Wucius WONG (王無邪) studied at the Columbus College of Art and Design in Columbus, Ohio, and later at the Maryland Institute, College of Art, in Baltimore, Maryland, where he obtained his B.F.A. and M.F.A. degrees. He returned to Hong Kong in 1965 and organized art and design courses in the Extramural Department of the Chinese University of Hong Kong. Between 1967 and 1974, he was assistant curator in contemporary art and design at the City Museum and Art Gallery, Hong Kong, and in 1974 he joined the Hong Kong Polytechnic as senior lecturer in graphic design, a position he has held since then. Privately he is a painter involved with the fusion of Oriental and Western traditions, and he has exhibited widely in Hong Kong, Saigon, Manila, Taiwan, Sao Paulo, London, New York, and other cities of the United States. In 1970/71 he was awarded a fellowship by the J.D.R. 3rd Fund, New York, which enabled him to visit the United States again for about ten months to observe contemporary art and art-education developments. His first book PRINCIPLES OF TWO-DIMENSIONAL DESIGN was published in 1972.

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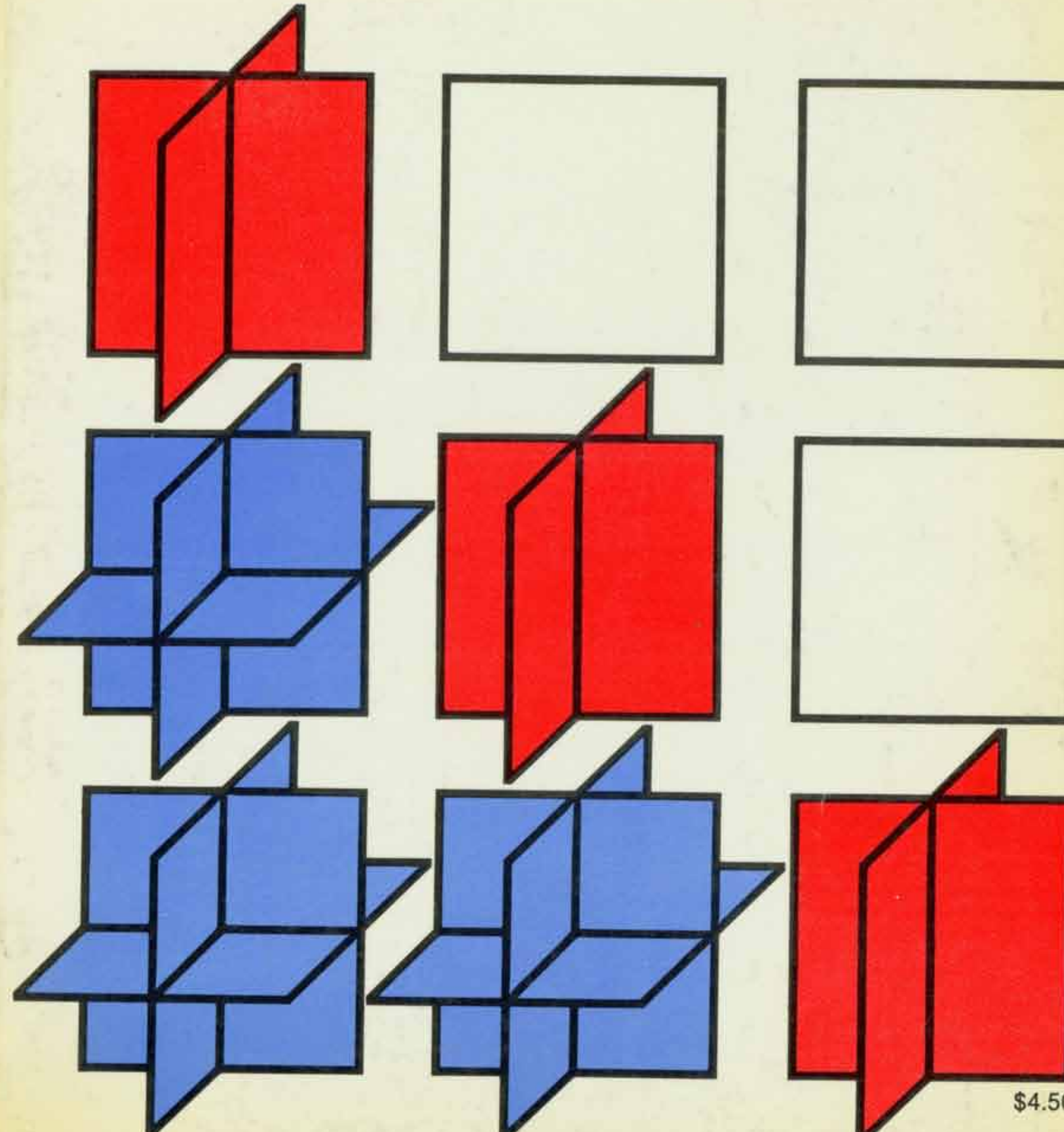

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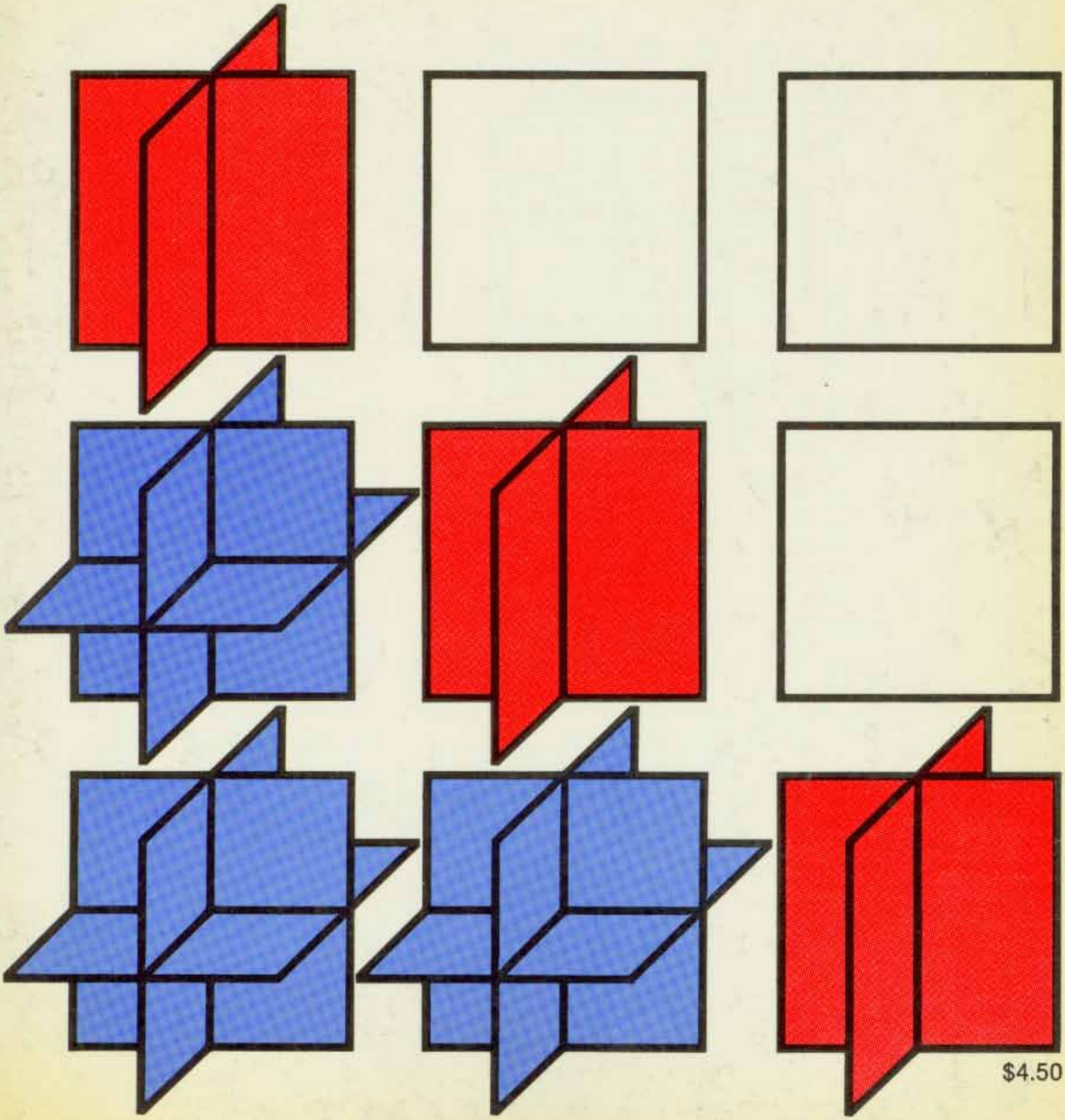

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PREFACE

Three-dimensional design is such a vast subject that a book of this size cannot cover all of it. We have not attempted to explore materials and techniques, direct work with mass and surface texture, or the intuitive approach to form. These aspects of three-dimensional design really demand constant experimentation and accumulated experience, and it is difficult for principles to be established and explained in words, diagrams, and photographs.

Instead, we have attempted to concentrate on the use of simple planes and lines in geometric construction. The approach here is analytical. Visual situations are examined and possibilities studied. Since cardboard and wooden sticks are the main materials involved, all technical problems are reduced to a minimum, and workshop facilities can be dispensed with.

This book is primarily intended to help beginning designers in the development of three-dimensional thinking. It aims particularly at those who are not inclined to think sculpturally. The step-by-step explanation of fundamental concepts and ideas are easy to follow logically, and this book can become a complete course for self-study. Certainly it can be of value also to professional designers, architects, artists, and teachers, as a tool for their creative thinking.

In many ways this book echoes my earlier book *Principles of Two-Dimensional Design* (1972). Both books have the same kind of approach and use the same terminology. This book, however, has been conceived as an independent unit, although it can be considered also as a sequel to the earlier book.

I wish to thank Mr. T. C. Lai, Director of Extramural Studies, Chinese University of Hong Kong, who first gave me the opportunity to develop the design courses on which most of the materials for this book are based. I am also grateful to Mr. Lui Lup-fan, Principal of the First Institute of Art and Design, Hong Kong, who supplied me with some of the illustrations; to Mr. Leung Kui-ting, who photographed the models; and to Mr. Cheung Shu-sun, who designed the cover.

My special thanks are due to my wife Pansy who helped, among many other things, in the preparation of the diagrams, and to whom this book is dedicated.

July 1976, Hong Kong W. W.

CONTENTS

CHAPTER 1: INTRODUCTION

The Two-dimensional World

What is a two-dimensional world? The two dimensions are length and breadth. They co-establish a planar surface, on which flat visible marks can be displayed, that has no depth except for an illusory kind. The marks have no thickness and can be either abstract or representational. The surface and the marks taken together reveal a two-dimensional world which differs completely from the world of our day-to-day experience.

The two-dimensional world is essentially a human creation. Drawing, painting, printing, dyeing, or even writing are activities which directly lead to the formation of the two-dimensional world.

Sometimes we may see three-dimensional things two-dimensionally, such as a view we enjoy just because of its sheer pictorial beauty. Today, with the progress of technology, a camera readily transforms everything in front of its lens into a flat picture, and television instantly transmits moving images to a defined surface. Textural marks on smooth natural materials such as stone, wood, etc. also suggest two-dimensional imagery. It is, however, through the human eye that the two-dimensional world gains its significance.

The Three-dimensional World

We live, in fact, in the three-dimensional world. What we see in front of us is not a flat picture with length and breadth only, but an expanse with physical depth, the third dimension. The ground underneath our feet stretches all the way to the distant horizon. We can look straight ahead, look back, look to the left, look to the right, look up, and look down. What we see is a continuum of space in which we are enveloped. There are many objects nearby which we can touch, and objects farther away which are also tangible if we try to reach for them.

Any object that is small, lightweight, and close to us can be picked up and turned around in our hands. Each movement of the object displays a different shape because the relationship between the object and our eyes has changed. If we walk straight ahead into a scene (this is not possible in the two-dimensional world), not only will the objects in the distance gradually become bigger, but their shapes will also change, for we will see more of certain surfaces and less of others.

Our understanding of a three-dimensional object can never be complete at a glance. A view from one fixed angle and distance may be deceptive. A circular shape first seen from some distance away may on closer examination turn out to be a sphere, a cone, a cylinder, or any shape which has a round base. To understand a three-dimensional object, we may have to view it from different angles and distances, and piece the information together in our minds for a complete grasp of its three-dimensional reality. It is through the human mind that the three-dimensional world gains its significance.

Two-dimensional Design

Two-dimensional design refers to the creation of a two-dimensional world with conscious efforts of organization of the various elements. Casual marking such as doodling on a flat surface may have chaotic results. This may be far from two-dimensional design, the main objective of which is to establish visual harmony and order, or to generate purposeful visual excitement.

Two-dimensional design is not within the scope of the present book, but some of its principles will be mentioned when relevant to our discussion.

Three-dimensional Design

Similar to two-dimensional design, three-dimensional design also aims at establishing visual harmony and order, or generating purposeful visual excitement, except that it is concerned with the three-dimensional world. It is more complicated than two-dimensional design because various views must be considered simultaneously from different angles, and much of the complex spatial relationships cannot be easily visualized on paper. Yet it is less complicated than two-dimensional design because it deals with tangible forms and materials in actual space, so that all the problems involving illusory representation of three-dimensional forms on paper (or any kind of flat surface) can be avoided.

Some people are inclined to think sculpturally but many others tend to think pictorially. These people may have some difficulties in three-dimensional design. Often they are so involved with the frontal view of a design they neglect other views. They may find internal structures of three-dimensional forms beyond comprehension, or be easily attracted by surface color and texture when volume and space are more important.

Between two-dimensional thinking and three-dimensional thinking, there is a difference in attitude. A three-dimensional designer should be capable

of visualizing mentally the whole form and rotating it mentally in all directions, as if he had it in his hands. He should not confine his image to one or two views, but should thoroughly explore the play of depth and the flow of space, the impact of mass and the nature of different materials.

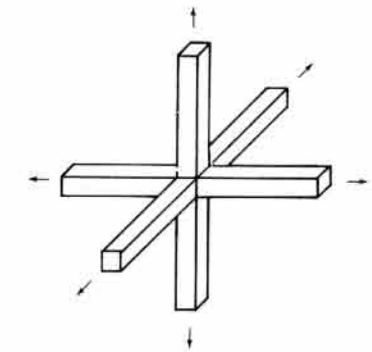
The Three Primary Directions

To start thinking three-dimensionally we must, first of all, know about the three primary directions. As mentioned earlier, the three dimensions are length, breadth, and depth. In order to obtain the three dimensions of any object, we must take measurements in the vertical, horizontal, and transverse directions.

Thus the three primary directions consist of a vertical direction which goes up and down, a horizontal direction which goes left and right, and a transverse direction which goes forwards and backwards. (Fig. 1)

For each direction we can institute a flat plane. In this way we can have a vertical plane, a horizontal plane, and a transverse plane. (Fig. 2)

Doubling such planes, the vertical plane now becomes the front and rear planes, the horizontal plane the top and bottom planes, and the transverse plane the left and right planes. With these, a cube can be constructed. (Fig. 3)



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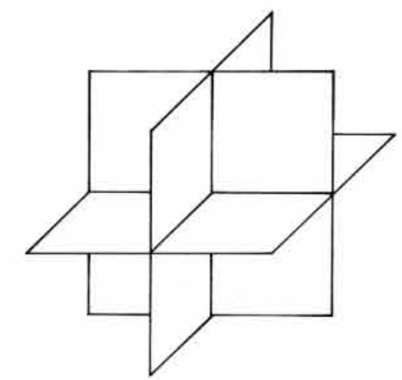

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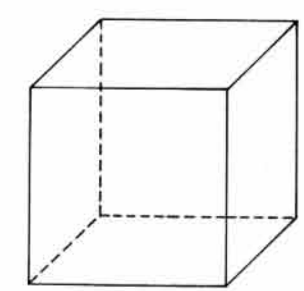

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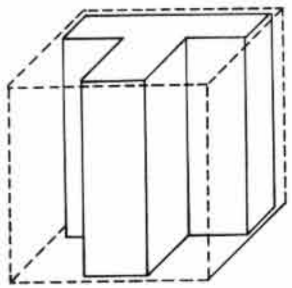

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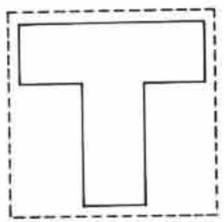

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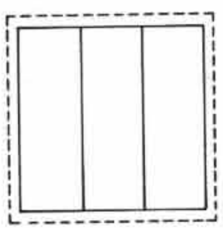

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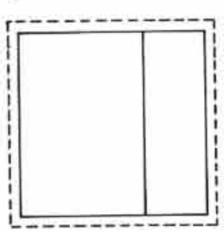

The Three Basic Views

Any three-dimensional form can be placed inside an imaginary cube with which three basic views can be established. (Fig. 4)

By projecting the form onto the top, front, and side planes of an imaginary cube, we can have:

(a) a plane view—view of the form as seen from the top; (Fig. 5)

(b) a front view—view of the form as seen from the front; (Fig. 6)

(c) a side view—view of the form as seen from the side. (Fig. 7)

Each view is a flat diagram, and these views together (occasionally supplemented by auxiliary and/or sectional views) provide the most accurate description of a three-dimensional form, although one needs to have some background knowledge of engineering drawing to be able to reconstruct the original form from these views.

Elements of Three-dimensional Design

In two-dimensional design, there are three sets of elements*:

(a) the conceptual elements—point, line, plane, and volume;

(b) the visual elements—shape, size, color, and texture;

(c) the relational elements—position, direction, space, and gravity.

Conceptual elements do not exist physically, but are perceived as being present. Visual elements, of course, can be seen, and constitute the final appearance of a design. Relational elements govern the overall structure and internal correspondences of the visual elements.

All these elements are just as essential for three-dimensional design, although we will define them in a slightly different way, and add a set of constructional elements for practical reasons. The constructional elements are, in fact, concrete realizations of the conceptual elements and will be indispensable in our future discussions.

*as listed in *Principles of Two-Dimensional Design* by Wucius Wong.

Conceptual Elements

A three-dimensional design can be conceived in the mind before it takes on physical shape. The design is thus defined by the following conceptual elements:

(a) point—a conceptual point indicates position in space. It has no length, breadth, or depth. It marks the two ends of a line, the single place where lines intersect, and the meeting of lines at a corner of a plane or the angle of a solid form. (Fig. 8)

(b) line—as a point moves, its path becomes a line. A conceptual line has length but no breadth or depth. It has position and direction. It de-

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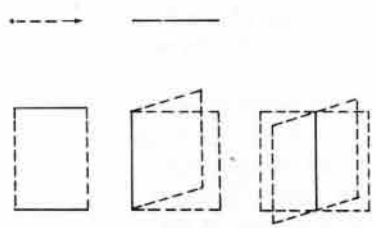

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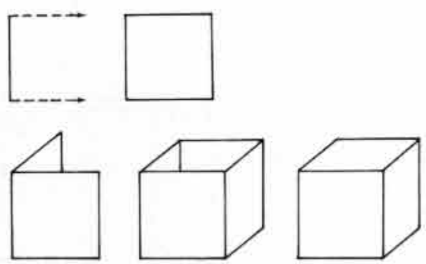

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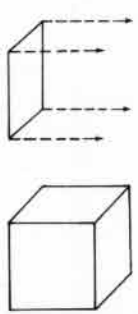


fines the border of a plane, and marks the place where two planes join or intersect each other. (Fig. 9)

(c) plane—the path of a line in motion (in a direction other than its own intrinsic direction) becomes a plane. A conceptual plane has length and breadth but no depth. It is bound by lines. It defines the external limits of a volume. (Fig. 10)

(d) volume—the path of a plane in motion (in a direction other than its own intrinsic direction) becomes a volume. A conceptual volume has length, breadth, and depth, but no weight. It defines the amount of space contained or displaced by the volume. (Fig. 11)

It is important to note that many of our three-dimensional ideas are first visualized on a flat piece of paper. We usually use a fine line to indicate the border of a plane or volume. This line is visual as it appears on the two-dimensional surface, but is conceptual when its only use is as a means of representing a three-dimensional form.

Visual Elements

Three-dimensional forms are seen differently from different angles and distances and under different lighting conditions. Therefore, we must consider the following visual elements to be independent of such variable situations:

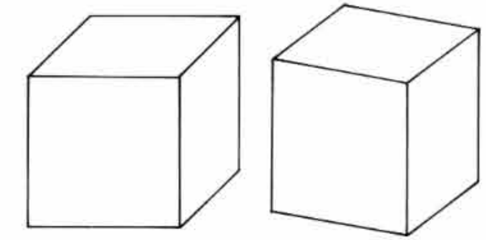
(a) shape—shape is the outward appearance of a design

and the main identification of its type. A three-dimensional form can be rendered on a flat surface by multiple two-dimensional shapes, and we must be aware of this to be able to visually relate all such different aspects to the same form. (Fig. 12)

(b) size—size is not just greatness or smallness, length or brevity, which can only be established by way of comparison. Size is also concrete measurement, and can be measured on any three-dimensional form in terms of length, breadth, and depth (or height, width, and thickness) from which its volume can be calculated. (Fig. 13)

(c) color—color, or light and dark value, is what most clearly distinguishes a form from its environment, and it can be natural or artificial. When it is natural, the original color of the material is presented. When it is artificial, the original color of the material is covered up by a coat of paint, or transformed by treating with some other method. (Fig. 14)

(d) texture—texture refers to the surface characteristics of the material used in the design. It may be naturally unadorned or specially treated. It may be smooth, rough, matt, or glossy as determined by the designer. It may be small-scale texture that accents two-dimensional surface decoration or bolder texture that accents three-dimensional tactility. (Fig. 15)



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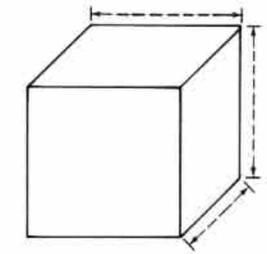

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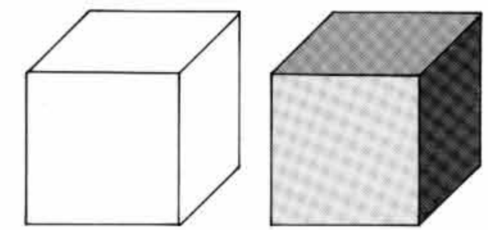

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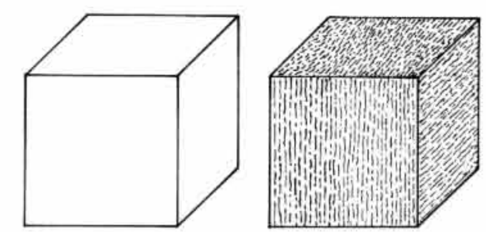

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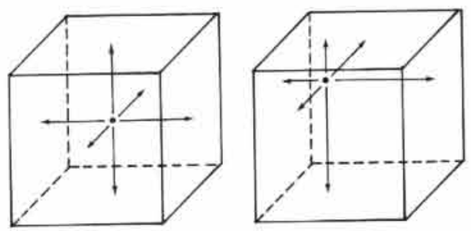

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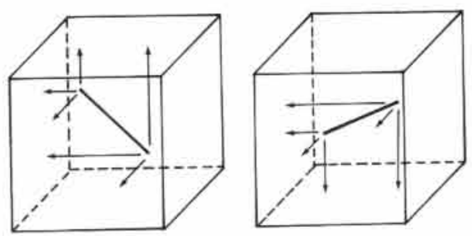

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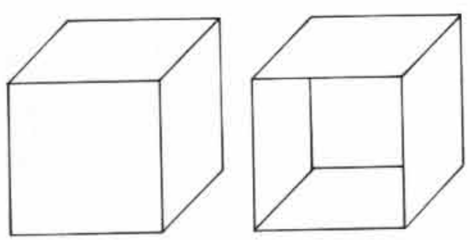

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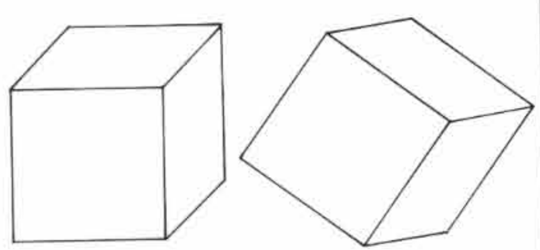


Relational Elements

Relational elements are more complicated in three-dimensional design than in two-dimensional design. Whereas in two-dimensional design a frame of reference is used, in three-dimensional design we can use an imaginary cube to establish the relationships.

(a) position—position must be ascertained by more than one of the three basic views. We have to know how a point is related to the front/rear, top/bottom, and side planes of the imaginary cube. (Fig. 16)

(b) direction—direction, too, should be seen from more than one view. A line could be parallel to the front/rear planes but oblique to all other planes of the imaginary cube. (Fig. 17)

(c) space—space here is, of course, actual and not illusory. It can be seen as positively occupied, unoccupied, or internally hollowed. (Fig. 18)

(d) gravity—gravity is real and has a constant effect on the stability of the design. We cannot have forms in mid-air without supporting, hanging, or anchoring them in some way. Some materials are heavy and some are light. The material used determines the weight of the form as well as its capacity to bear gravitational loads of other forms on top of it. All three-dimensional structures are subject to the laws of gravity and this means certain arrangements and positioning are just not possible. (Fig. 19)

Constructional Elements

Constructional elements have strong structural qualities and are particularly important for the understanding of geometric solids. These elements are used to indicate the geometric components of three-dimensional design:

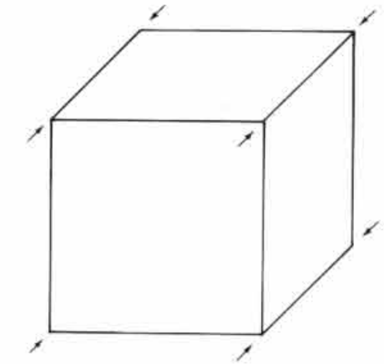
(a) vertex—when several planes come to one conceptual point, we have a vertex. Vertices can be projected outward or inward. (Fig. 20)

(b) edge—when two nonparallel planes are joined together along one conceptual line, an edge is produced. Again edges may be projected outward or inward. (Fig. 21)

(c) face—a conceptual plane which is physically present becomes a surface. Faces are external surfaces which enclose a volume. (Fig. 22)

Ideally all vertices should be sharp and pointed, all edges should be sharp and straight, and all faces should be smooth and flat. In reality this depends on the materials and techniques, and certain minor irregularities are normally unavoidable.

Constructional elements can help to precisely define volumetric forms. For example, a cube has eight vertices, twelve edges, and six faces.



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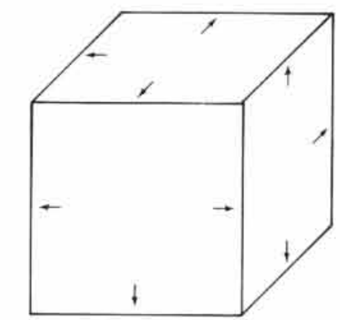

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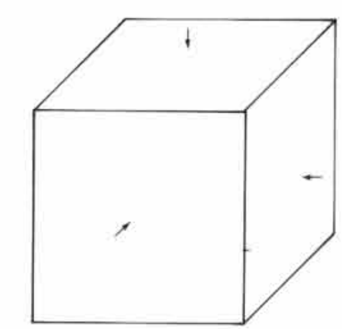

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Form and Structure

Form is a term easily confused with *shape*. Earlier it was pointed out that a three-dimensional form can have multiple two-dimensional shapes when rendered on a flat surface (see Fig. 12). This means that shape is really only one aspect of form. When a form is rotated in space, each step of rotation reveals a slightly different shape, because a different aspect is seen by our eyes.

Form, then, is the total visual appearance of a design, although shape is its main identifying factor. We also identify form by size, color, and texture. In other words, all the visual elements are referred to collectively as form.

Structure governs the way a form is built, or the way a number of forms are put together. It is overall spatial organization, the skeleton beneath the fabric of shape, color, and texture. The external appearance of a form can be rather complex, while its structure is relatively simple. Sometimes the internal structure of a form may not be immediately perceived. Once this is discovered, the form can be better understood and appreciated.

Unit Forms

Smaller forms which are repeated, with or without variations, to produce a larger form are referred to as *unit forms*. Sometimes these repeated units are called *modules*.

A unit form may be made of even smaller components, which can be called *sub-unit forms*.

A larger unit may be made of two or more unit forms in a constant relationship that appears frequently in a design. They are called *super-unit forms*.

Repetition and Gradation

Unit forms can be used in exact repetition or in gradation.

Repetition means that the unit forms are identical in shape, size, color, and texture. Shape is the most important visual element of unit forms, so that we can have unit forms repeated in shape but not in size. Color and texture can vary if desired, but they are not within the scope of this book.

Gradation means transformation or change in a gradual, orderly manner. Here the sequential arrangement is very important, otherwise the order of gradation cannot be recognized.

We can have gradation in shape, with the shape changing slightly from one unit to the next, or gradation in size, with the units repeated or graduated in shape.

CHAPTER 2: SERIAL PLANES

Points determine a line. Lines determine a plane. Planes determine a volume.

A line can be represented by a series of points. (Fig. 23)

A plane can be represented by a series of lines. (Fig. 24)

A volume can be represented by a series of planes. (Fig. 25)

When a volume is represented by a series of planes, each plane is a cross section of the volume.

Serial Planes

Thus, to construct a volumetric form, we can think in terms of its cross sections, or how the form can be sliced up at regular intervals, which will result in serial planes.

Each serial plane can be considered as a unit form which may be used either in repetition or in gradation.

As mentioned, repetition refers to repeating both shape and size of the unit forms. (Fig. 26)

Gradation refers to gradual variation of the unit form, and it can be used in three different ways:

(a) gradation of size but repetition of shape; (Fig. 27)

(b) gradation of shape but repetition of size; (Fig. 28)

(c) gradation of both shape and size. (Fig. 29)

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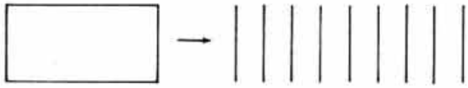

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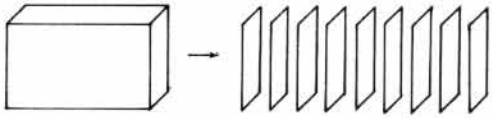

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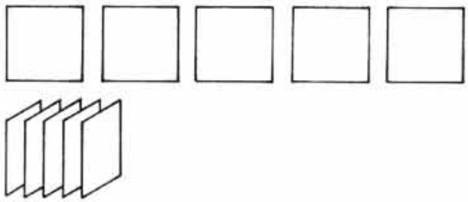

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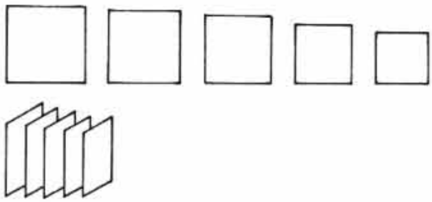

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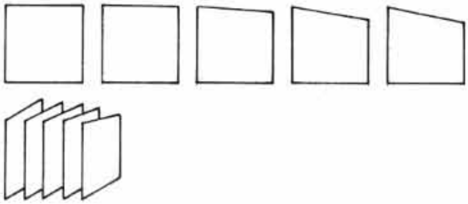

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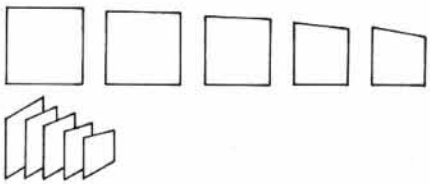

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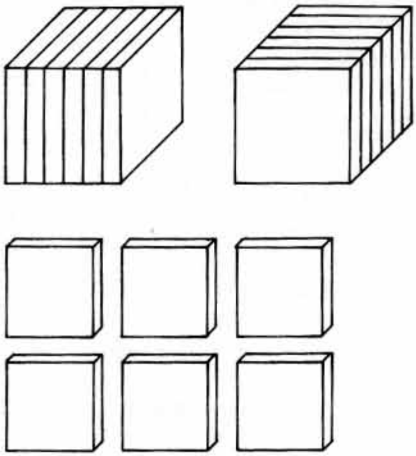

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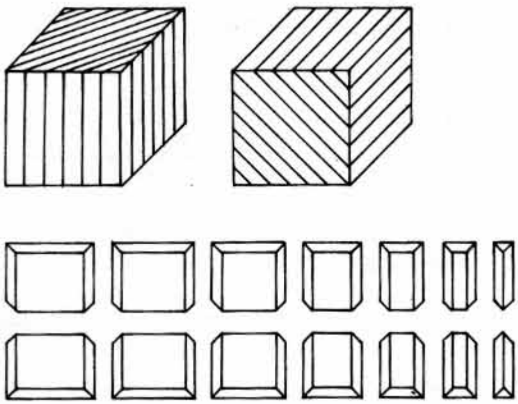

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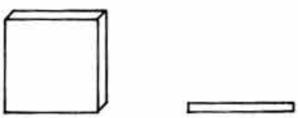

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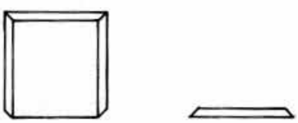


Dissection of a Cube

To illustrate a bit further, we can dissect a cube into a number of thin planes of the same thickness.

The simplest way is to dissect along the length, breadth, or depth, in parallel layers. As a result, a number of serial planes are obtained which are repeats in both shape and size (Fig. 30).

The same cube can also be dissected diagonally. There are many ways to do this. Our diagram here shows a kind of diagonal dissection resulting in serial planes with gradation of shape. Size is gradational too. The height remains constant, but the breadth increases or decreases gradually. (Fig. 31)

It should be pointed out that in dissection along the length, breadth, or depth all serial planes have squared edges. (Fig. 32)

In diagonal dissection, all serial planes have bevelled edges. (Fig. 33)

The edges may not be of much significance if the planes are extremely thin, but if they are thick, influences of the edges on the design should not be overlooked.

In arranging serial planes, the relational elements should be taken into consideration. The two main relational elements which must not be neglected are position and direction.

Positional Variations

Position has to do with, first of all, spacing of the planes. If no directional variations are introduced, all the serial planes will be parallel to one another, each following the next successively, with equal spacing between them.

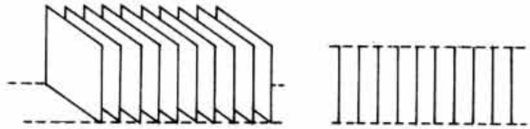
Let us assume that all the planes are squares of the same size. If one plane follows another in a straight manner, then the two vertical edges of the planes trace two parallel straight lines, with a width the same as the breadth of the planes. (Fig. 34)

Spacing between the planes can be made narrow or wide, with different effects. Narrow spacing gives the form a greater feeling of solidity, whereas wide spacing weakens the suggestion of volume. (Fig. 35)

Without changing the spacing between the planes, the position of each plane can be shifted gradually towards one side or back and forth. This causes the volumetric shape to undergo various distortions. (Fig. 36)

Again without changing the spacing between the planes, the position of each plane can be shifted gradually upwards or downwards. This can be easily done if the planes are hung or supported in midair. (Fig. 37)

If the planes are placed on a baseboard, we can reduce the height of the planes to suggest the effect of their gradual sinking-in just by positional variation in a vertical manner. (Fig. 38)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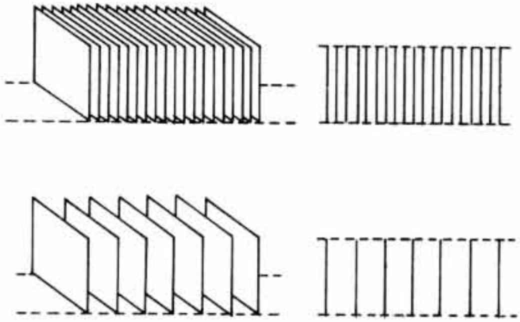
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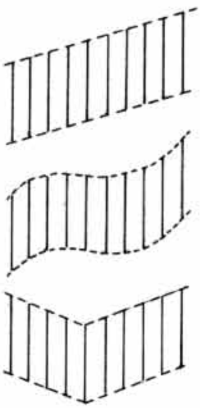
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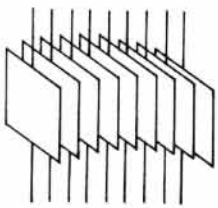
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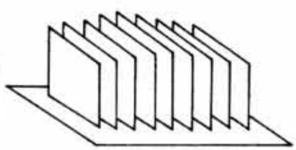
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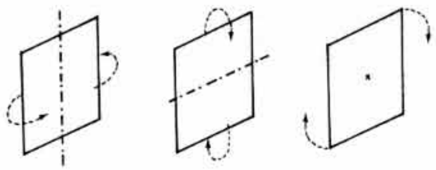

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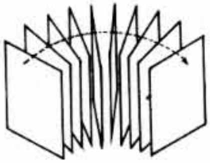

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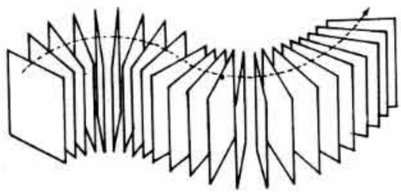

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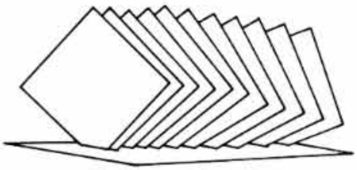

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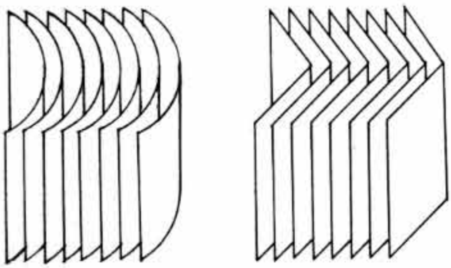


Directional Variations

Direction of the planes can be varied in three different ways:

(a) rotation on a vertical axis; (Fig. 39)

(b) rotation on a horizontal axis; (Fig. 40)

(c) rotation on its own plane. (Fig. 41)

Rotation on a vertical axis requires a diversion of the planes from parallel arrangement. Position is definitely affected, because every directional change simultaneously demands positional change.

The planes in this case can be arranged in radiation, forming a circular shape. (Fig. 42)

Or they can form a shape with curves left and right. (Fig. 43)

Rotation on a horizontal axis cannot be done if the planes are fixed on a horizontal baseboard. If they are fixed on a vertical baseboard, their rotation on a horizontal axis would be essentially the same as the rotation on a vertical axis described above.

Rotation on its own plane means that the corners or edges of each plane are moved from one position to another without affecting the basic direction of the plane itself. This results in a spirally twisted shape. (Fig. 44)

The planes can be physically curled or bent if desired. (Fig. 45)

Construction Techniques

Any kind of sheet material can be used for making serial planes. Acrylic sheets are excellent when a transparent effect is desired. Plywood boards can be used for construction in a very large scale. Most of the models shown in this chapter have been made of thick cardboard, which can be handled easily. The thickness of the cardboard ensures firm adhesion to the baseboard if there is one.

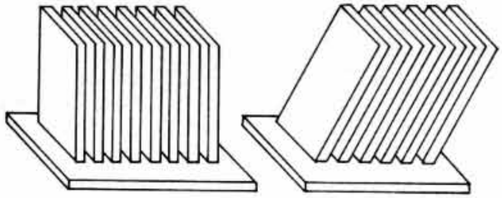
For cardboard construction, adhesives that give a quick, strong bond are the best. The serial planes should stand in a vertical position on the horizontal baseboard for maximum firmness and stability. Tilted planes are possible only when the materials and the bond are both extremely strong, and the joining edge of each plane is precisely bevelled. (Fig. 46)

For reinforcement purposes, additional plane(s) can be used next to the top or side edges of the planes. This is recommended only when those edges of the planes play a rather insignificant role in the final shape of the design. (Fig. 47)

Horizontally arranged serial planes demand a very strong bond if only one vertical board is used for attachment. (Fig. 48)

Normally two or more vertical boards should be used for horizontal serial planes. (Fig. 49)

A vertical supporting core can be used for horizontal serial planes of a free-standing shape if desired. (Fig. 50)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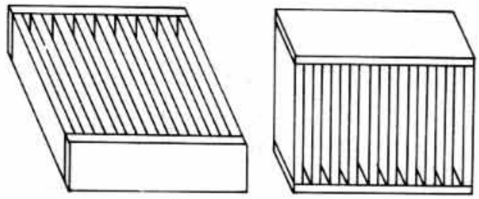
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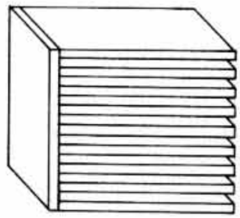
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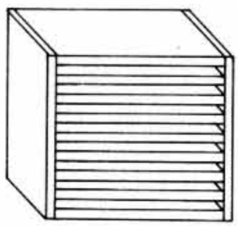
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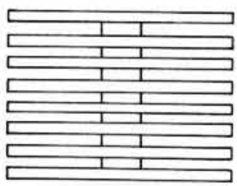
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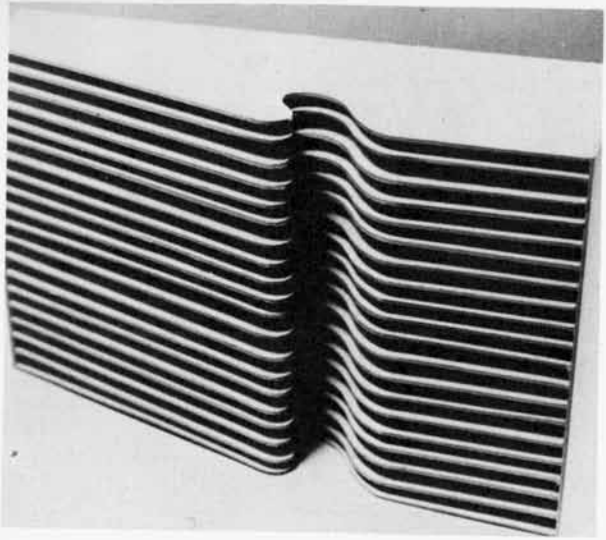

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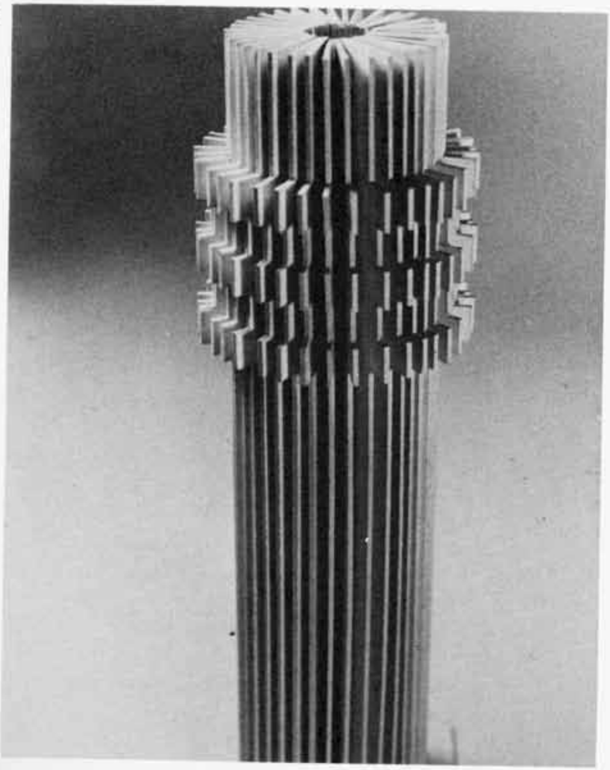
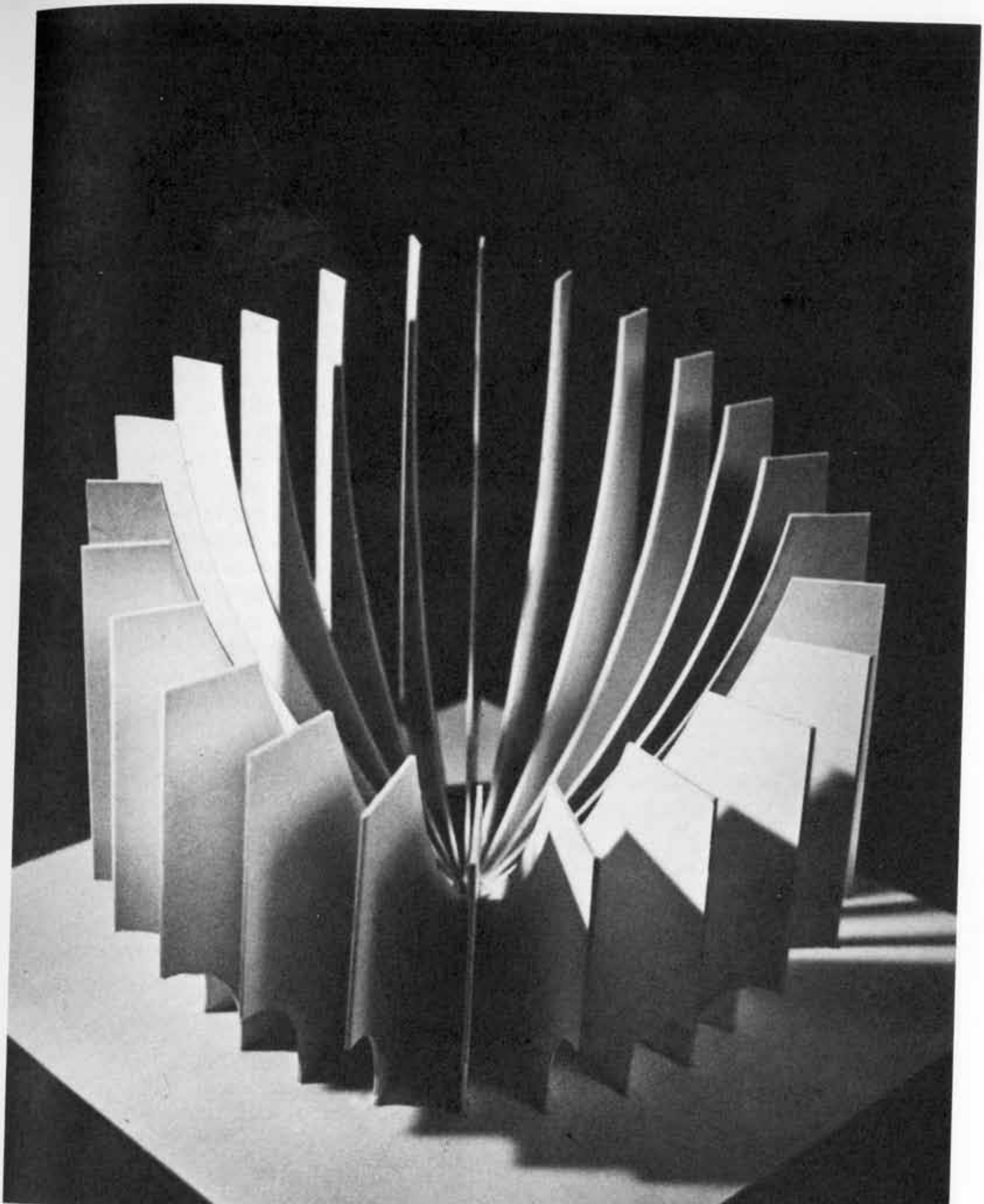


Figures 51 to 66 all illustrate the same design problem in projects by different students.

Figure 51—this is constructed of horizontal serial planes which are repeated both in shape and size. The planes are all parallel to one another with equal spacing in between, and they are anchored to two vertical planes.

Figure 52—here a number of repetitive vertical planes are placed around a common vertical axis. The result is a cylindrical shape.

Figure 53—the arrangement is similar to Figure 52. Here the serial planes increase gradually in height from the foreground to the background. The volumetric feeling of the form is not very strong because the spacing between planes is rather wide along the circumference of the shape.



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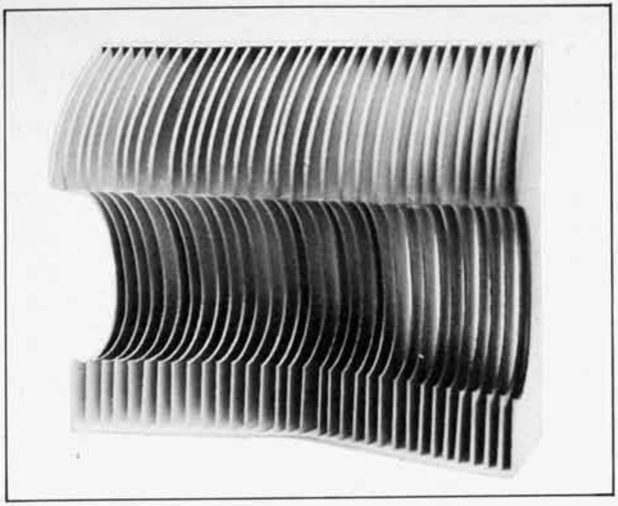

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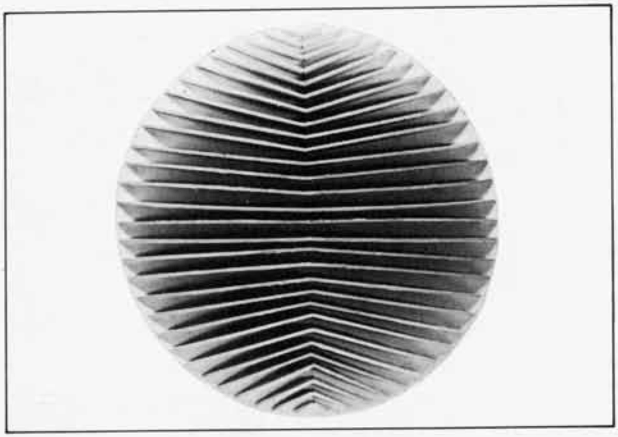

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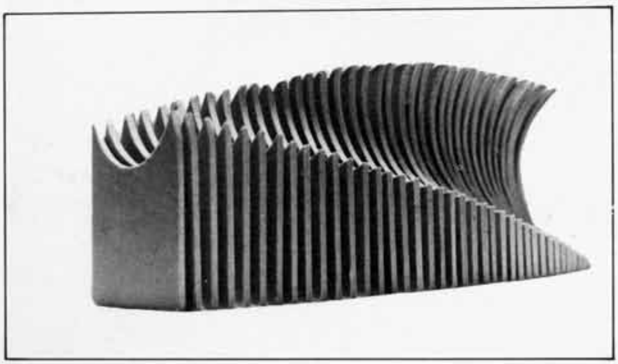


Figure 54—at a glance, it seems that all the serial planes are identical both in shape and size. A closer study reveals that they have a subtle gradation of shape. While the upper part of the structure is straight all across, the lower part subtly bends inward in a V-shape.

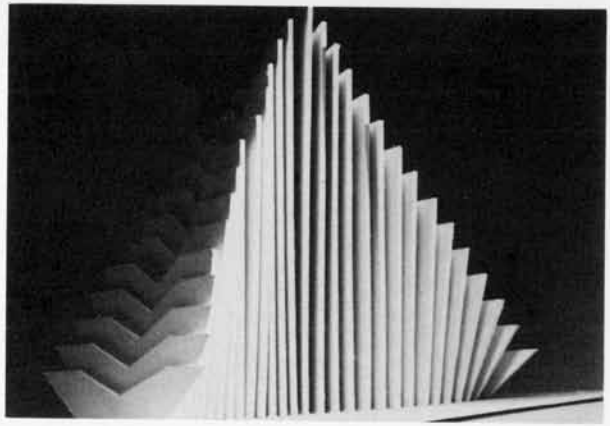
Figure 55—with a straight plane standing in the middle of the structure, all other planes are bent in increasingly sharper angles. The volumetric form suggested here is an emerging spherical shape.

Figure 56—this shows the effective use of gradation of shape. Each plane is obtained by the combination of a positive rectangular shape and a negative circular shape. The former has a constant width but the latter grows bigger and bigger and moves gradually downward and forward. The straight edges of the rectangular shape remain straight at the front but those at the rear change gradually into sweeping curves to echo the negative circular shapes.

Figure 57—this is a triangular structure which is the result of gradation of both shape and size of the serial planes. The short, wide V-shaped planes at the two sides become tall and narrow towards the middle by gradation of size and shape.

Figure 58—circular planes of exactly the same size and shape have been used in this structure. The sinking-in effect of the planes on the backboard is due to positional variation. The two loops which make the general shape very much like the numeral 8 are the result of directional variation.

Figure 59—the use of gradation of shape is quite obvious here, and gives the feeling of planes emerging from or sinking into the baseboard.



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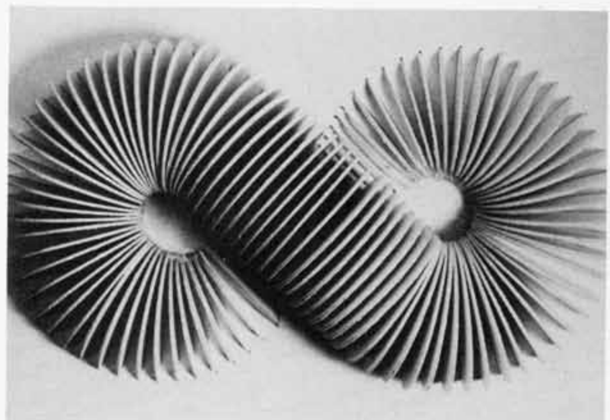

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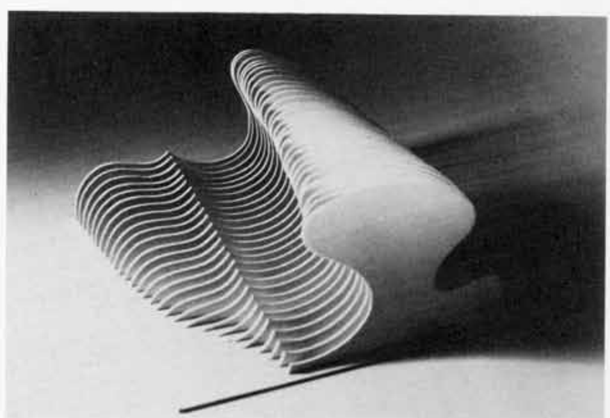

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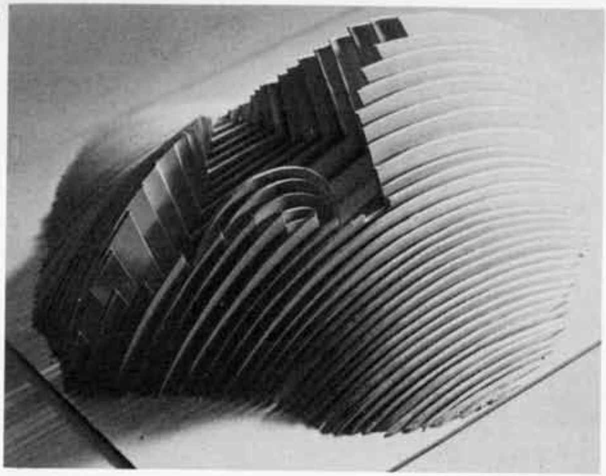

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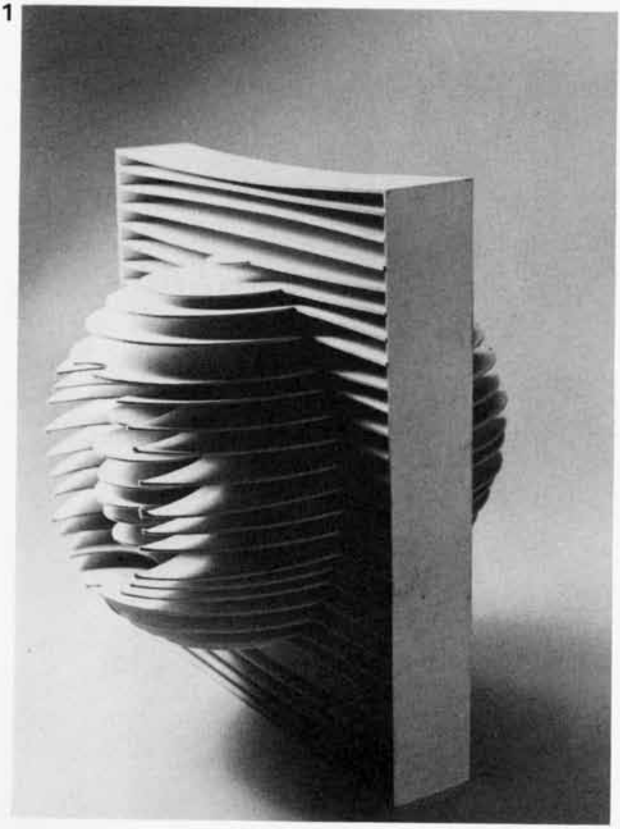
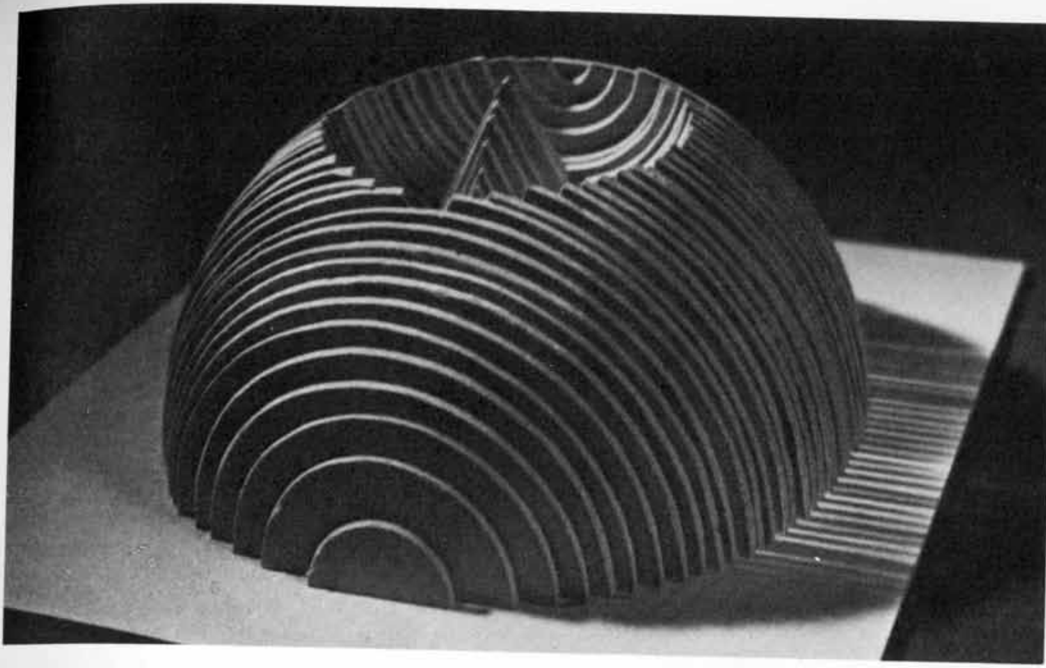


Figure 60—gradation of shape is used here in a rather complicated way. The form rises from the baseboard in high relief, but it splits up in the center to reveal another form within the deep concavity.

Figure 61—this is a free-standing form with a projecting semi-sphere in the front and another in the back. Both semi-spheres have a concave portion, inside of which a smaller semi-sphere is nested. The effect is similar to Figure 60.

Figure 62—the play of concavity and convexity here is the same as in Figure 60.

Figure 63—here the semi-spherical shape has been cut into two parts, and the shape of each part is further modified. A prominent negative shape now becomes the focal point of the design.



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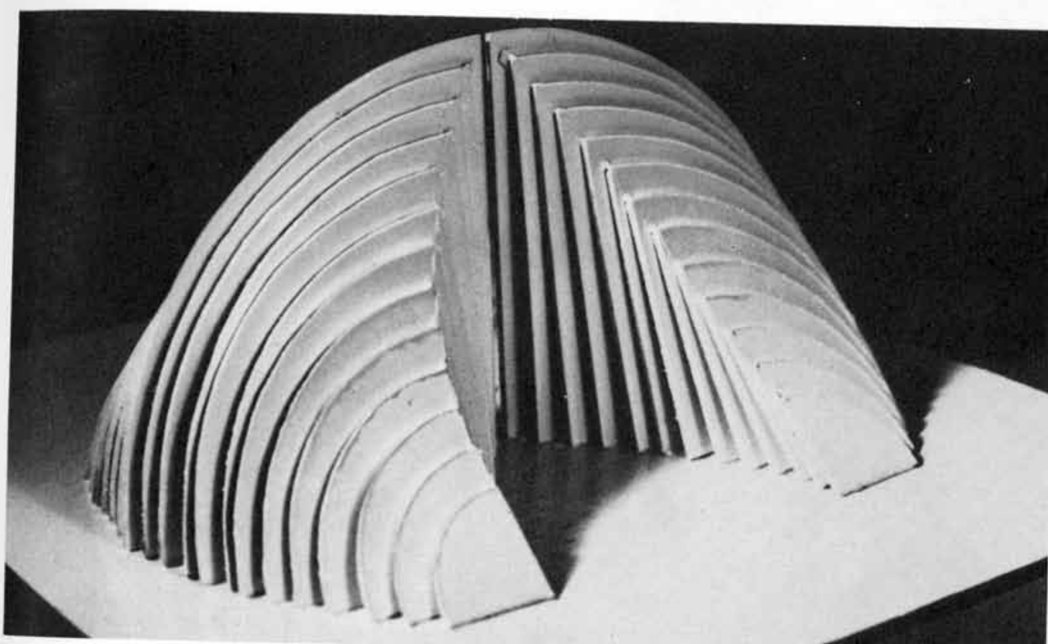

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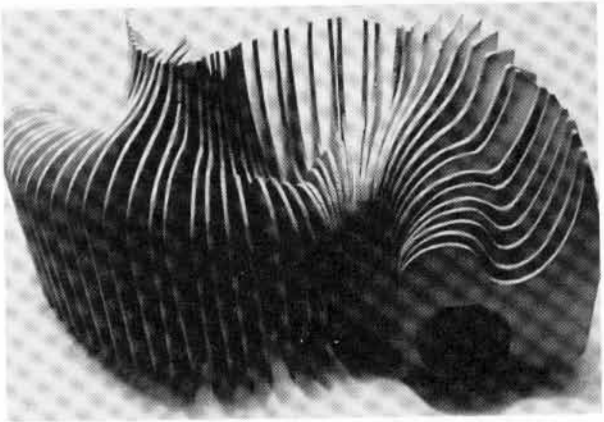

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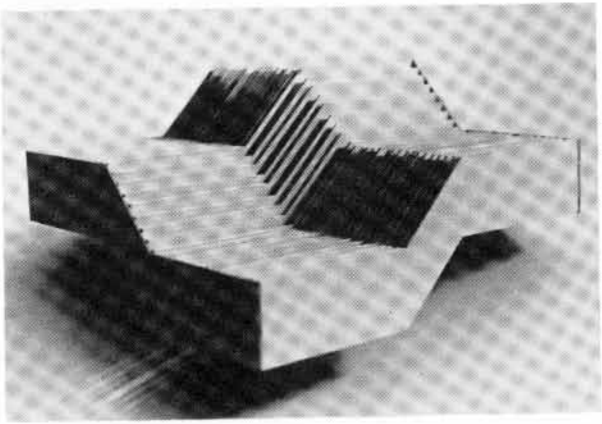

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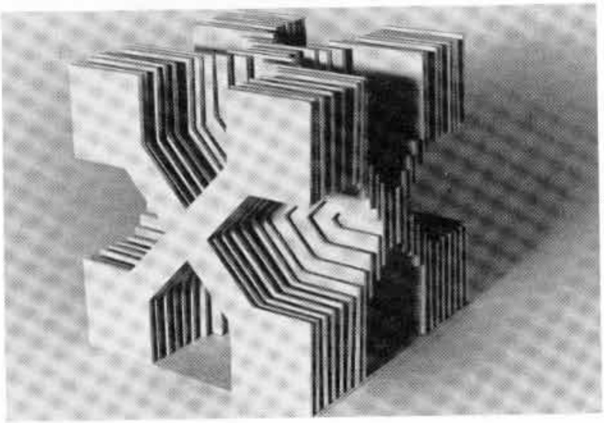


Figure 64—in this form, gradation of shape is used in combination with directional variation. Note the introduction of a negative shape which runs like a tunnel at the lower part of the design.

Figure 65—all the planes in this structure are repetitive in shape and size, but are arranged in a slightly zigzag manner by positional variation. This zigzag arrangement echoes the shapes of the planes themselves. The result is an interesting shape with faceted faces and identical front, rear, left, and right views.

Figure 66—this not only has identical views from four sides, but from top and bottom also. Each of the six views displays the letter X in the same shape and size. To construct this, negative shapes are introduced into square serial planes which are all repetitive in size. Some are repetitive in shape and some are graduated in shape.

CHAPTER 3: WALL STRUCTURES

Cube, Column, and Wall

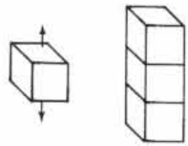
Starting with a cube, we can place a second cube above and a third cube below it. (Fig. 67)

Now we have a column of three cubes that can be extended in either direction to include any desired number of cubes. (Fig. 68)

The column can also be repeated left and right. When a number of columns are erected, one adjacent to another, we have a wall. The wall structure is basically two-dimensional. The cube has been repeated in two directions, first in the vertical direction and then in the horizontal direction.

Each cube is a spatial cell in the wall structure. These spatial cells are arranged two-dimensionally on a frontal plane. (Fig. 69)

All formal two-dimensional structures can become wall structures with the addition of some depth, and their structural sub-divisions can be made into spatial cells. (Fig. 70)



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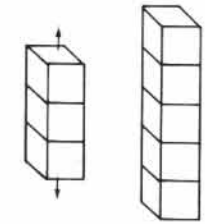

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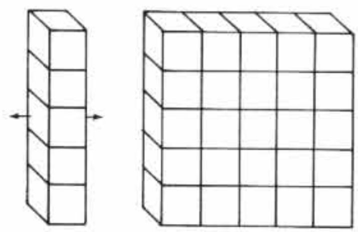

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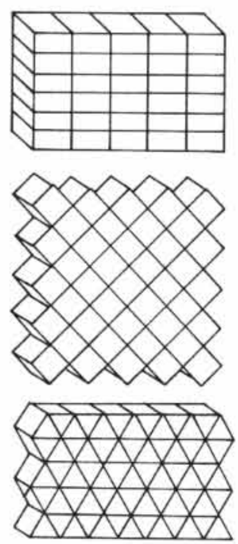

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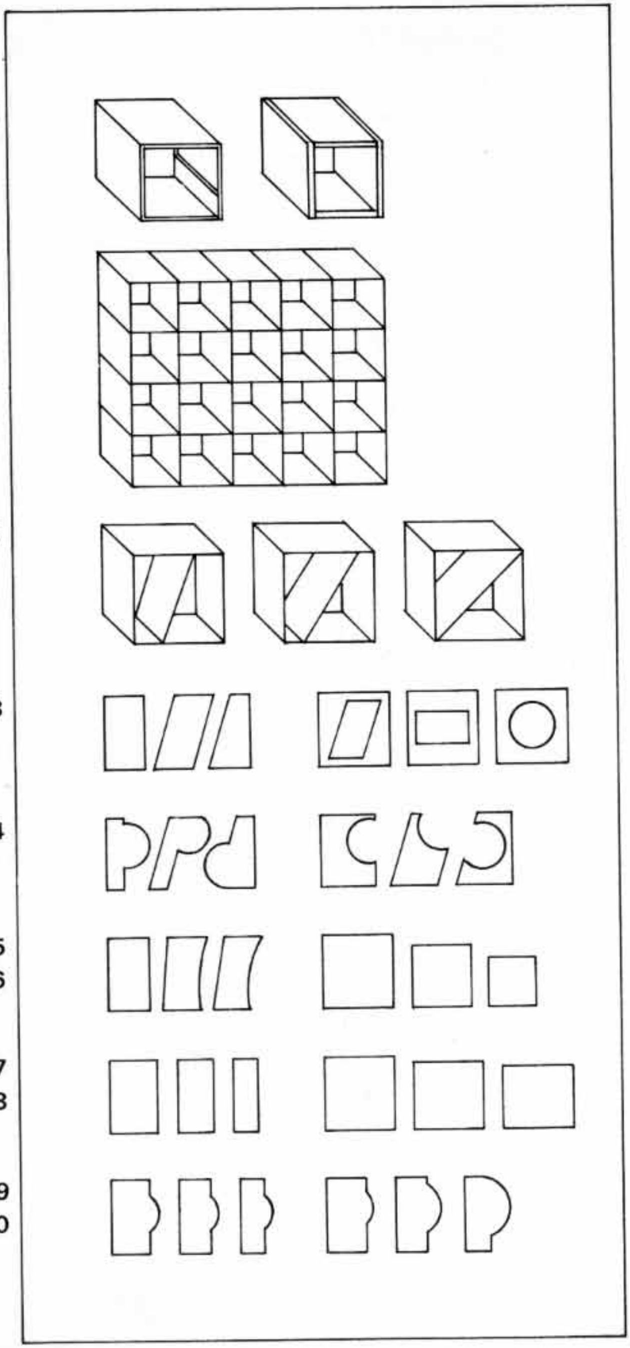

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Spatial Cells and Unit Forms

To explore the various possibilities of making wall structures, we can first bend a strip of thin cardboard or glue four pieces of thick cardboard together to form a cube without the front and rear planes. (Fig. 71)

This is our simplest spatial cell. We can see through it and place a unit form inside. The unit form can be as simple as a flat plane used repetitively or with slight variations. (Fig. 72)

As a planar shape, the unit form can be positive or negative. (Fig. 73)

It can be a combination of two positive shapes or one positive and one negative. (Fig. 74)

Unit forms can be used in gradation of shape if desired. (Fig. 75)

Gradation of size can be effected by:

(a) enlarging or reducing proportionately; (Fig. 76)

(b) changing of width only; (Fig. 77)

(c) changing of height only; (Fig. 78)

If the unit form is a combination of two smaller shapes, size of one can be kept constant while size of the other varies. (Fig. 79) Or both shapes can vary in different ways. (Fig. 80)

Positional Variations of Unit Forms

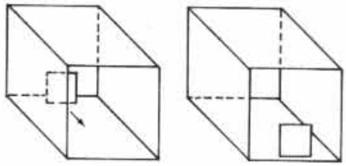
Variations of positioning of the unit forms can be accomplished by:

(a) moving the shape forward or backward; (Fig. 81)

(b) moving the shape up or down; (Fig. 82)

(c) moving the shape left or right; (Fig. 83)

(d) reducing the height or width of the shape to suggest the feeling of its sinking into one of the enclosing planes. (Fig. 84)



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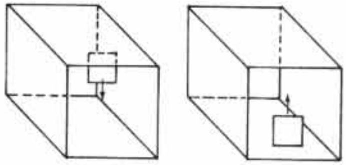

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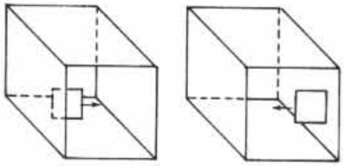

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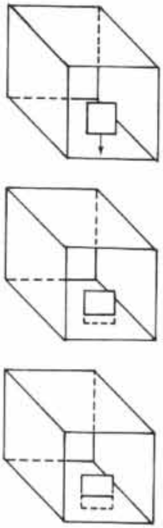

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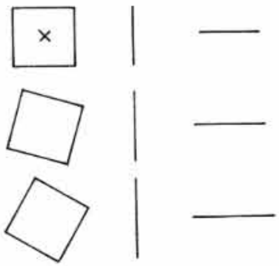

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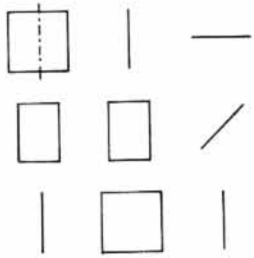

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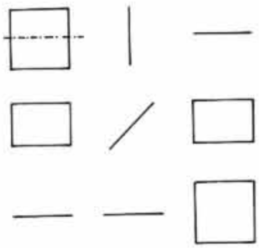

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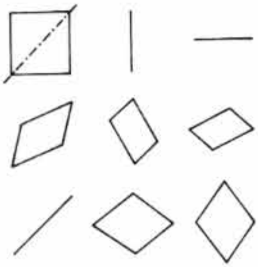


Directional Variations of Unit Forms

Inside each spatial cell, the unit form can be rotated in any direction desired. During each step of rotation, it will be seen differently from the front.

Let us observe the effects of rotating a square shape. In Figures 85 to 88, the first vertical column represents the front views, the second vertical column the side views, and the third vertical column the plane views.

Rotation on the shape's own plane does not change the shape at all in the front view. The side view of the shape is always a line. The plane view of the shape is also always a line. (Fig. 85)

Rotation along a vertical axis makes the square shape, in the front view, which becomes a narrower and narrower oblong that decreases finally to a line. In the side view it is first a line which gradually becomes a square. In the plane view, the shape remains a line of constant length that varies in direction. (Fig. 86)

Rotation along a horizontal axis is very similar to rotation along a vertical axis. The shape remains a line of constant length, not in the plane view, but in the side view. (Fig. 87)

Rotation along a diagonal axis leads to more complicated results. In the front view, the square is transformed into a diagonal line after a series of graduated parallelograms. Different shapes of parallelograms are also seen in the side and plane views. (Fig. 88)

Unit Forms as Distorted Planes

If greater three-dimensional effects are desirable, unit forms can depart from the characteristics of a flat plane. Two or more flat planes can be used for the construction of one unit form, or a simple flat plane can be treated in the following ways to become a unit form:

(a) by curling; (Fig. 89)

(b) by bending along one or more straight lines; (Fig. 90)

(c) by bending along one or more curved lines; (Fig. 91)

(d) by cutting and curling; (Fig. 92)

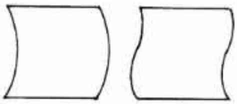
(e) by cutting and bending. (Fig. 93)

Wall Structures Not Remaining Flat

When one spatial cell is placed on another, the flat frontality of the wall structure can be made slightly more three-dimensional by positional variation. (Fig. 94)

A similar effect can be obtained by varying the depths of the spatial cells. (Fig. 95)

Directional variation in the arrangement of the spatial cells is possible but must be done with care, as too much rotation may make the side planes of the spatial cells too prominent.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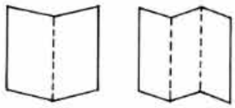
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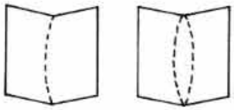
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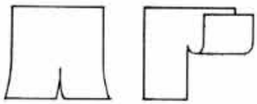
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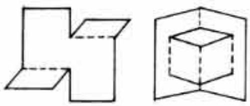
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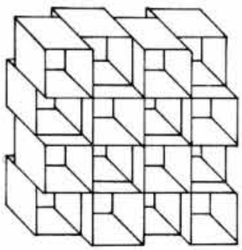
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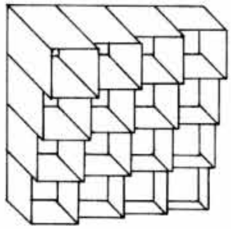
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Modifications of Spatial Cells

Greater three-dimensional quality can be achieved by the modification of spatial cells.

Enclosing planes of the spatial cells can be trimmed so that some of the front edges are not perpendicular to the base or side planes. (Fig. 96)

The straight edges of the spatial cells can be changed to curvilinear edges. (Fig. 97)

The enclosing planes of the spatial cells can be constructed so they are not at right angles to one another. (Fig. 98)

The spatial cells can be so designed that they are part of the unit form structure. (Fig. 99)

The spatial cells can become the unit forms, or we can have unit forms to erect a wall structure without the use of spatial cells. (Fig. 100)

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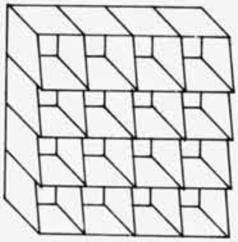

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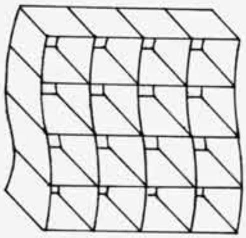

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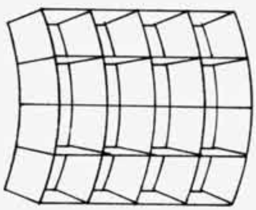

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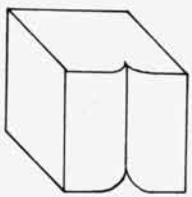

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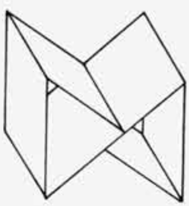
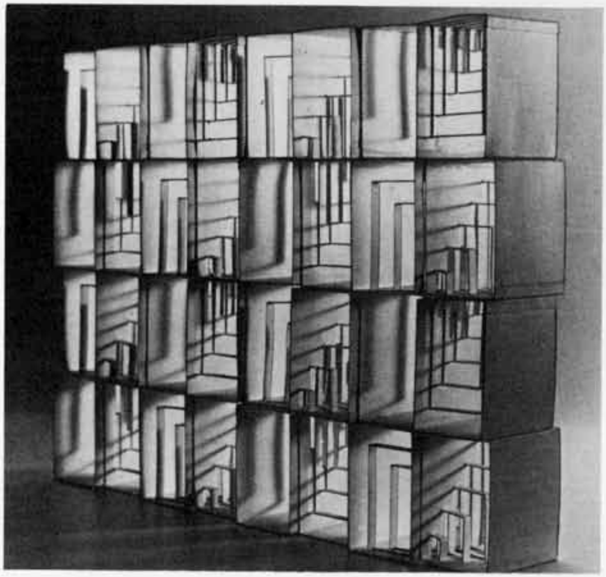


Figures 101 to 113 are examples of student projects solving the design problem of creating wall structures.

Figure 101—spatial cells here are arranged with slight positional variation. The linear unit forms are, in fact, part of the enclosing planes of the spatial cells which have been treated in a way similar to Figure 93.

Figure 102—unit forms are cutout shapes from the enclosing planes of the spatial cells. They are interlocked in an interesting way. Spatial cells are made of cardboard cubes with top and bottom planes missing, and therefore they become parallelograms in the plane view when the side edges are pulled by the interlocking unit forms.



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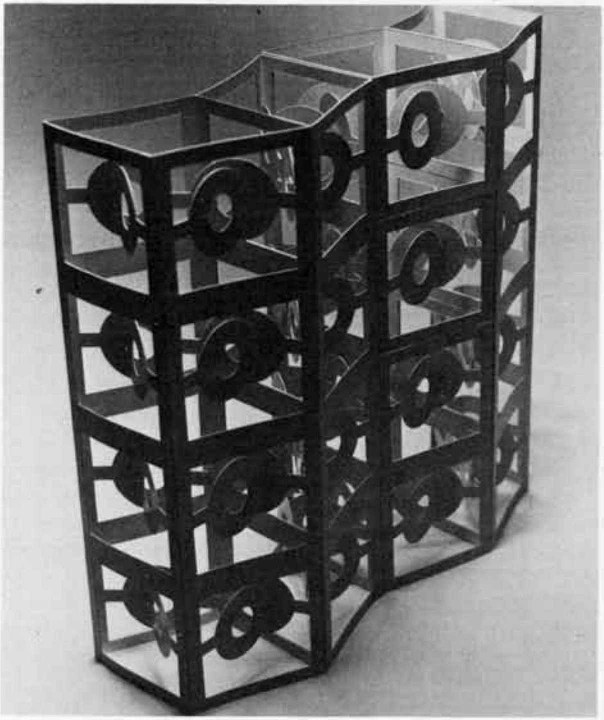

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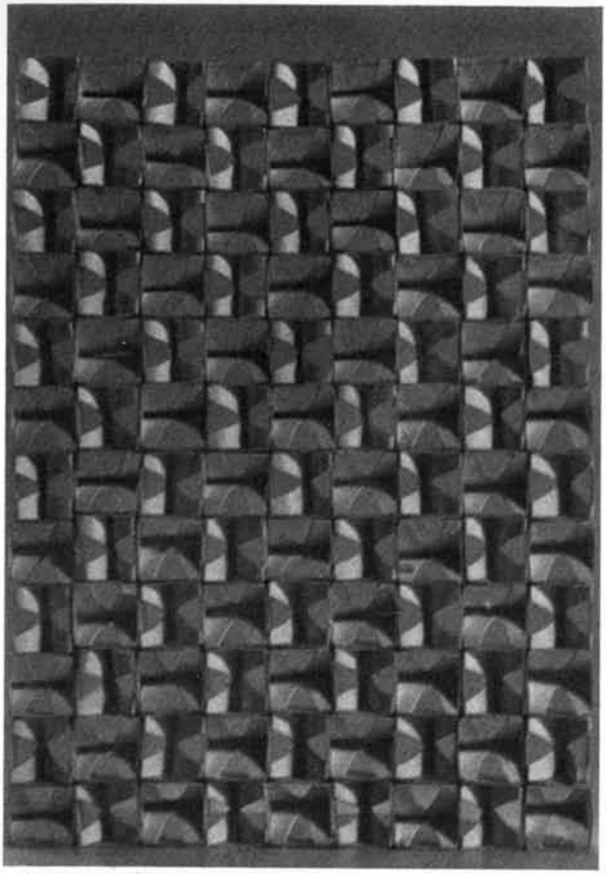

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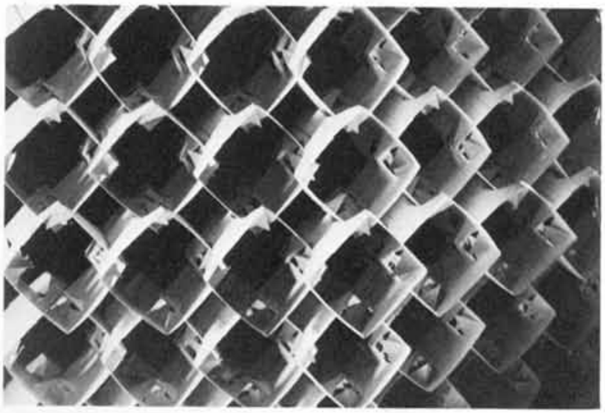
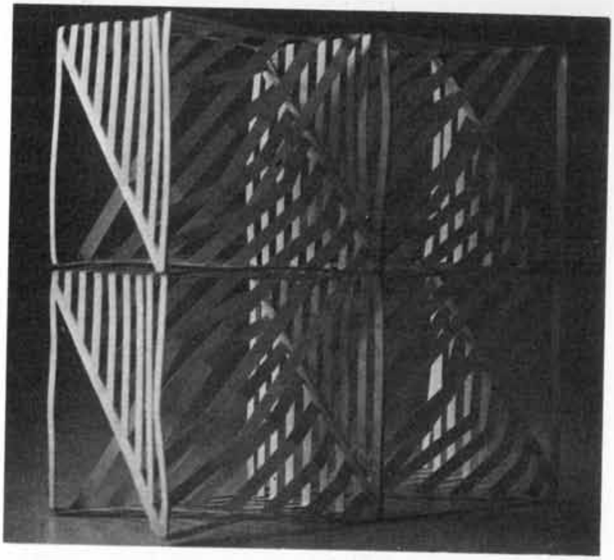


Figure 103—spatial cells here are specially constructed in a way very much like Figure 99. Triangular negative shapes are made on the curled planes. The result gives a tactile feeling of texture after the spatial cells have been repeated many times.

Figure 104—interpenetrating spatial cells are here arranged with some positional variation. The interpenetrated areas have been distorted by cutting and bending, but no separate unit forms are introduced in the spatial cells.

Figure 105—similar to Figure 101, unit forms here are strips cut and folded inward from the side planes of spatial cells. Some parts of the side planes have been removed. The whole design has a transparent effect with delicate linear elements.

Figure 106—spatial cells have been so greatly transformed that they become unit forms that are very linear in character. The depth of the design is shallow, but it contains a large number of tilted planes in various directions.



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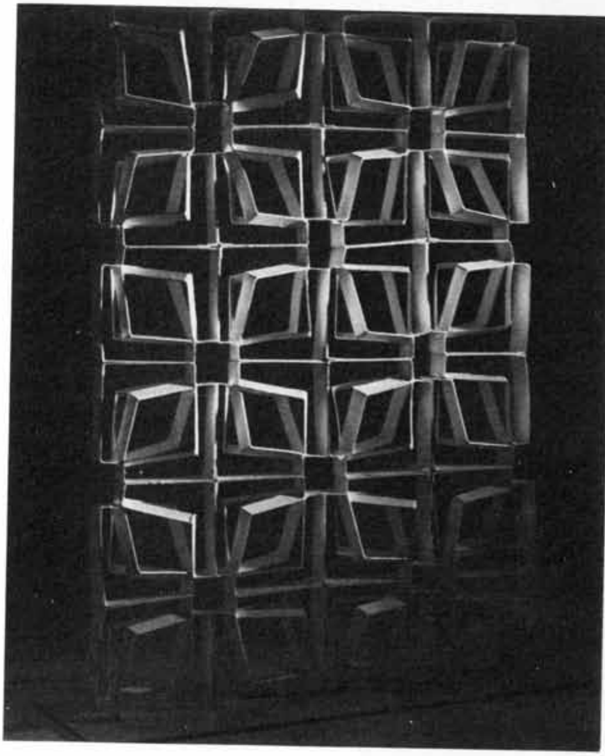

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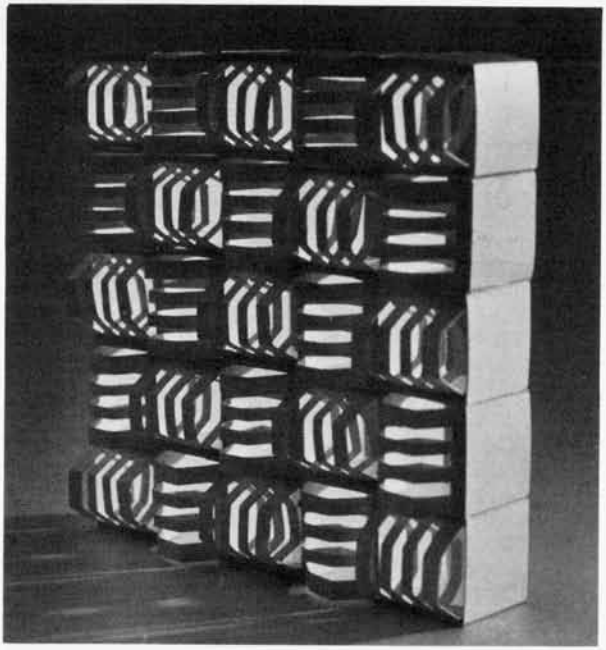

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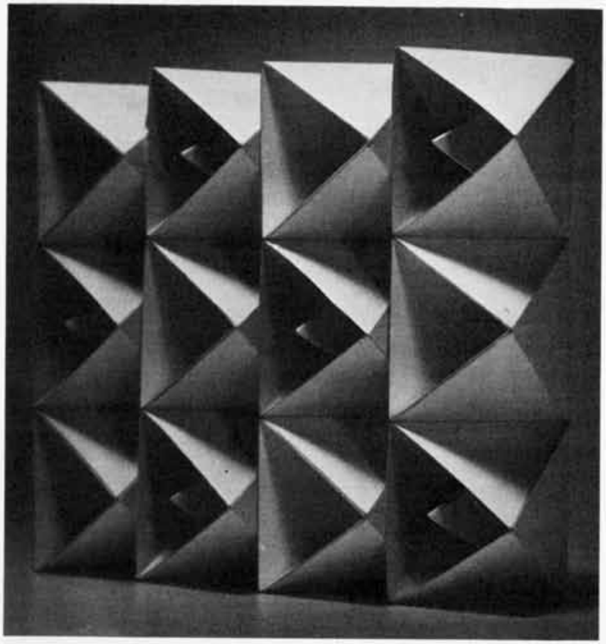

Figure 107—unit forms are placed in each spatial cell with slight projection from the front plane of the wall structure.

Figure 108—spatial cell and unit form are one and the same in this design. Triangular planes instead of square planes have been used in the construction.

Figure 109—again, the spatial cells also serve as the unit forms. The arrangement shows a gradation of cylindrical shapes. As contact between curved surfaces is rather restricted, the whole wall structure is quite flexible and can be curled at will.

Figure 110—the faceted surface of this structure has a relief effect. This is achieved by cutting, scoring and folding of flat continuous planes.

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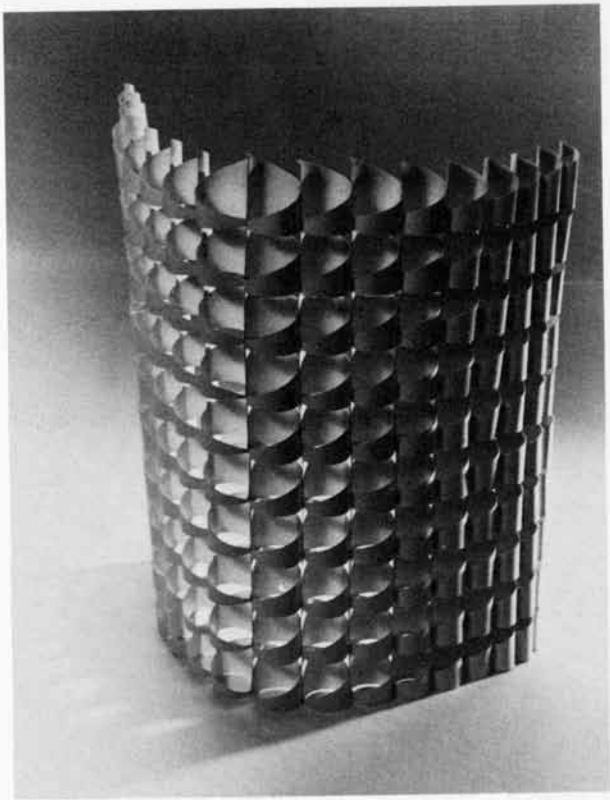

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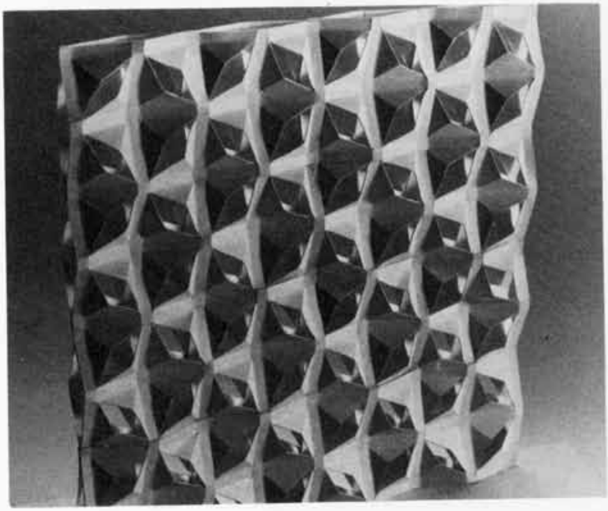

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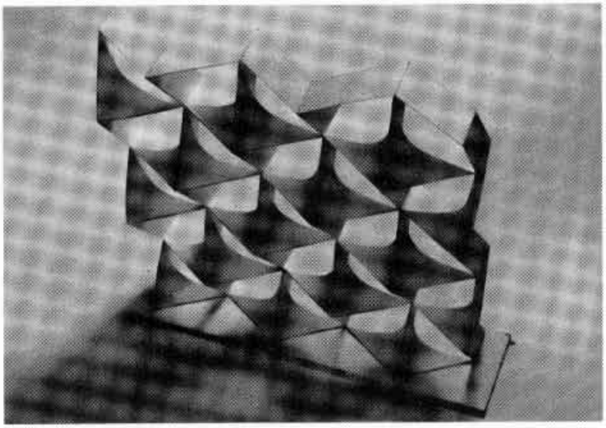

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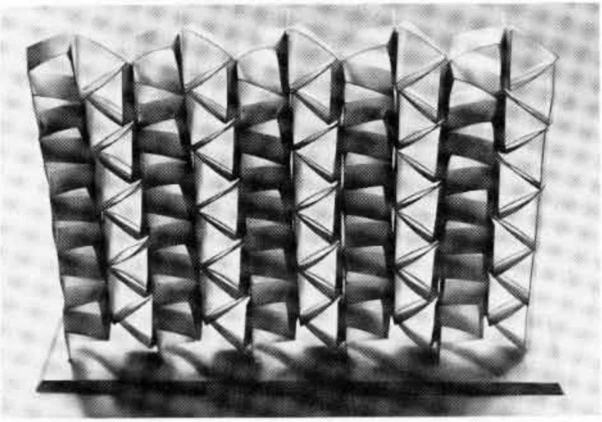

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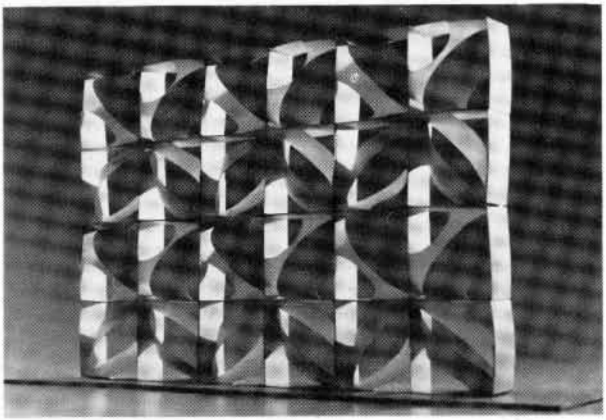


Figure 111—each spatial cell is triangular. The unit form inside it is a piece of curled plane joining two edges of the spatial cell.

Figure 112—a strip of thin cardboard is folded three times to form a spatial cell which is also the unit form. In folding, the beginning and the ending of the strip do not overlap, but instead the right edge of the beginning of the strip touches the left edge of the ending of the strip. This causes a slight twist of the planes in the resulting form.

Figure 113—the spatial cells are cubical and arranged one directly above or adjacent to the next. The unit forms are made of curled strips of thin cardboard.

CHAPTER 4: PRISMS AND CYLINDERS

The Basic Prism and Its Variations

As we have seen in the last chapter, a number of cubes placed one directly above the other makes a column. This is actually also the shape of a prism.

A prism is a form with ends which are similar, equal, and parallel rectilinear figures, and with sides which are rectangles or parallelograms. For the sake of convenience, we can have a basic prism which has parallel square ends and rectangular sides that are all perpendicular to the ends. (Fig. 114)

From this basic prism, the following variations can be developed:

(a) the square ends can be changed to triangular, polygonal, or irregularly-shaped ends; (Fig. 115)

(b) the two ends can be non-parallel to one another; (Fig. 116)

(c) the ends do not have to be of the same shape, size, and/or direction; (Fig. 117)

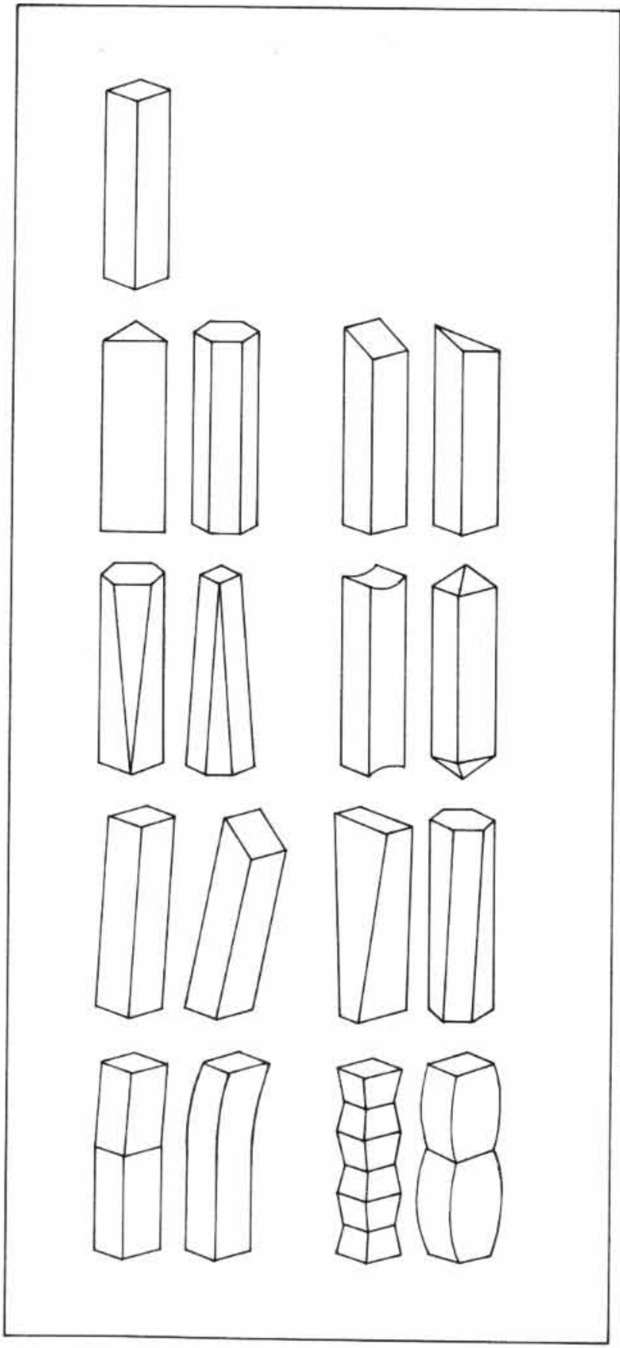
(d) the ends do not have to be flat planes; (Fig. 118)

(e) the edges do not have to be perpendicular to the ends; (Fig. 119)

(f) the edges do not have to be parallel to one another; (Fig. 120)

(g) the body of the prism can be curved or bent; (Fig. 121)

(h) the edges of the prism can be curved or bent. (Fig. 122)



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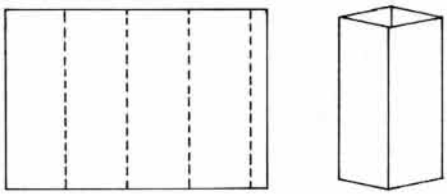

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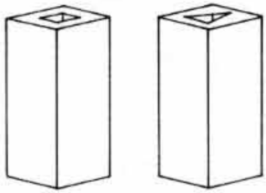

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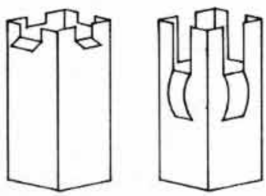

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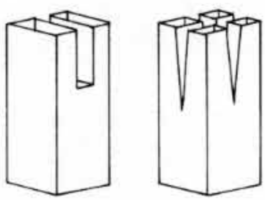

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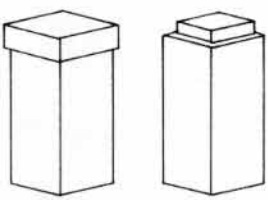


The Hollowed Prism

If the prism is not of solid material, but constructed of cardboard, then variations and transformations can be even more complicated.

Let us make a hollowed prism by using one sheet of thin cardboard which is scored, folded, and glued together. The ends of this prism are open, without covering planes. (Fig. 123)

Ends, edges, and faces of this prism can all be treated in special ways.

Treatment of the Ends

The ends of the hollowed prism can be treated in one or more of the following ways:

(a) the ends may be covered up, but instead of using a flat continuous plane for each end, we can have planes containing negative shapes; (Fig. 124)

(b) the edges or faces near the two ends can be cut into different shapes, and the resulting loose pieces can be curled or folded if necessary; (Fig. 125)

(c) the ends can be split into two or more sections; (Fig. 126)

(d) a specially designed shape can be formed on or attached to the ends. (Fig. 127)

Treatment of the Edges

Treatment of the edges usually affects the faces as well. Diversion from parallel edges not only changes the rectangularity of the shapes of the faces, but sometimes leads to warped or faceted faces which can be very interesting. Ends of the prisms may also be affected.

Our illustrations here show the following treatments:

(a) nonparallel straight edges; (Fig. 128)

(b) wavy edges; (Fig. 129)

(c) chain of rhombic shapes along the edges; (Fig. 130)

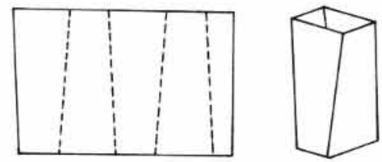
(d) circular shapes developed along the parallel straight edges; (Fig. 131)

(e) intersecting edges; (Fig. 132)

(f) complicated pattern scored on the surface of the thin cardboard before it is folded to form a prism. Some of the lines of the pattern are also the edges of the prism. (Fig. 133)

Other edge treatments may be just simple subtraction or addition of shapes along the edges.

In subtraction, negative shapes are introduced along the edges.



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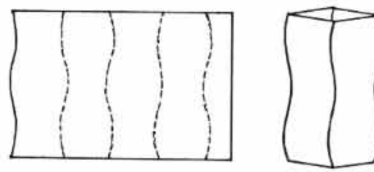

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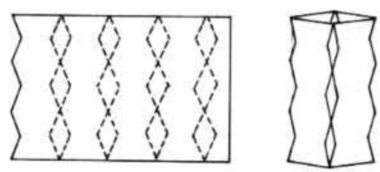

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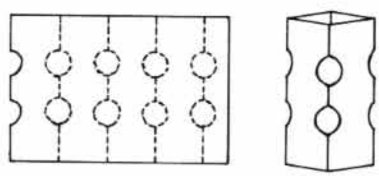

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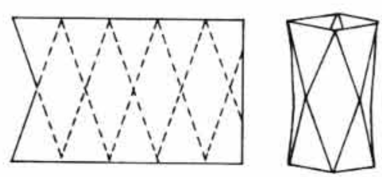

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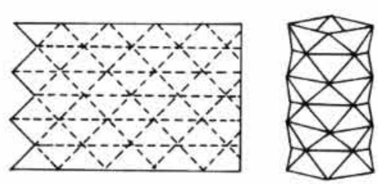

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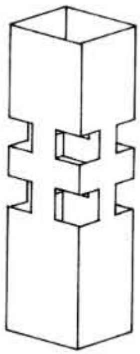

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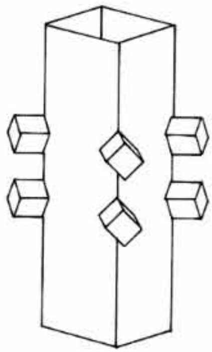

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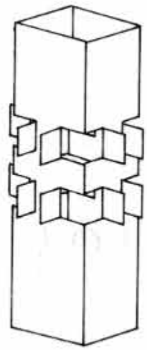

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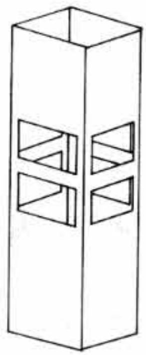

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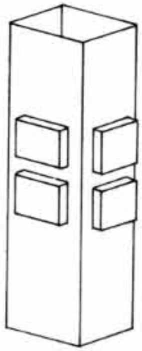

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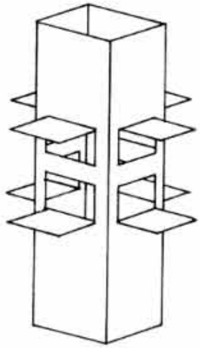


As each edge is the joining of two faces, negative shapes are made by cutting away some parts of both of these adjacent faces. (Fig. 134)

In addition, separately made shapes are attached to the edges. Such shapes may cover or intrude a little bit on the adjacent faces unless the shapes are strictly planar in nature. (Fig. 135)

It is possible to have lines cut and scored or shapes partially cut along the edges and on the adjacent faces. By bending such shapes inwards (or sometimes outwards as well) without detaching them, a play of positive and negative forms is created. (Fig. 136)

Treatment of the Faces

Face treatment is very much the same as edge treatment.

In subtraction, holes are made on the faces. Any negative shape which does not lead to loose parts or weakening of the structure can be used. (Fig. 137)

Addition allows any shape with a flat base to be adhered to the flat faces. Additional shapes can always be fitted to negative shapes on the faces. (Fig. 138)

Half-cut shapes can always remain hinged or folded in and out on the faces of the prism. (Fig. 139)

Joining of Prisms

Two or more prisms can be used in one design by joining them in various ways.

Joining can be done easily by

face contact, whether the prisms are parallel or not parallel. The bond in this case is very strong as long as the glue is strong. (Fig. 140)

Edge contact is weaker because the area along the edges on which glue can be applied is very limited. In cardboard construction, it is possible that the face of one prism can be extended to form the face of another prism, in which case the strength of the face plane will be the strength of the bond. If the cardboard is thin, one prism is really hinged on the other one and the joint is a flexible one. (Fig. 141)

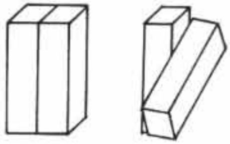
End contact doubles the height of the prism. In this case, there should be flat planes covering the ends, and the joining is actually done by adhesion of one plane to another, as in face contact. (Fig. 142)

The end of one prism can be joined to the face of another, making a T shape or L shape. If the ends of the prisms are mitred, an L shape can also be formed. (Fig. 143)

Two crossed prisms can be interlocked if the body of one prism is fitted into the body of another. (Fig. 144)

We can construct two crossed prisms which are integrally united to one another by constructing some of the double faces out of the same piece of cardboard. (Fig. 145)

Union of a number of prisms joined at the ends can lead to a framelike structure or a structure with linear continuity. (Fig. 146)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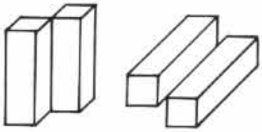
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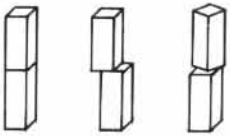
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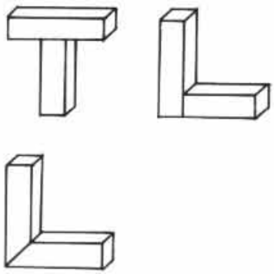
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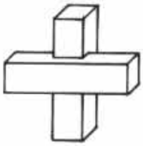
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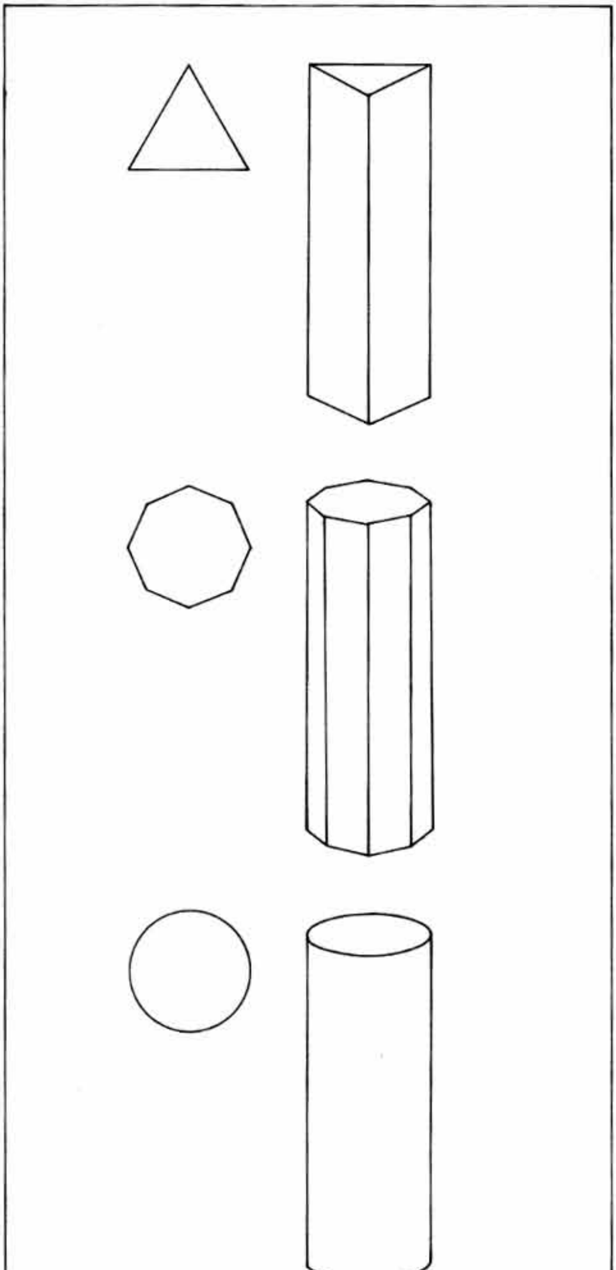


The Prism and the Cylinder

The minimum number of flat planes we can use for the sides of a prism is three, which results in a prism with a triangular top and bottom.

If we increase the number of sides in the prism, the top and bottom shapes will change from triangles to polygons. The more sides a polygon has, the less angular and closer to circular it becomes. For instance, an octagon is much less angular than a triangle, and thus an octagonal prism has a much rounder body than a triangular one.

By increasing the number of sides of a polygon infinitely, a circle may finally be reached. In the same way, by increasing the number of sides of a prism infinitely, a cylinder may finally be created. (Fig. 147)

The body of a cylinder is defined by one continuous plane, without beginning or end, and the top or bottom of a cylinder is in the shape of a circle.

Variations of a Cylinder

We may say that the standard cylinder consists of two parallel circular ends of the same size and a body perpendicular to the ends. From the standard, the following deviations are possible:

(a) the body can be slanting; (Fig. 148)

(b) the ends can be of any round-cornered shape; (Fig. 149)

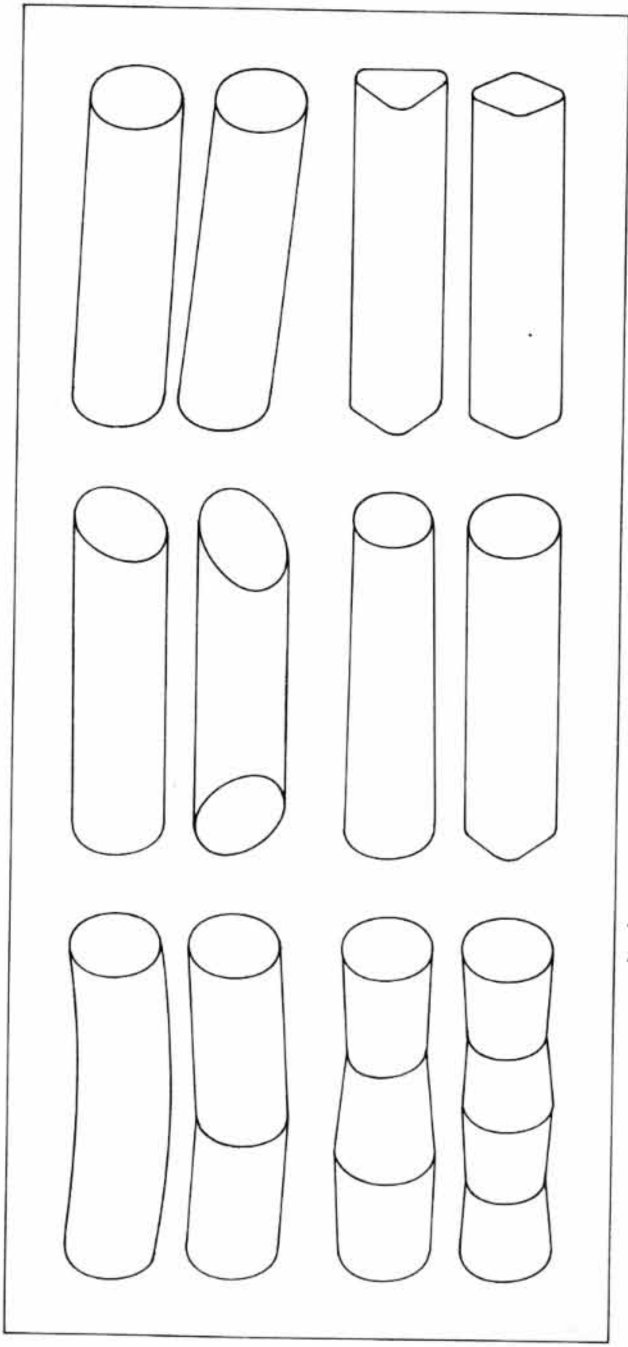
(c) the ends can be nonparallel to each other; (Fig. 150)

(d) the ends can be of different sizes or shapes; (Fig. 151)

(e) the body can be bent; (Fig. 152)

(f) the body can expand or contract at intervals. (Fig. 153)

End and face treatments can be applied to the cylinder in the same way as they are applied to the prism.



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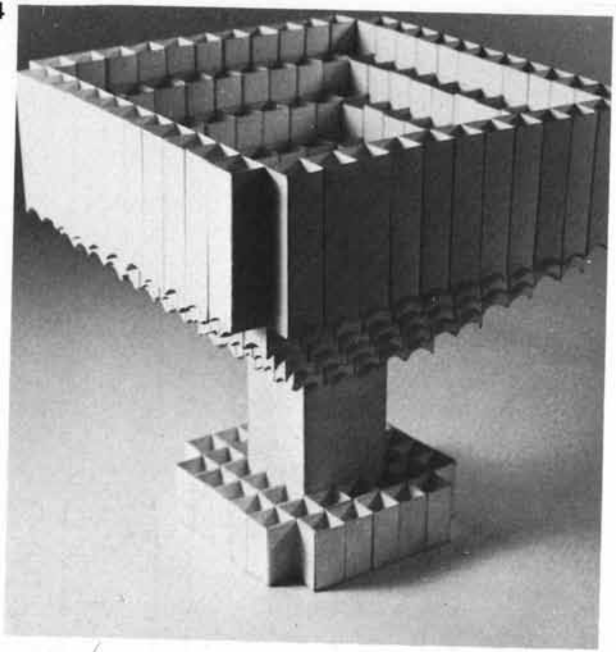

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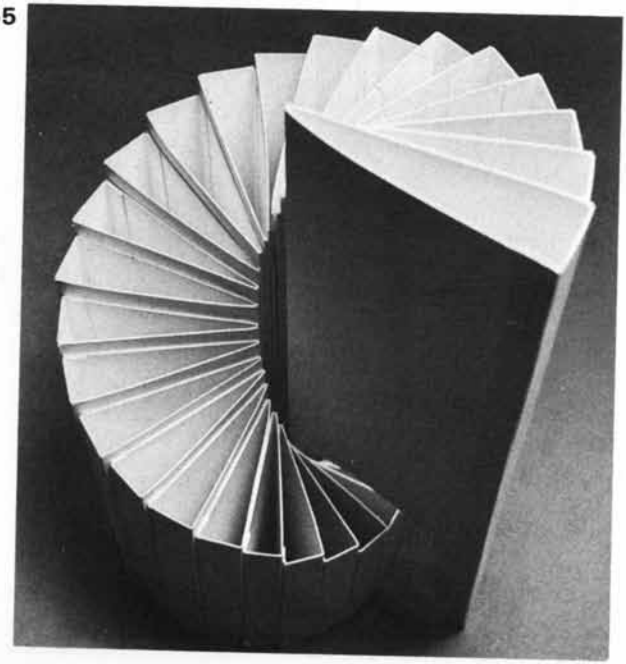


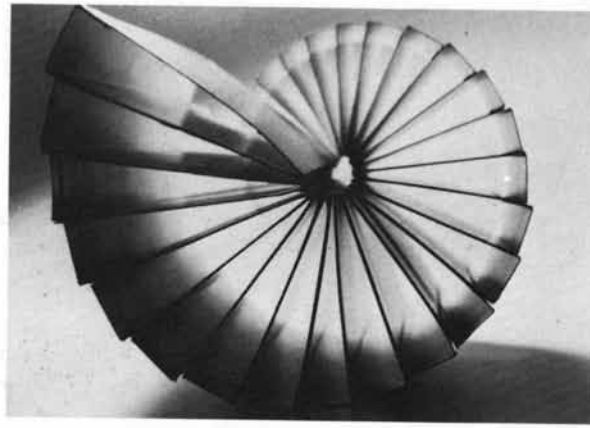
Figures 154 to 163 all illustrate different approaches in the use of prisms. Figure 157 is a single prism with surface treatment of the body and the faces, the other projects all explore possibilities of using prisms as unit forms in design.

Figure 154—numerous square prisms of varying heights have been used. Note that near the lower ends, the faces of many of the prisms have been trimmed into circular shapes.

Figure 155—this spiral design is made of a number of triangular prisms which rise gradually in height. The lower ends of the taller prisms have been shaped to produce an area of cavity for the accommodation of the shorter prisms which mark the beginning of the upward spiral.

Figure 156—this is another view of the same design illustrated in Figure 155.

Figure 157—the body shape of this prism has been much transformed. Face treatment also reveals some negative circular shapes in the inner layer of the construction.



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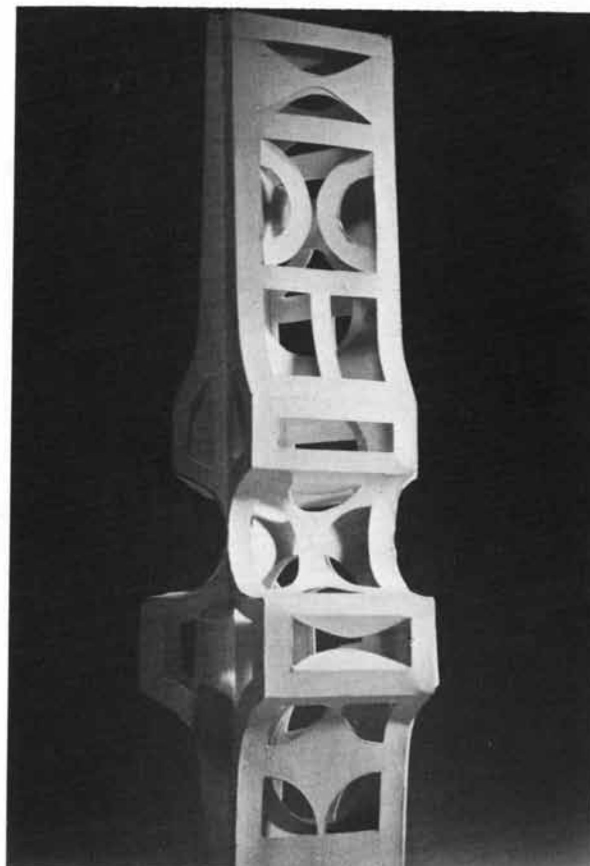

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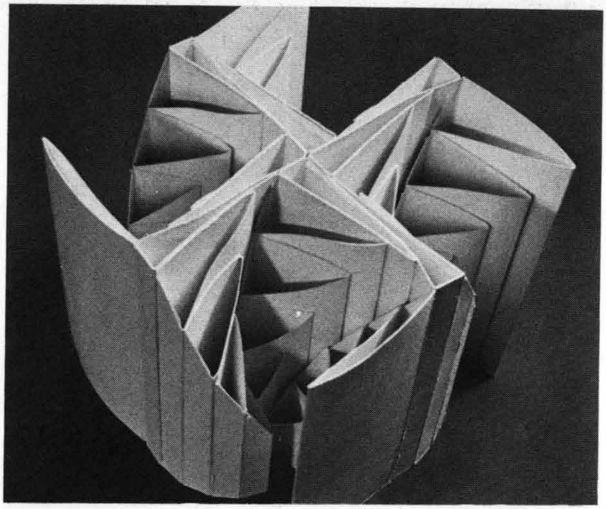

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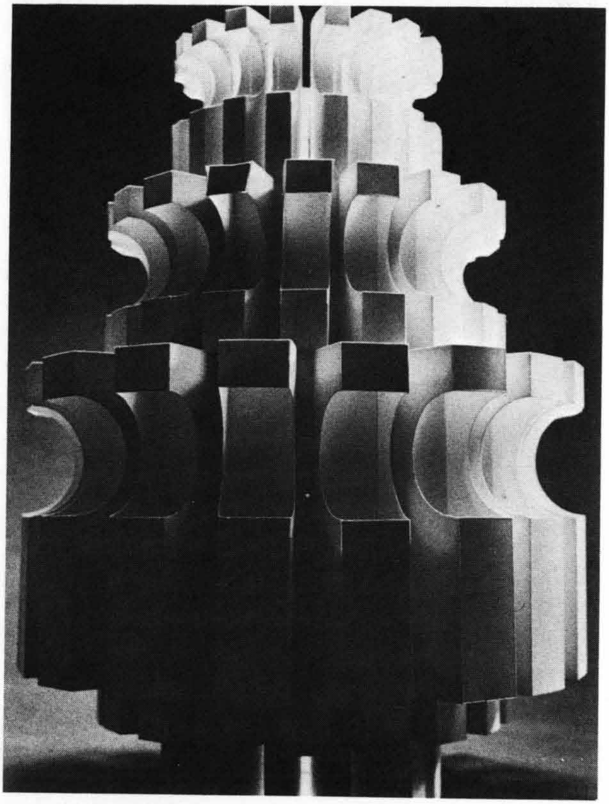

Figure 158—four sets of triangular prisms in gradation of size and shape have been used in this design.

Figure 159—this consists of three concentric layers. The innermost layer has the tallest but also narrowest prisms. The outermost layer has the shortest but biggest prisms.

Figure 160—this is constructed of seven prisms, all of which are bent sharply near the bottom, while also treated on the faces with zigzag patterns.

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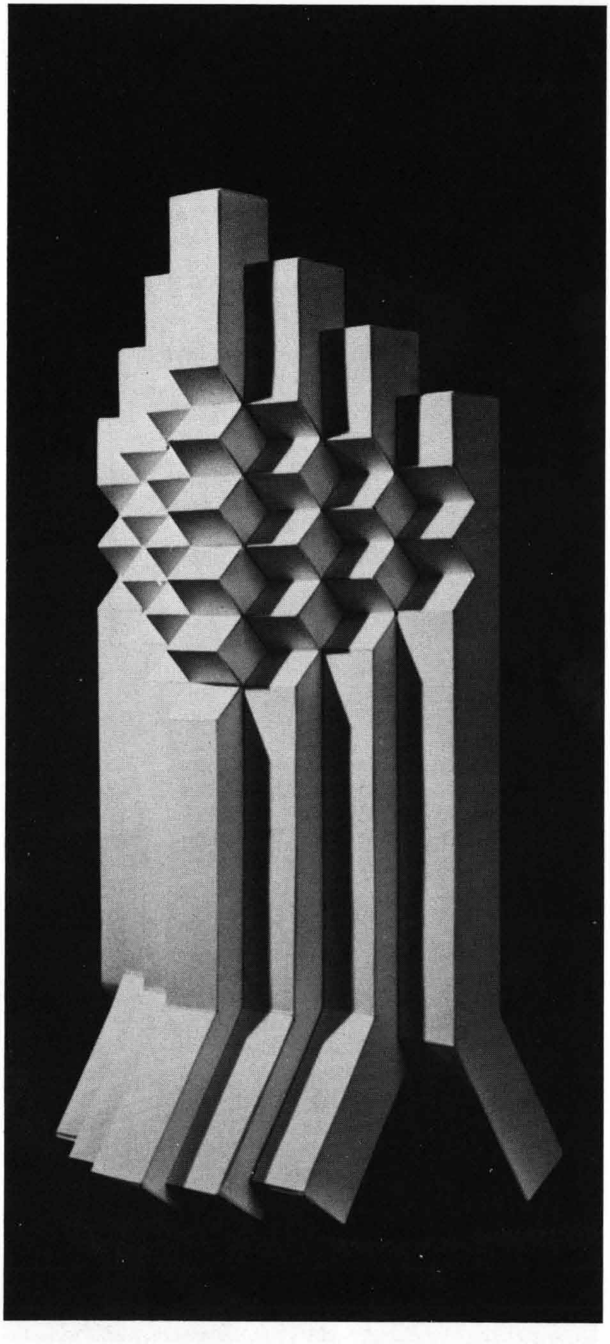

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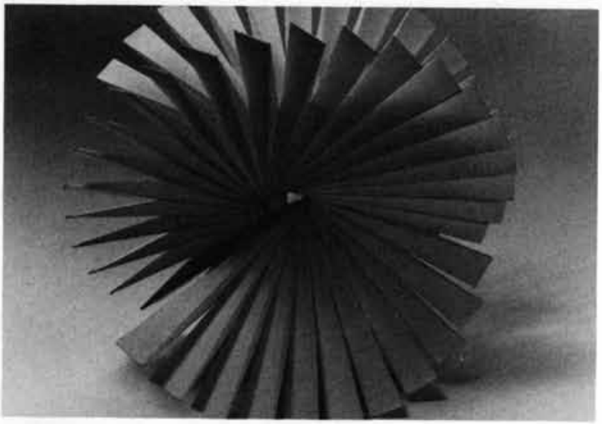

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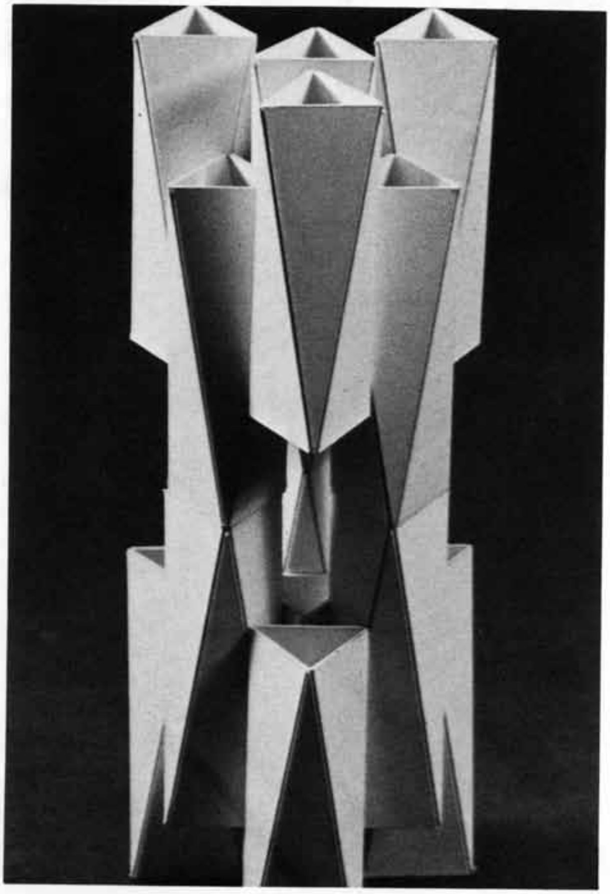

Figure 161—each prism is actually a wedge shape constructed of four elongated isosceles (equal-legged) triangles and has two flat-tipped ends. The spiral construction is the result of gluing a number of such prisms together by face contact.

Figure 162—triangular planes have also been used for the prisms in this design. Each prism consists of six triangular planes, and the ends are in triangular shapes which are open and not covered. The construction is made by edge and end contact.

Figure 163—prisms used in this design have been constructed of three triangular planes and one rectangular plane. The lower end of each prism is in a triangular shape, but the top end is only a slit opening between two planes. The prisms are arranged in a fanlike manner.

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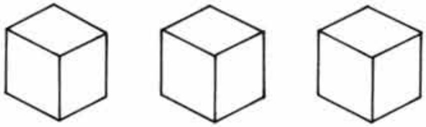

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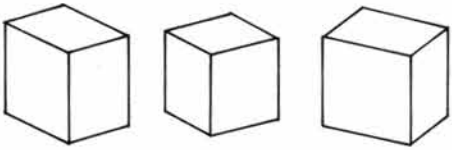

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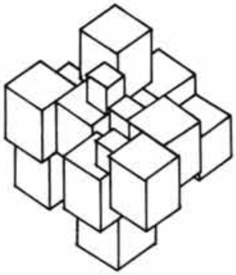

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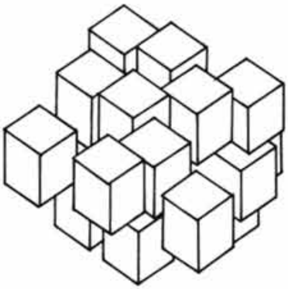

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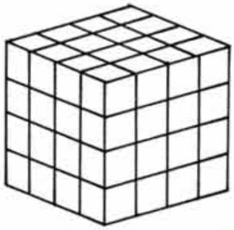


CHAPTER 5: REPETITION

Repetition of Unit Forms

Repetition of unit forms has been briefly mentioned in Chapter 1. We have also seen that many of the examples illustrated in Chapters 2, 3, and 4 contain unit forms in repetition.

In the narrowest sense, repetition of unit forms means that all the visual elements—shape, size, color, and texture—of the unit forms should be the same. (Fig. 164)

In a broad sense, identical color or texture among unit forms can constitute repetition. Of course, the unit forms have to relate to one another by similarity or gradation of shape as well, otherwise they cannot be grouped as unit forms. (Fig. 165)

Shape, in any case, is the most essential visual element when we speak of unit forms. Thus, when we speak of repetition of unit forms, repetition of shape must always be included. It provides an immediate feeling of unity even though the unit forms are rather informally arranged. (Fig. 166)

Visual unity is further strengthened when the unit forms are repeated both in shape and size. (Fig. 167)

If a high degree of regularity in organization is desired, such unit forms can be put together in a design guided by a repetition structure. (Fig. 168)

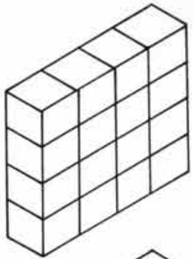
Repetition Structure

The wall structure described in Chapter 3 is already a kind of repetition structure, except that it is only two-dimensional in nature. (Fig. 169)

To obtain a truly three-dimensional structure, this wall structure can be extended forwards and backwards. In this way, it not only has a front view but can be seen properly from all sides. (Fig. 170)

We can define a repetition structure as one in which the unit forms, or the spatial cells containing them, are put together in regular sequence and pattern so that they all relate to one another in the same manner.

It is not easy to illustrate on paper the various types of repetition structure in three-dimensional design. The simplest way is to analyze these structures in terms of vertical layers or horizontal layers. Vertical or horizontal layers are actually the same thing in most symmetrical designs which can be turned sideways for a different viewing. (Fig. 171)



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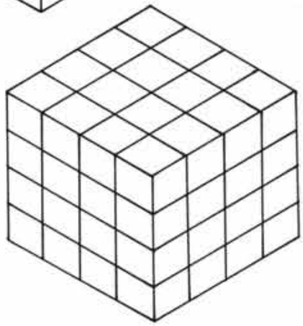

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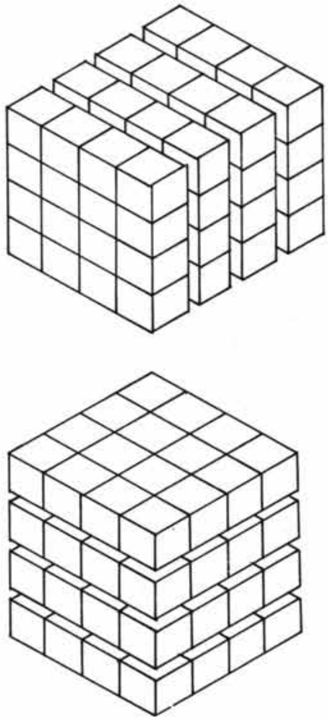

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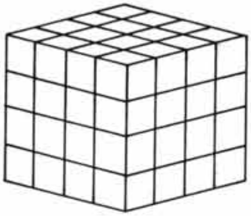

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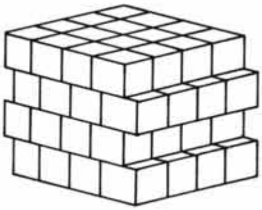

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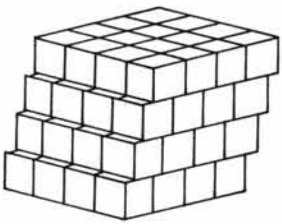

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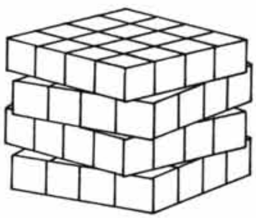

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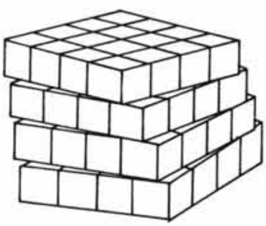


Arrangements of the Layers

To illustrate the organization of a repetition structure, let us start with arranging four layers of spatial cells or unit forms.

The simplest arrangement is to have each layer directly above the next. (Fig. 172)

Then we shift the positions of alternate layers. (Fig. 173)

Or we can arrange them in positional gradation. (Fig. 174)

Directional variation is also possible. Directions of alternate layers can be shifted. (Fig. 175)

Or we can arrange the layers in directional gradation. (Fig. 176)

Organization Within Each Layer

Within each layer, there are numerous ways of arranging the unit forms, and alternate layers can be arranged differently. We have illustrated nine spatial cells or unit forms in one layer to explore the various possibilities. First we arrange them in three rows and put them closely against one another. (Fig. 177)

The positions of the rows can be shifted. (Fig. 178)

There can be gaps between the spatial cells or unit forms. (Fig. 179)

If all the spatial cells or unit forms do not touch one another, the adjacent layer can be arranged differently to help hold the spatial cells or unit forms of the first layer in position. (Fig. 180)

Directional variation can be introduced among the spatial cells or unit forms. (Fig. 181)

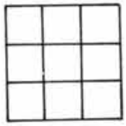
Joining of Unit Forms

Spatial cells, which are usually of simple geometric shapes, can usually be joined to one another by face contact, but unit forms, when used without spatial cells, may be of shapes or in positions which demand various kinds of joining.

Face contact certainly gives the firmest bond. This can be full face contact or partial face contact. (Fig. 182)

Edge-to-face or edge-to-edge contacts tend to be weaker and may give flexible joints. (Fig. 183)

Vertex-to-face, vertex-to-edge or vertex-to-vertex contacts are generally difficult to control, and care must be exercised if such joints are necessary. (Fig. 184)



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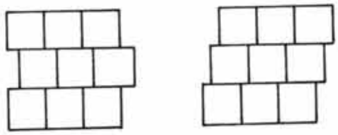

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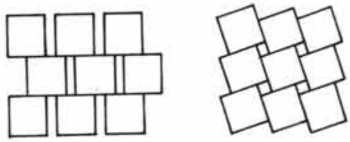

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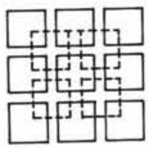

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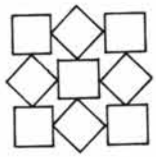

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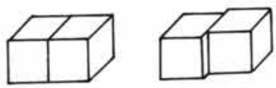

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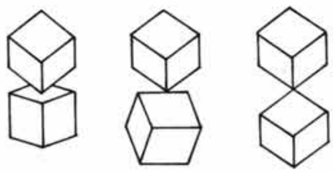

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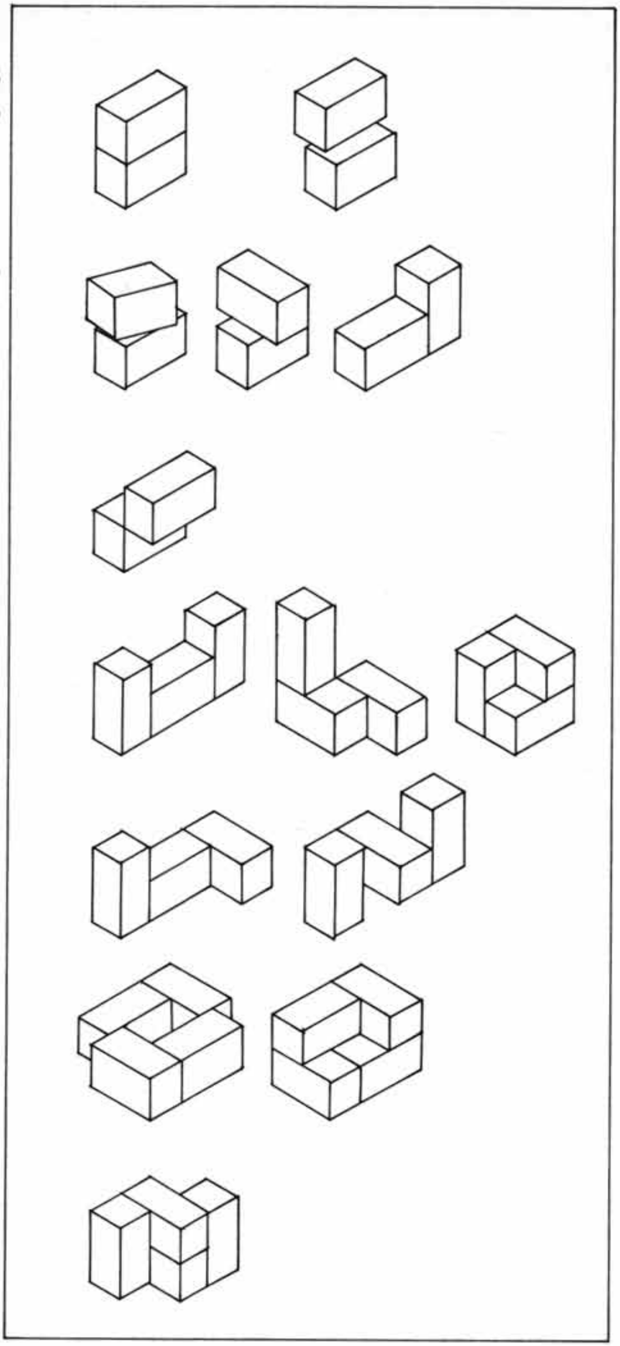


Square Prisms as Unit Forms or Spatial Cells

The structure becomes a bit more complex if the unit form or the containing spatial cell is not a cube with three equal dimensions. We have illustrated a square prism as an example, to see how many ways two or more of these units can be put together.

Certainly we can place one directly above another by face contact. (Fig. 185)

We can place one above another without aligning the edges. (Fig. 186)

The two prisms can be positioned in different directions. (Fig. 187)

They can be in edge-to-edge contact. (Fig. 188)

Three prisms can form more complicated shapes. (Fig. 189)

Four give wider possibilities of interesting combinations. (Fig. 190)

Once the relationship of the two or more prisms is established, the new shape can be repeated in a repetition structure.

L-Shape Unit Form or Spatial Cell

The basic square prism we have just seen can be composed of two cubes. Three cubes can make a basic L-shape which has a right-angle bend and two arms pointing towards different directions.

With an L-shape unit form or spatial cell, possibilities in construction can be quite challenging. (Fig. 191)

We can first study the L-shape as a flat shape to see how two or more L-shapes combine to form new shapes. (Fig. 192)

Then we can use two or more three-dimensional L-shapes to create new shapes which are truly three-dimensional in character. (Fig. 193)

Again, the new shape can be repeated in a repetition structure.

Unit Forms in a Repetition Structure

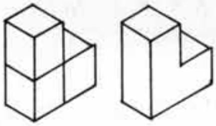
Most unit forms are far more complicated than the plain cube, the square prism, or even the L-shape. In organizing the unit forms into a repetition structure, the following points should be noted:

(a) unit forms cannot float in space and must be anchored properly. The influence of gravity cannot be ignored;

(b) strength of the structure must be taken into consideration.

(c) the front view should not be emphasized to the neglect of the other views;

(d) unit forms can interlock with or interpenetrate one another. Space between unit forms on one layer can be filled by unit forms of the next layer. Concavity and convexity can complement each other. (Fig. 194)



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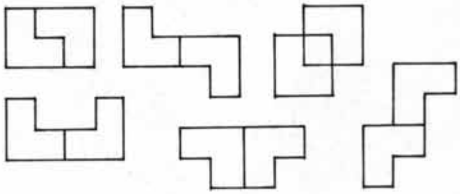

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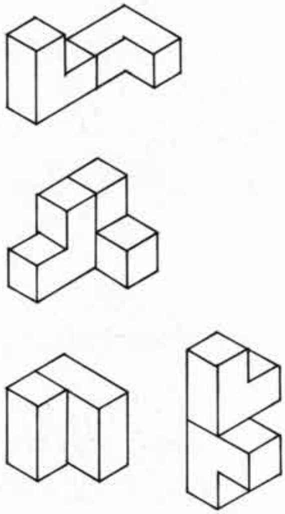

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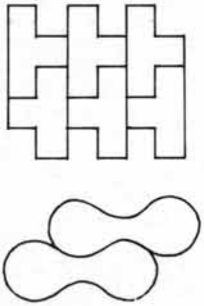

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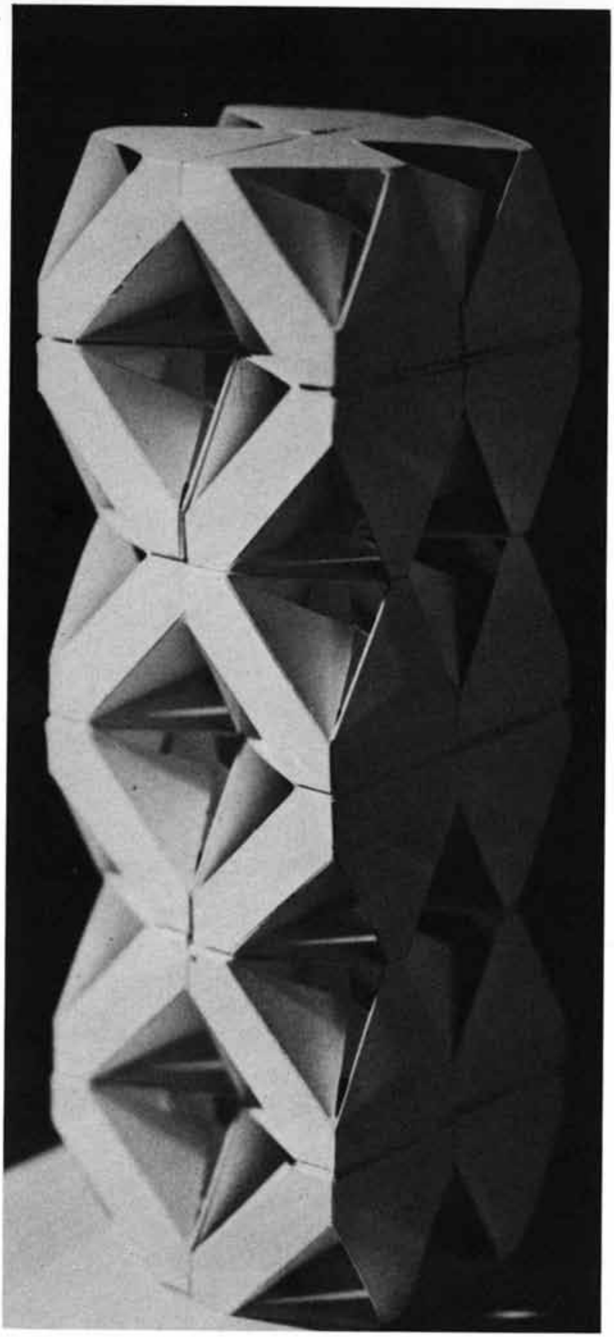
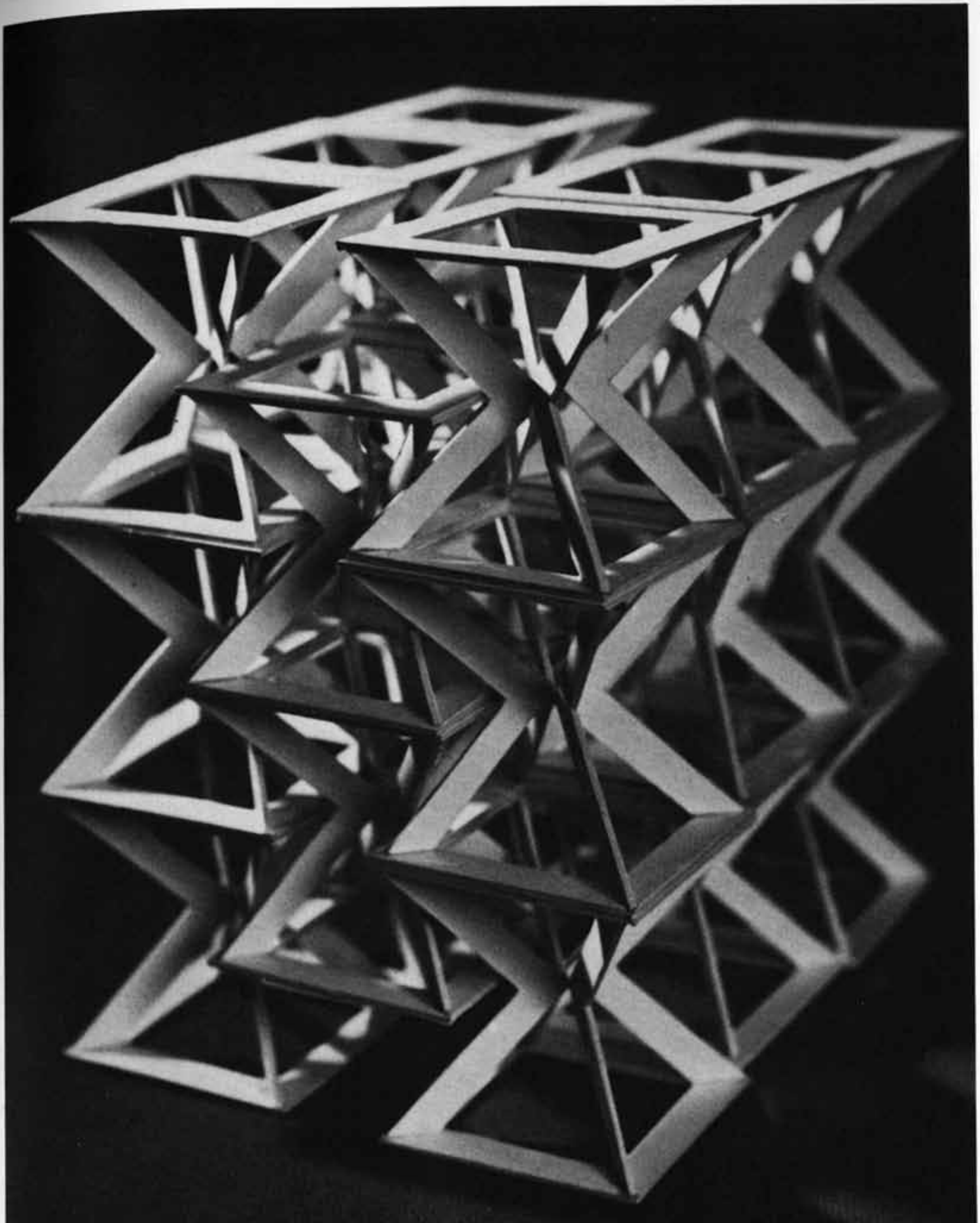


Figures 195 to 202 all illustrate the repetition of unit forms (including all visual elements) in a repetition structure.

Figure 195—there are six horizontal layers, each layer containing four unit forms. Each unit form is actually developed from a cube.

Figure 196—unit forms used in this design are also developed from a cube. Each unit form has square top and bottom, but a very narrow waist. There are three vertical layers, and it is interesting to notice how the central layer is fitted into the negative space between the left and right layers.



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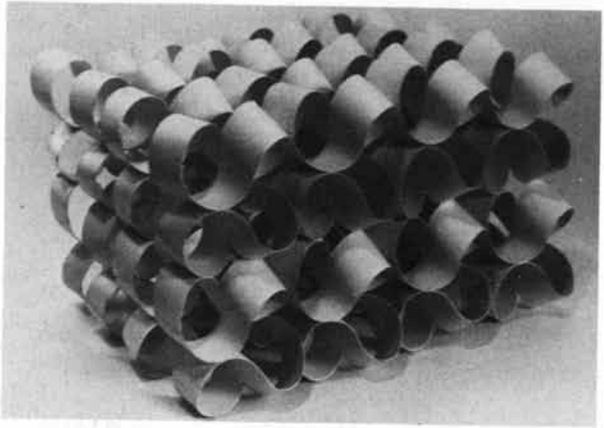

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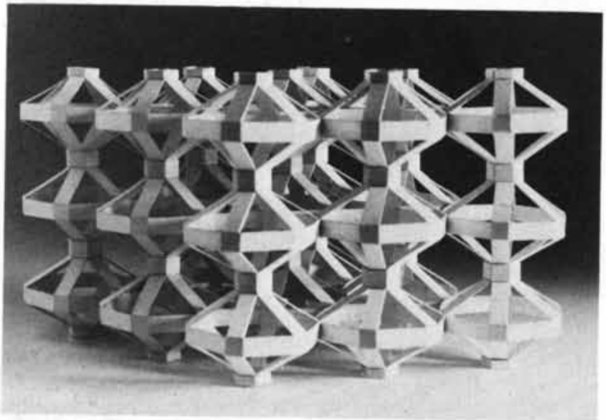

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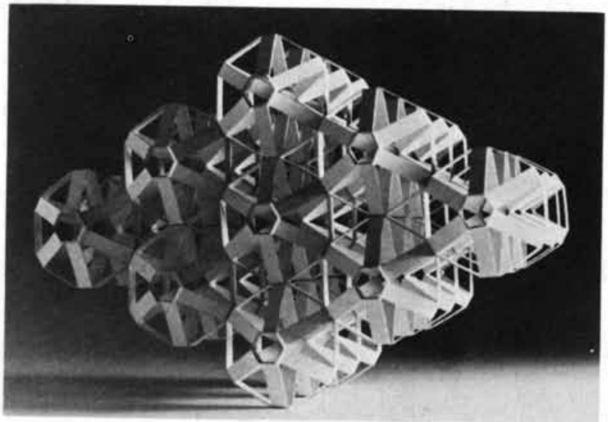


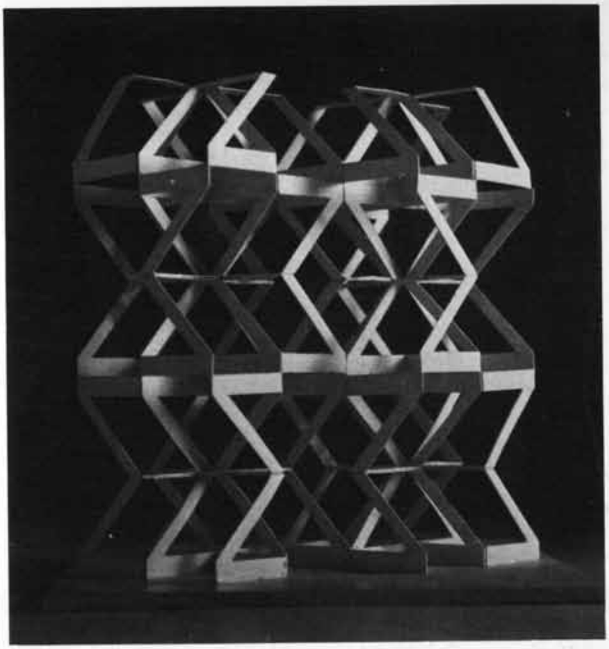
Figure 197—four horizontal layers comprise this design. Each unit form is made of a strip of thin cardboard split at both ends into two narrow bands. At each end, the narrow bands are curled and joined. The final shape is like the numeral 8 lying on its side.

Figure 198—The plane view of each unit form is a hexagon. The side view is a rhombus. The unit forms are joined to one another at the vertices, which are not pointed but flattened. There are three horizontal layers, with nine unit forms in each layer.

Figure 199—another view of Figure 198. The top view is now the side view.

Figure 200—the unit form here looks like the letter X or Z, and is derived from a hollowed cube with side planes partially cut and removed. There are five horizontal layers altogether.

Figure 201—a Y-shaped flat plane is used for construction of the spherical unit form. To do this the three arms of the Y-shape are curled and joined together. The design is built of seven horizontal layers, but the number of unit forms for each layer is in gradation.



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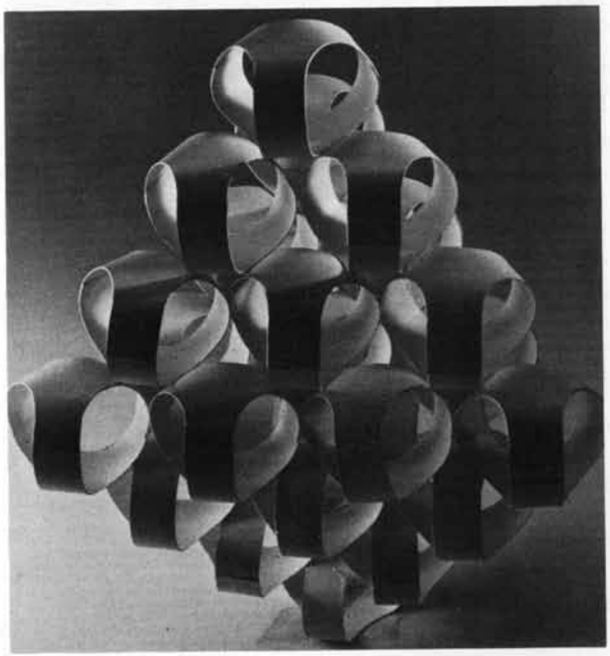

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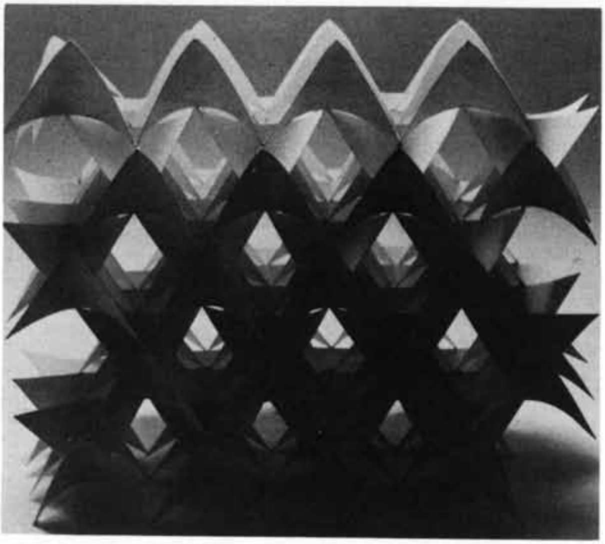
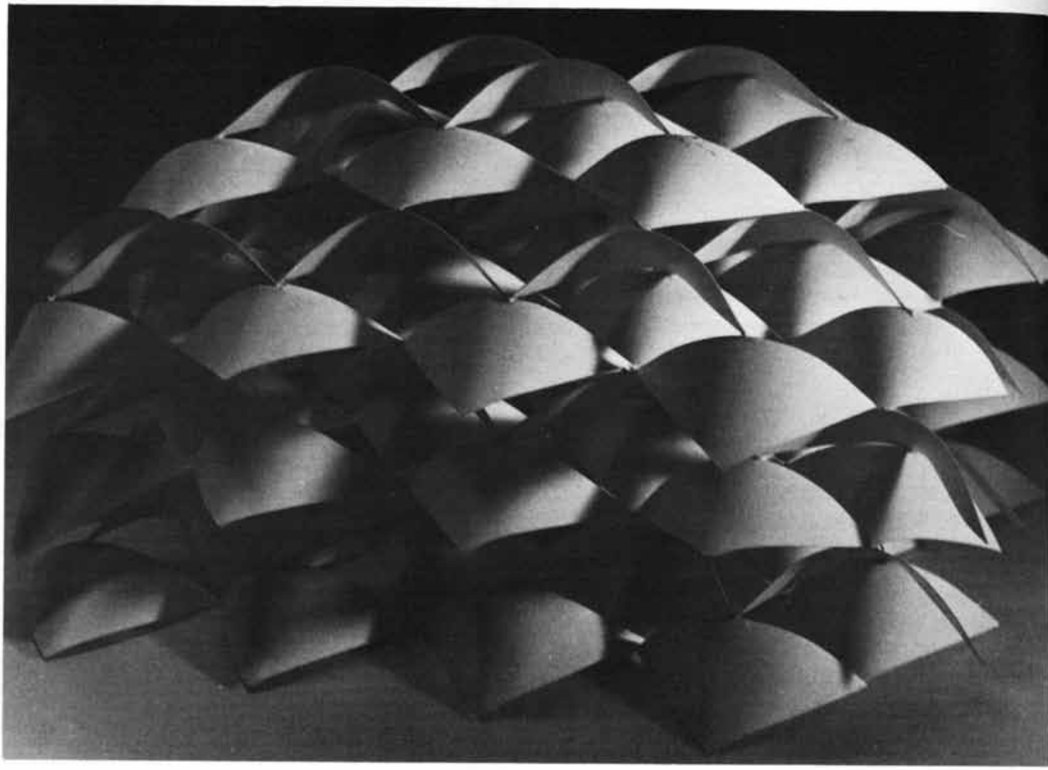
202 

Figure 202—the unit form for this design is remarkably simple. It is a triangular piece that has been slightly curled. The joining is either by vertex-to-vertex or vertex-to-edge contact. The structure may be rather fragile, but it gives the design an attractively delicate effect.

Figure 203—this is a different view of Figure 202.

203 

CHAPTER 6: POLYHEDRAL STRUCTURES

The Platonic Solids

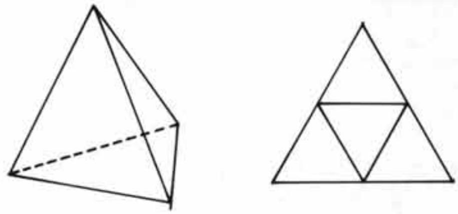
Polyhedra are fascinating shapes, which can be adopted as basic structures in three-dimensional design. Among them are five fundamental regular geometric solids that are of prime importance. As a group they are called Platonic solids, and include the tetrahedron (four faces), the cube (six faces), the octahedron (eight faces), the dodecahedron (twelve faces), and the icosahedron (twenty faces). Each is constructed of regular faces, all congruent, and their vertices are regular polyhedral angles.

The tetrahedron contains four faces, four vertices, and six edges. Each face is an equilateral triangle. (Fig. 204)

If it rests on one of its faces, the plane view is an equilateral triangle. If it rests on one of its edges, in a rather unstable way, then its plane view is, unexpectedly, a square. (Fig. 205)

The tetrahedron is the simplest among the Platonic solids, but it is the strongest structure that can be made by man.

The cube is the best known shape among the Platonic solids. We have mentioned it frequently right from the beginning of this book. It contains the three primary directions and is indispensable for the establishment of the three basic views (see Chapter 1).



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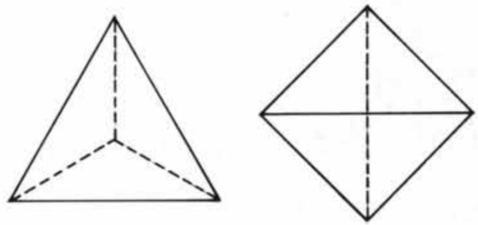

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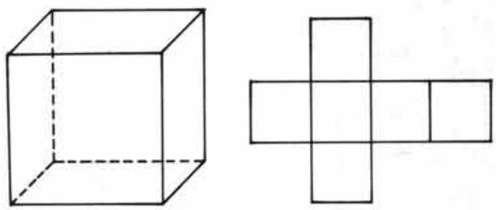

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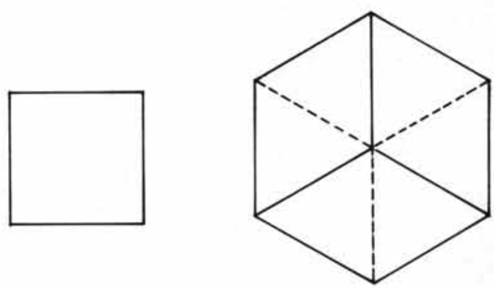

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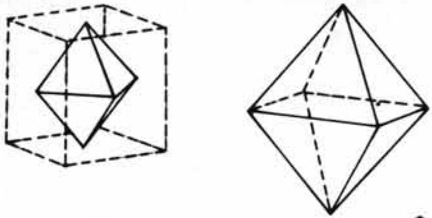

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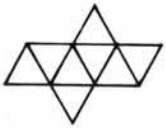

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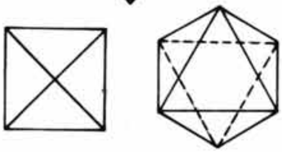

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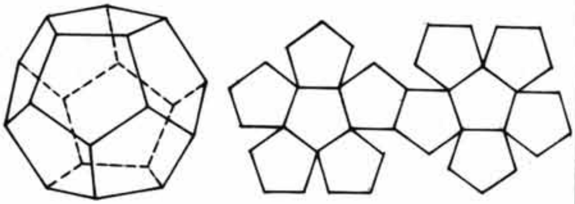

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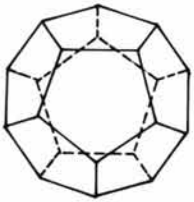

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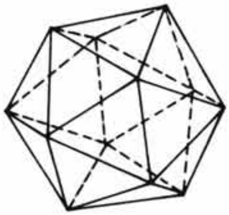

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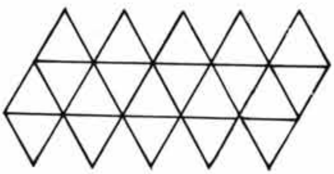

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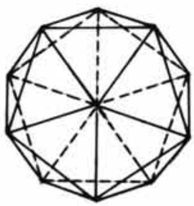


There are six faces, eight vertices, and twelve edges in a cube. Each face is a square. All angles are right angles. (Fig. 206)

If it rests on one of its faces, the plane view is a square. If it rests on one of its vertices, then its plane view is a regular hexagon (six sides). (Fig. 207)

The octahedron is the dual of the cube. This means that to form an octahedron, each vertex of the cube is replaced by a face of the octahedron, and each face of the cube by a vertex of the octahedron. (Fig. 208)

An octahedron has eight faces, six vertices, and twelve edges. Each face is an equilateral triangle. (Fig. 209)

If it rests on one of its vertices, the plane view is a square. If it rests on one of its faces, the plane view is a hexagon (six sides). (Fig. 210)

The dodecahedron is composed of regular pentagons (five sides). It has twelve faces, twenty vertices, and thirty edges. (Fig. 211)

If it rests on one of its faces, the plane view is a regular decagon (ten sides). (Fig. 212)

The icosahedron is the dual of the dodecahedron. It has twenty faces, twelve vertices, and thirty edges. (Fig. 213)

Each face is an equilateral triangle, just as in the tetrahedron and the octahedron. (Fig. 214)

If it rests on one of its vertices, the plane view is also a regular decagon (ten sides). (Fig. 215)

The Archimedean Solids

Besides the five Platonic solids, which are completely regular polyhedra, there are quite a number of semi-regular polyhedra called the Archimedean solids. These semi-regular polyhedra are also constructed of regular polygons. The difference between the Platonic and the Archimedean solids is that each Platonic solid is built of only one type of regular polygon, whereas each Archimedean solid is built of more than one type of regular polygon.

Altogether there are thirteen Archimedean solids, but only the simpler and more interesting ones are introduced here.

The cuboctahedron is one which contains fourteen faces, twelve vertices, and twenty-four edges. (Fig. 216)

Among the fourteen faces, eight are equilateral triangles and six are squares. (Fig. 217)

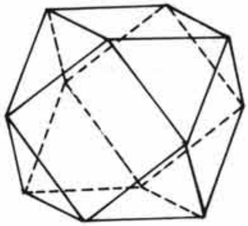
If it rests on one of the triangular faces, the plane view is a hexagon (six sides). (Fig. 218)

The truncated octahedron is one which contains fourteen faces, twenty-four vertices, and thirty-six edges. (Fig. 219)

It is obtained by chopping away the six vertices of an octahedron, and replacing them by six square faces.

Among the fourteen faces, eight are regular hexagons and six are squares. (Fig. 220)

If it rests on one of the hexagonal faces, the plane view is a dodecagon (twelve sides) with



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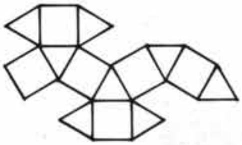

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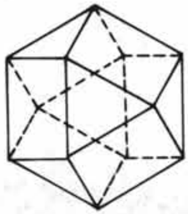

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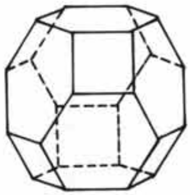

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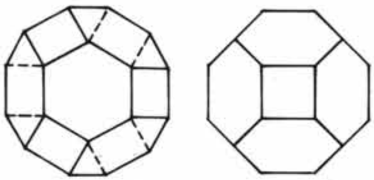

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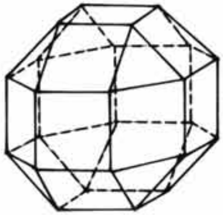

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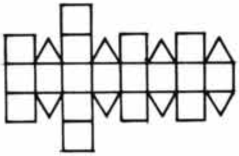

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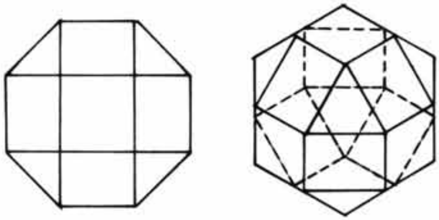

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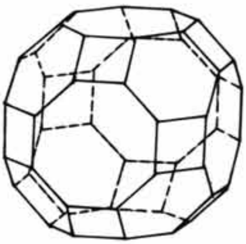

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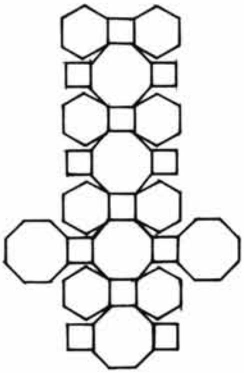

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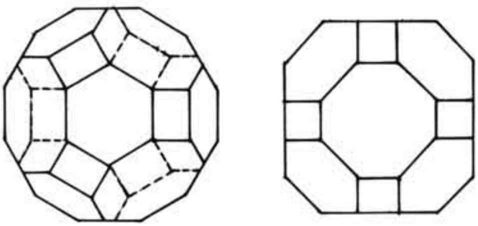

unequal adjacent sides. If it rests on one of the square faces, the plane view is an octagon (eight sides) with unequal adjacent sides. (Fig. 221)

The rhombicuboctahedron, or small rhombicuboctahedron, to distinguish it from the great one, which is described next, is a solid which contains twenty-six faces, twenty-four vertices, and forty-eight edges. (Fig. 222)

Among the twenty-six faces, eight are equilateral triangles and eighteen are squares. (Fig. 223)

If it rests on one of the square faces, the plane view is a regular octagon (eight sides). If it rests on one of the triangular faces, the plane view is a regular hexagon (six sides). (Fig. 224)

The great rhombicuboctahedron (or truncated cuboctahedron) contains twenty-six faces, forty-eight vertices, and seventy-two edges. (Fig. 225)

Among the twenty-six faces, twelve are squares, eight are regular hexagons (six sides), and six are regular octagons (eight sides). (Fig. 226)

If it rests on one of the hexagonal faces, the plane view is a regular dodecagon (twelve sides). If it rests on one of the octagonal faces, the plane view is an octagon (eight sides) with unequal adjacent sides. (Fig. 227)

Interesting designs can be developed from any of the polyhedra. All provide the fundamental structure for face treatment, edge treatment, and vertex treatment.

Face Treatment

If the polyhedron has been constructed so that it is hollow inside, the simplest face treatment is to make negative shapes on some or all of the faces, revealing the empty space inside. (Fig. 228)

Each entire flat face of the polyhedron can be replaced by an inverted or projected pyramidal shape, constructed of joined or interlocking planes. In this way the external appearance of the polyhedron may be transformed into a stellated polyhedral shape. (Fig. 229)

Separately constructed shapes can be attached to the faces of the polyhedron. (Fig. 230)

Edge Treatment

Along the edges of a polyhedron, shapes can be added or subtracted. When they are subtracted, faces are also affected because we cannot remove anything from an edge without removing a part of the adjoining faces. (Fig. 231)

Straight edges of the polyhedron can become curvilinear or bent. This will cause the flat faces to bulge or cave in, in accordance with the new edge shapes. (Fig. 232)

Each single-line edge can be replaced by double- or multi-line edge, and this will lead to the creation of new faces. (Fig. 233)

Interlocking of the face planes along the edges can take place in varied ways. (Fig. 234)


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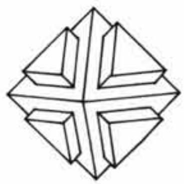
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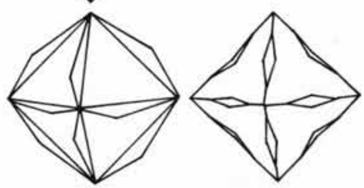
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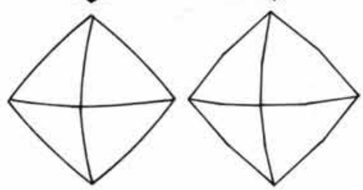
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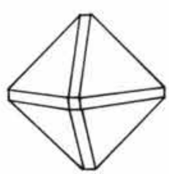
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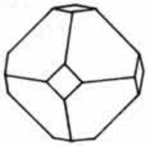

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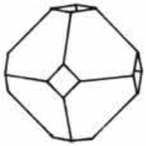

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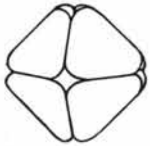

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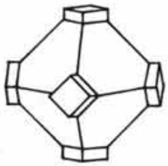

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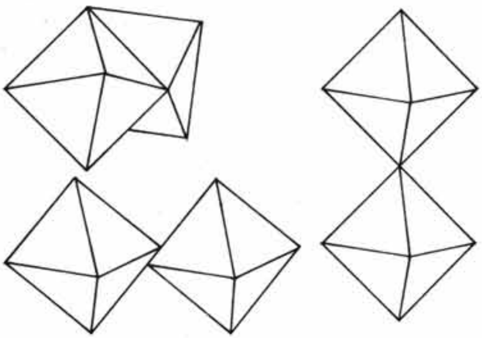

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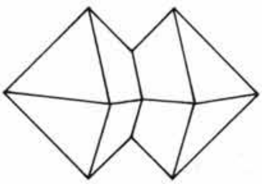


Vertex Treatment

Vertex treatment normally affects all the faces which join one another at the single point of the vertex. One way to treat vertices is by truncation, which means that the vertices are cut off and new faces are formed on the cut areas. Truncation usually leads to creation of a new polyhedral shape. We have already described the truncated octahedron among the Archimedean solids. The polyhedron illustrated here, however, is not an Archimedean solid because the triangular faces have not been transformed into regular hexagons after truncation. (Fig. 236)

If the polyhedron is hollowed, truncation reveals a hole at each vertex. Such holes may be specially treated so that the borders are not just simple straight lines. (Fig. 237)

Additional shapes can be formed on the vertices. (Fig. 238)

Joining of Polyhedral Shapes

For a more complicated structure, two or more polyhedral shapes of the same or different designs can be joined together by face contact, edge contact, or vertex contact. (Fig. 239)

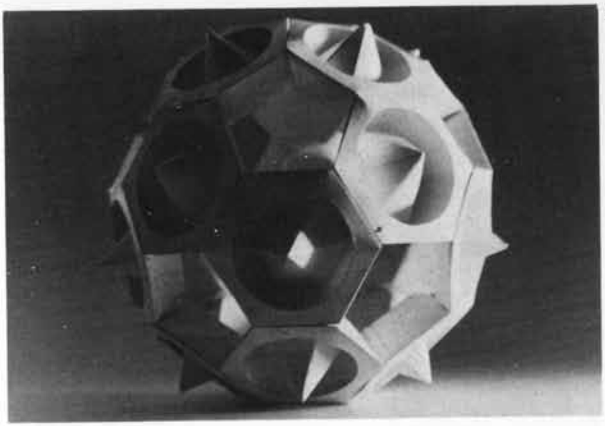
For greater structural strength or for design reasons, vertices can be truncated during vertex contact, edges flattened during edge contact, or the volume of one polyhedral shape made to penetrate the volume of another. (Fig. 240)

Figures 241 to 255 illustrate polyhedrons with various surface treatments. Some of the projects show polyhedra used as unit forms.

Figure 241—the structure is an icosahedron. All its vertices have been truncated, and in place of the vertices are pentagonal holes. Each of the triangular faces is now a regular hexagon on which a sunken-in circle and a projecting pyramidal shape have been constructed.

Figure 242—this is a dodecahedron with simple edge and face treatments that do not transform the original shape of the structure.

Figure 243—eight octahedra have been used for this design. Each octahedron is given both face and vertex treatment. Face treatment is simple: negative circles are cut on all the faces. Vertex treatment is complex: the angles of the vertices are inverted so that the octahedron appears truncated.



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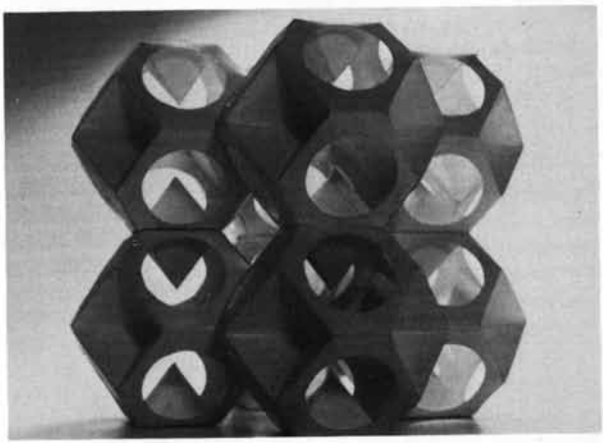

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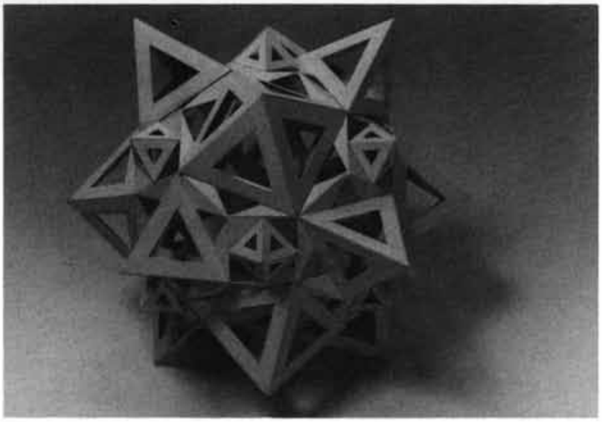

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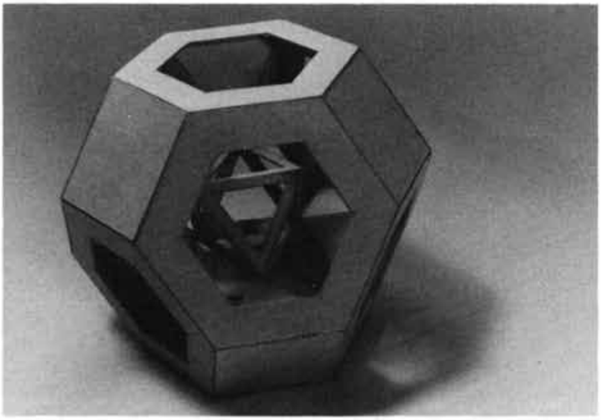

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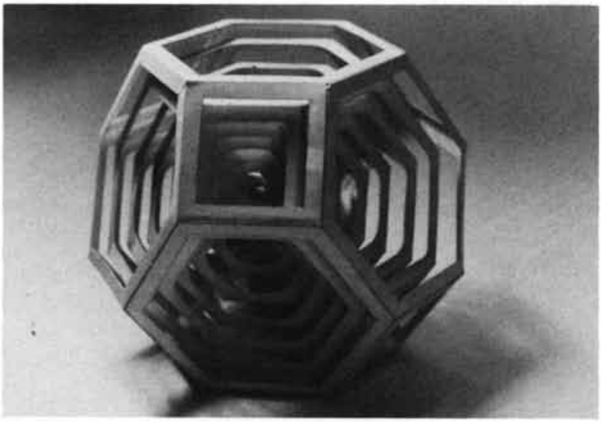

Figure 244—the structure for this complicated design is the great rhombicuboctahedron, which consists of octagonal, hexagonal, and square faces. Negative shapes are cut on all the faces and tetrahedral and semi-octahedral shapes are added.

Figure 245—a negative hexagonal shape is made on each of the hexagonal faces of a truncated octahedron, through which one can see the interesting interior polyhedral shape. It is a linear octahedron set among inwardly pointing square and hexagonal pyramids built on the underside of the faces.

Figure 246—the structure of this design is also the truncated octahedron. All the faces have been stripped to the edges, revealing six layers of the same shape in size gradation contained inside.

Figure 247—face treatment has brought much transformation to this icosahedron. Each face is replaced by a projecting tetrahedron whose vertex is split open, with enclosing planes curled out and internal space revealed.

Figure 248—like Figures 245 and 246, this highly complex design has been developed from a truncated octahedron. Each hexagonal face is divided into six triangular sections, and each square face is divided into four triangular sections, all with cut and curled-out shapes. Additional shapes are also projected from sections of the hexagonal faces.

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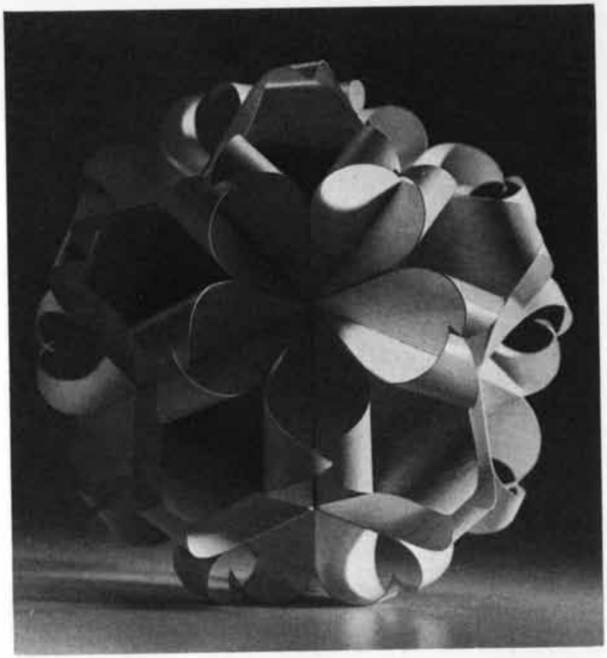

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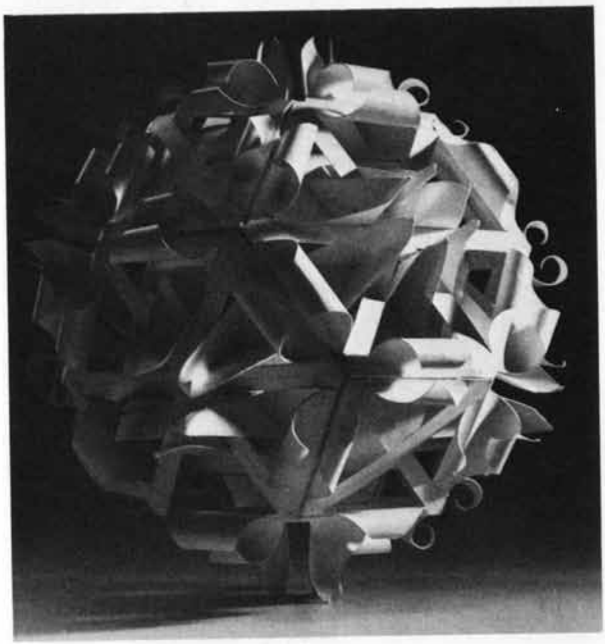

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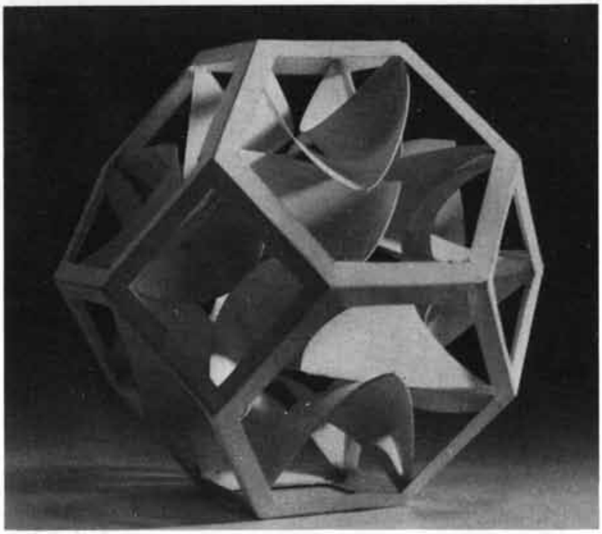

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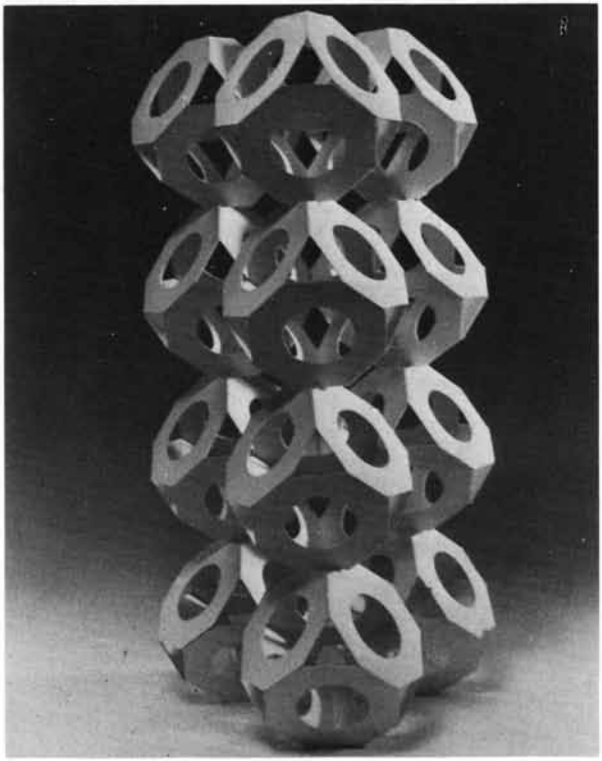


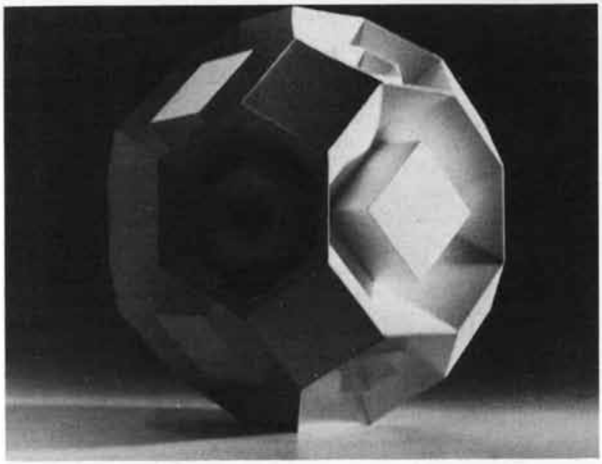
Figure 249—most parts of the faces of the truncated octahedron have been cut away. The main activity of the design takes place inside the polyhedral framework.

Figure 250—twelve truncated cubes have been used to compose this design. Each face of the cubes contains a negative circular shape which resonates visually with the triangular holes formed at the truncated vertices.

Figure 251—here the faces of the great rhombicuboctahedron have been treated with shapes projecting both inward and outward.

Figure 252—a dodecahedron has been used as the basic structure for this design. On each of the pentagonal faces, a pentagonal pyramid is built, but all the faces are stripped to the edges. The vertex of the pyramid, instead of projecting all the way out, is pushed inward. The result is a complicated design composed completely of linear elements.

Figure 253—this design is composed of two truncated octahedra, each of which shows a play of negative shapes and concave and convex forms.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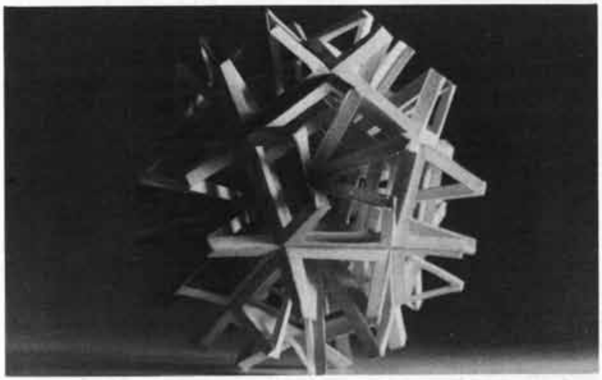
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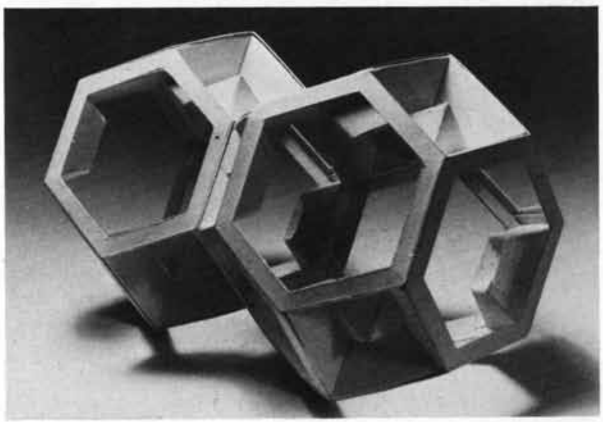
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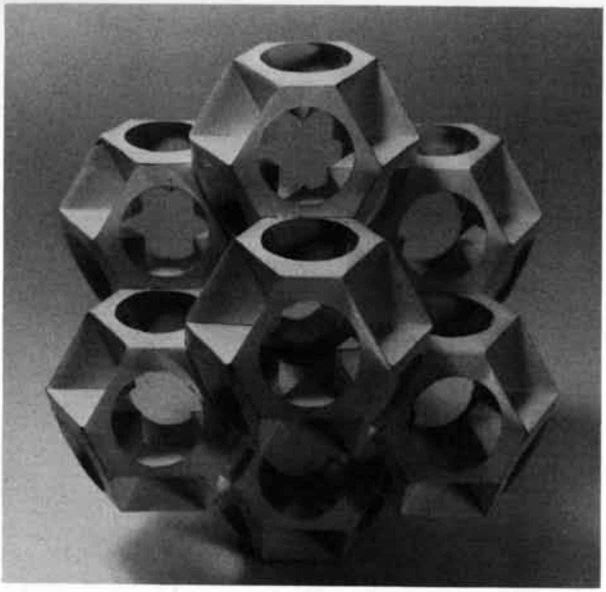

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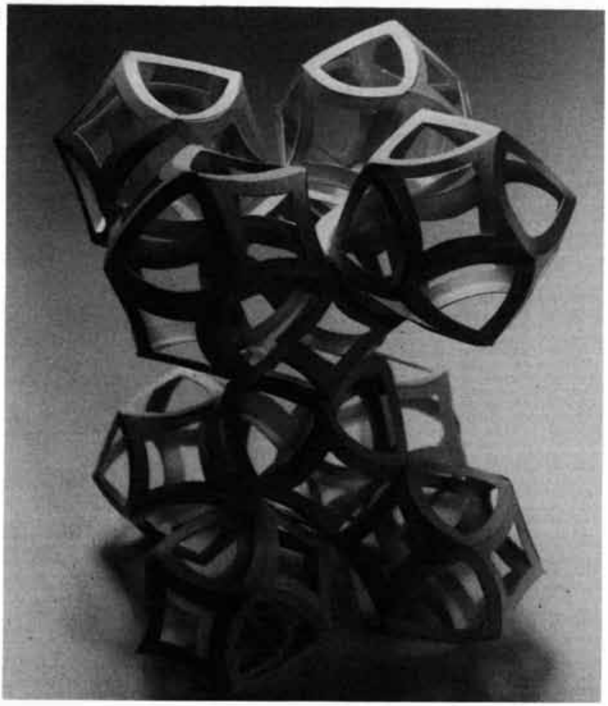


Figure 254—there are eight truncated octahedra in this design altogether. Each contains inverted vertices and negative shapes.

Figure 255—this consists of ten cuboctahedra, each with curved edges and open faces. The effect is very much that of a linear structure with no straight lines at all.

CHAPTER 7: TRIANGULAR PLANES

In the last chapter we saw that three out of five of the Platonic solids, the tetrahedron, the octahedron, and the icosahedron, are constructed of triangular planes. Triangular planes are also used for the construction of projecting or introjecting pyramidal shapes created from the faces of any polyhedron. Thus triangular planes are of considerable importance in three-dimensional design and cannot be ignored. (Fig. 256)

Equilateral Triangles

To explore the possibilities of construction with triangular planes, we can use a narrow strip of thin cardboard and divide it into a series of equilateral triangles. (Fig. 257)

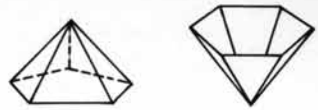
Cutting one triangle from the strip, we have a flat plane with three equal sides and three angles of sixty degrees each. (Fig. 258)

Two linked triangles may be folded in any desirable angle. This can be a free-standing three-dimensional shape. (Fig. 259)

Three linked triangles can make a tetrahedron with one face missing. (Fig. 260)

Four linked triangles can make a complete tetrahedron. (Fig. 261)

Five linked triangles can make a double-tetrahedron with one face missing. (Fig. 262)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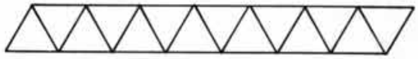
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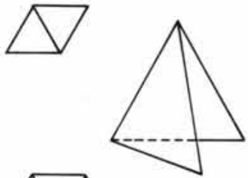
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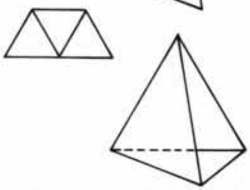
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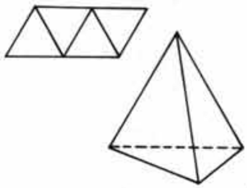
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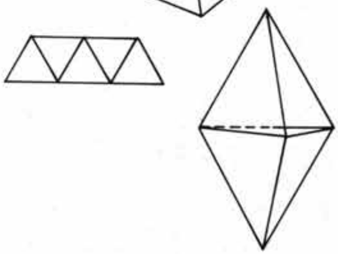
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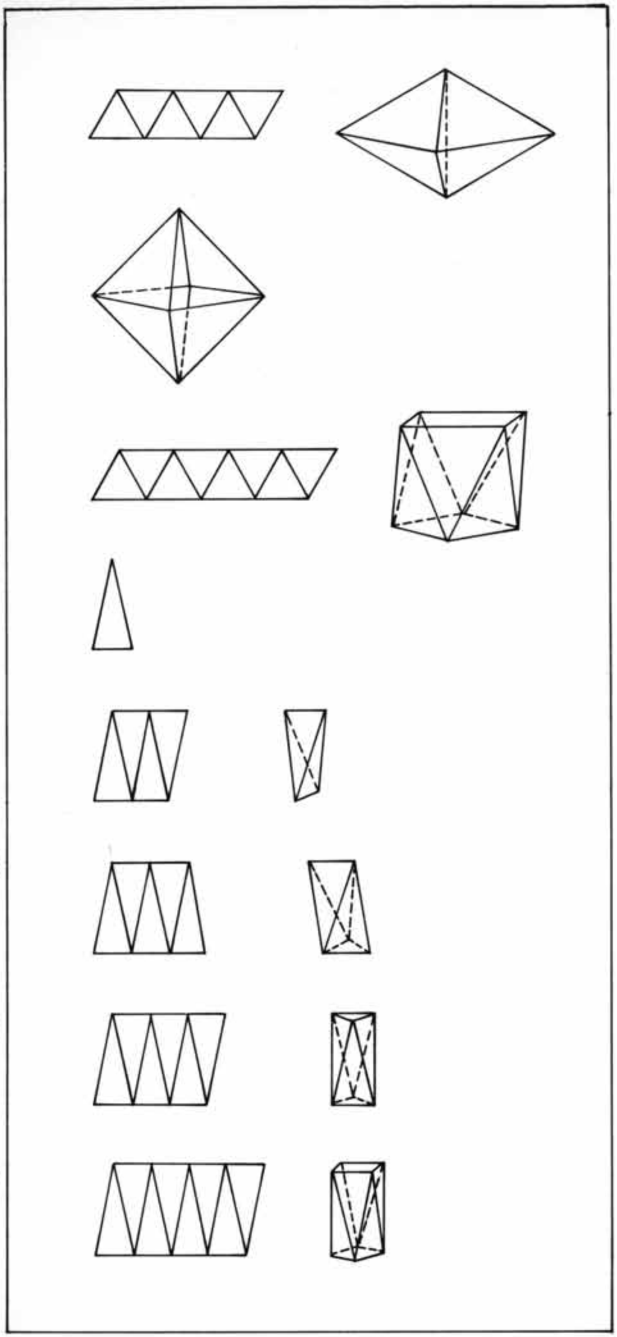

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Six linked triangles can make a complete double-tetrahedron. (Fig. 263)

They can also form an octahedron with two faces missing. (Fig. 264)

Eight linked triangles can make a prismatic shape, with a hollowed square top and a hollowed square bottom. The two hollowed square shapes are of the same size but in different directions. (Fig. 265)

Isosceles Triangles

The equilateral triangles can be elongated to form narrow and tall isosceles triangles, with two equal sides. (Fig. 266)

Four linked triangles of this kind can make a much distorted tetrahedron which may also be described as a prism with two wedge-shape ends. (Fig. 267)

Five linked triangles can make a prism with an open triangular shape at one end and a wedge-shape at the other end. (Fig. 268)

Six linked triangles can make a prism with an open triangular shape at each end. (Fig. 269)

Eight linked triangles can make a prism with open square ends. (Fig. 270)

Examples using the prisms formed of isosceles triangles can be found in Chapter 4, in which Figure 161 contains prisms made of four linked triangles and Figure 162 contains prisms made of six linked triangles.

Unequal-sided Triangles

Just as a narrow strip of thin cardboard can be divided into a number of equilateral or isosceles triangles, it can also be divided into a number of triangles with unequal sides. (Fig. 271)

With six or eight linked unequal-sided triangles, we can construct prisms very similar to Figure 269 or 270 if all the angles of the triangles are acute angles.

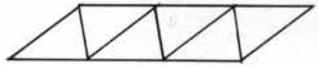
Unequal-sided triangles of different shapes and sizes can be used to build irregular tetrahedra or octahedra which may become exciting elements in a design. (Fig. 272)

The Octet System

Just as squares can fill up two-dimensional space without gaps, cubes can fill up three-dimensional space without gaps. (Fig. 273)

Equilateral triangles can fill up two-dimensional space without gaps, but tetrahedra cannot fill up three-dimensional space without gaps. With three octahedra in edge-contact positions, we discover that the space left over exactly accommodates one tetrahedron. (Fig. 274)

Thus when octahedra and tetrahedra are used together, they can fill up three-dimensional space without gaps. This is called the octet system, and it can produce structures of amazing strength that use a minimum of materials. (Fig. 275)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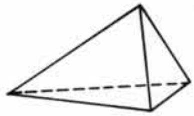
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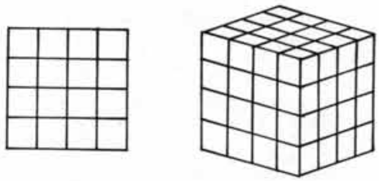
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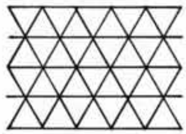
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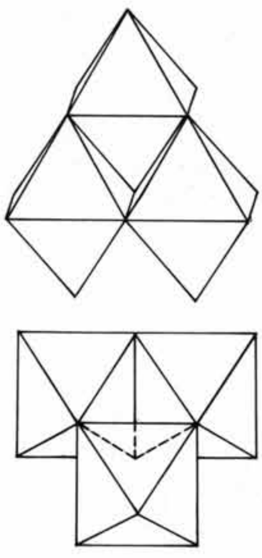
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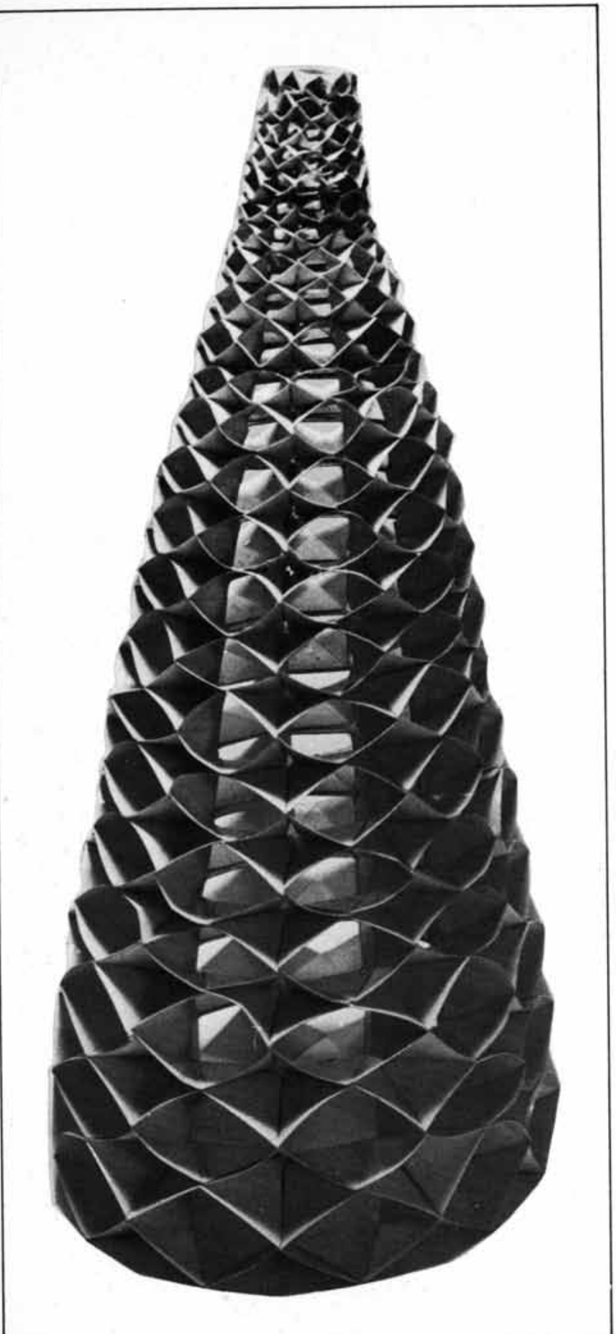
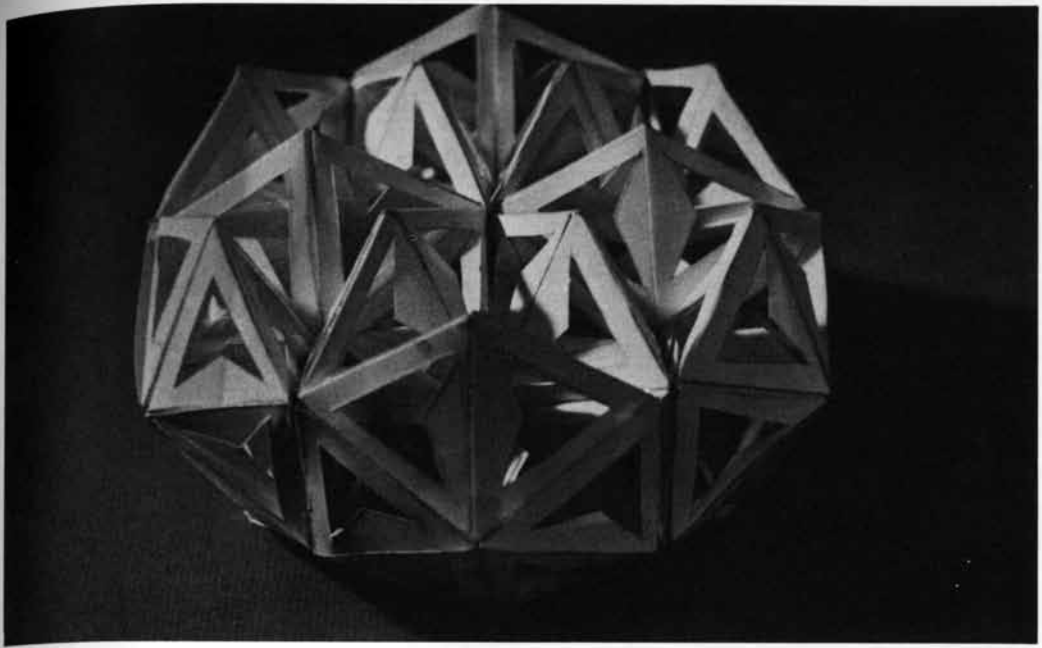


Triangular planes offer unlimited possibilities in design. Regular or irregular tetrahedra, octahedra, and pyramidal shapes can be joined together with unexpected effects. Figures 276 to 284 demonstrate some of the varied constructions that can be created from triangular planes.

Figure 276—eight linked triangles have been used to construct one unit form, which is similar to Figure 265. A number of such unit forms makes a ring, which is one layer of the design. Layers of the same construction but in diminishing sizes establish the structure for this design.

Figure 277—all faces of the tetrahedron used here are almost stripped to the edges. Six groups of these are arranged in a radiating manner.

Figure 278—a total of ten tetrahedra are used. Each has one of the vertices pushed in and then out in an interesting way.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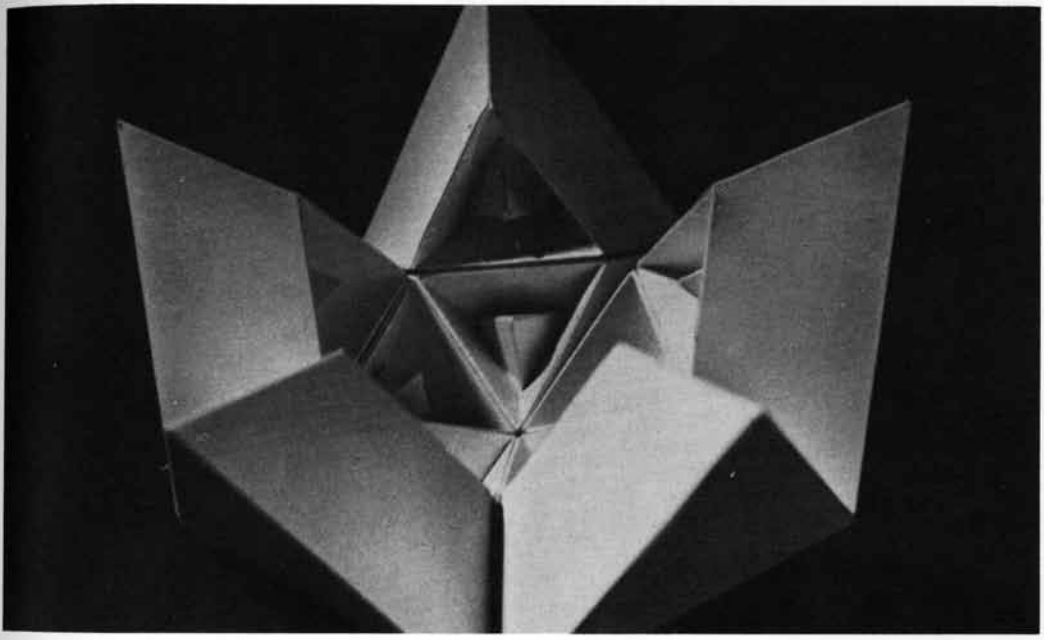
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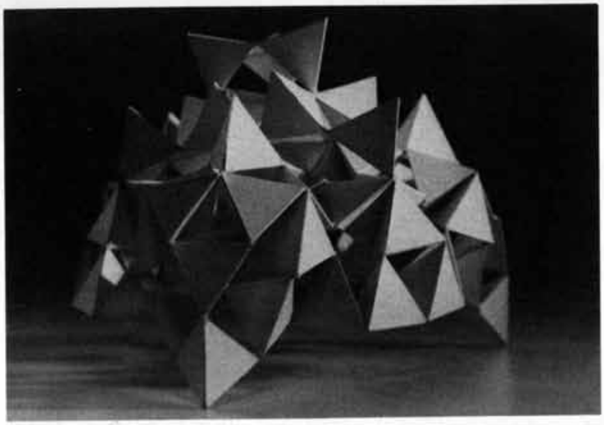

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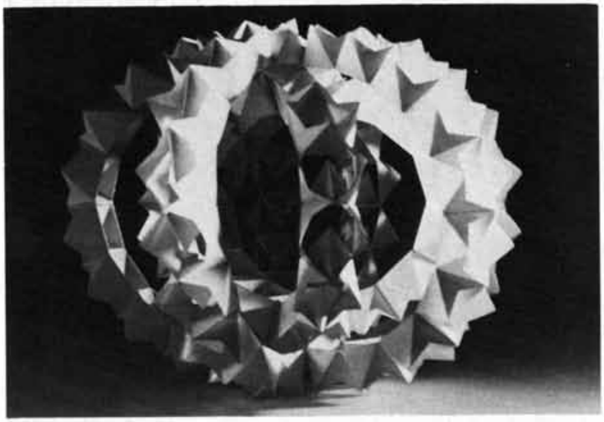

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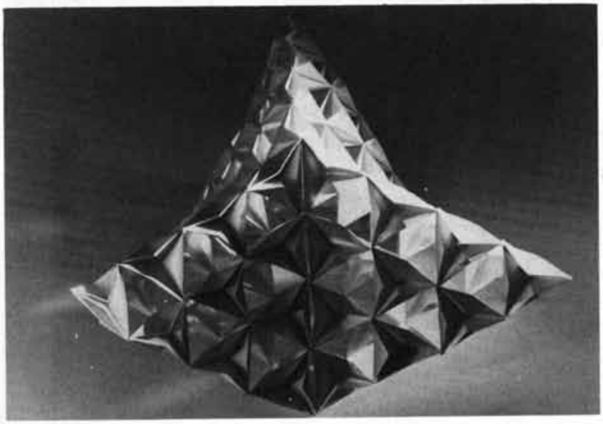


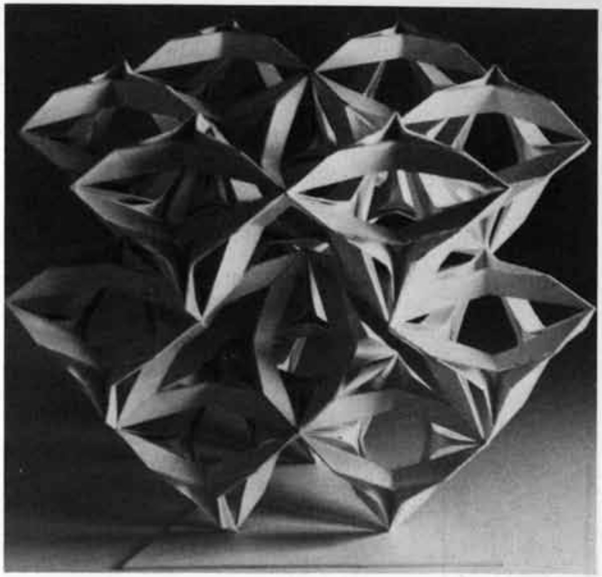
Figure 279—a number of tetrahedra have been glued together by vertex contact. Structurally, this is not very strong, but the form has a feeling of openness, even though all the faces of the tetrahedra are solid.

Figure 280—each unit form is made of several triangular planes. The unit forms are glued to one another by face contact, forming a circular ring which is repeated several times in the final design.

Figure 281—three folded triangular planes have been used to construct each unit form. Twenty unit forms in vertex contact make one large tetrahedral super-unit form, four of which are then put together in one design.

Figure 282—one element of the unit form is constructed of three linked and folded triangular planes. Four of such elements in vertex contact make one unit form, and these unit forms in vertex contact build the design.

Figure 283—each unit form consists of nine linked triangles, three of which are isosceles and six of which are right-angled. This results in a prismatic shape, with a triangular shape at one end and a hexagonal shape at the other end. An additional element built also of linked triangles is positioned inside the prismatic shape. The unit form is repeated fifty-five times in a triangular wall structure which is not flat but curved.



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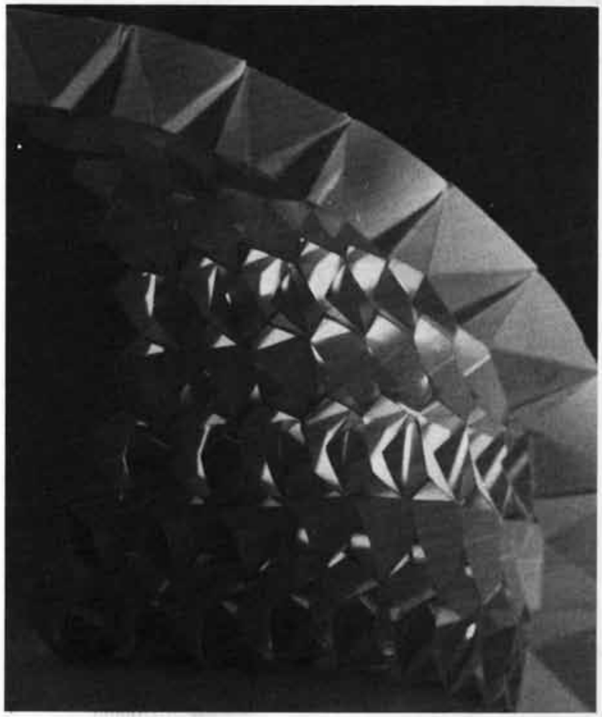

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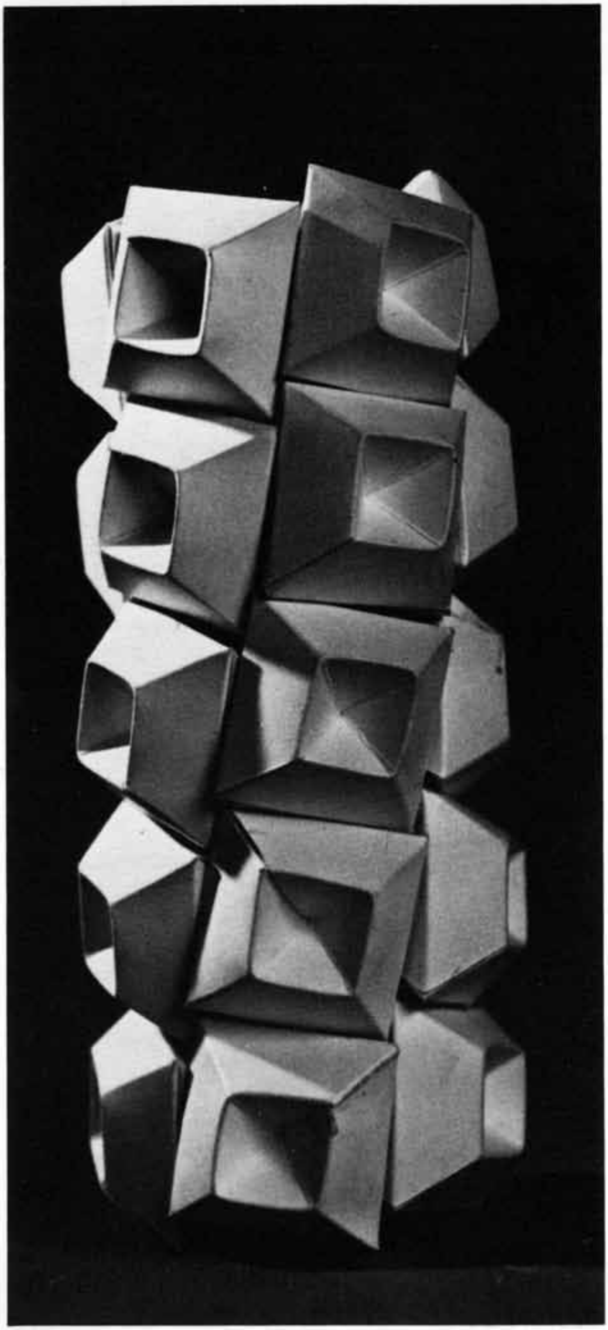


Figure 284—there are twenty-five unit forms in five layers, or five columns. Each unit form is an octahedron with one vertex pushed inward. The structure is built by means of face contact. An interesting aspect of this design is that each column is not perpendicular to the ground plane but slanting.

CHAPTER 8: LINEAR FRAMEWORK

Construction with Planes

So far we have been dealing with three-dimensional forms constructed of flat planes of even thickness. To construct any solid geometric form which consists of all flat faces and straight edges, we can cut the planes in the shapes of the faces and glue them together, with or without internal reinforcement.

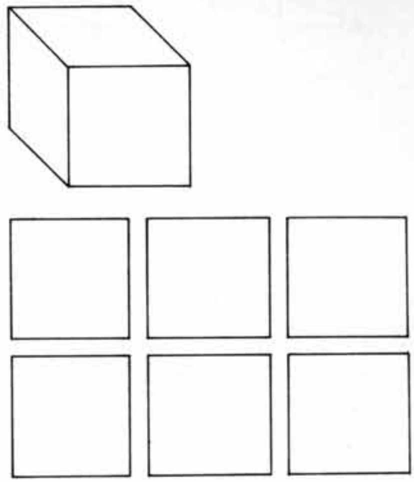
For instance, a solid cube consists of six square faces. To build this, six square planes are required. The thickness of the planes is of little visual significance because it is normally concealed. (Fig. 285)

Construction with Lines

All geometric forms with straight edges can be reduced to a linear framework. In constructing this, each edge is transformed into linear materials which mark the borders of the faces and form the vertices where they join.

In any geometric form, there are always more edges than faces. Thus construction with lines is more complicated than construction with planes. Using the cube again as an example, there are only six faces, but there are twelve edges, and the twelve edges become twelve linear sticks which must be connected in order to construct the linear framework of a cube. (Fig. 286)

In our exploration of linear relationships, the sticklike elements



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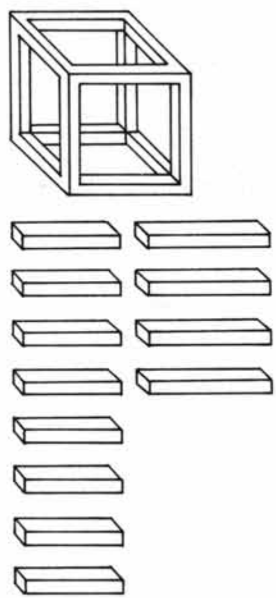

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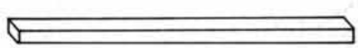

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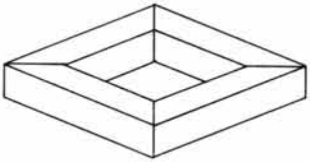

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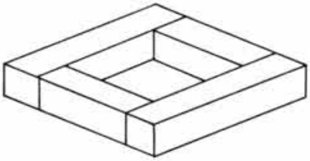

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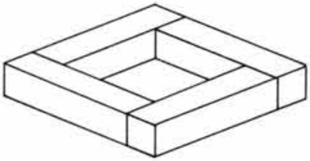

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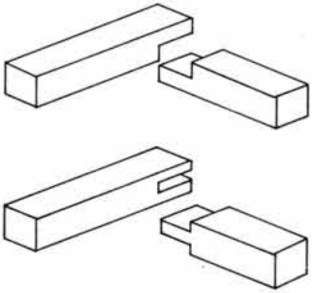


can be wooden sticks with square cross sections. The shapes are, in fact, elongated prisms with their own faces, edges, and ends. (Fig. 287)

Joints

In using wooden sticks for construction, we first need to know about joints. To build a flat square frame, four wooden sticks of the same length can be mitred and glued together. Such joints are neat and fairly strong. (Fig. 288)

A simpler way to make a flat square frame is to have two slightly longer and two slightly shorter wooden sticks with square-cut ends. The ends of the shorter pieces are glued to the side faces of the longer pieces. The length of the longer pieces equals the external measurement of the square frame, whereas the length of the shorter pieces equals the internal measurement of the square frame. (Fig. 289)

We can also use four wooden sticks, with square-cut ends, all of the same length. This is the simplest way of making a square frame. The external measurement of the final square frame is the sum of the length and thickness of a wooden stick, and the internal measurement of the final square frame is the difference between the length and the thickness of a wooden stick. (Fig. 290)

Joints made with square-cut ends are not as strong as those made with mitred ends. Stronger ends could be made if the end of one wooden stick overlaps another wooden stick, both having a portion cut away. This is called a half-lap joint. More complicated mortise-and-tenon joints can be made for still greater strength. Certainly though, for making small models, complicated joints are not necessary. (Fig. 291)

Components for Linear Framework

With a top and bottom square frame, we only need four supporting wooden sticks, cut to the length of the internal measurement of the square frame, to erect the cube. (Fig. 292)

Variations on the linear framework of the cube can be made in one or more of the following ways:

(a) the top or bottom frame, certainly, can be of a shape other than the square; (Fig. 293)

(b) the shape of the top frame can be of the same shape and size as the bottom frame, or of the same shape but not the same size; (Fig. 294)

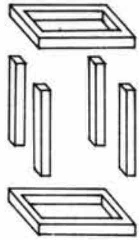
(c) the direction of the top frame can be the same as or different from that of the bottom frame; (Fig. 295)

(d) the top frame can be tilted in space and nonparallel to the plane of the bottom frame; (Fig. 296)

(e) the supporting sticks can be all of the same length or of varying lengths; (Fig. 297)

(f) the supporting sticks can be all perpendicular or at an angle to the bottom frame; (Fig. 298)

(g) the supporting sticks can be parallel or nonparallel to one an-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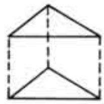
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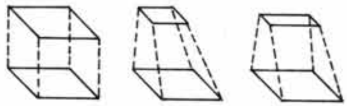
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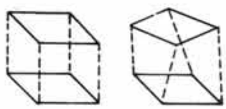
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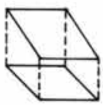
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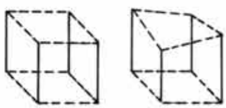
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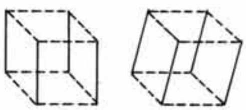
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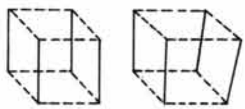
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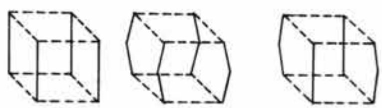
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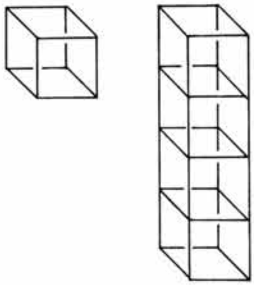

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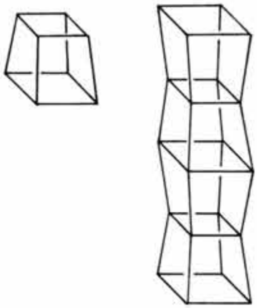

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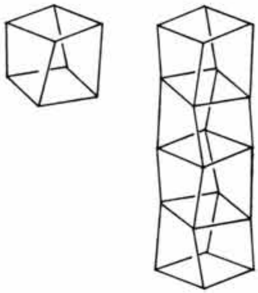

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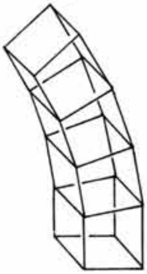


other; (Fig. 299)

(h) the supporting sticks can be straight or bent, or a mixture of both kinds. (Fig. 300)

Repetition of the Linear Framework

So far we have seen how a simple linear framework can be constructed. To take this further, we can repeat the section of linear framework as many times as desired by placing one unit above the next. Each section can be considered as one unit.

If each unit has parallel top and bottom frames of the same shape, size, and direction, and parallel supporting sticks of equal length, then by placing one unit on another in the same direction, we will have a vertical structure with straight edges. (Fig. 301)

Normally, the top frame of the unit below becomes the bottom frame of the unit above.

If each unit has parallel top and bottom frames of the same shape and direction, but not of the same size, this means that the supporting sticks, though of the same length, cannot remain parallel to one another, and the resulting structure will have zigzag edges. (Fig. 302)

If each unit has parallel top and bottom frames of the same shape and size, but not of the same direction, this means that the supporting sticks, again, cannot remain parallel to one another, and the resulting structure will have a twisted body. (Fig. 303)

If each unit has nonparallel top and bottom frames of the same shape and size, this means that the supporting sticks will have to be of unequal lengths, and the resulting structure will have a curved or bent body. (Fig. 304)

Stacking of Repeated Units

Repeated units can be stacked so that the bottom frame of the unit above does not coincide exactly with the top frame of the unit below. The units can be shifted gradually in position or direction. (Fig. 305)

The column thus created can be placed horizontally if it cannot remain stably in a vertical position or for aesthetic reasons. (Fig. 306)

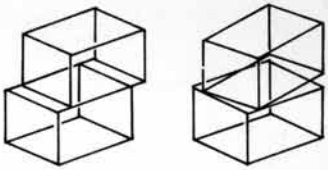
In more complex structures, repeated columns can be used.

Addition and Subtraction

Within the top or bottom frame, or between supporting sticks, or inside the space defined by the linear framework, additional linear shapes can be positioned for strengthening the structure or just making it more interesting. (Fig. 307)

After this additional support, it is possible that some or all of the original supporting sticks, or part of the top or bottom frame, can be removed for aesthetic or other reasons. (Fig. 308)

Sticks which compose the top or bottom frame or are between the two frames can exceed the length of the cube. (Fig. 309)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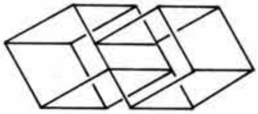
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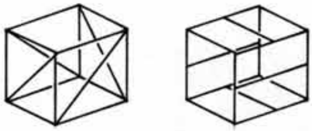
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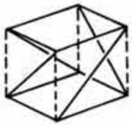
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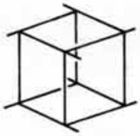
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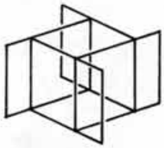
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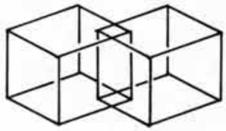
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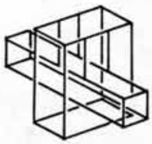
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Additional frames can be formed outside the linear framework. (Fig. 310)

Interpenetration

Interpenetration occurs when part of one linear framework is inside the space defined by another linear framework. (Fig. 311)

A smaller linear framework can be suspended inside a larger one with additional supporting or hanging elements. (Fig. 312)

Figures 313 to 318 are all projects in construction of linear frameworks. Some of the examples in earlier chapters, made of cardboard but with all the faces stripped to the edges, could be looked upon as projects of this kind too. They are figures 196, 198, 200, and possibly 277.

Figure 313—here nine units of linear framework have been used. Each unit is constructed of two square frames and four parallel supporting sticks of the same length. The units are glued to one another in directional rotation.

Figure 314—this structure consists of two units, each divided into four sections, with one section of the top unit overlapping one section of the bottom unit. Diagonal lines are erected inside the units, replacing all vertical supporting sticks.

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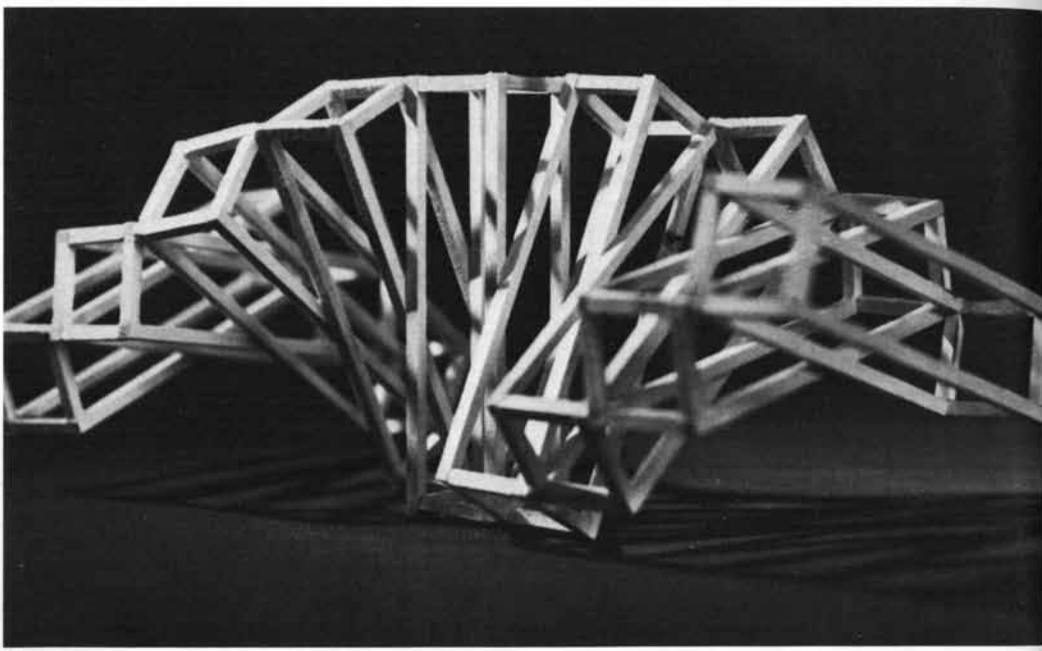

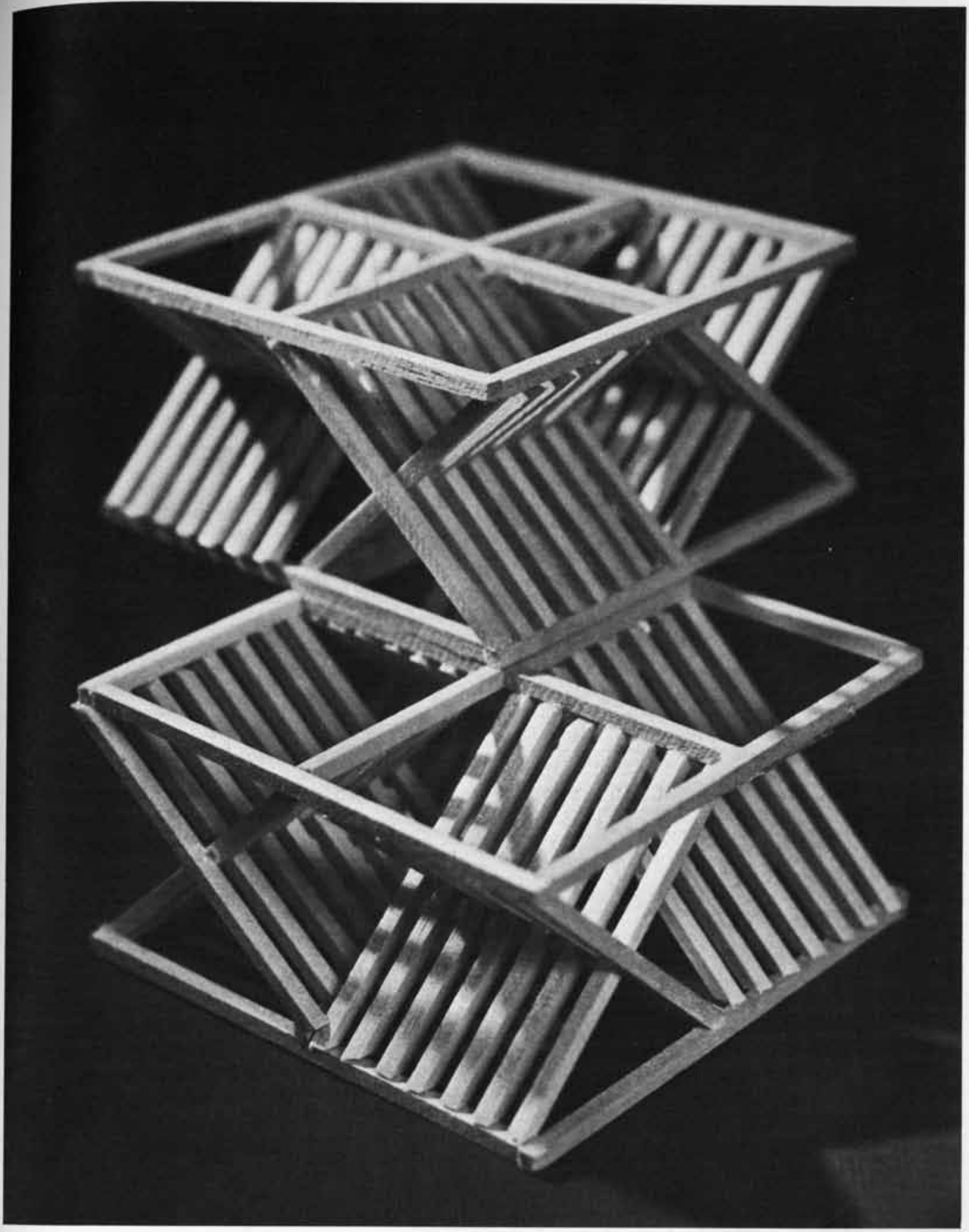

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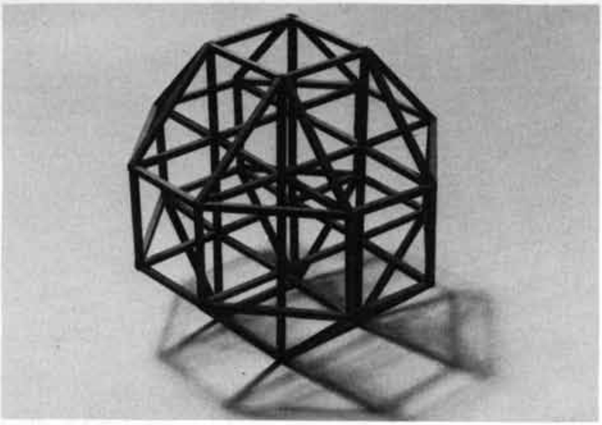

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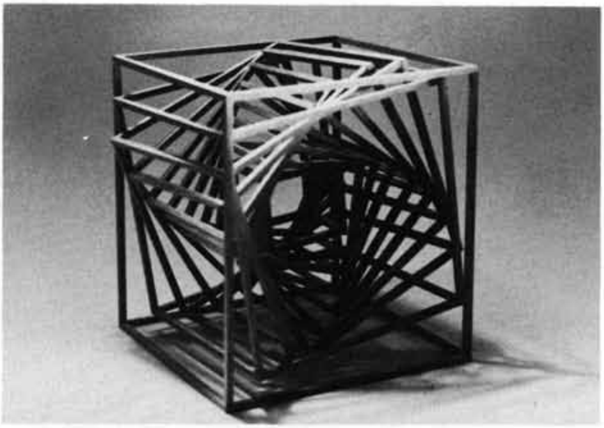

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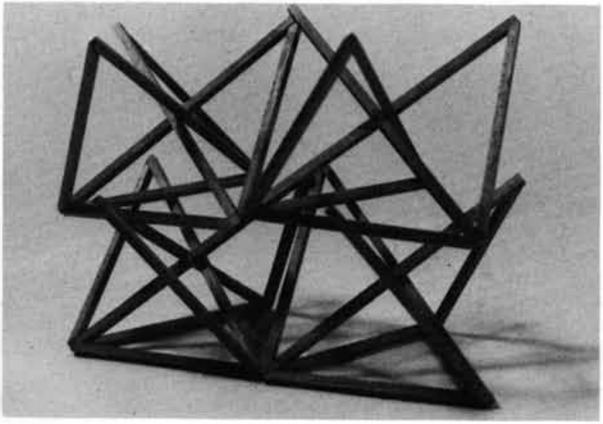
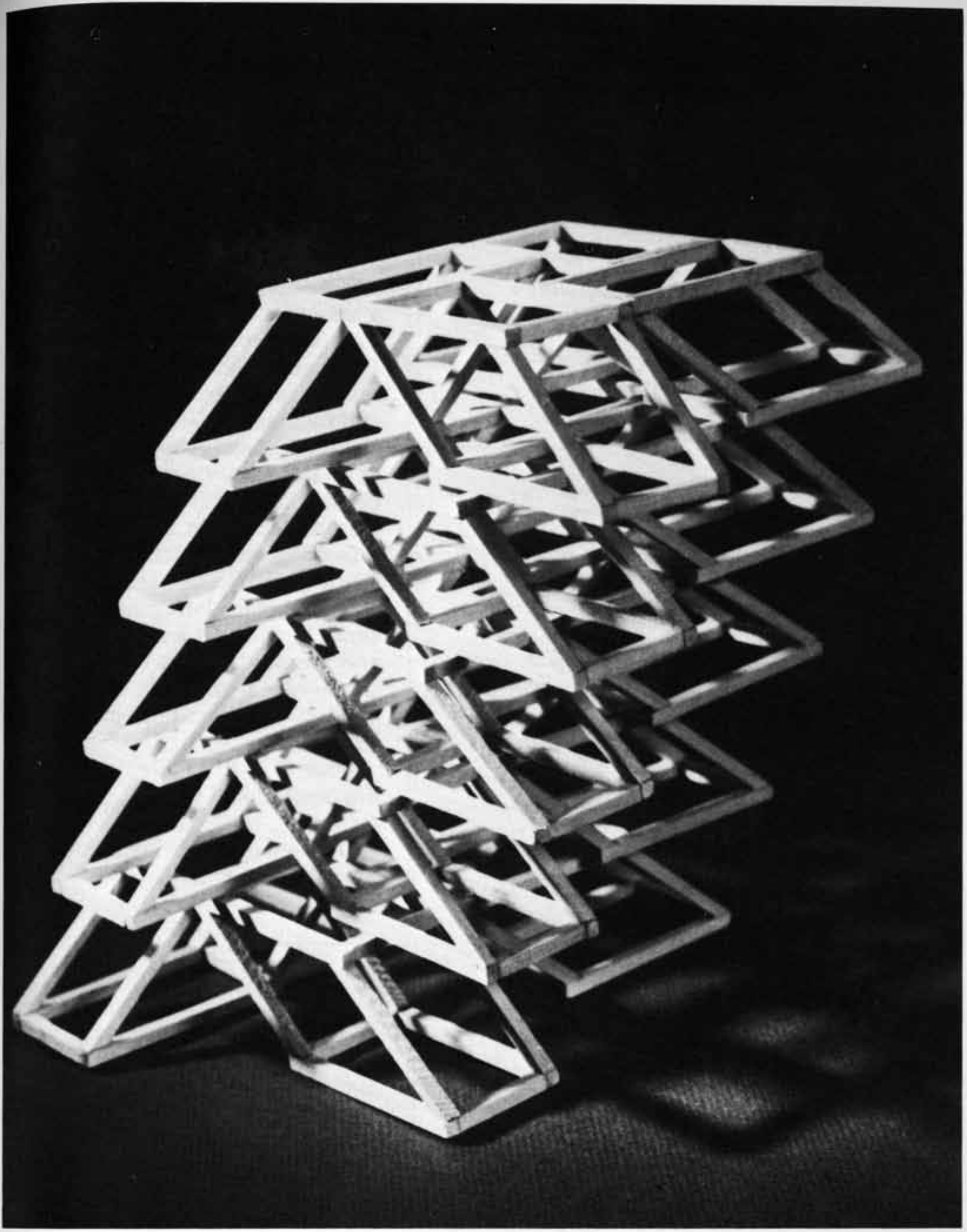


Figure 315—the structure is a rhombicuboctahedron, inside of which additional linear elements are developed that link the vertices.

Figure 316—here each unit is the framework of a cube and the units are in gradation of size and direction, one inside another.

Figure 317—there are four units in this design. Each unit was originally the framework of a cube but most of its vertical and horizontal elements have been removed after the addition of diagonal elements to the structure.

Figure 318—the structure contains five layers, with four units in each layer. Each unit is a slanting prismatic shape.



CHAPTER 9: LINEAR LAYERS

Building Up of Linear Layers

In the last chapter we saw how linear frameworks could be constructed. If we take away the supporting sticks from a linear framework, we are left with a top frame and a bottom frame, which can be considered two layers, a top layer and a bottom layer. (Fig. 319)

Between these two layers a number of intermediate layers can be stacked, and the shape thus erected will be the same as the original linear framework. For example, if the framework is in the shape of a cube, the four supporting sticks of the framework can be replaced by layers of square frames in the same shape and size as the top and bottom frames. The resulting shape has solid side planes, but hollowed top and bottom planes. (Fig. 320)

Now, if desired, we can shift the positions of the layers to make a slanting prism. (Fig. 321)

Or we can rotate each layer gradually. (Fig. 322)

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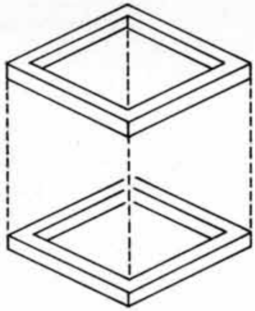

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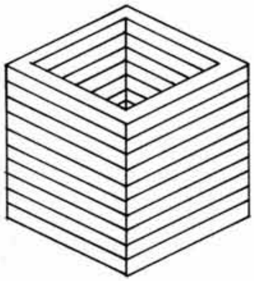

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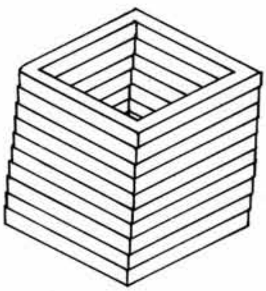

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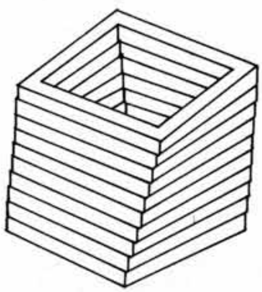


Variations and Possibilities

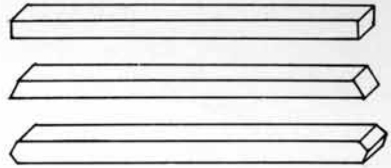
To simplify our thinking process, we can use a single wooden stick for each layer and see what variations and possibilities we can have.

First of all, the two ends of the wooden stick can be shaped in whatever way is desirable. (Fig. 323)

In building up the layers, the sticks can be all of the same length or have varying lengths. (Fig. 324)

We can position one stick directly above the next, but we can also arrange them in positional or directional gradation. (Fig. 325)

The body of the stick can be specially treated. (Fig. 326)



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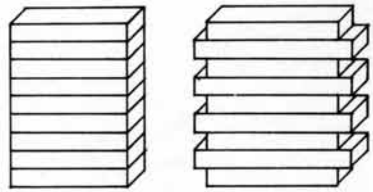

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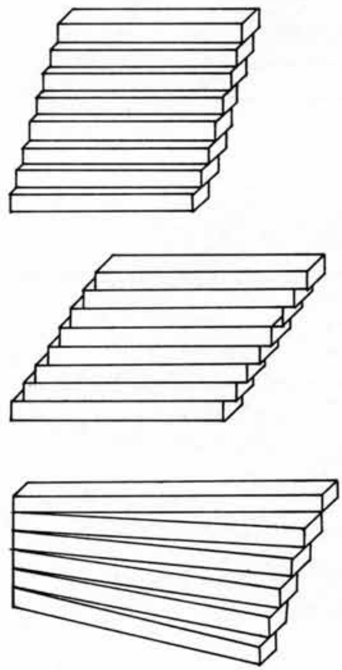

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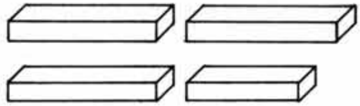

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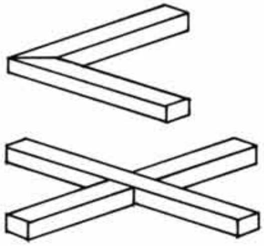

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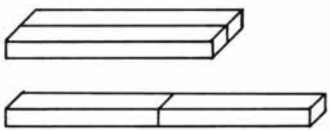

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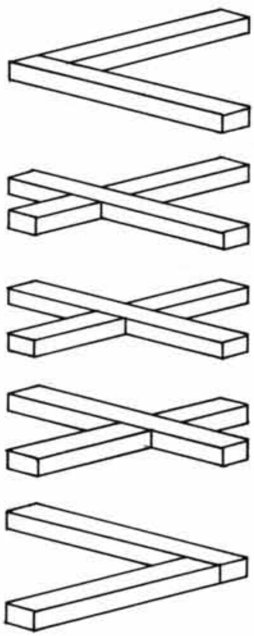


Gradation of Shape in Layer Construction

Possibilities in gradation of shape can be explored if we have more than one wooden stick in each layer. Suppose we have two sticks in each layer of our construction. The two sticks can be of the same or different lengths. (Fig. 327)

They can be joined at one end to form a V-shape, or they can cross each other to form an X-shape. The angle of joining or crossing can vary from one layer to the next. (Fig. 328)

They can also be glued together laterally or longitudinally. (Fig. 329)

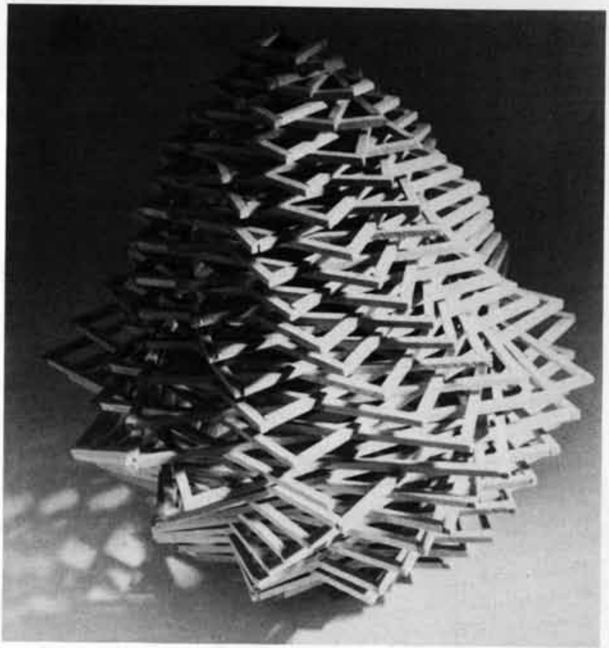
Let us observe the following example in layer construction. The top layer is a V-shape with the joint pointing to the left. In the layers immediately below this, the two sticks begin to overlap each other gradually in a half-lap joint, forming an X-shape. The central layer is an X-shape with the intersection right at the middle. In the layers immediately underneath this, the intersection of the X-shape moves gradually to the right. Finally it becomes a V-shape with the joint pointing to the right and it marks the bottom layer. (Fig. 330)

With more sticks for each layer, and positional and directional variations, more complicated effects easily can be achieved.

Figures 331 to 338 all show the use of linear layers in three-dimensional structures.

Figure 331—each layer is a simple square frame in this seemingly complex construction. The square frame is in gradation of size as well as gradation of direction.

Figure 332—there are four groups of linear layers. In each group, a wooden stick rotates and becomes longer and longer. The four groups are joined together in an X-shaped structure.



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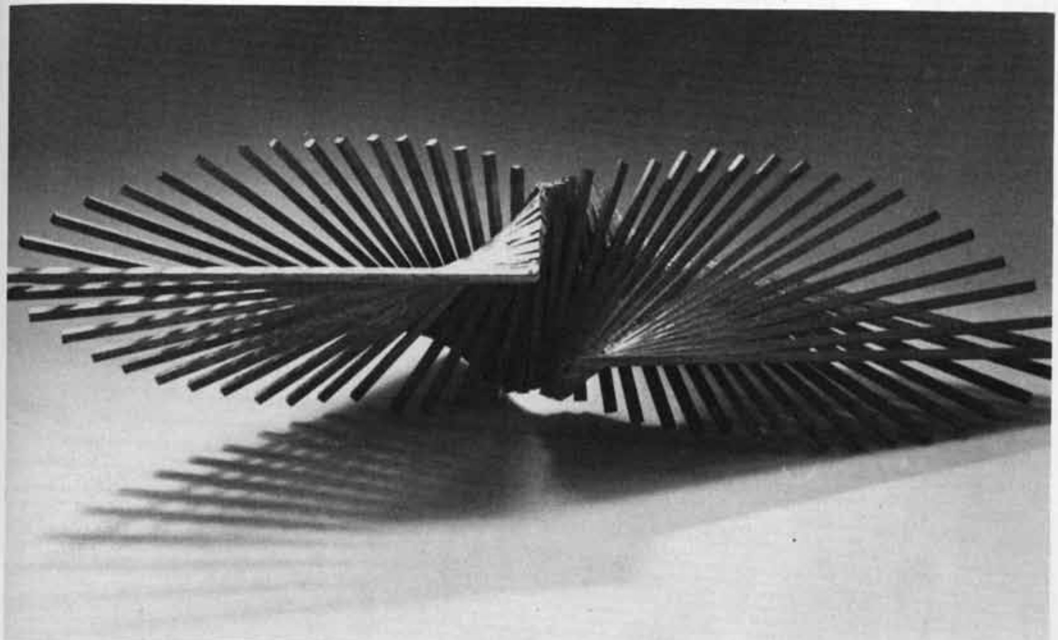

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Figure 333—similar to Figure 332, here we also find rotating sticks forming curved planes, four of which are put together in one design.

Figure 334—this contains twenty groups altogether, each constructed of six rotating sticks in gradational lengths. The overall shape of this design is an irregular tetrahedron.

Figure 335—there are only two groups of rotating sticks in this design. All sticks are of the same length.

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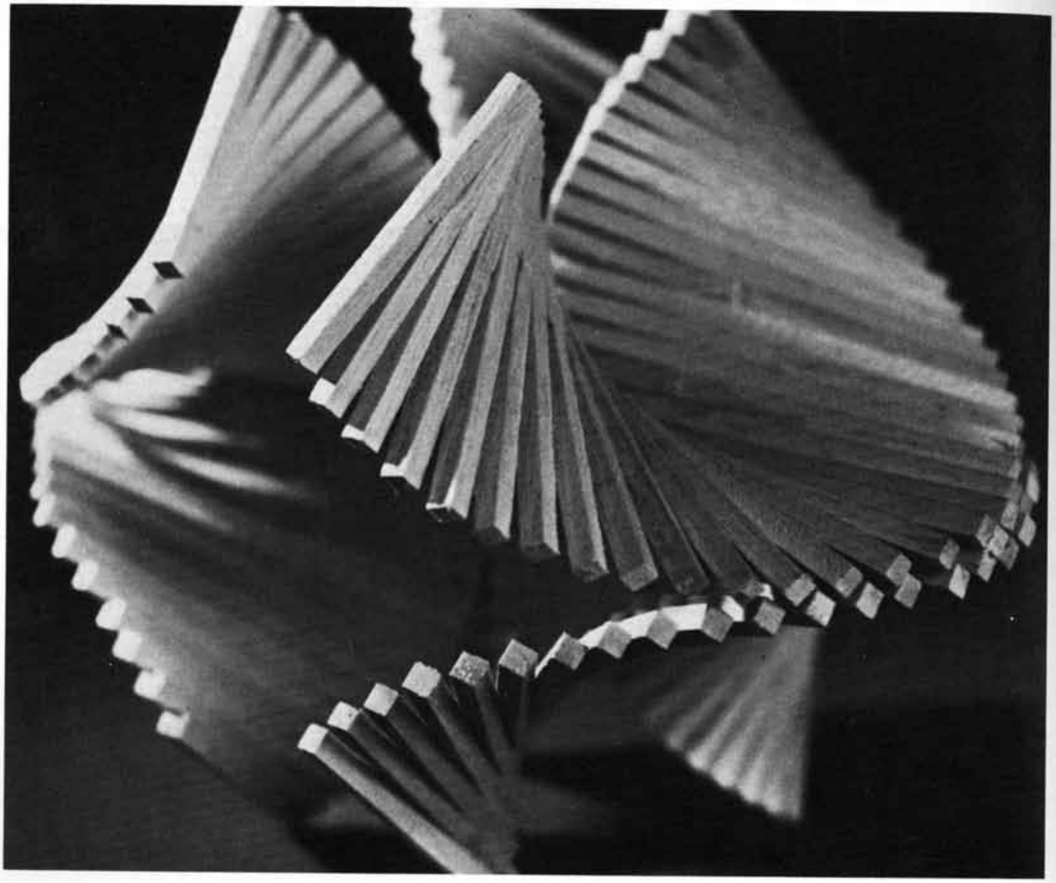

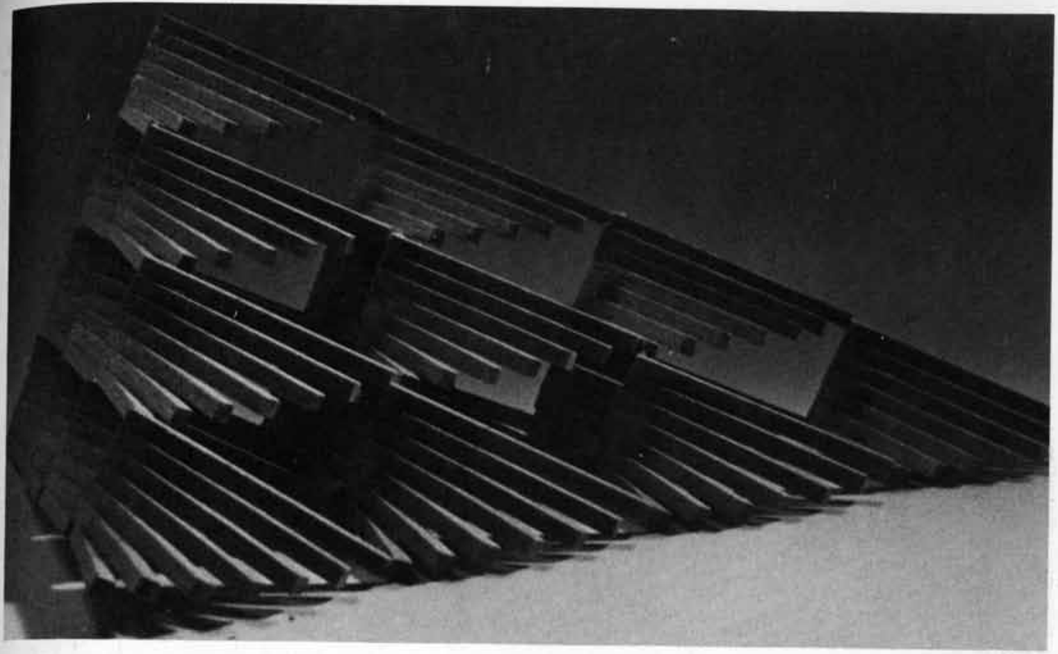
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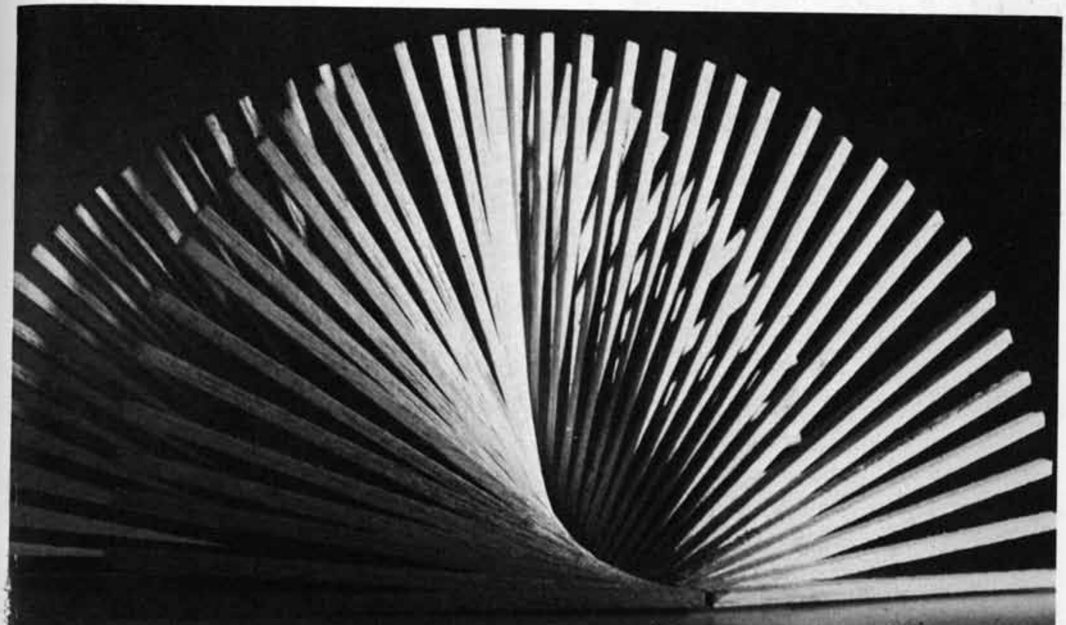
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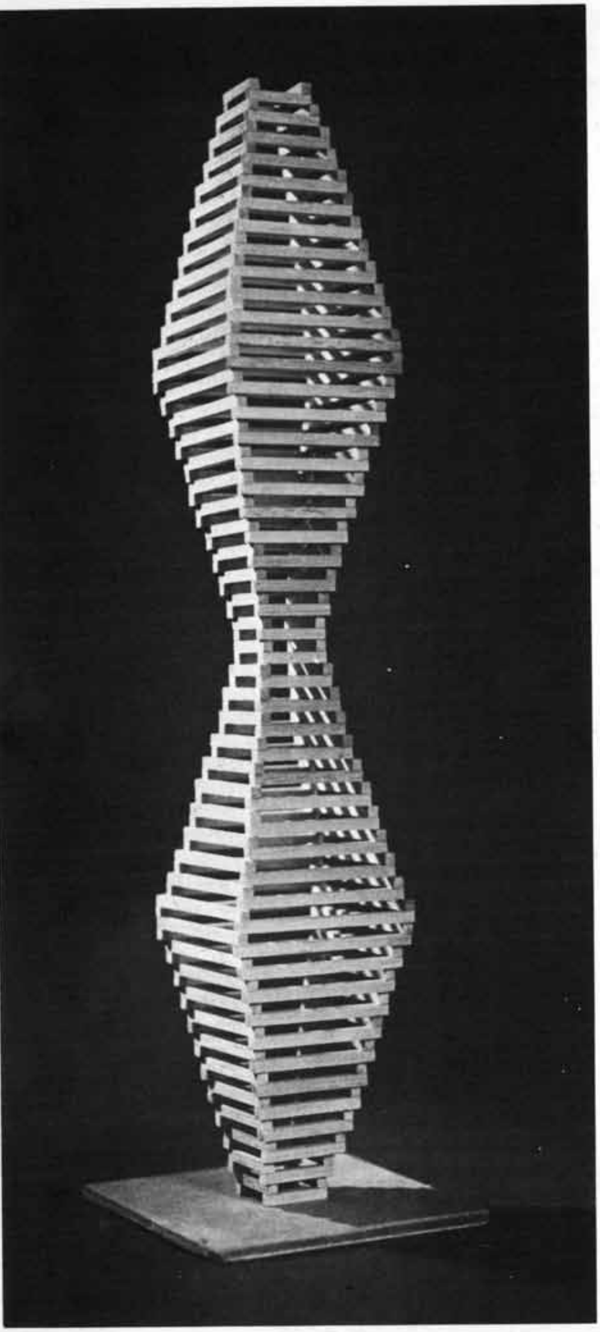
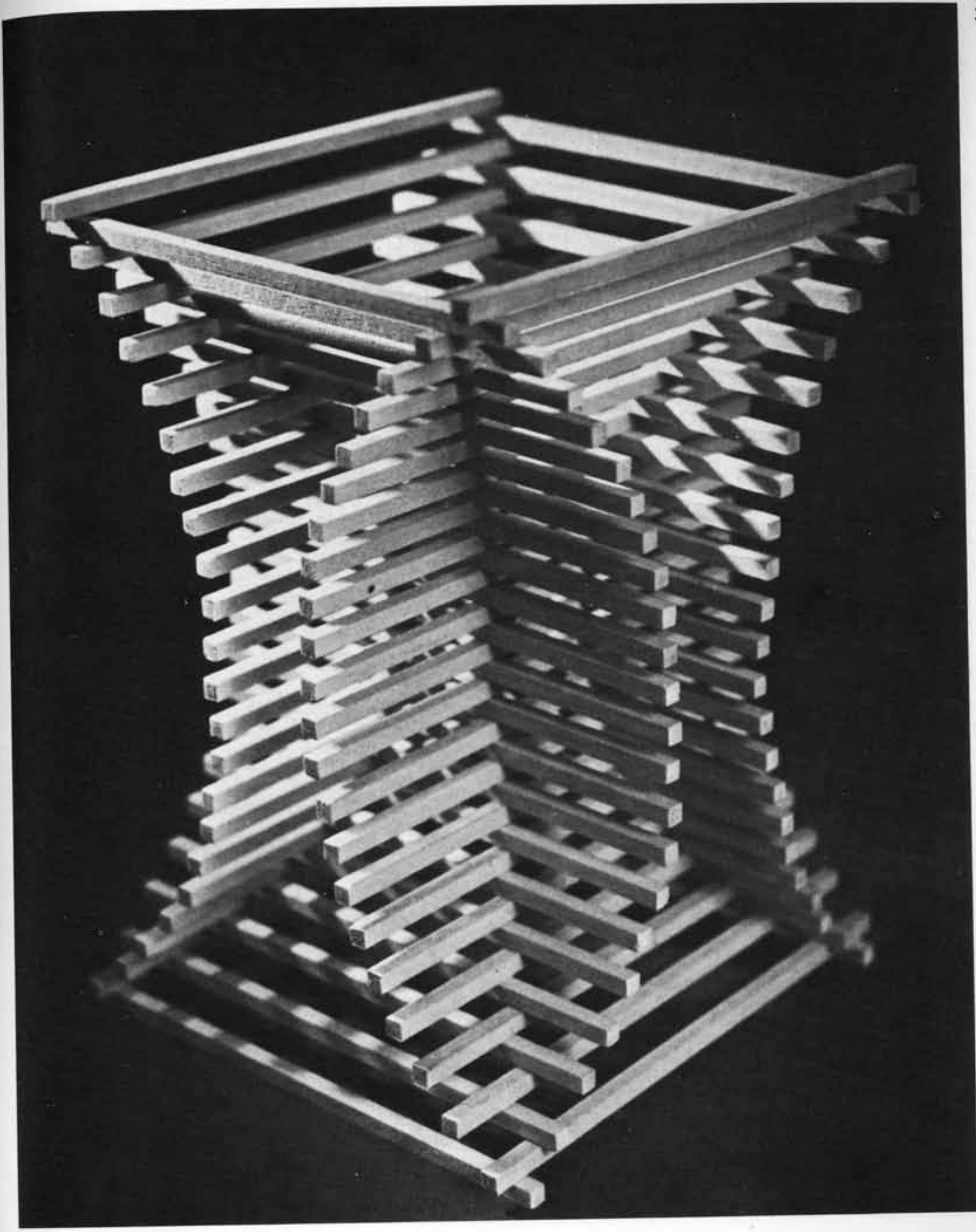


Figure 336—here each square frame is separated into two layers, one layer with two sticks pointing forward and backward, and the next layer with sticks pointing sideways. Gradation of the size of the square frames, created by gradation of the lengths of the sticks, has made this into an interesting towering shape.

Figure 337—similar to Figure 336, we have sticks pointing at different directions in alternate layers. The lengths of the sticks remain unchanged, but the distance between two parallel sticks in each layer narrows and widens gradually.

Figure 338—this is shown on page 100. It is constructed more or less on the same principle as Figure 337.



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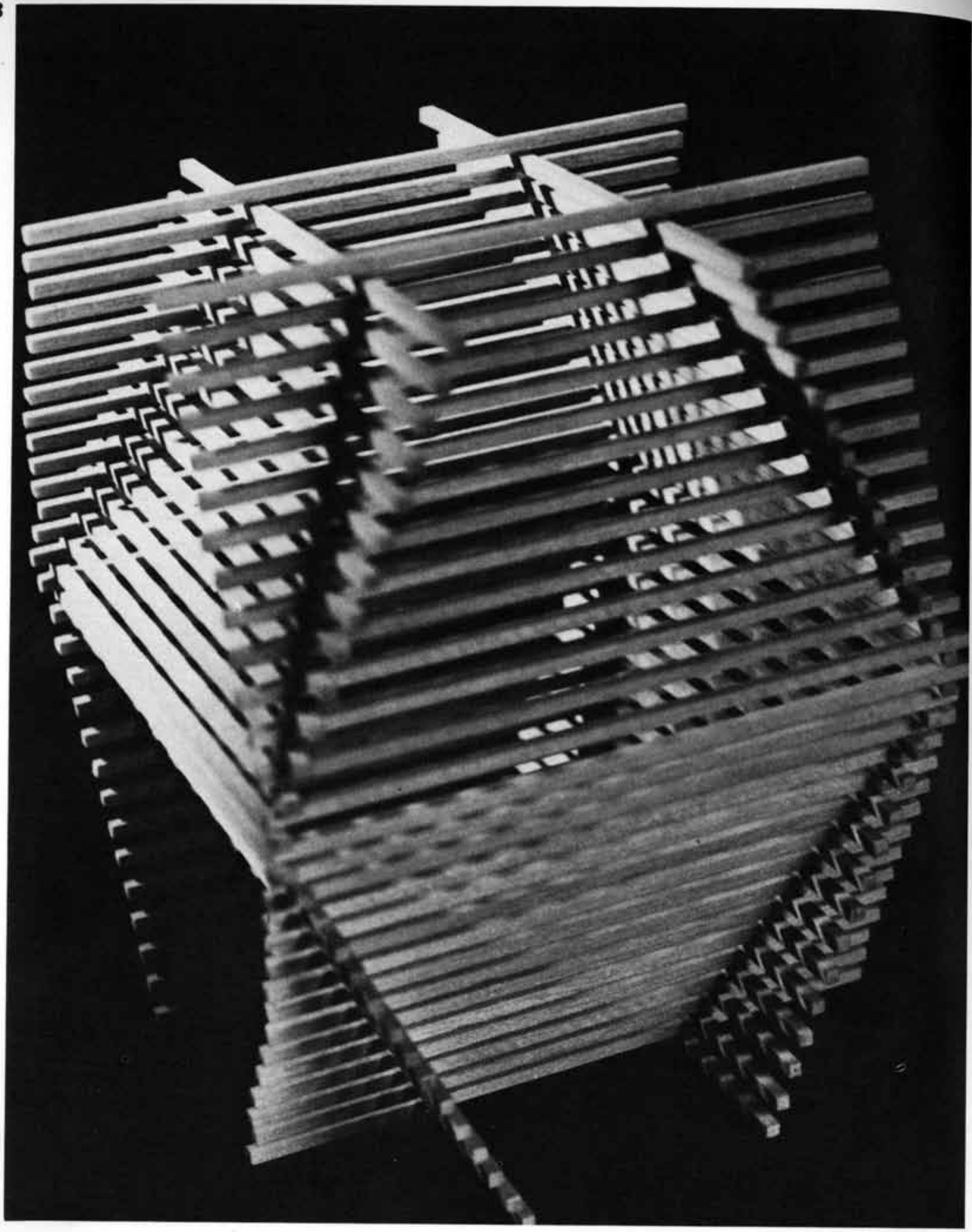


CHAPTER 10: INTERLINKING LINES

Interlinking Lines on a Flat Plane

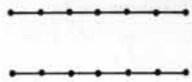
On a flat plane let us draw two straight lines of the same length and on each of them mark seven equally spaced points. (Fig. 339)

Interlinking lines can be created by joining the points on one of the straight lines to those on the other. If the two straight lines are parallel and we join the points in the order of their positioning, a pattern of parallel interlinking lines are produced. If we join the points in the reverse order of their positioning, the interlinking lines will all intersect one another at one new point which is half-way between the two straight lines. (Fig. 340)

If the two straight lines are nonparallel, interlinking lines may all be parallel, or in directional gradation, or in intersection at many new points. In the last case, a curved edge is produced although the interlinking lines are all straight. (Fig. 341)

If the two straight lines are joined to each other at an angle, interlinking lines may all be parallel, or in intersection at many new points. In the latter case, a curved edge is also produced. (Fig. 342)

If we mark the equally spaced points not on straight lines but along an arc of a circle, interlinking lines created between those points may be all parallel, or in intersection at many new points, producing a curved edge, as in the examples above. (Fig. 343)



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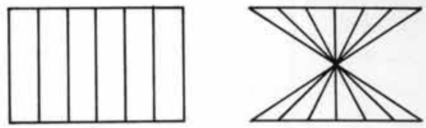

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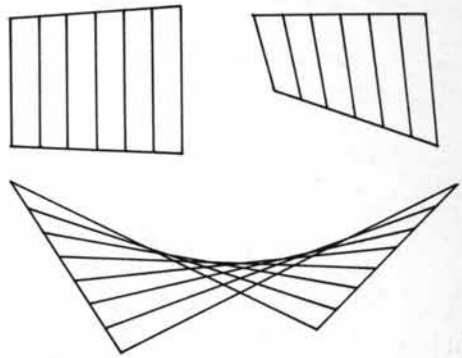

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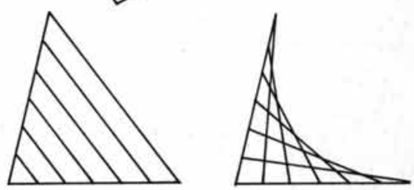

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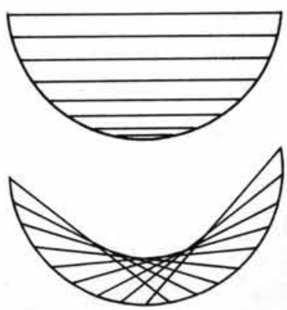

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Interlinking Lines in Space

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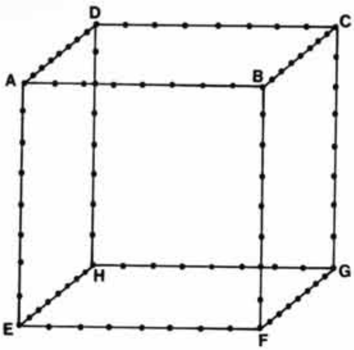

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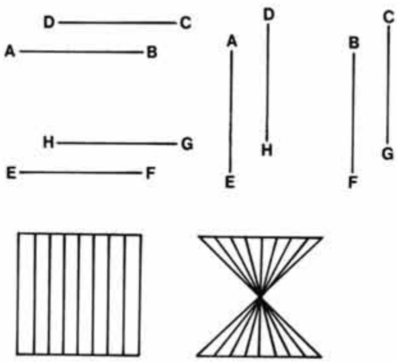

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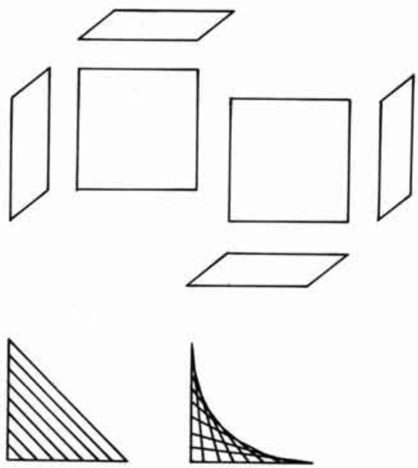


To explore possibilities of interlinking lines in space, we can use a linear framework in the shape of a cube, with vertices A, B, C, D, E, F, G, and H. On each of the edges, represented by sticks, seven equally spaced points are marked between the vertices. (Fig. 344)

AB, CD, EF, and GH are parallel sticks. So are AE, BF, CG, and DH. Interlinking lines developed between parallel sticks have the same results as those on the flat planes illustrated in Figure 340. This means that they are either all parallel or in intersection at one new point. (Fig. 345)

AB, BC, CD and DA are sticks on the same plane. So are sticks DA, AE, HE and DH; or sticks AB, BF, EF and AE; or sticks CD, DH, GH and CG; or sticks EF, FG, GH and HE; or sticks BC, CG, FG and BF. Any two adjacent sticks from the above groups can produce interlinking lines similar to those illustrated in Figure 342. (Fig. 346)

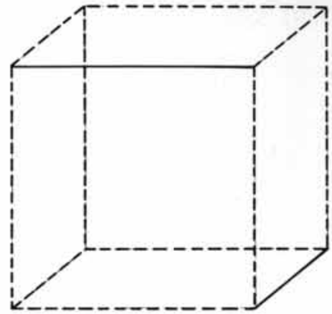
As we have seen, sticks which are parallel to each other or on the same plane produce interlinking lines basically of two-dimensional nature. Three-dimensional effects can be achieved only if the sticks are nonparallel and on different planes.

For instance, sticks AB and FG in Figure 344 are nonparallel and on different planes. To develop interlinking lines, we can either connect A to F and B to G, or connect A to G and B to F. (Fig. 347)

If we connect A to F and B to G, the interlinking lines can form a surface which is slightly curved. (Fig. 348)

If we connect A to G and B to F, the curved surface formed by the interlinking lines is even more prominent. It is not only curved but twisted. (Fig. 349)

Other pairs of sticks which can produce similar effects are AB and HE, AB and DH, AB and CG; BC and EF, BC and GH, BC and AE, BC and DH; CD and HE, CD and FG, CD and AE, CD and BF; DA and BF, DA and CG, DA and EF, DA and GH.



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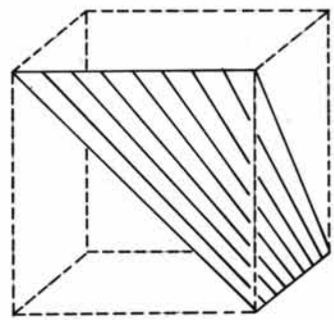

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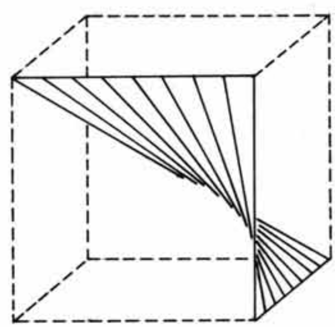

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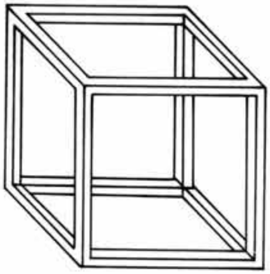

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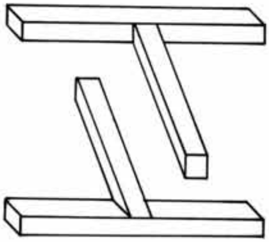

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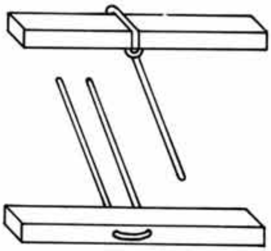

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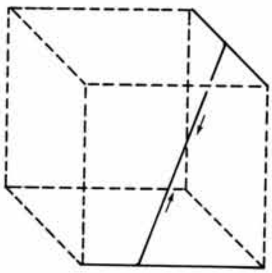


Materials and Construction

The linear framework always must be made of rigid material, such as the wooden sticks, in order to stand firmly and provide strong support for the interlinking lines. (Fig. 350)

With a rigid linear framework, the interlinking lines may be of rigid or soft material. Rigid interlinking lines can simply be glued to the faces of the members of the framework, and their ends are normally shaped to facilitate adhesion with maximum face contact. (Fig. 351)

If the interlinking lines are of soft material, such as thread made of cotton, nylon, or other substances, they can be tied or fixed by some means to members of the framework. (Fig. 352)

Soft interlinking lines must be stretched taut between two anchoring points and, in doing so, tension is created. The framework has to be strong enough to withstand such forces. (Fig. 353)

Planar Construction for Interlinking Lines

If a linear framework is not used, we can use simple planar shapes in a construction for the development of interlinking lines. Planar construction may be stronger than a linear framework if the material used is of adequate thickness and rigidity.

Clear acrylic sheets are ideal for this purpose, as the transparency of the material allows full display of the intricacies of interlinking lines. Opaque material may tend to become too prominent as a form and at least partially obstruct vision of the play of interlinking lines.

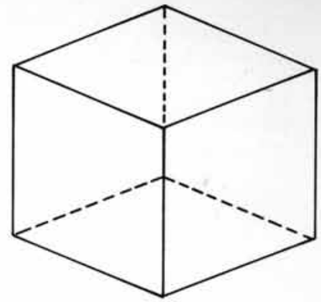
Interlinking Lines Within a Transparent Cube

To explore the effect of curved surfaces formed of interlinking lines with as little interference of the framework as possible, we can use six square acrylic sheets to build a cube. (Fig. 354) On the top plane, a number of evenly spaced tiny holes forming a circular shape can be drilled. The same can be done on the bottom plane. (Fig. 355)

Now we can construct interlinking lines with nylon or cotton thread between the top and bottom planes.

If the interlinking lines are all parallel to one another and perpendicular to the top and bottom planes, the result is a cylindrical shape. (Fig. 356)

If the interlinking lines are all slanting, and nonparallel to one another, the result is a hyperboloid with a continuous curved surface. (Fig. 357)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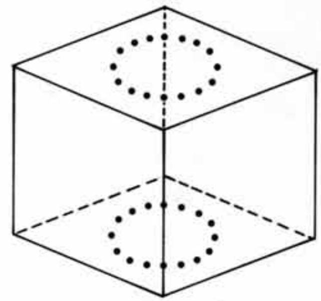
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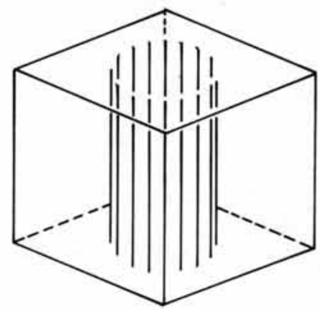
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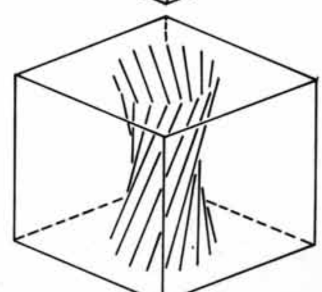
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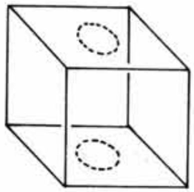

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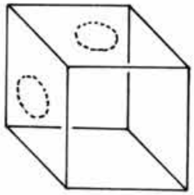

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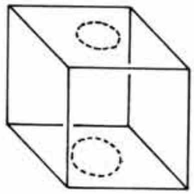

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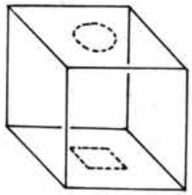

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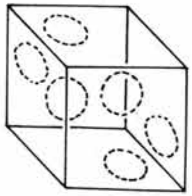


More complicated and interesting results can be achieved by varying the design just described in one or more of the following ways:

(a) the position of the circular shapes can be moved from the center towards the edges or corners of the top and bottom planes; (Fig. 358)

(b) one or both of the circular shapes can be moved to the side planes of the cube; (Fig. 359)

(c) the size of the two shapes can be different; (Fig. 360)

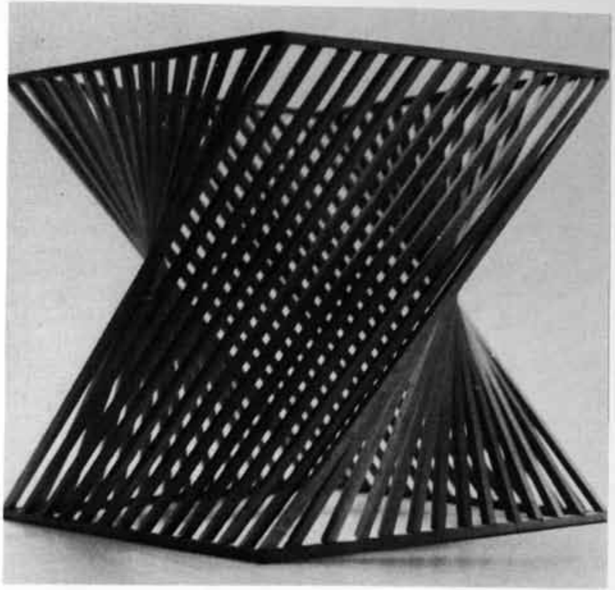
(d) one shape can be different from the other. Both can be non-circular if desired; (Fig. 361)

(e) several sets of interlinking lines can be constructed within the same transparent cube. (Fig. 362)

Figures 363 to 368 illustrate projects using rigid wooden sticks for the construction of interlinking lines. Figures 369 to 374 feature interlinking lines in soft materials.

Figure 363—rigid interlinking lines are constructed within the framework of a cube. The four vertical supporting sticks of the framework are removed afterwards.

Figure 364—here a spiral shape is cut from a flat plane. It is raised and lowered, supported by the interlinking lines.



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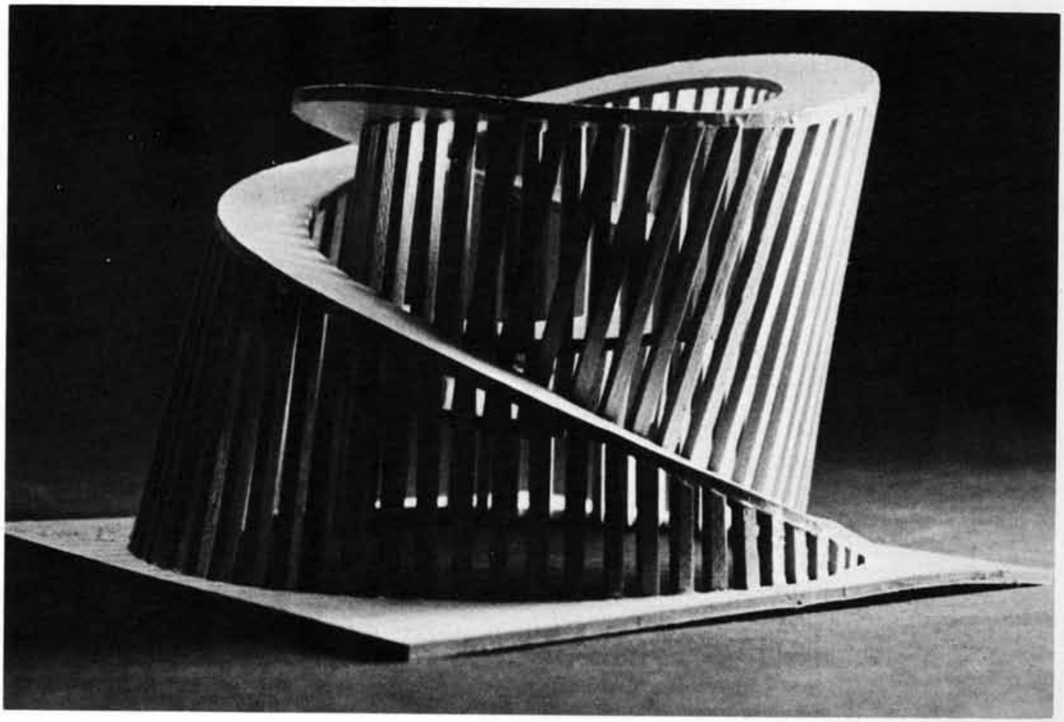

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Figure 365—the framework is a strong one, composed of vertical, horizontal, and diagonal members. All interlinking lines are parallel to the ground plane, but they are in directional gradation, forming gentle curved surfaces.

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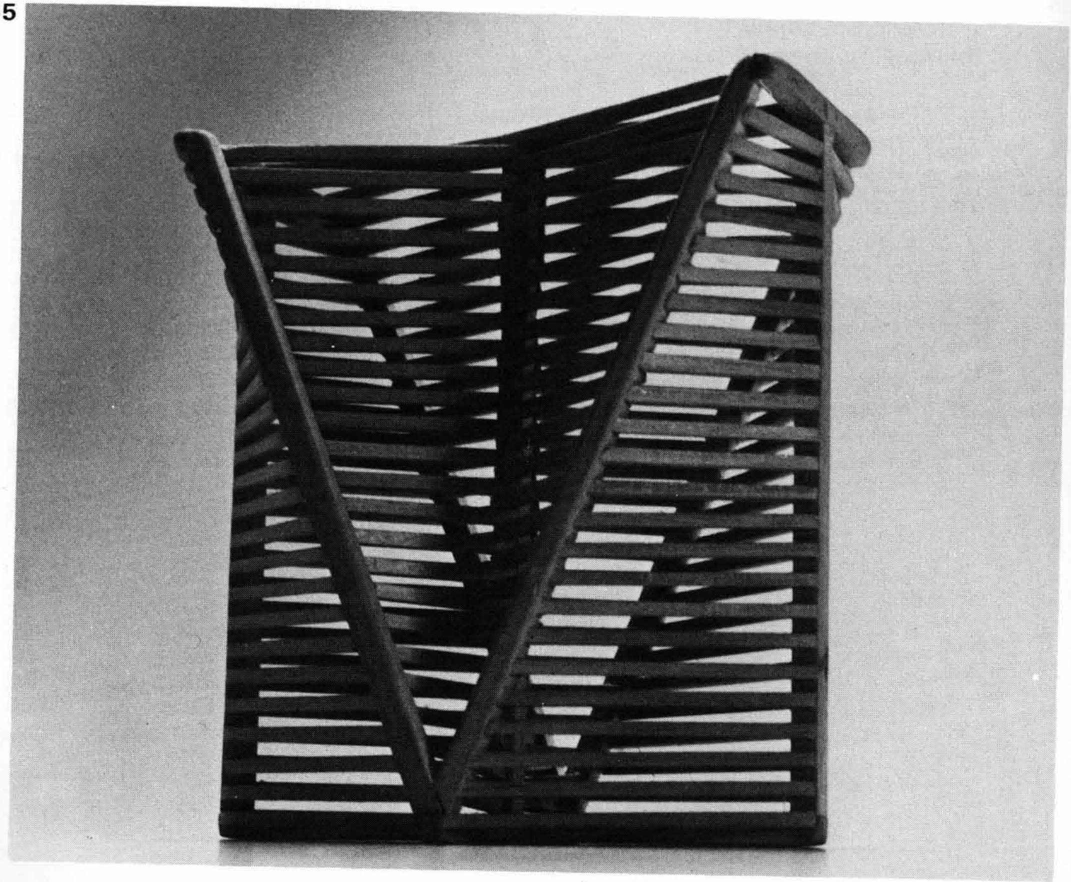

Figure 366—the framework is an octahedron. Six sets of interlinking lines are developed near the six vertices.

Figure 367—six triangular frames rotating around a common axis form this framework. The whole structure is reinforced by interlinking lines which enclose the space inside with curved surfaces.

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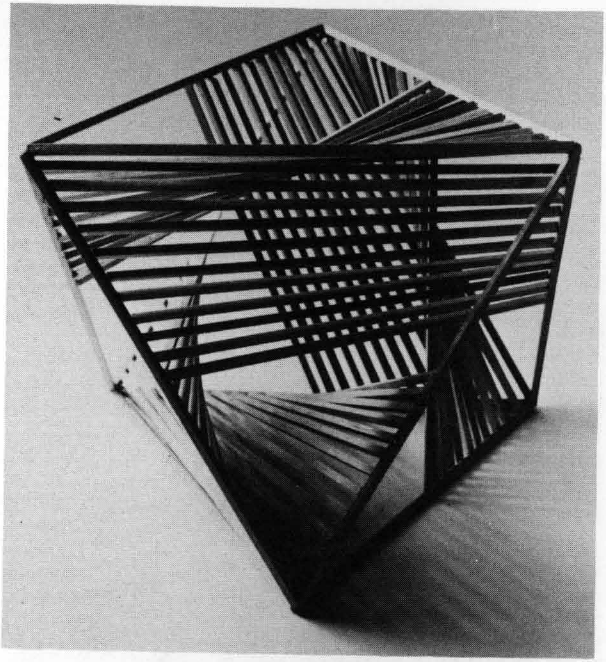

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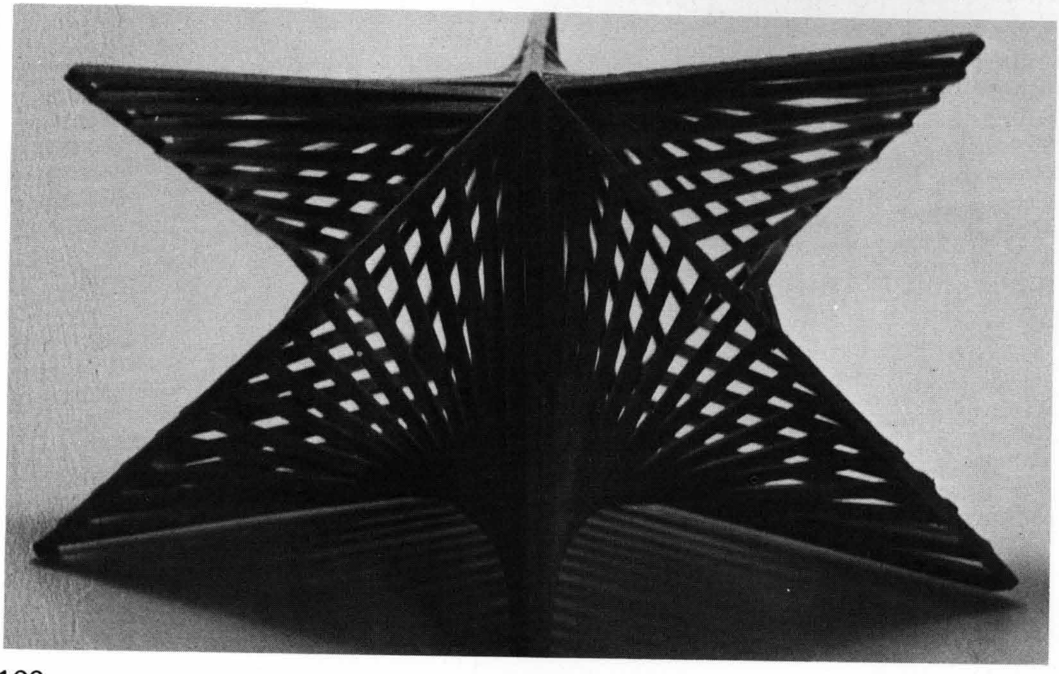

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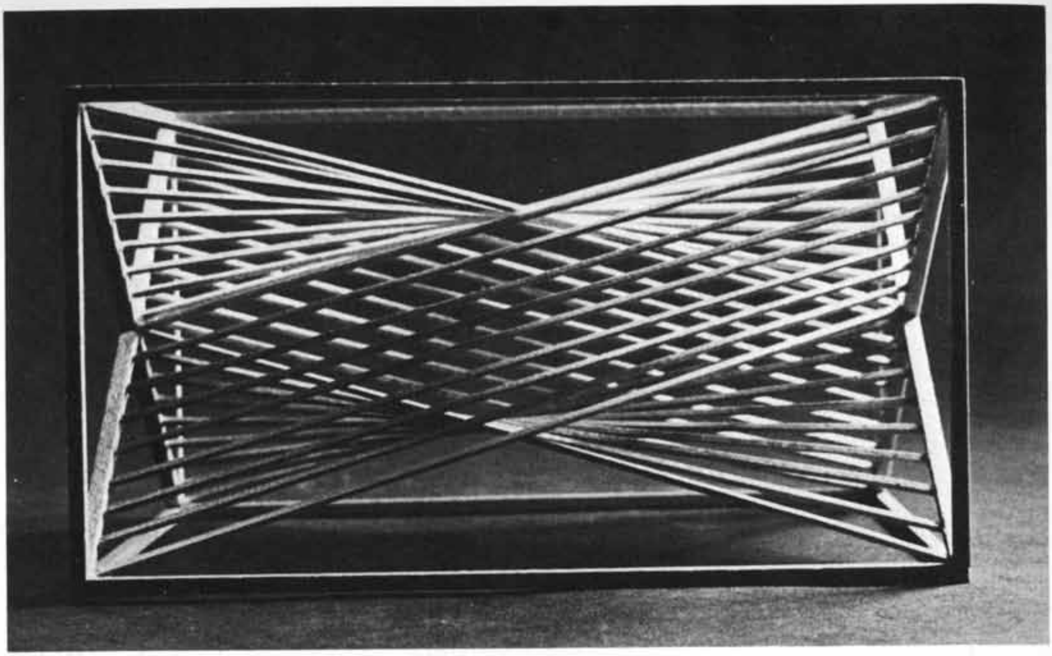

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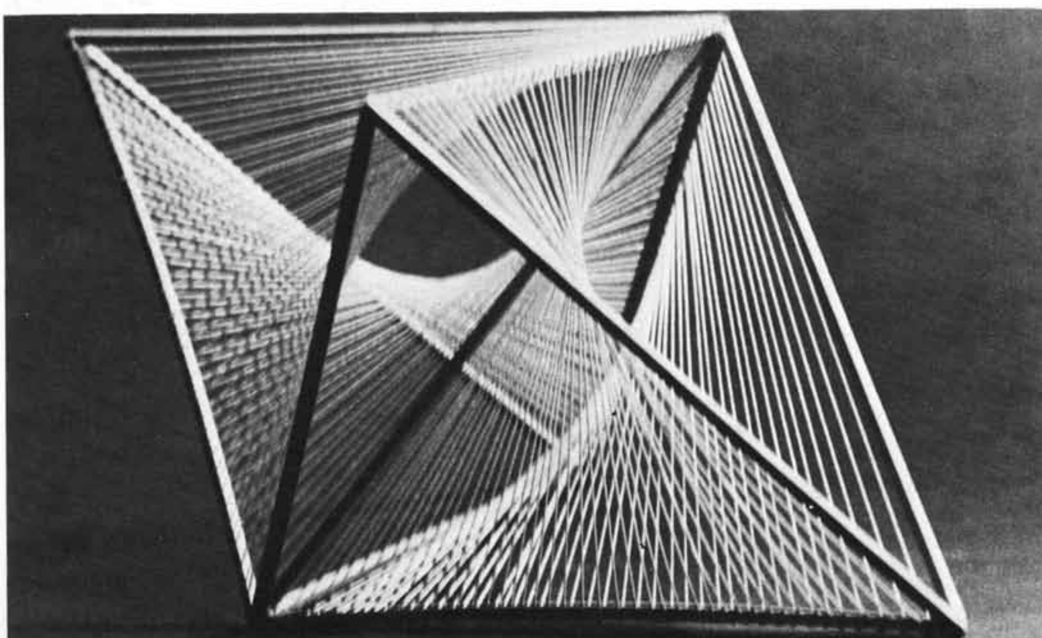
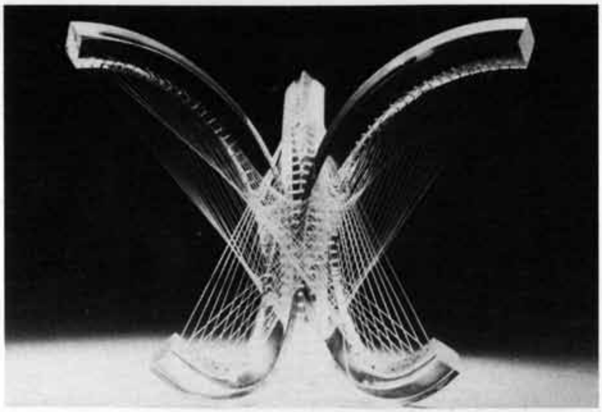


Figure 368—here the framework is built of two square frames and four parallel connecting sticks of the same length perpendicular to the square frames. Within each square frame, an X-shape is erected, and interlinking lines are developed between the two X-shapes.

Figure 369—eight isosceles triangular frames have been used for this octahedral framework. One stick is added inside between two opposite vertices to strengthen the structure, but two sticks of the outside framework are removed. Soft cotton thread is used for the interlinking lines.

Figure 370—the framework consists of three curvilinear plastic sticks. Nylon thread winds up and down and forms an interesting network among the curves.

Figure 371—four planar shapes of the same shape and size and five circular discs of varying sizes, all made from clear acrylic sheets, have been combined in this structure. Interlinking lines in nylon thread are developed between the circular discs as well as between the discs and the outside supporting shapes.



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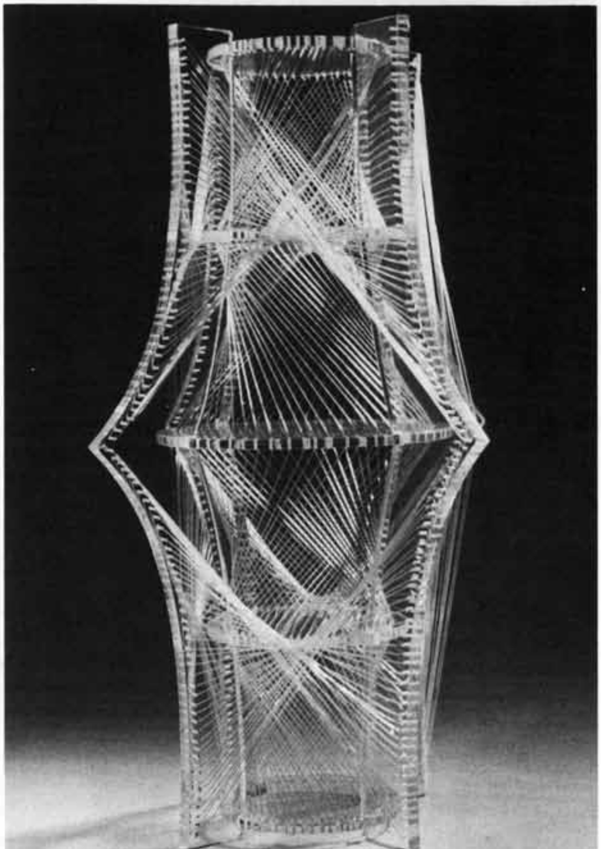

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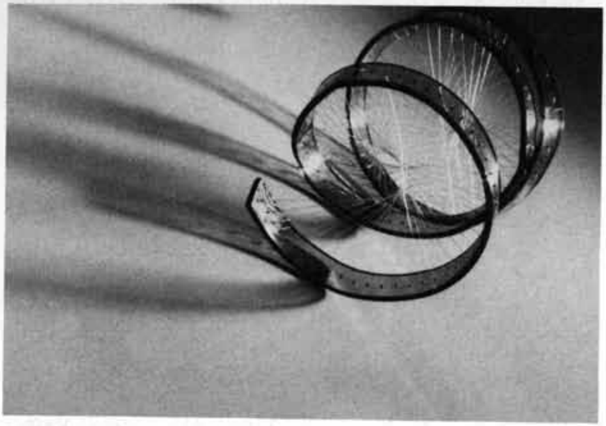

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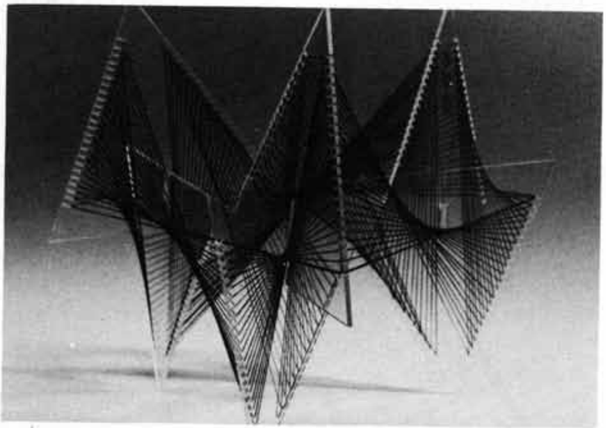

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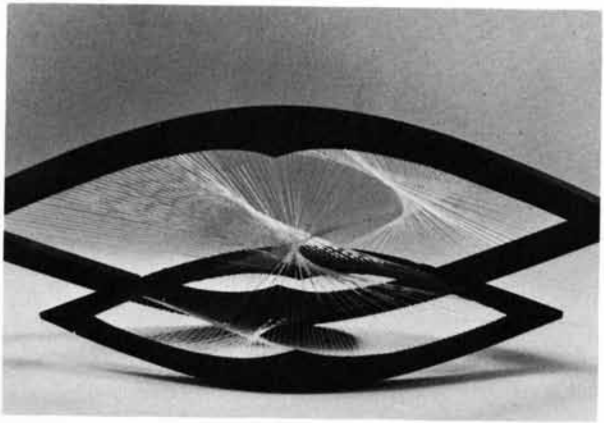

Figure 372—here a spiral plastic band has been used for the development of interlinking lines.

Figure 373—several triangular shapes made of clear acrylic sheets compose this structure. The main interest of the design is the interlinking lines, which stand out sharply among the transparent planes because of the dark color of the cotton thread.

Figure 374—in this design, the planar shapes, made of opaque acrylic sheets in dark color, are more prominent than the nylon interlinking lines, which are transparent and colorless. The effect is just opposite to that of Figure 373.