above list is not intended to be complete, but rather to show the range of rapid communications which is available. The designer can add to these commands as he wishes, for the number and variety possible is not limited. However, he must then program each added command and be sure there is no coding conflict with other commands.

SUMMARY

The Total Design

After the general planning and organizing of the design solutions, the designer would begin, perhaps, to place elements within this context. In the case of architectural design he may begin calling-up basic cube shapes--manipulating them into walls of various sizes and placing them about. Other elements of the design could be added, deleted, manipulated, and tested at will. Eventually the design becomes more and more complete as more and more details are designed.

Details can be designed by selecting the area of interest with the stylus, enlarging it to fill the screen, and designing with the basic sapce-forms, or previously designed elements. If the area of interest cannot be adequately seen, it may be necessary to cut a section and rotate it into view. Once a detail is resolved, its topological description exists in the computer, and eventually the description of the entire design solution is there. This total body of information is required to construct the design. The manner in which it is conveyed to the builder may vary from numerically controlled plotter drawings to the direct transference of the mass of information to the contractor's own CRT display.

Walls, roof assemblies, floor assemblies, and other useful groups of space-forms could be stored in the computer to be used repeatedly. This would be of great importance to the designer, so that he would not have to redesign each element every time he needs it. Ultimately it is expected that details of all manufactured items will be stored in the computer for the designer's reference and use.

Vast quantities of data from many other sources could also be stored and made accessible to the designer. This information might come from political and juridicial bodies in the form of building codes and regulations. It might also come from universities and research centers, or from any further source having or producing information pertinent to any of the design or building professions.

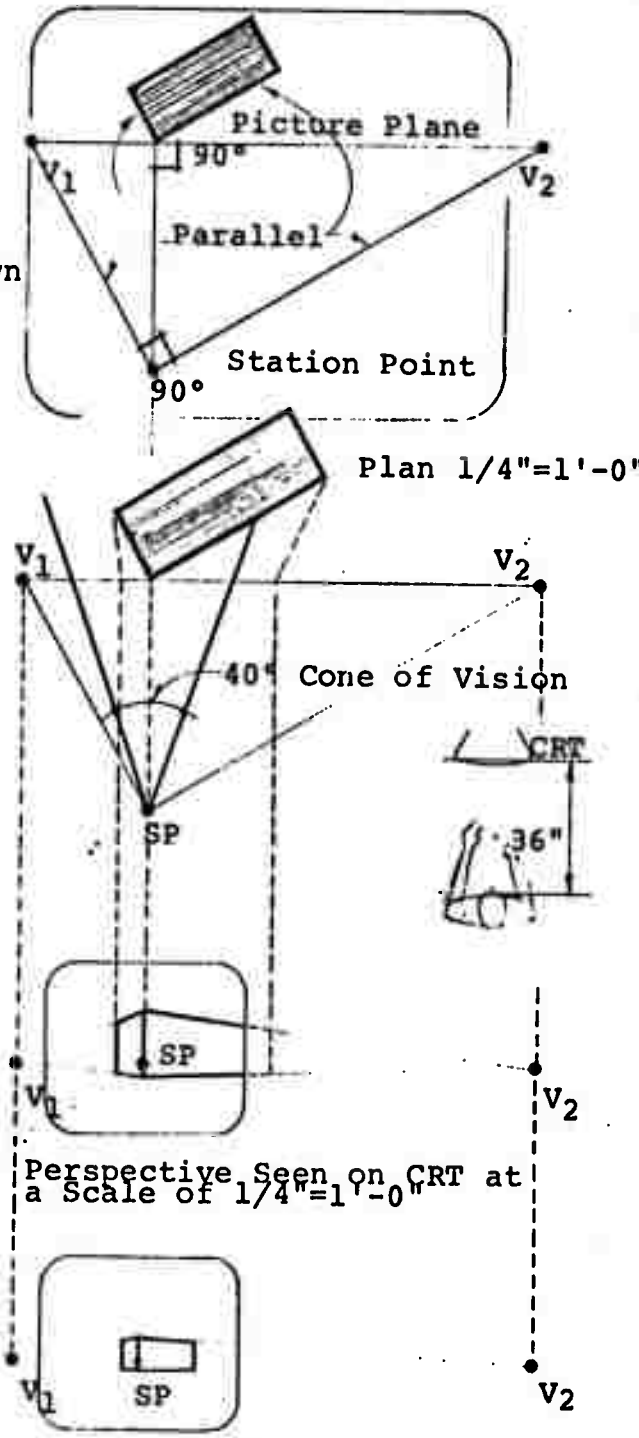
In summary, the entire design approach proposed herein is generated from the basic space-forms. These three-dimensional forms are used by the designer as building blocks to design at every scale--from the most minute details of a given building to the eventual placement of the building in the context of its surroundings.

ADDENDA

THE PERSPECTIVE CONCEPT

Stephen L. Macdonald

In our three-dimensional computer graphic design, "scale" of the Cathode Ray Tube (CRT) images is irrelevant except as it applies to the viewing distance in perspective. That is, the viewing distance from the operator to the CRT should correspond with the station point to object of the perspective being shown on the screen. If we assume a distance of three feet from the viewer to the CRT, then the perspective in view there should have a station point scale (say 1/4" per foot) corresponding to the three feet from viewer to CRT, or in this case 36" x 4 or 144 feet.



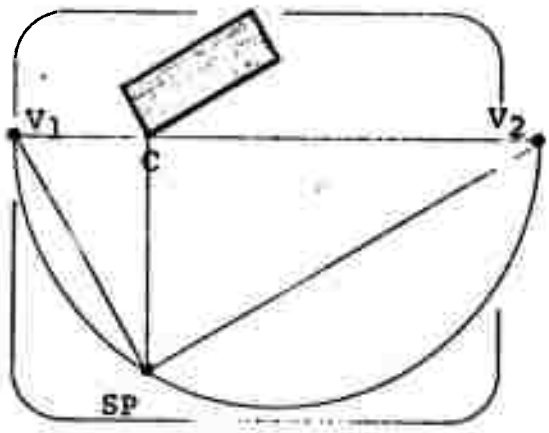
Perspective Seen on CRT after Zooming away. Scale is now 1/8"=1'-0"

Zooming in or out on the object does not change the dimensions of the object, but does change the physical scale of the object as viewed on the screen; thus making it possible to maintain the three foot relationsip between viewer and perspective. While zooming, only the station point and vanishing points remain constant as seen on the screen, since by definition these points form a 90° angle; and, therefore, there can be no change in the proportional relationship between station point and vanishing points.

For example, if we take our former example where the SP is 144 feet away from the building and zoom away to 288 feet; we must now reduce the plan scale from 1/4"=1'-0" to 1/8"=1'-0" in order to maintain the proper viewing distance of three feet from the CRT. This is consistent with real life viewing as one moves away from an object.

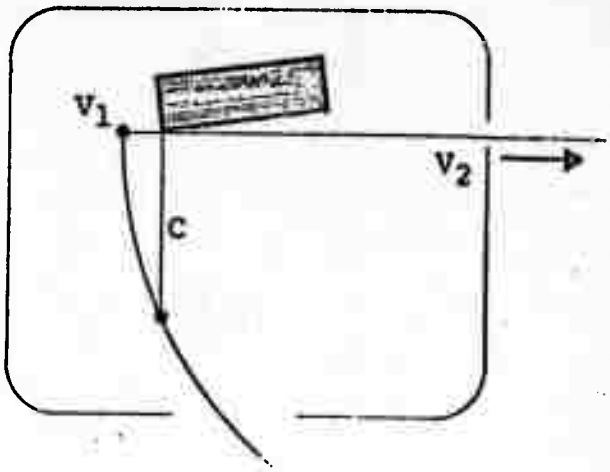
Throughout the perspective concept of zooming, the actual distance between operator and the CRT remains constant at three feet while the apparent change distance from the object to viewer is accomplished through scale change. This does not mean that when the image reaches full size on the screen that closer examination cannot continue. The scale of the image continues to enlarge over full size until one passes through the image. For example, when the image reached a scale ten times full size, the situation would be equivalent to viewing the full size object at a distance of 36" - 10 or 3.6" away and filling the screen with a 40° cone of vision. This process could continue with slowed control into microscopic examination.

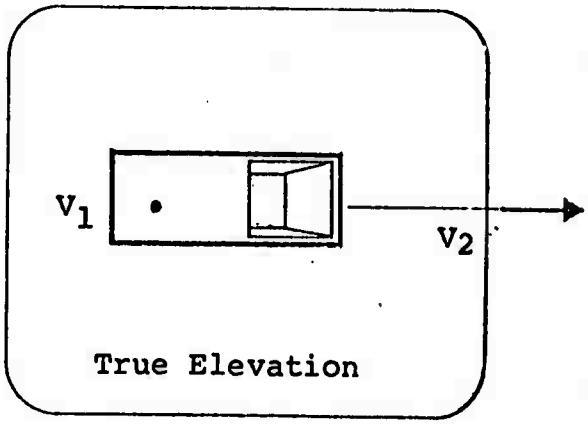
For enlarging purposes all of the above assume a viewing distance of three feet in order to see the image in true perspective. If one wished to make a presentation to a group of people at some distance, it would be necessary to have an enlarging technique which would alter the size without changing the shape of the image. By applying a scaler or multiplication factor to all coordinates, this effectively enlarges while increasing the appropriate viewing distance; if one multiplied by two, the size of the image would be doubled on the screen and the proper viewing distance would be increased from three feet to six feet. Most people do not understand that considerable distortion exists in perspective viewing if the viewer is not at a distance corresponding to the actual station point distance for the scale involved.



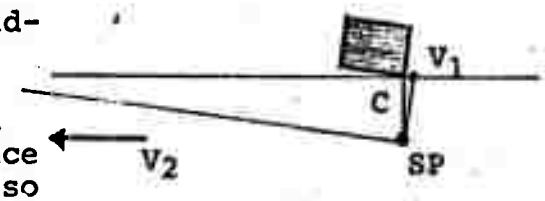
Moving around an object or, in our case, rotating the object is quite different. Without zooming, the SP to object remains constant (c), but the vanishing point relationships change. As a rectangular building

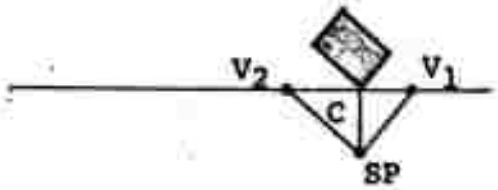
rotates closer to a straight elevation, the half circle containing the two vanishing points and SP becomes very large. As V_1 passes behind the building, V_2 will be, for all practical purposes, at infinity; and now we are dealing with a one-point perspective. Except for the assumed limiting cone of vision, a very long building would still appear to vanish toward the ends. However, for purposes of design, there are many occasions when one wants to view a building in true elevation. Therefore, an arbitrary decision is made to snap the viewed building into true elevation whenever a vanishing point passes behind a building. This means that all planes parallel to the elevation plane would also be in true elevation while all other planes would vanish to the one point. As one continues to rotate the building to the left, V_1 moves to the right until it emerges from behind the building. V_2 will now have flipped over to the far left (near 00) and the image now snaps back into true perspective. Rotation can continue until a new face comes into elevation and V_2 passes behind the building.

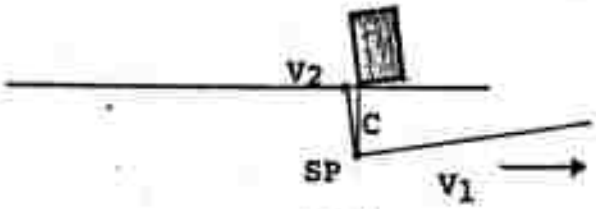




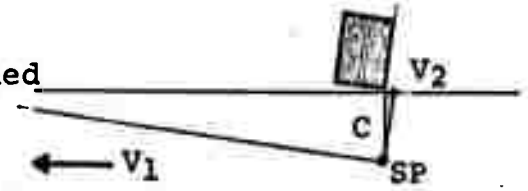
So far we have discussed only that aspect of rotation which takes place in a horizontal plane. We must also consider what takes place in a vertical plane. The vertical vanishing movements will behave exactly as the horizontal vanishing movements just discussed. When a vertical vanishing point passes behind an object, the vertical edges of the form will become parallel as in true elevation.

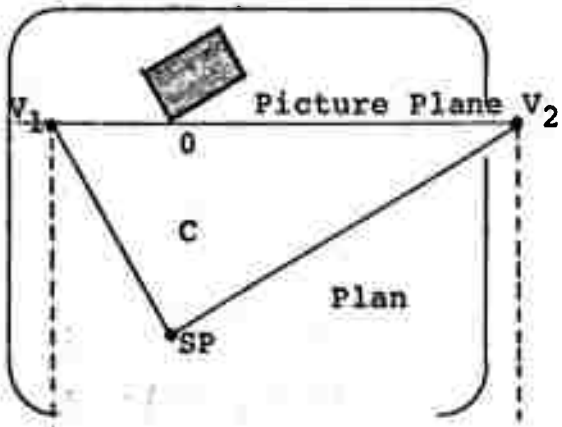




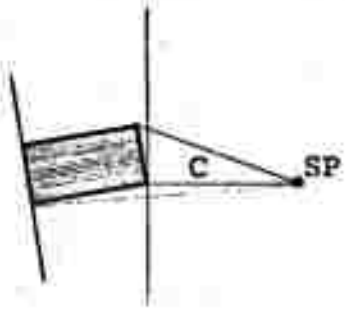


The combination of vanishing points in both axes can best be understood by thinking of the events in sequence. If the building is first rotated in plan and the horizontal vanishing points V_1 and V_2 determined those rotated vertically as seen from the side after plan rotation,



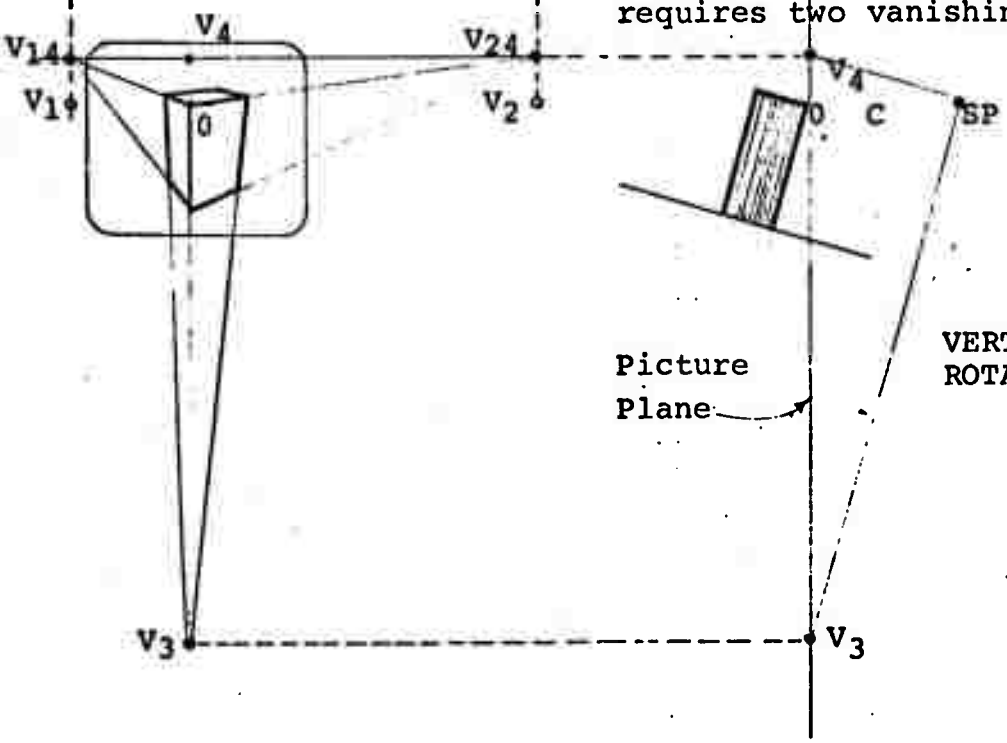


HORIZONTAL ROTATION



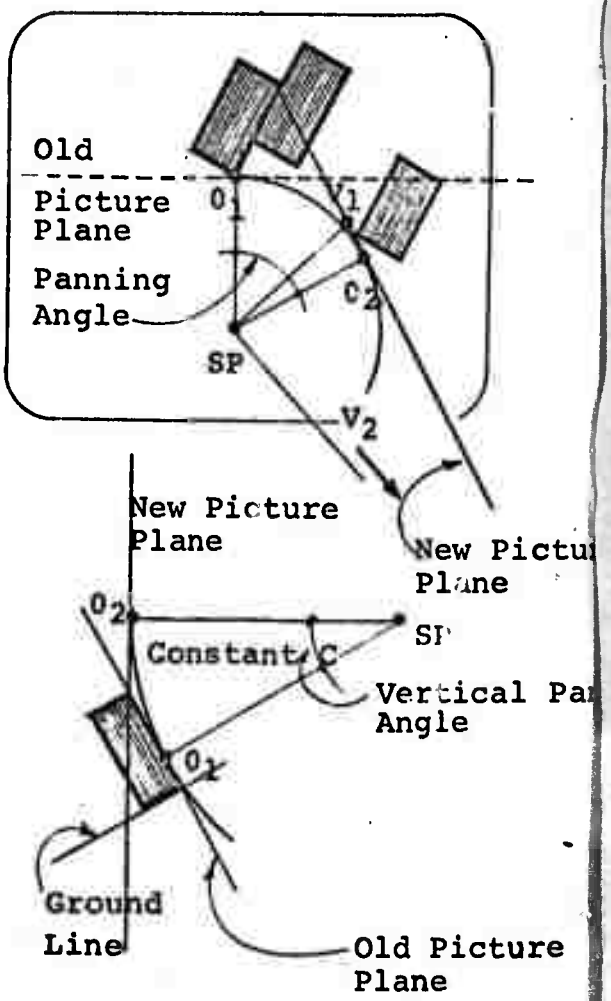
A large second vertical rotation will distort the original horizontal planes because the corners are moving closer to the picture plane and therefore must be computed in orthographic projection before determining the image corners in the picture plane.

Resulting Image:
Number of vanishing points are related to the number of faces exposed. Each rectangular plane requires two vanishing points.



then the vertical vanishing points V_3 and V_4 can be determined. In the example V_1 and V_2 are combined with V_4 to form two new vanishing points, V_{14} and V_{24}, which are used in the final image. If the building had been rotated vertically in the opposite direction, V_1 and V_2 combine with V_3 to form the two new vanishing points.

By a similar process of rotation, horizontally and vertically, the vanishing point for any edge or sets of parallel edges can be determined. In some instances where the number of buildings and forms becomes complex, it may seem desirable to rotate the object about the centroid of the viewer. Because this requires more machine time, it seems better to leave this to the discretion of the designer. He could do this by typing the command "rotate" and selecting with the stylus a specific corner of one of the space-forms which seems appropriate to him.



Panning introduces another concept of perspective in which the picture plane and the station point to object line, SP,0 remain in perpendicular to each other and both rotate about the station point. This means the object point 0 may not be in contact with any part of a building. In this case the vanishing points are constantly changing as in rotation because the buildings are, in fact, rotating in relation to the picture plane and about the station point rather than about the object point 0. Vanishing points can be determined in the usual way at any degree of pan rotation. Composite vertical and horizontal pans can be handled like rotation except all forms would rotate about the station point.

Scanning, or the act of passing the image across the screen at right angles to the axis of the viewer SP,0 is one in which the picture plane, station point, and vanishing points remain fixed while the object moves horizontally or vertically across the screen without rotation. The appearance of the object in positions 1., 2., and 3. will be different because the relationship between point 0 and the object is changing. The image is moving in relation to the vanishing points and 0.

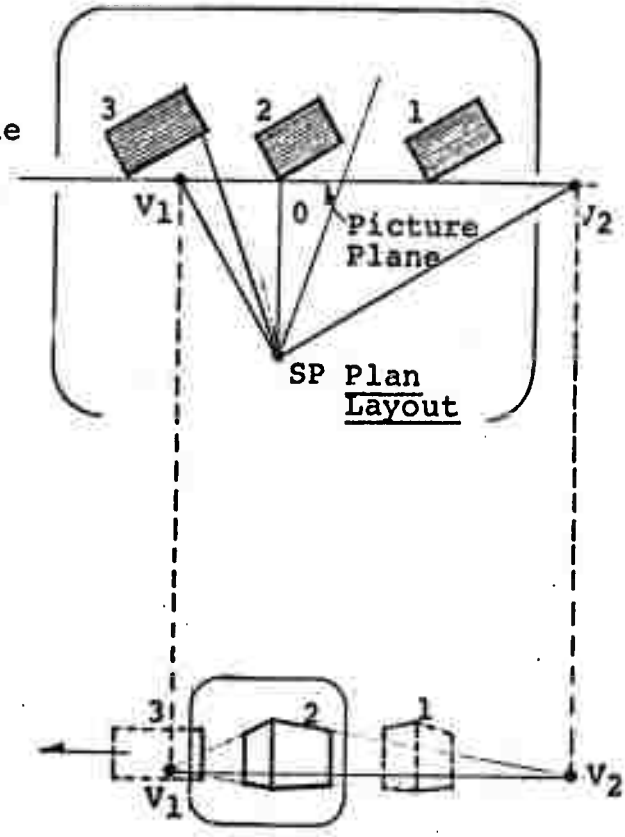


Image Moving Across Screen