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.

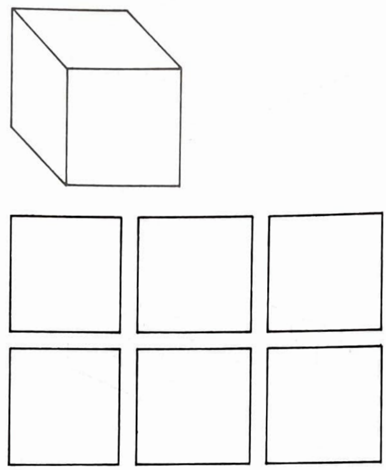
For instance, a solid cube consists of six square faces. To build this, six square planes are required. The thickness of the planes is of little visual significance because it is normally concealed. (Fig. 285)

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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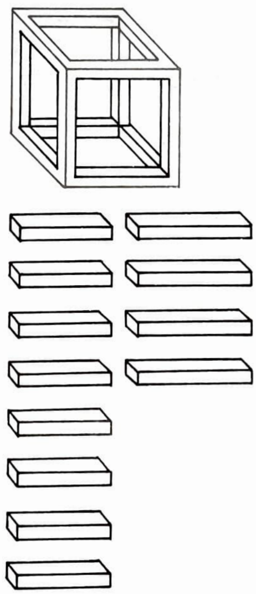

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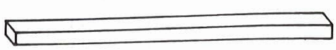

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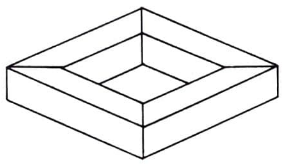

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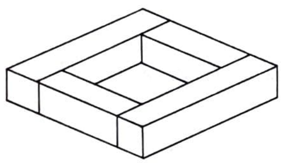

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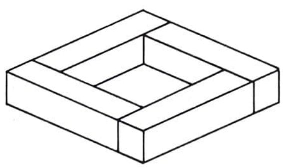

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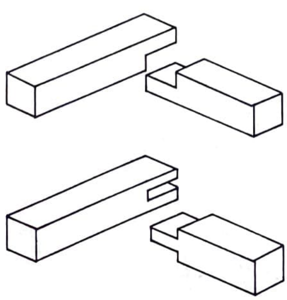


can be wooden sticks with square cross sections. The shapes are, in fact, elongated prisms with their own faces, edges, and ends. (Fig. 287)

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)

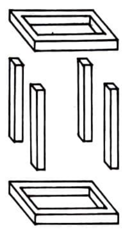
(c) the direction of the top frame can be the same as or different from that of the bottom frame; (Fig. 295)

(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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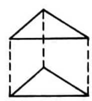

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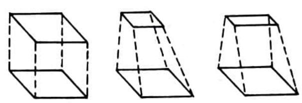

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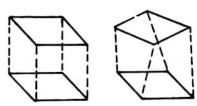

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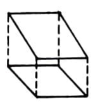

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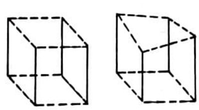

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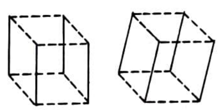

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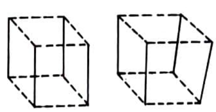

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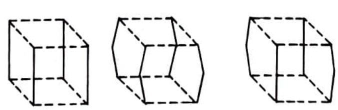

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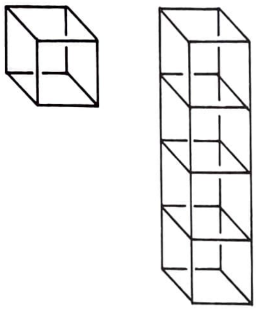

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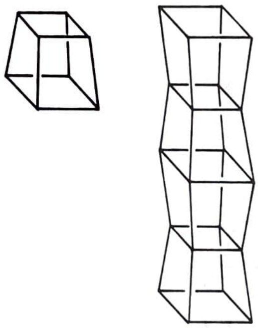

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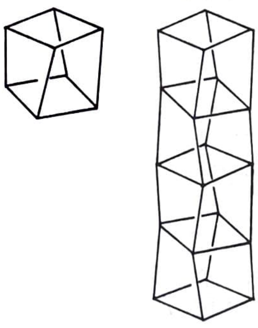

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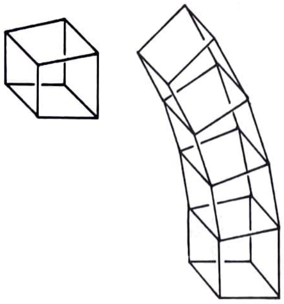


other; (Fig. 299)

(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)

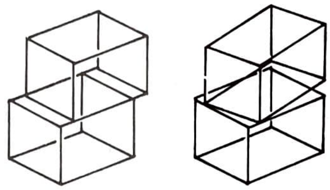
In more complex structures, repeated columns can be used.

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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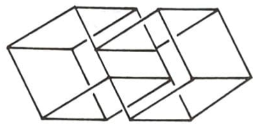
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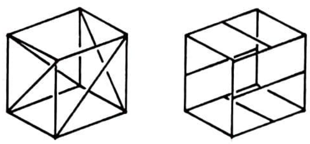
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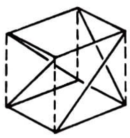
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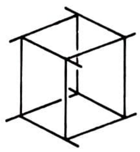
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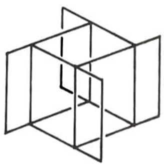
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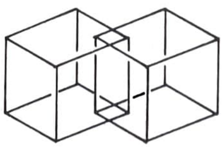
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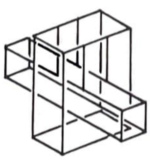
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Additional frames can be formed outside the linear framework. (Fig. 310)

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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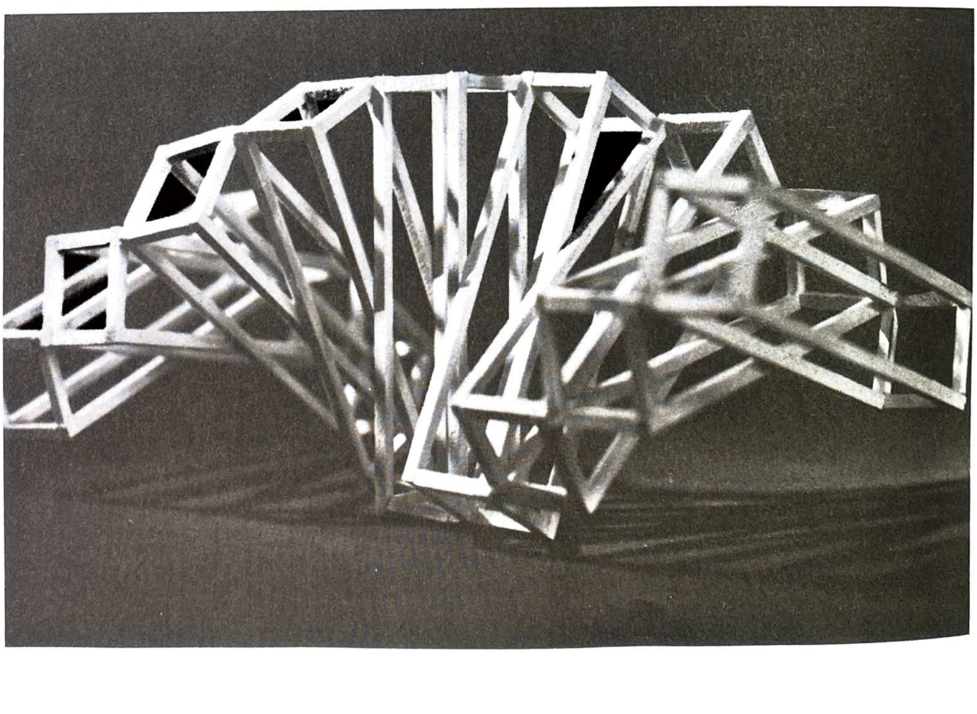

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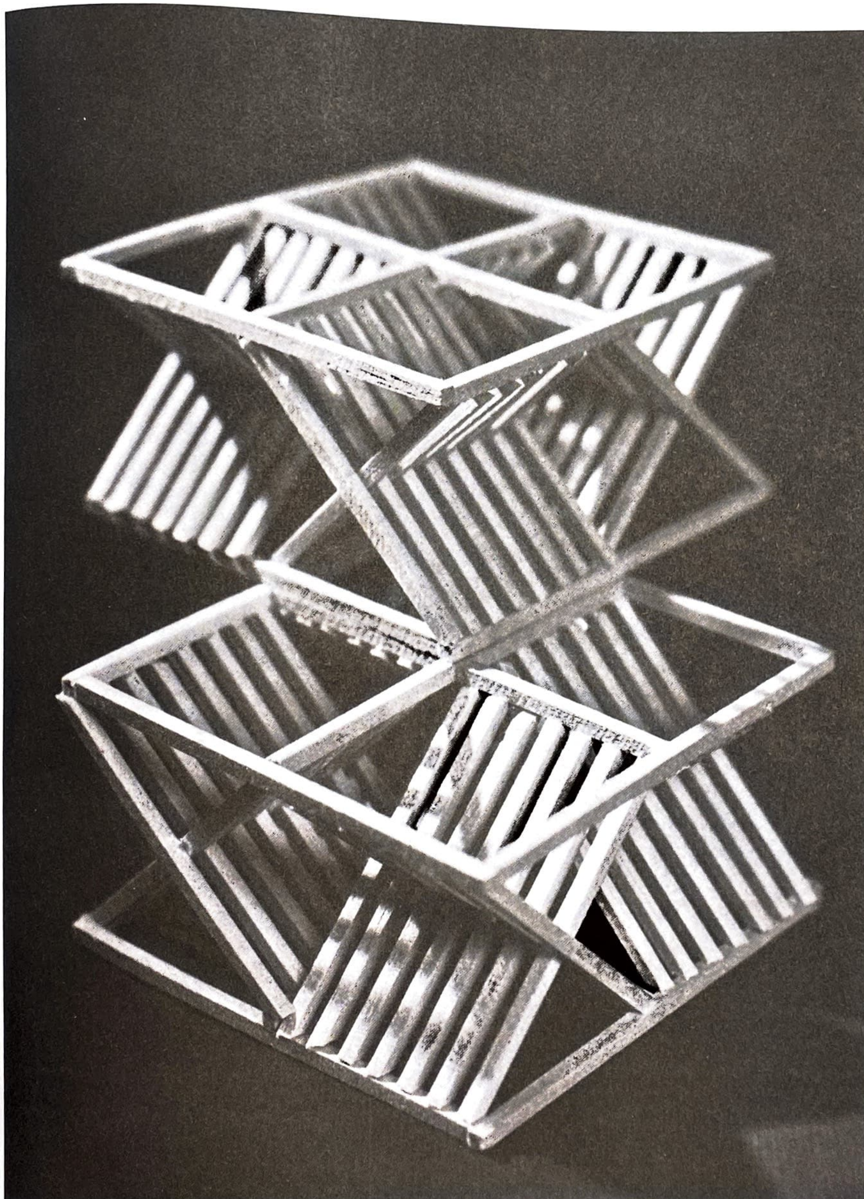

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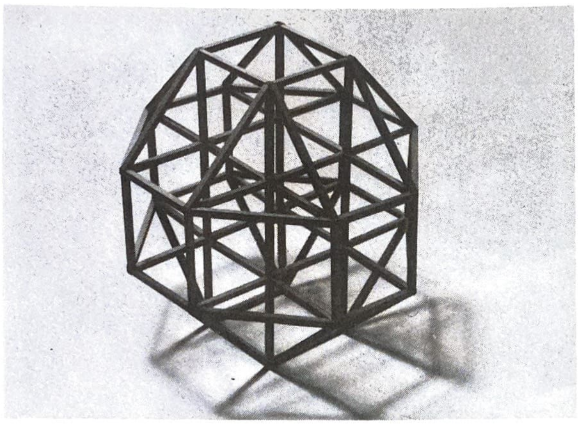

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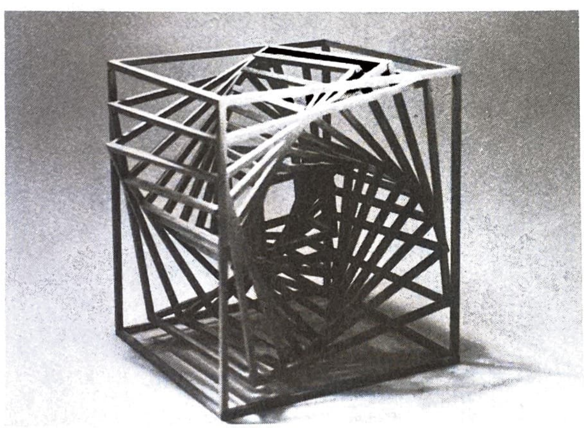

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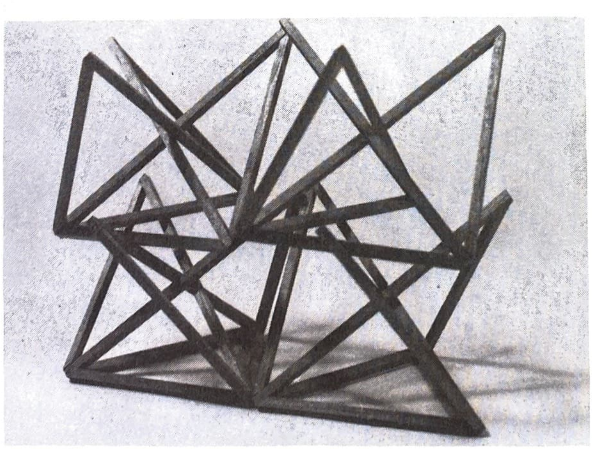

Figure 315—the structure is a rhombicuboctahedron, inside of which additional linear elements are developed that link the vertices.

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.

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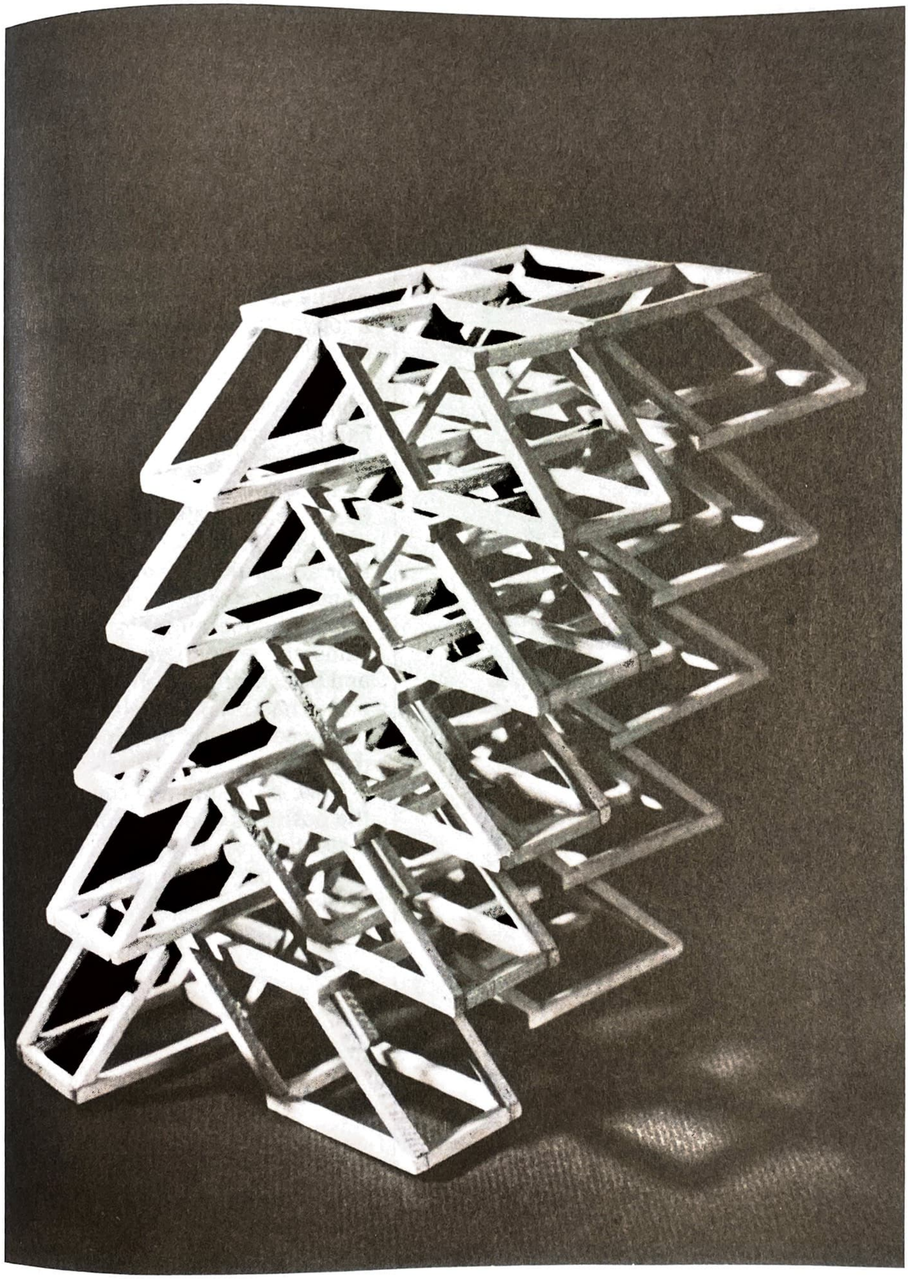

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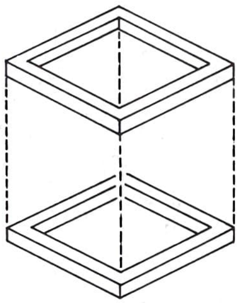

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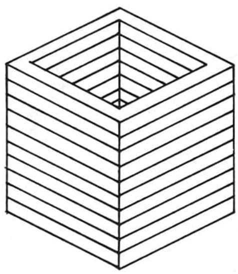

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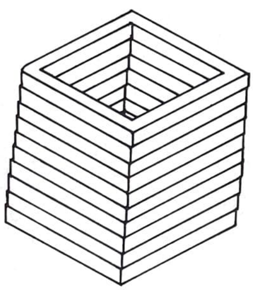

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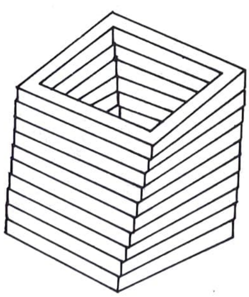


CHAPTER 9: LINEAR LAYERS

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)

Variations and Possibilities

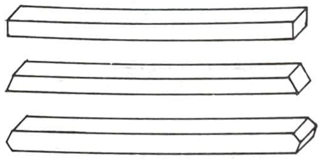
To simplify our thinking process, we can use a single wooden stick for each layer and see what variations and possibilities we can have.

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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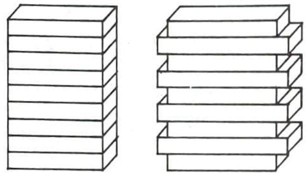

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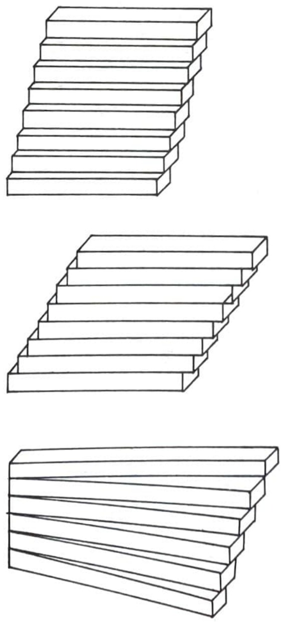

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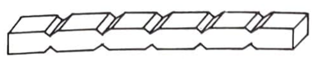

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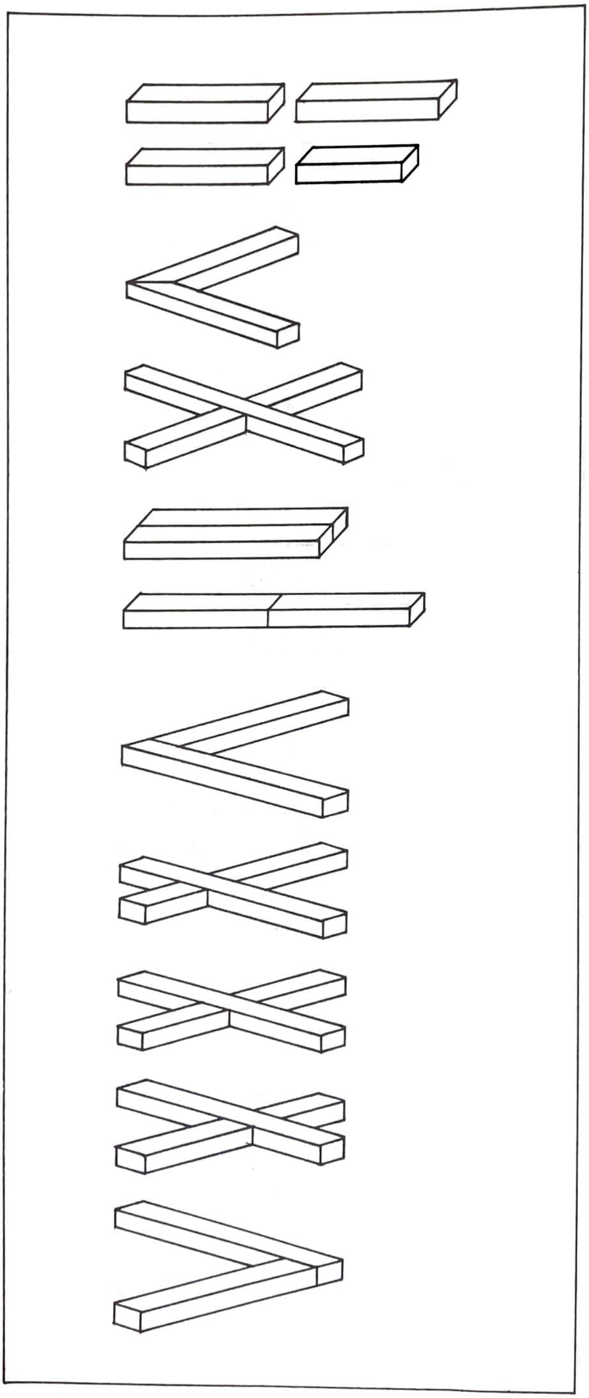


Gradation of Shape in Layer Construction

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)

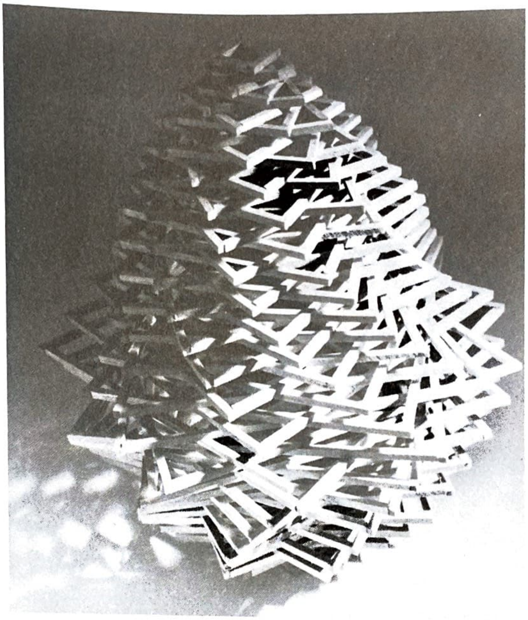
Let us observe the following example in layer construction. The top layer is a V-shape with the joint pointing to the left. In the layers immediately below this, the two sticks begin to overlap each other gradually in a half-lap joint, forming an X-shape. The central layer is an X-shape with the intersection 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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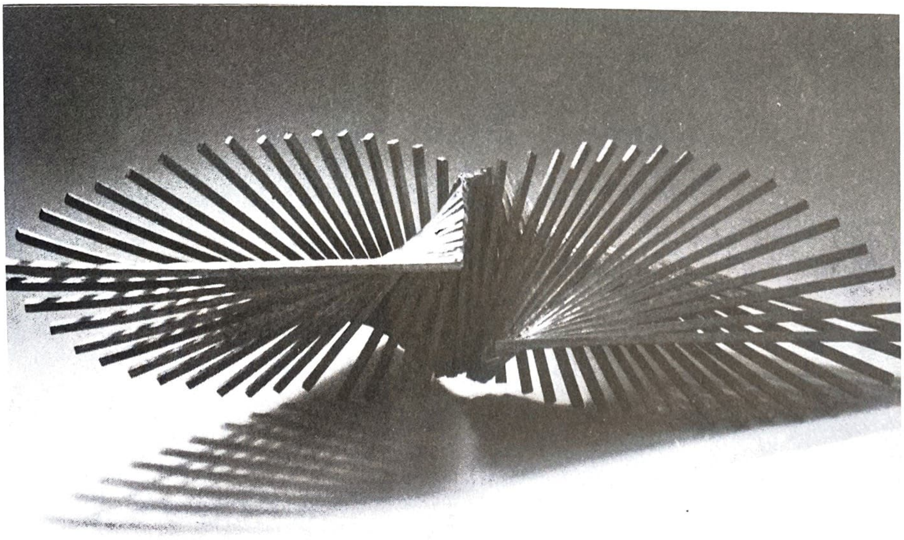

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Figure 333—similar to Figure 332, here we also find rotating sticks forming curved planes, four of which are put together in one design.

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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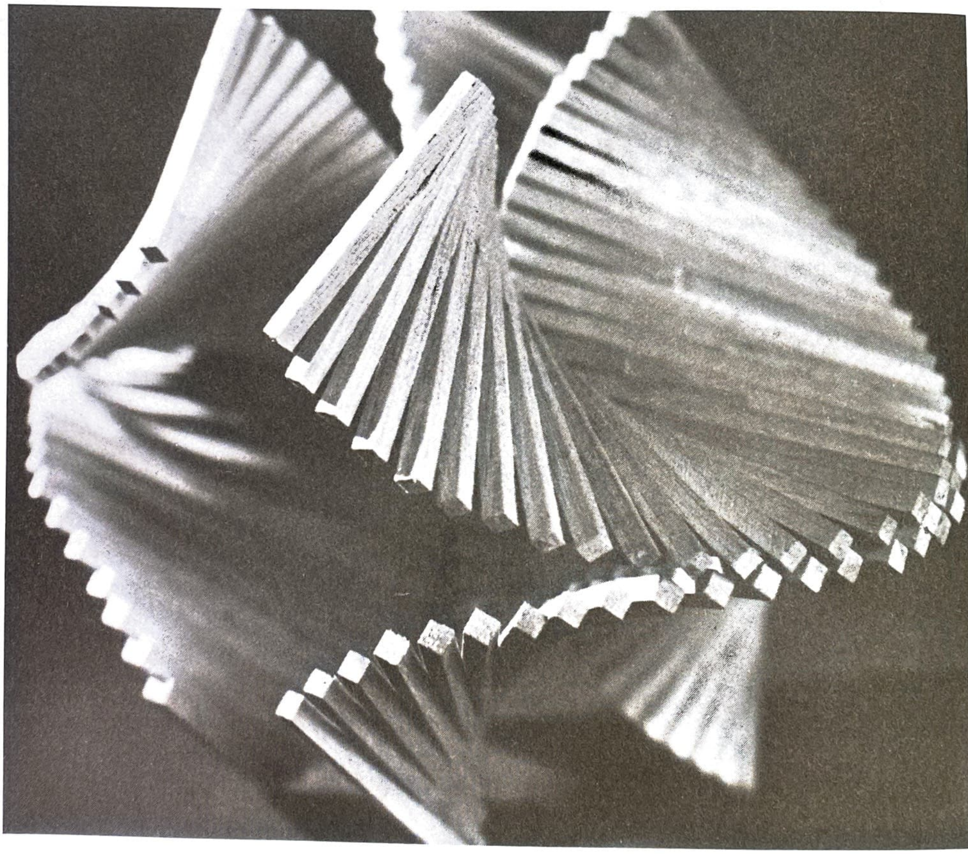

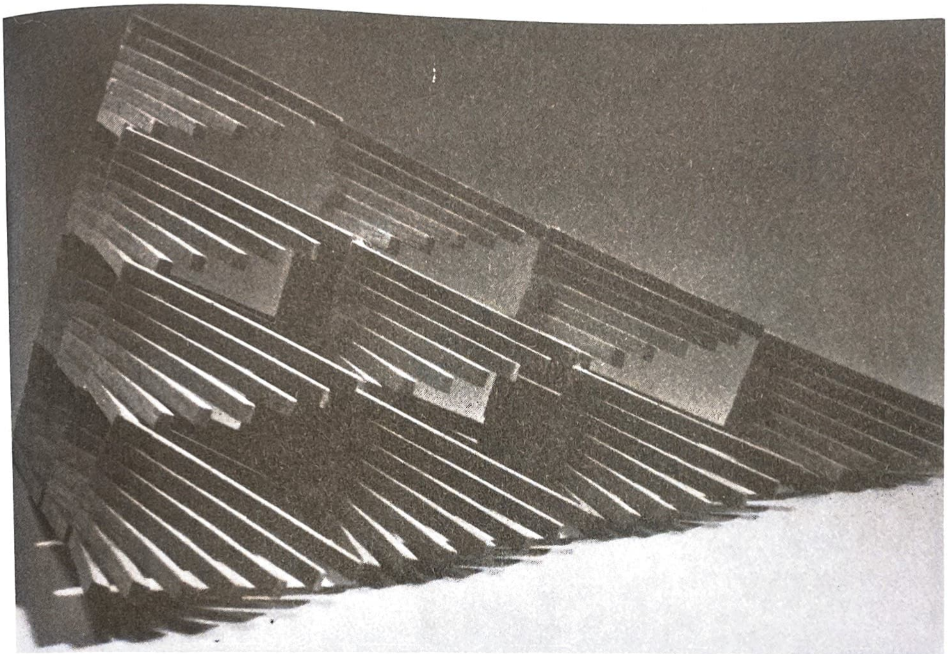

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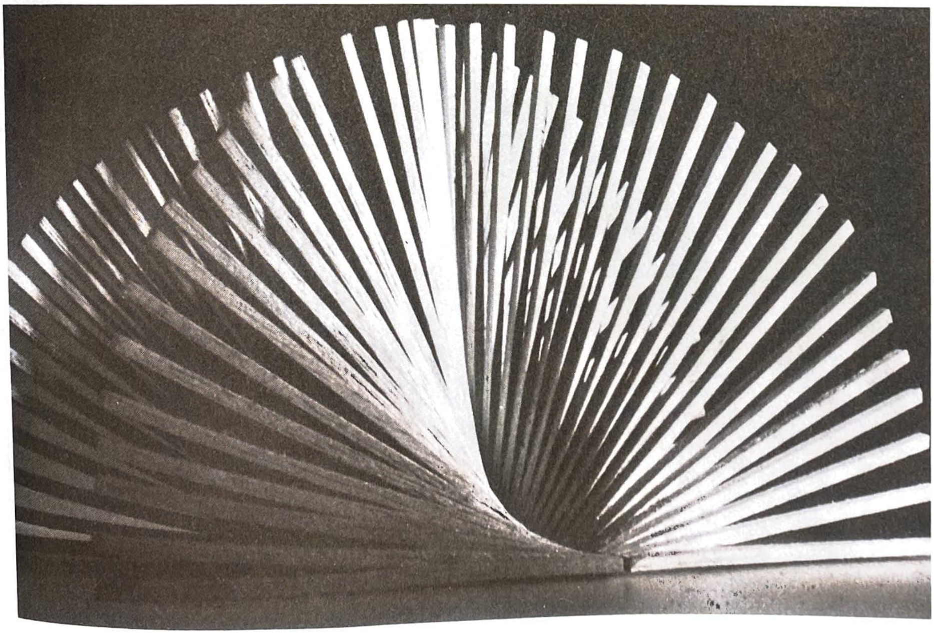

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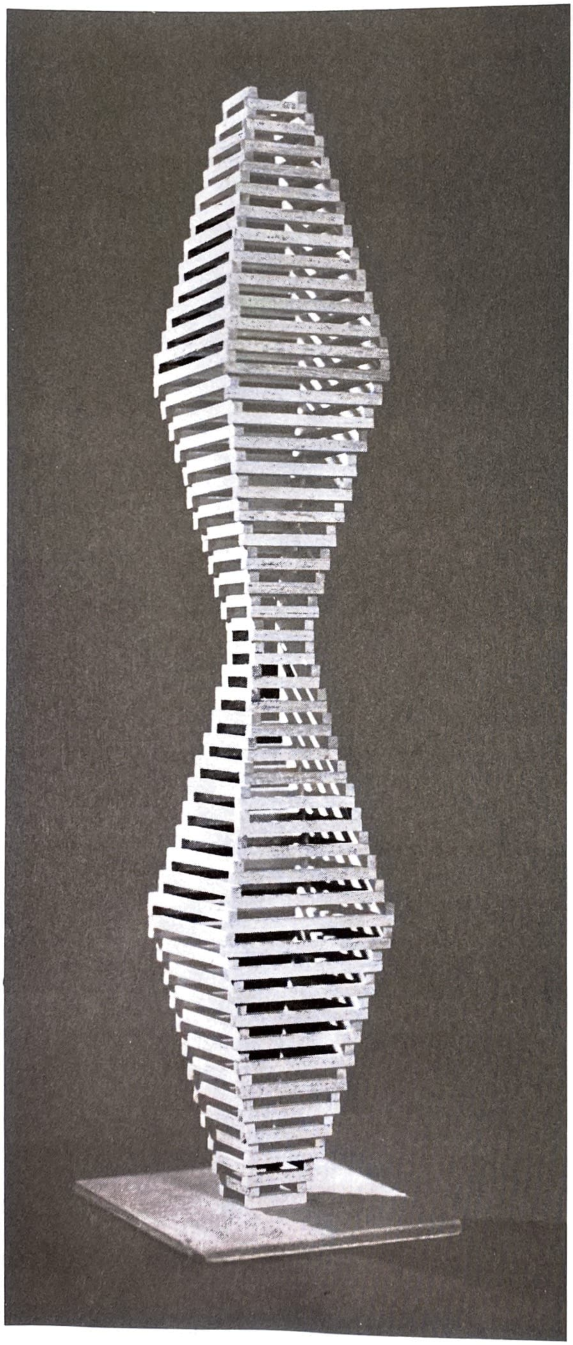

Figure 336—here each square frame is separated into two layers, one layer with two sticks pointing forward and backward, and the next layer with sticks pointing sideways. Gradation of the size of the square frames, created by gradation of the lengths of the sticks, has made this into an interesting towering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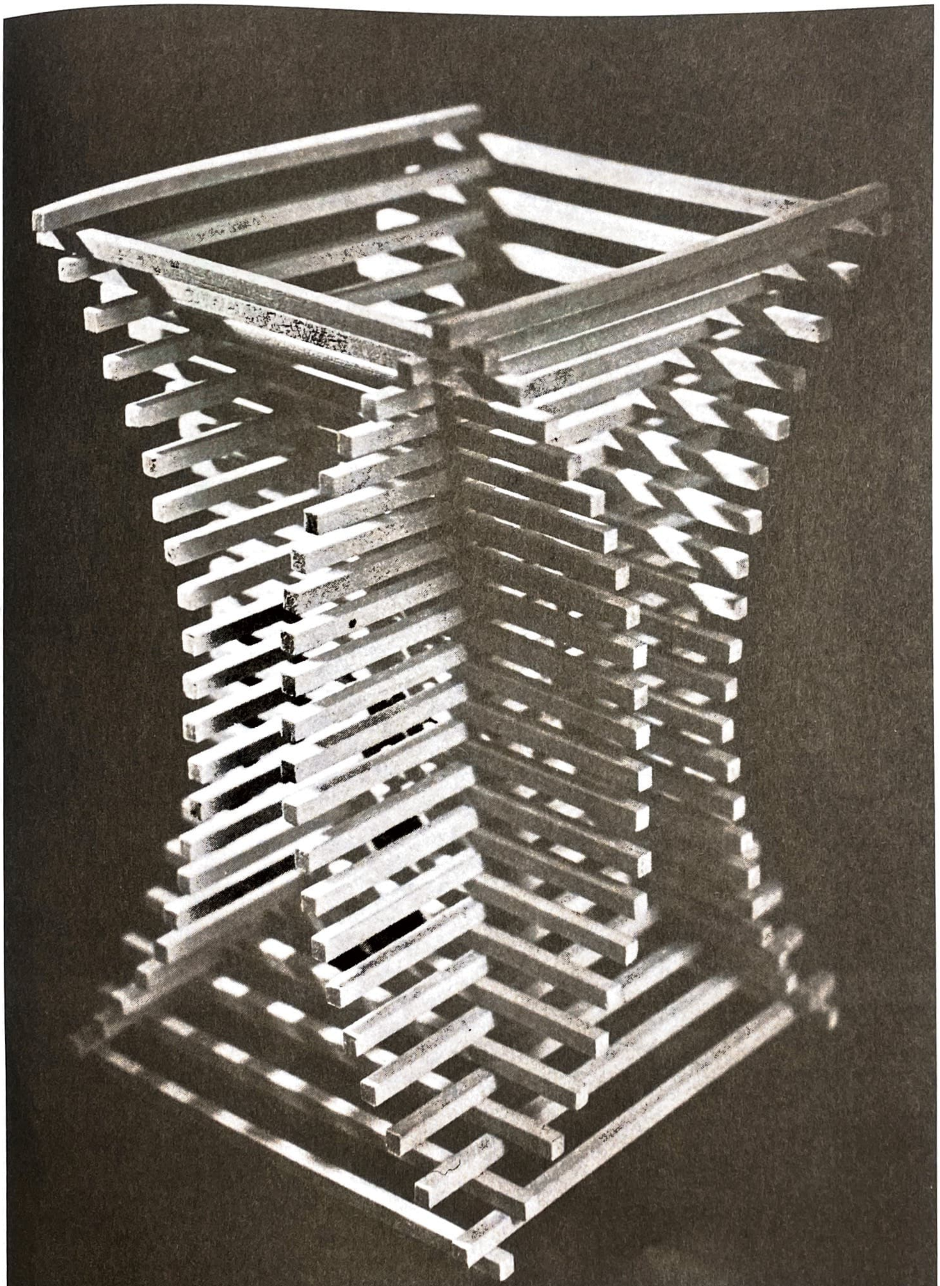

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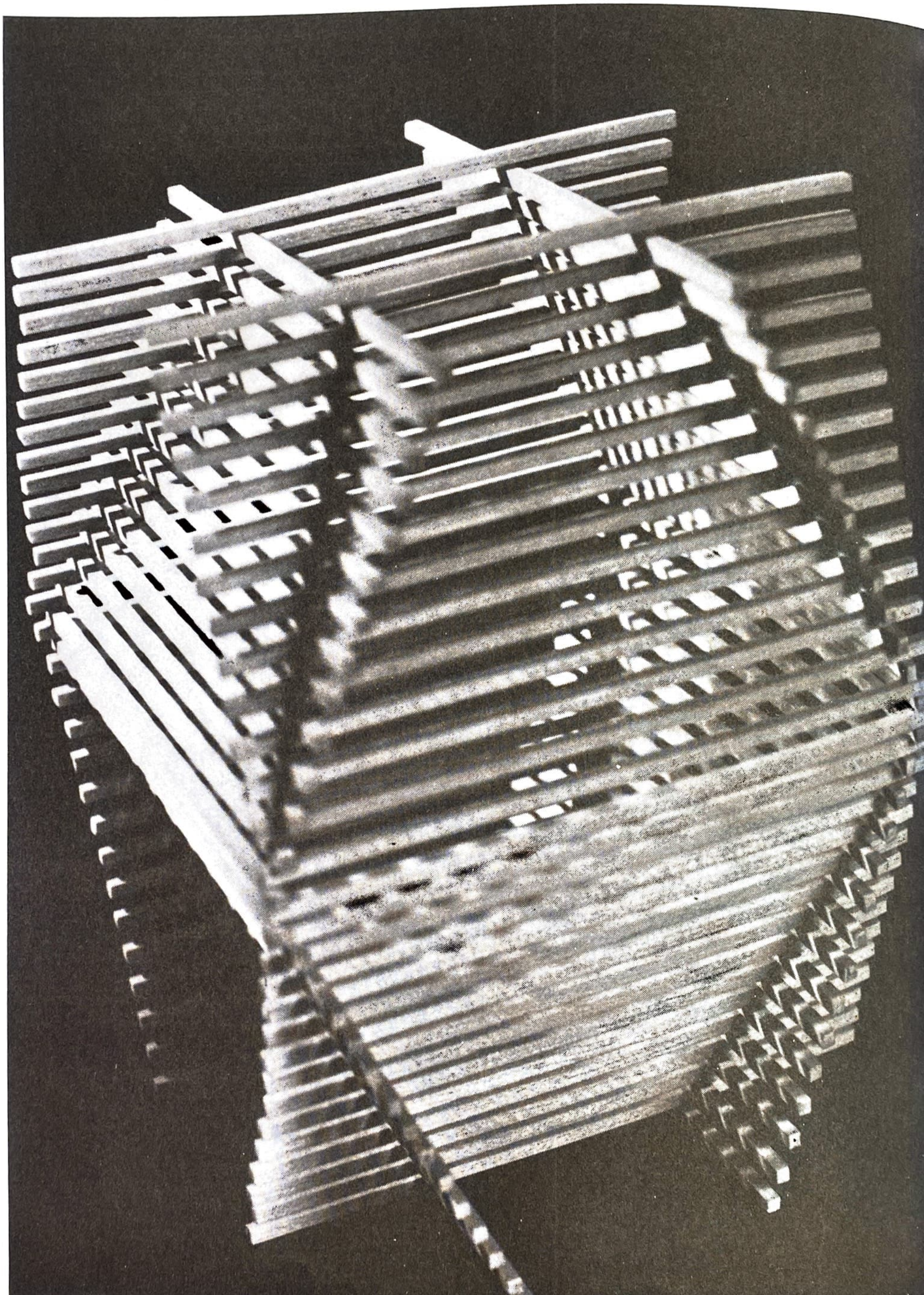

CHAPTER 10: INTERLINKING LINES

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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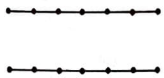

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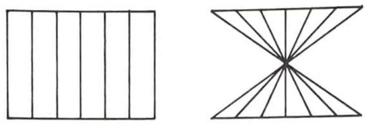

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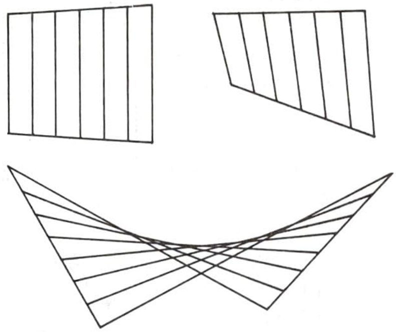

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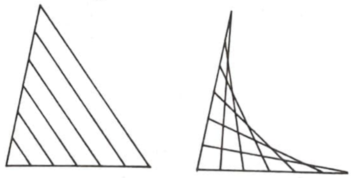

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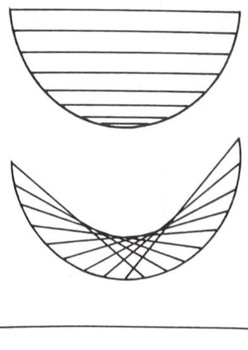

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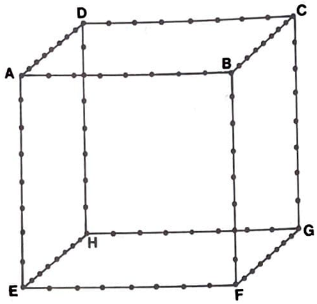

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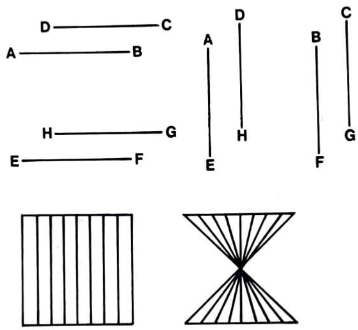

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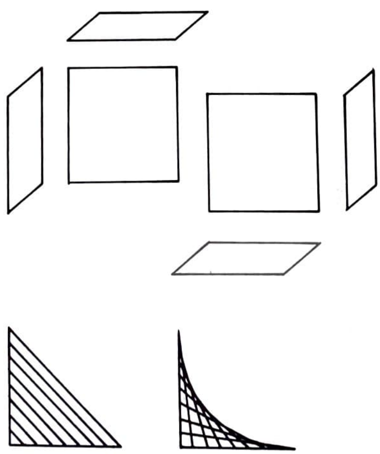

Interlinking Lines in Space

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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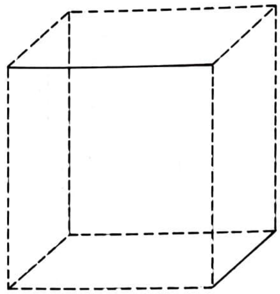

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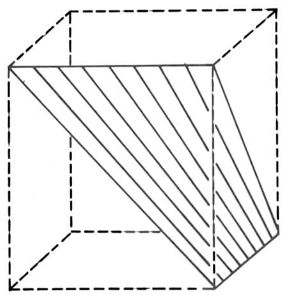

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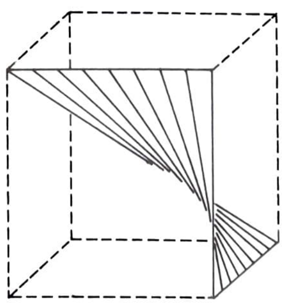

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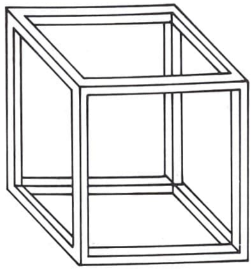

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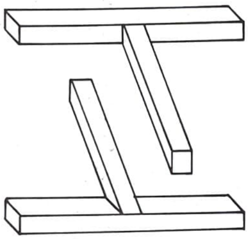

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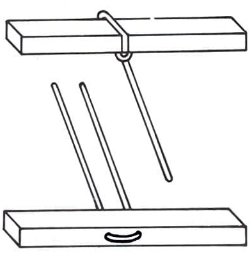

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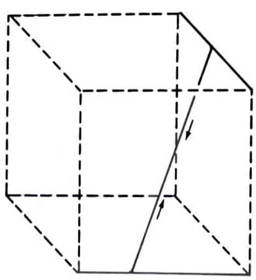


Materials and Construction

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.

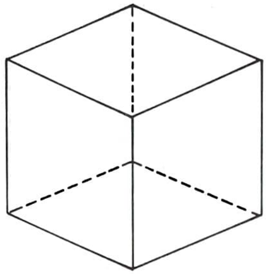
Interlinking Lines Within a Transparent Cube

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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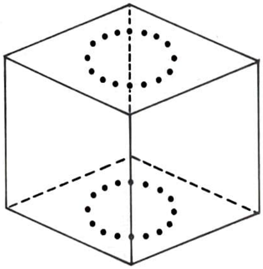

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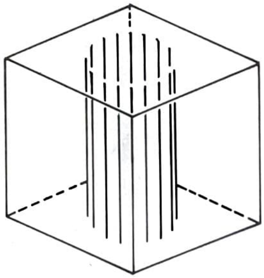

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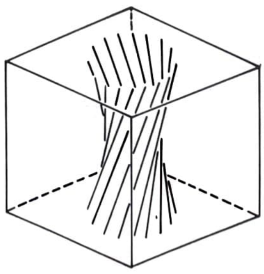

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More complicated and interesting results can be achieved by varying the design just described in one or more of the following ways:

(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)

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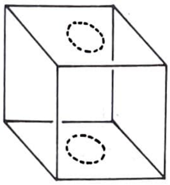

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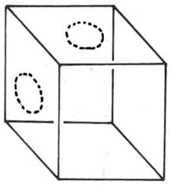

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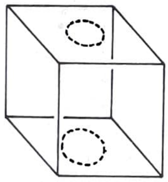

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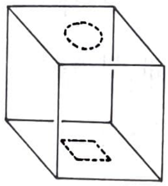

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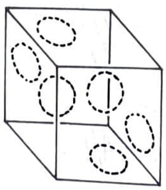
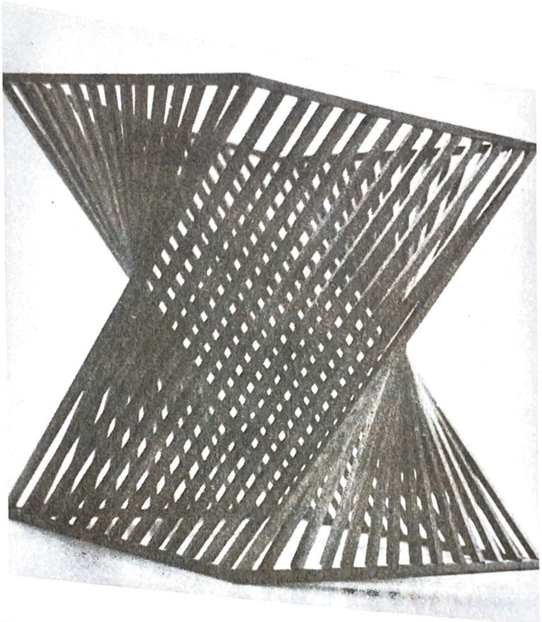


Figures 363 to 368 illustrate projects using rigid wooden sticks for the construction of interlinking lines. Figures 369 to 374 feature interlinking lines in soft materials.

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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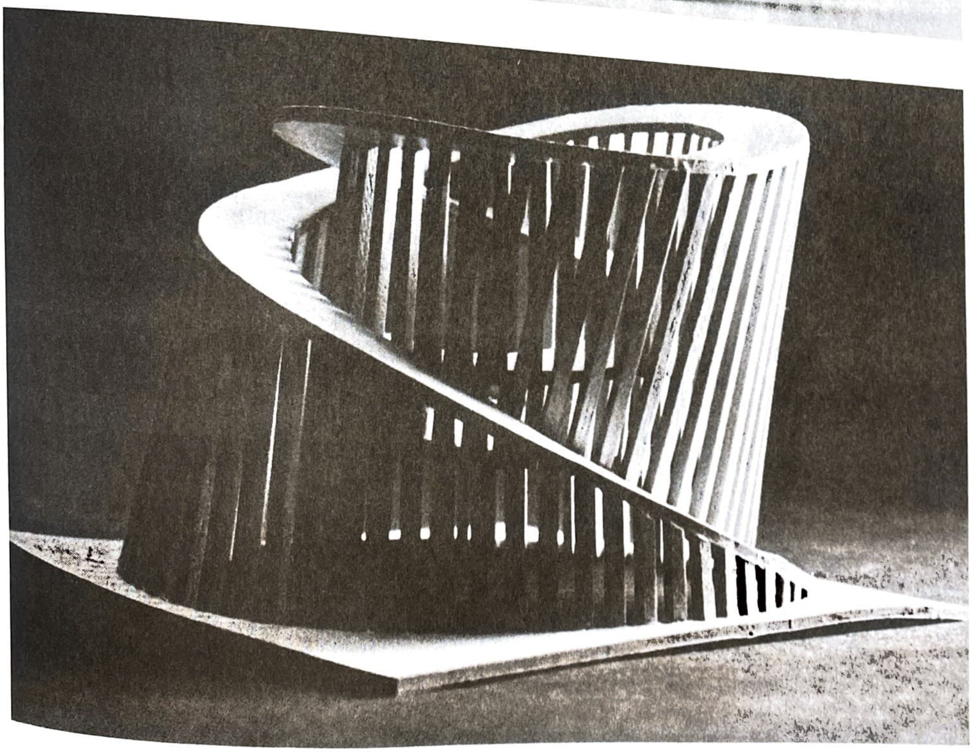

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Figure 365—the framework is a strong one, composed of vertical, horizontal, and diagonal members. All interlinking lines are parallel to the ground plane, but they are in directional gradation, forming gentle curved surfaces.

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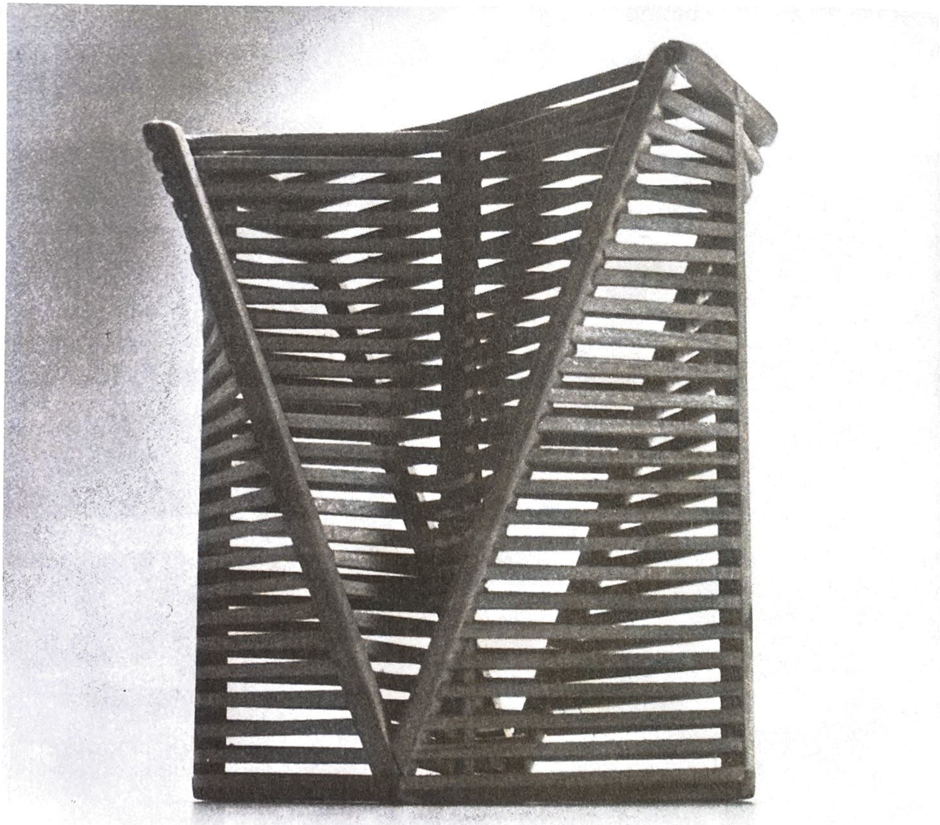

Figure 366—the framework is an octahedron. Six sets of interlinking lines are developed near the six vertices.

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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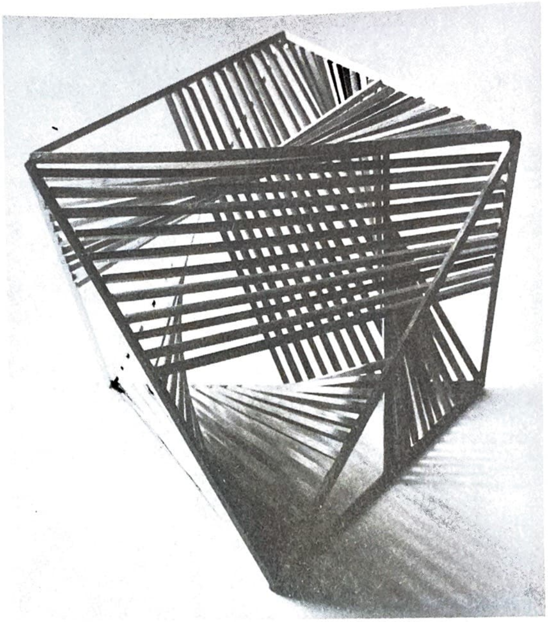

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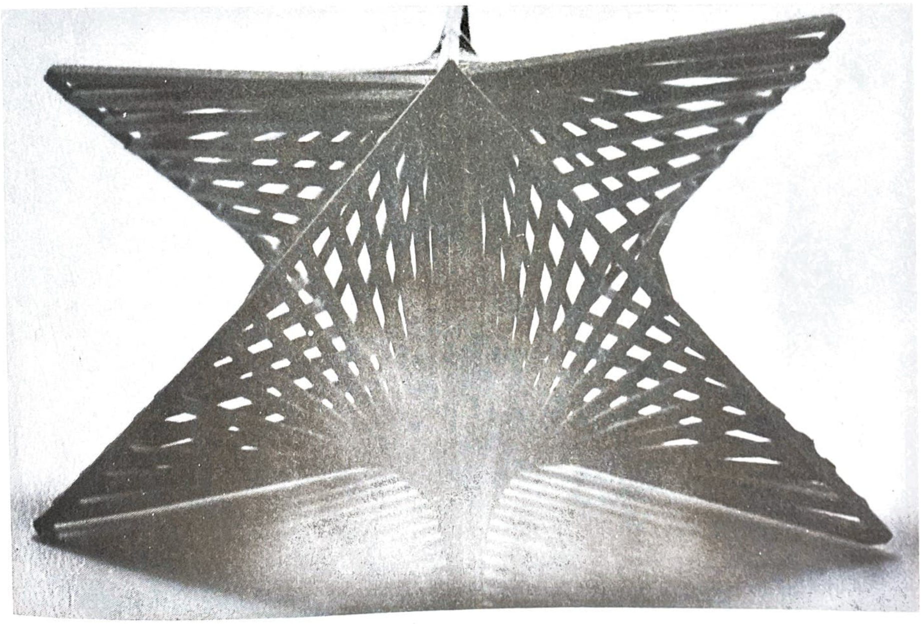

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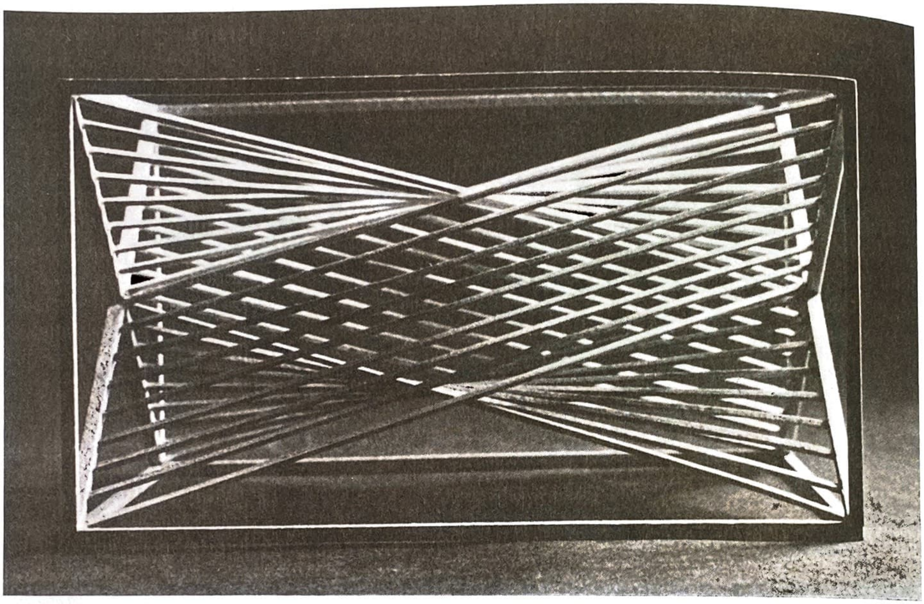

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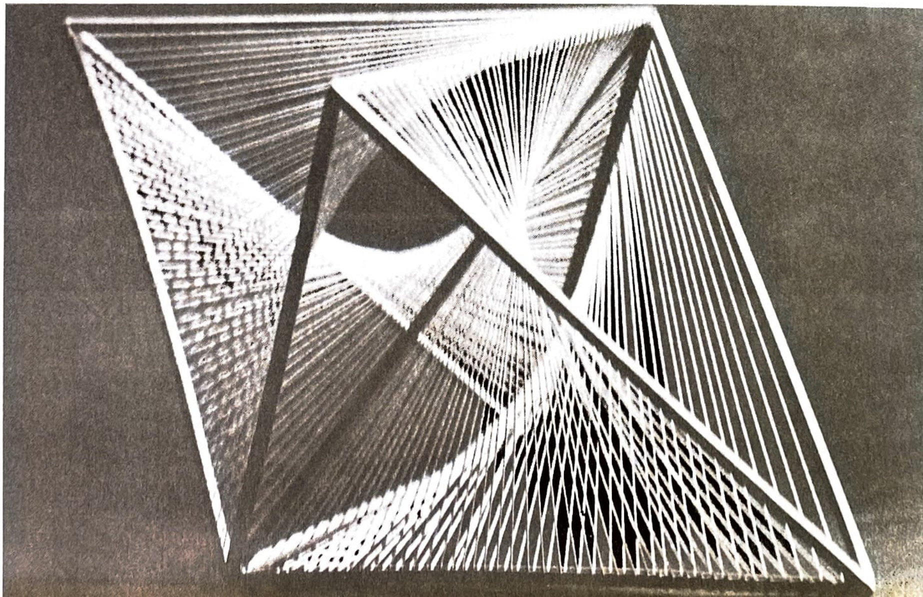
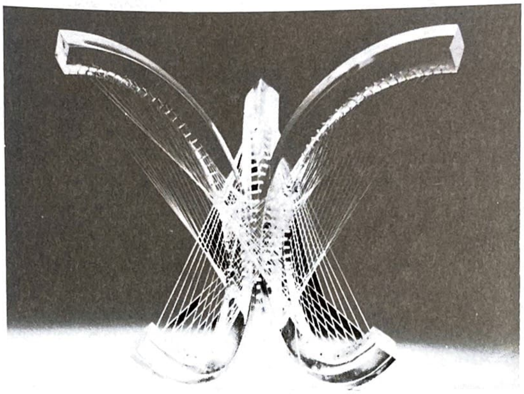


Figure 368—here the framework is built of two square frames and four parallel connecting sticks of the same length perpendicular to the square frames. Within each square frame, an X-shape is erected, and interlinking lines are developed between the two X-shapes.

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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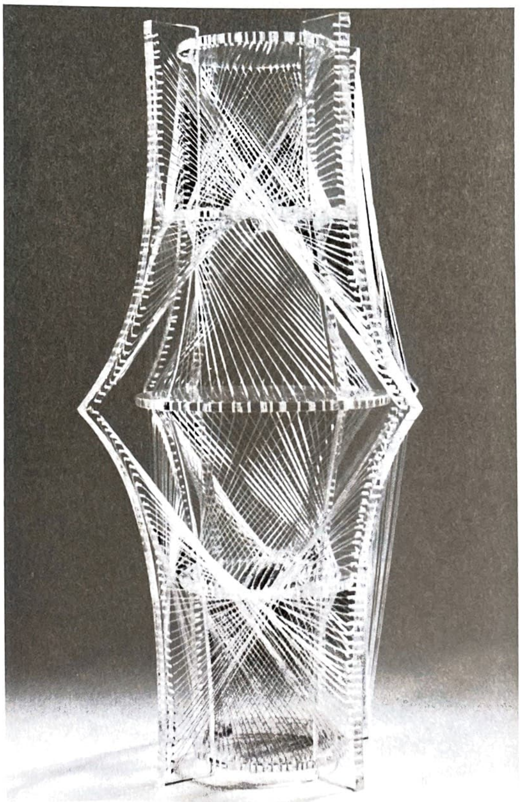
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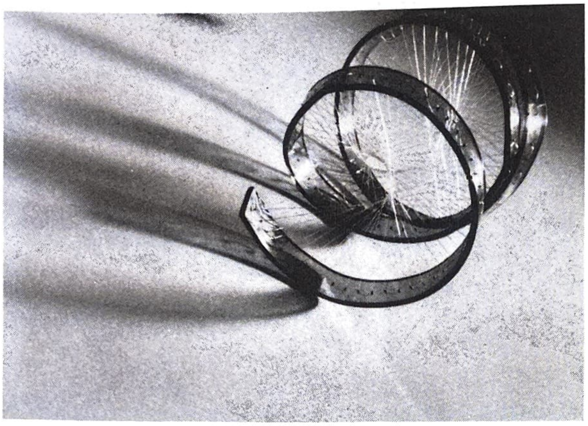

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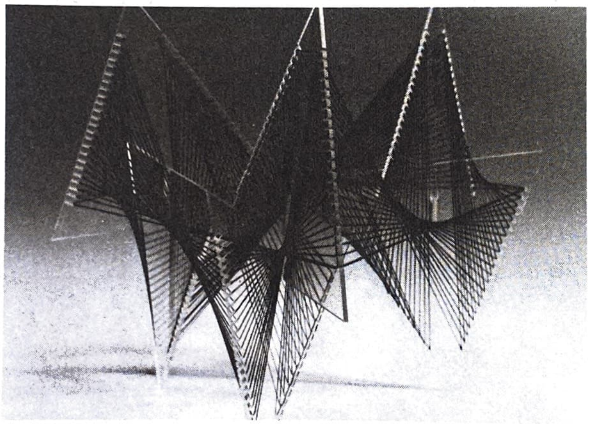

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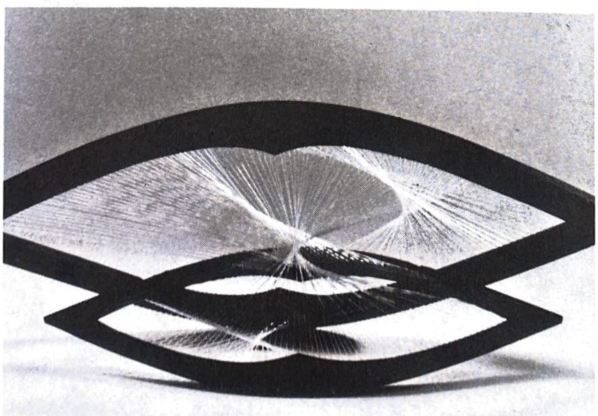

Figure 372—here a spiral plastic band has been used for the development of interlinking lines.

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.