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POLYHEDRAL AND MOSAIC TRANSFORMATIONS

Duncan Stuart

SOME THOUGHTS ON DESIGN EDUCATION

Vernon Shogren

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This article is divided into two parts: Text and Finger Movies. The Finger Movies make up the left hand portion of the magazine.

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Historically one of man's major preoccupations has been that of finding various kinds of order. He has sought this order in the environment in which he found himself, in the way he occupied this environment, and in the comment which he made concerning the state of his being. Somehow, this condition has grown from an inner necessity for ordering his universe. The question of whether this universe is *really ordered* in the sense indicated remains a moot one.

One aspect of this ordering process is being examined in this work—that of the orderly subdivision of space. We make no pretense of an exhaustive examination, but limit ourselves to certain rather primitive notions about space. These notions largely revolve around ideas of dividing spaces into *most equally* distributed points; or sets of points distributed in space by interconnecting lines of more or less standard length and the planes which such points and lines define. Even while we do this we conceive only an idealized sort of space which may or may not bear any resemblance to the palpable world in which we live. Such a study leads to notions which caused the Greeks to envision what we call Polyhedra and their two-dimensional counterparts, Mosaics.

Our study will center around the polyhedra and the mosaics and will undertake to describe a set of transformations which will allow us, more easily, to view them as a single closed and comprehensive entity.

As we have indicated, the Greeks were responsible for laying the foundation for these studies in the remote past. Between the Greeks and our own immediate history a period known as the Renaissance rekindled an interest in these forms, as we see in the works of various artists: the drawings of Paolo Uccello and Leonardo da Vinci, the engravings of Albrecht Dürer. In a more scientific direction the astronomer, Kepler, was bemused by the notion that the polyhedra in some mysterious way explained the positions of the planets within our solar system.

In more recent times, this renewed interest seems to have achieved some impetus from the discovery of similar regularities in natural form. The study of crystalline objects revealed that four of the five regular polyhedra actually seem to occur in nature.

During the voyage of the HMS Challenger, Haeckel found the marvelous microscopic skeletons of the sea creatures known to us as *radiolaria* which displayed many of the regular properties of polyhedra. In more recent times, we have seen that man's preoccupation with problems of *closest packing* as related to the innermost properties of structures of nature is at least in part related to polyhedral regularities.

However practical these recent interests may appear to be, the chief interest remains, from Greeks to modern man, an aesthetic one. For the regularity of these forms somehow creates a sense of dazzling wonder in man's eyes. As H. S. M. Coxeter in his book *Regular Polytopes* remarks about Klein's Lectures on the Icosahedron, "To be sure there is little more to it than that: Klein's lectures cast a fresh light on the general quintic equation, but if Klein had not been an artist he might have expressed his results in purely algebraic terms."

We feel that this study reveals a fresh and more meaningful way of describing the relationships between the various polyhedra and to the two-dimensional mosaics. So far as this author knows the first actual working model of the ideas to be presented was discovered by R. B. Fuller somewhere around the year 1947. Since this time this author, with the aid of many others, has expanded this discovery into the more comprehensive one which follows.

Should we wish to write a set of rules allowing us to define regularity in the sense used now, we would write the following for the two-dimensional case of the regular and semi-regular Mosaics.

1) A Regular Mosaic must be composed of only one kind of plane polygon.
2) These plane polygons must be equilateral, equiangular and rectilinear.

3) The polygons must mutually join at their edges and vertices so as to totally fill a flat plane of infinite extensibility.
4) In a similar fashion, a Semi-Regular Mosaic must be totally composed of plane polygons as defined in 2)—but now, more than one kind of plane polygon may be employed in a single mosaic network.
5) There must be the same number and kinds of polygons, joined in the same order (or its enantiomorph) at each of the vertices of a network.
6) The corner angles of the polygons which join at a single vertex must total in aggregate, 360°.
7) A straight line drawn at random on the plane of the mosaic will cross the boundaries of any polygon no more than twice.

Similarly, for Regular and Semi-Regular Polyhedra we may write a comparable set of defining rules of combination. We pair these with the above rules.

1) A Regular Polyhedron must enclose a volume of space with a surface composed of only one kind of plane polygon.
2) These plane polygons must be equilateral, equiangular and rectilinear.
3) The polygons must mutually join at their edges and vertices so as to completely fill a single imaginary spherical surface passing through the joined vertices.
4) In a similar fashion, a Semi-Regular Polyhedron must be totally composed of plane polygons as defined in 2)—but now, more than one kind of polygon may be used in a single polyhedron.
5) There must be the same numbers and kinds of polygons, joined in the same order (or its enantiomorph), at each of the vertices of the polyhedral surface.
6) For Regular and Semi-Regular Polyhedra, the corner angles which join at a single vertex must total in aggregate, less than 360°.
7) The plane of any polygon, if extended, must not pass through the interior volume of the polyhedron. And, a plane passed through the polyhedron at random will always have a single closed polygon at its line of intersection with the polyhedral surface.

Table 1 which follows illustrates the 18 possible Regular and Semi-Regular Polyhedra which subscribe to these rules*. Their properties are **described** in the following table.

	Name	Vertices	Faces	Edges	△	□	⬠	⬡	⯃	◯
1.	Tetrahedron	4	4	6	4	—	—	—	—	—
2.	Octahedron	6	8	12	8	—	—	—	—	—
3.	Cube (Hexahedron)	8	6	12	—	6	—	—	—	—
4.	Icosahedron	12	20	30	20	—	—	—	—	—
5.	Dodecahedron	20	12	30	—	—	12	—	—	—
6.	Cuboctahedron	12	14	24	8	6	—	—	—	—
7.	Icosadodecahedron	30	32	60	20	—	12	—	—	—
8.	Truncated Tetrahedron	12	8	18	4	—	—	4	—	—
9.	Truncated Octahedron	24	14	36	—	6	—	8	—	—
10.	Truncated Cube	24	14	36	8	—	—	—	6	—
11.	Truncated Icosahedron	60	32	90	—	—	12	20	—	—
12.	Truncated Dodecahedron	60	32	90	20	—	—	—	—	12
13.	Snub Cube	24	38	60	32	6	—	—	—	—
14.	Snub Dodecahedron	60	92	150	80	—	12	—	—	—
15.	Lesser Rhombicuboctahedron	24	26	48	8	18	—	—	—	—
16.	Greater Rhombicuboctahedron	48	26	72	—	12	—	8	6	—
17.	Lesser Rhombicosidodecahedron	60	62	120	20	30	12	—	—	—
18.	Greater Rhombicosidodecahedron	120	62	180	—	30	—	20	—	12

Table 1

* We have excluded the special cases of the "prism" and "prismoid" polyhedra—the only members of these groups appearing being the cube and octahedron.

In a like manner, we may define the possible Mosaics subscribing to the rules we have written. Table 2 which follows, shows the possibilities available to us. Of course, there are many more mosaics which can be assembled from regular polygons—but in every case other than the ones shown, there is a violation of rule 5). An identical set of circumstances exists with respect to the polyhedra—but in this instance such joinings lead to violations of rules 3) and 5). The following table lists the possible Regular and Semi-Regular Mosaics in two basic groups. The first of these contains the mosaics possessing two-way symmetry. The second group contains the mosaics exhibiting three-way symmetry. Mosaics number 2 and 6 exhibit *right hand* and *left hand* symmetries.

	Name	Faces Per Vertex	△	□	⬡		
Two-Way	1. Square	4	—	4	—	—	—
	2. Triangle-square	5	3	2	—	—	—
	3. Square-octagon	3	—	1	—	2	—
Three-Way	4. Triangle	6	6	—	—	—	—
	5. Lesser Triangle-hexagon	4	2	—	2	—	—
	6. Greater Triangle-hexagon	5	4	—	1	—	—
	7. Hexagon	3	—	—	3	—	—
	8. Triangle-dodecagon	3	1	—	—	—	2
	9. Triangle-square-hexagon	4	1	2	1	—	—
	10. Square-hexagon-dodecagon	3	—	1	1	—	1

Table 2

8

These are the possible Regular and Semi-Regular Polyhedra. The first five in order are: 1) Tetrahedron, 2) Octahedron, 3) Cube, 4) Icosahedron, 5) Dodecahedron. The next two are *combined* forms, 6) the Cuboctahedron which combines the faces of Octahedron and Cube and 7) the Icosadodecahedron which combines the faces of Icosahedron and Dodecahedron. The next five forms in numerical order are the Truncated versions of the five regular polyhedra. They are: 8) Truncated Tetrahedron, 9) Truncated Octahedron (Tetrakaidecahedron or *Kelvin* body), 10) Truncated Cube, 11) Truncated Icosahedron, 12) Truncated Dodecahedron. The next two forms are the Snub forms which, with the Icosahedron, bear a most unique part in the transformative story we tell here. They are: 13) Snub Cube, 14) Snub Dodecahedron. The last four of our polyhedra are two pairs of Lesser and Greater Rhombic forms. For special discussion of the Greater Rhombic forms, see Figure 8. The last four forms bear the names: 15) Lesser Rhombicuboctahedron, 16) Greater Rhombicuboctahedron, 17) Lesser Rhombicosidodecahedron, 18) Greater Rhombicosidodecahedron.

Perhaps the broadest classification we may make of these forms is that of separating them into two groups; those which may be combined in various ways to fill all space, and those which cannot be so combined. The ones with the space filling ability are numbers, 1, 2, 3, 6, 8, 9, 10, 15 and 16. These are all *initial points* or *end points* in our transformative story. The remainder, Numbers 4, 5, 7, 11, 12, 13, 14, 17 and 18 have their origins in *Icosahedral-Dodecahedral* type configurations which occur as in between stages of the transformations and thus possess no such space filling properties. We will see that numbers 4, 13 and 14, the Icosahedron, the Snub Cube and the Snub Dodecahedron occupy specially unique positions in our transformative story in that they are *in between* forms which recur in many different transformations. These last three forms have their two dimensional counterparts in the triangle-square and the more complex triangle-hexagon mosaics shown in the next figure.

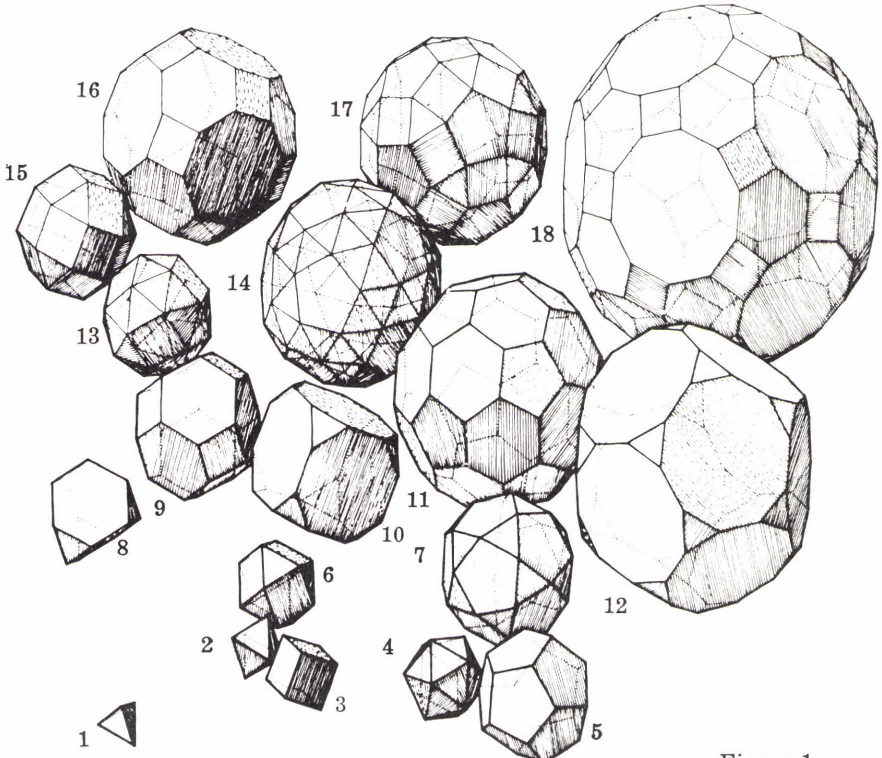


Figure 1

These are the possible Regular and Semi-Regular Mosaics. They are, in numerical order: 1) the Square, 2A) and 2B) the righthand and lefthand Triangle-Square and 3) the Octagon-Square. These are the only ones possessing the two-way symmetry of the square. The remainder of the possible mosaic patterns possess the three-way symmetry of the Triangle and Hexagon. These latter ones are 4) the Triangle, 5) the lesser Triangle-Hexagon, 6A) and 6B) the righthand and lefthand greater Triangle-Hexagon, 7) the Hexagon, 8) the Triangle-Dodecagon, 9) the Triangle-Square-Hexagon, and 10) the Square-Hexagon-Dodecagon.

Numbers 2A, 2B, 6A and 6B are the mosaic counterparts of the Icosahedron-Snub Cube-Snub Dodecahedron triad described in Figure 1. Their position with respect to our transformative story will be more fully described in Figures 11 and 13. It is further noted that mosaics 9 and 10 are contained one within the other—and we will find their counterparts in our polyhedron story in the explanation of the transformations leading to the greater rhombic polyhedra (see Figure 8).

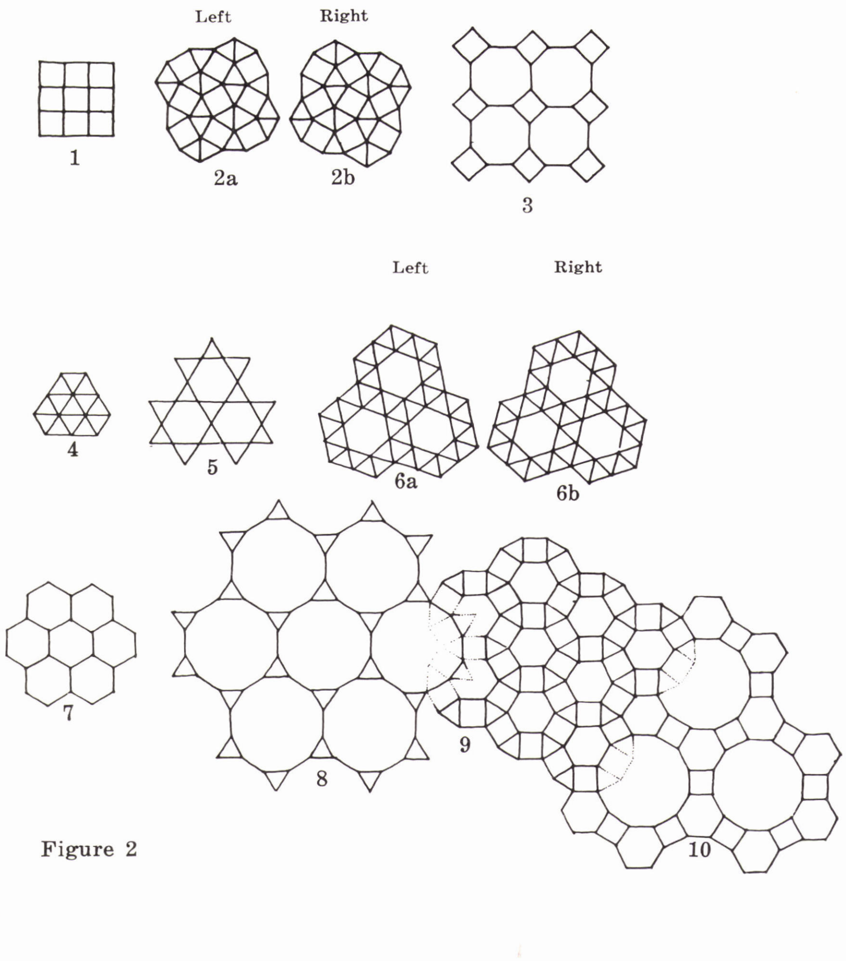


Figure 2

In this illustration we show a *classical* series of transformations which allow us to convert one polyhedron into another. In the upper left-to right row we see a Cube converted into a Tetrahedron by an alternate removal of its vertices. In the second row the Tetrahedron is in turn converted to an Octahedron by truncation of its vertices. In the third row a somewhat more complex truncation converts the Octahedron into an Icosahedron. In a like manner, in the fourth row we convert the Cube to a Dodecahedron. In the first two instances the process is more or less self-explanatory and the achievement of regular polyhedra takes place with no special consideration. In the latter two instances, however, there exists no intrinsic properties of either Octahedron or Cube which tells us how to make the indicated removals so that a regular figure will result. We must have *a priori* knowledge of both Icosahedron and Dodecahedron in order to know where to make the indicated cuts. In a similar fashion, but under even more complex systems of truncation, the forms of Snub Cube and Snub Dodecahedron may be accomplished. However, during these truncations, the figures have the distressing property of losing their dimensionality during transformation.

Analogous problems are encountered when one attempts to deal with regular and semi-regular mosaics in this way.

On the other hand, the transformations which we show in the accompanying *finger movies* maintain their dimensionality during transformation and generate the Icosahedron, Dodecahedron, Snub Cube, Snub Dodecahedron and all of the related forms without recourse to any other special knowledge than the rules of transformation described in Figure 4.

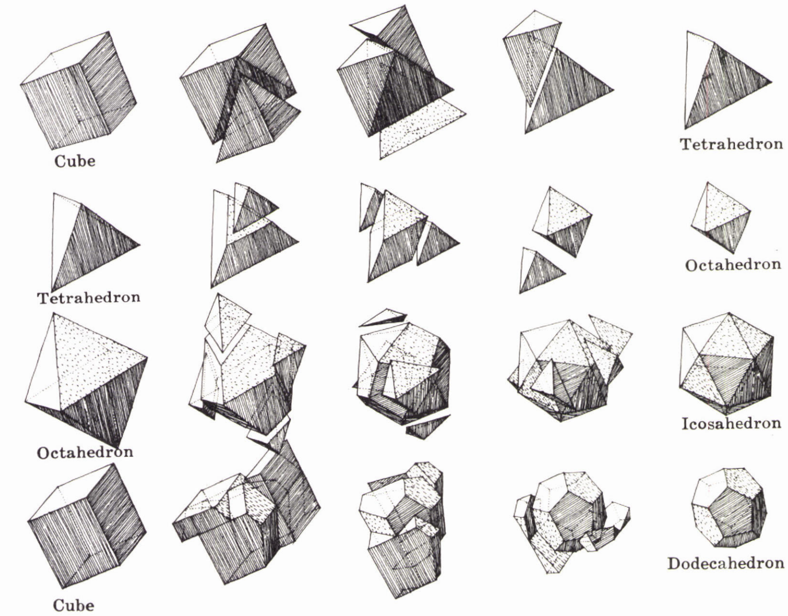
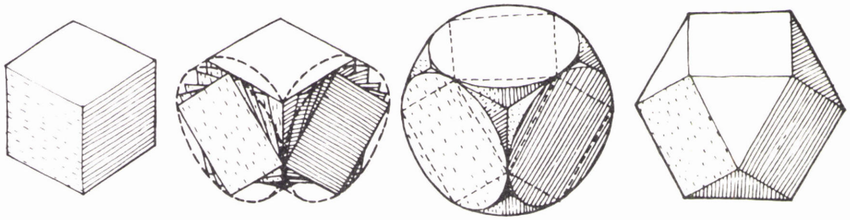


Figure 3

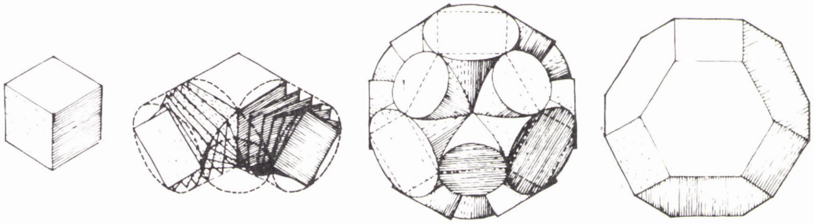
Here we see the two types of transformations which we employ to convert any one of the polyhedra initially shown into any other. We have chosen Cube as our point of departure though we could, as easily, have started with any other polyhedron. The simplest type of transformation is shown in the upper horizontal series. We begin at the left with Cube and accomplish our transformation by allowing its faces to rotate about axes passing through their centers. If two adjoining faces remain connected at one of their paired vertices, the faces transform under rotation in the manner shown in the second illustration from the left. Clearly we can see that the vertices of each of these rotating squares may generate the surface of a cylinder equal in diameter to the diagonal of the square. With two faces there are two such cylinders whose axes of symmetry intersect at the center of the cube. The line of junction between these two cylinders serves as the path which must be followed by the connected vertices. The next illustration in this series shows all of the possible cylinders that may be related in this way to the initial Cube. The final illustration shows the Cuboctahedron which results from transforming all of the initial Cube faces in this manner.

A second type of transformation is shown in the lower series. This one has the added feature of an extra edge which lies between the two faces to be transformed. The edge serves as a kind of gear which links the rotation of the two faces. The edge movement generates a new cylinder of possible positions for its ends. This cylinder is of different diameter than the cylinders related to the square faces. The trajectory of the vertices of the faces is found at the lines of junction between the *edge* cylinder and the two *face* cylinders. Because these cylinders differ in diameter this trajectory no longer lies in a flat plane but becomes a space curve. The next illustration in this series shows all of the cylinders related to the faces and the edges which describe the transformation ending in the final illustration, the Truncated Octahedron.

With these two types of transformation we are able to generate all of the polyhedra shown in Figure 1. During the process of generation, we are able to preserve at all times the dimensionality of the various figures and, unlike *classical transformations* shown in Figure 3, we need have no recourse to further special considerations. Figures 5, 6 and 7 which follow describe the basic transformative sequences which allow us to generate these polyhedra. Figure 8 undertakes a more complex problem of describing the special case of the two Greater Rhombic forms and the special problem of their relationship to this transformative story.



TRANSFORMATION BY FACE ROTATION
cube to cuboctahedron

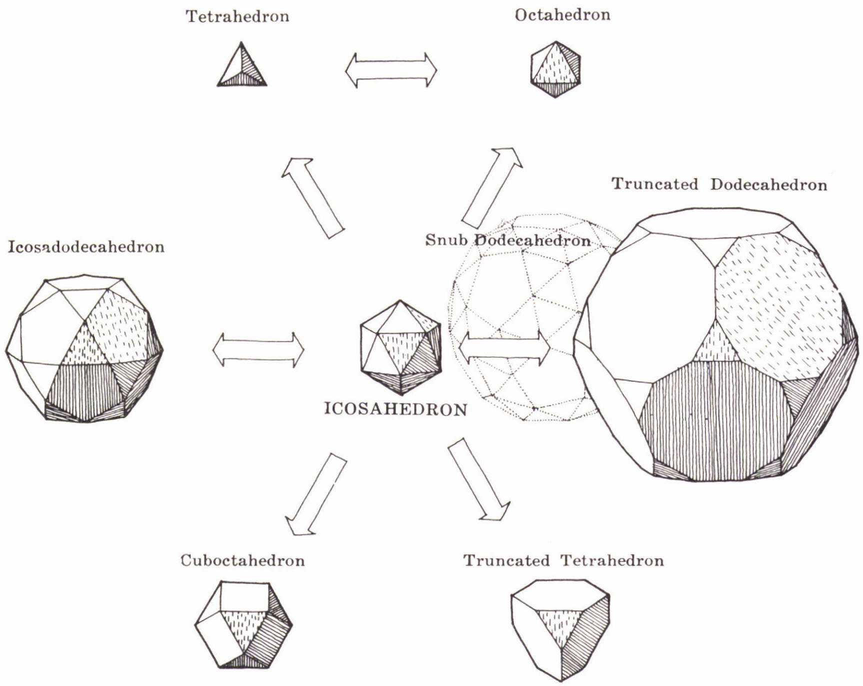


TRANSFORMATION BY FACE AND EDGE ROTATION
cube to truncated octahedron

Figure 4

The next three figures show the special uniqueness of certain polyhedra on our list. This one describes the special position of the Icosahedron; first, the Icosahedron results as an intermediate point in the transformations both of Octahedron to Cuboctahedron and Tetrahedron to Truncated Tetrahedron. In a somewhat different fashion the Icosahedron occupies an *end point* in the transformation, Icosahedron to Truncated Dodecahedron—with an intermediate form in this transformation being the Snub Dodecahedron. Finally, the Icosahedron serves as an end point in the transformation, Icosahedron to Icosadodecahedron. We have also indicated, in the upper part of the illustration, that there is still another transformation. In this one, the Tetrahedron can be transformed into the Octahedron with no intermediate stage.

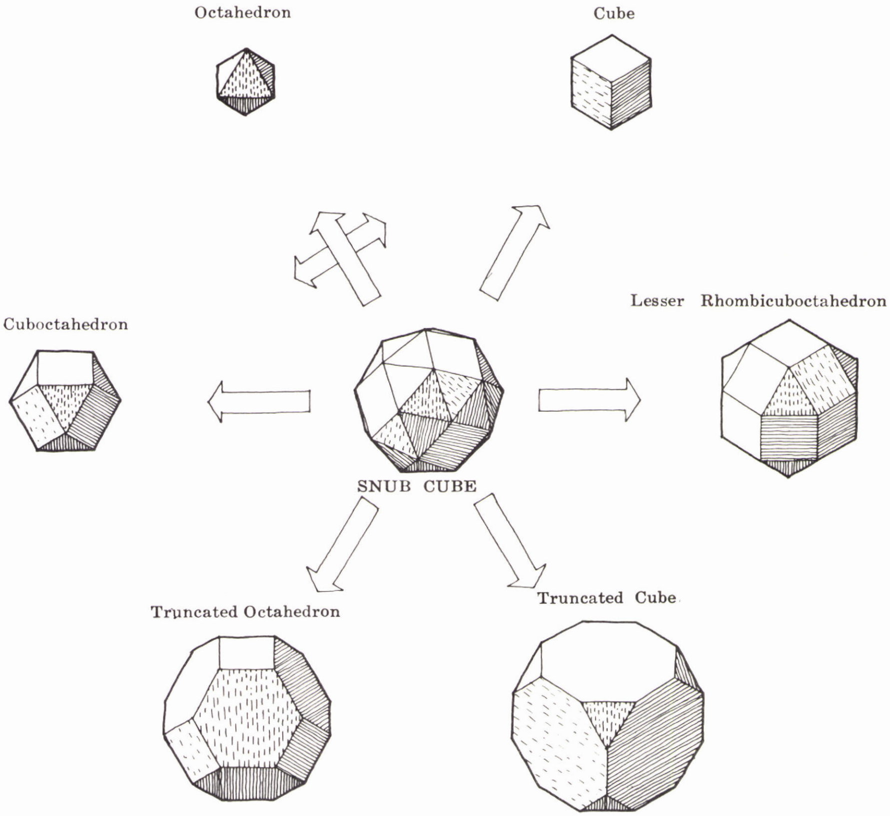
The end points of the transformative sequences which have Icosahedron as an intermediate stage are forms which in connection with other regular or semi-regular forms can be brought together in closest packing to fill all space. Conversely the forms which grow out of the sequences employing Icosahedron as a starting point have no such proclivity.



THE ICOSAHEDRAL TRANSFORMATIONS

Figure 5

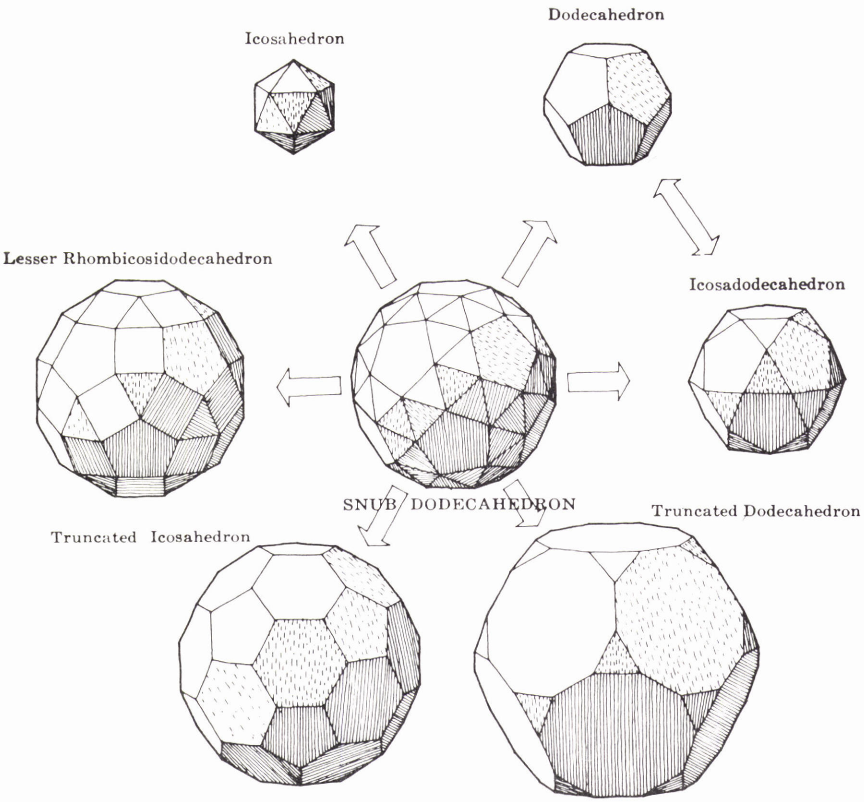
Here we show the special position of Snub Cube within this story. This form occupies a neutral point between three pairs of transformations. First, as a mid-point between Cuboctahedron and Lesser Rhombicuboctahedron and second, as mid-point in the two transformations—Octahedron to Truncated Cube and Cube to Truncated Octahedron. It is noted that in each of these transformations that the *large* end point is the truncated version of the topological dual of the initial point, i.e., the Octahedron leads to Truncated Cube, Cube being the topological dual of Octahedron. We further note that in the manner similar to the Tetrahedron to Octahedron sequence shown in Figure 5 there is a similar transformation here, that of Cube to Cuboctahedron, which does not possess an intermediate form. All of the *end points* of these sequences may be conbined in various ways to fill all space—while the mid-point, Snub Cube, will not.



THE SNUB CUBE TRANSFORMATIONS

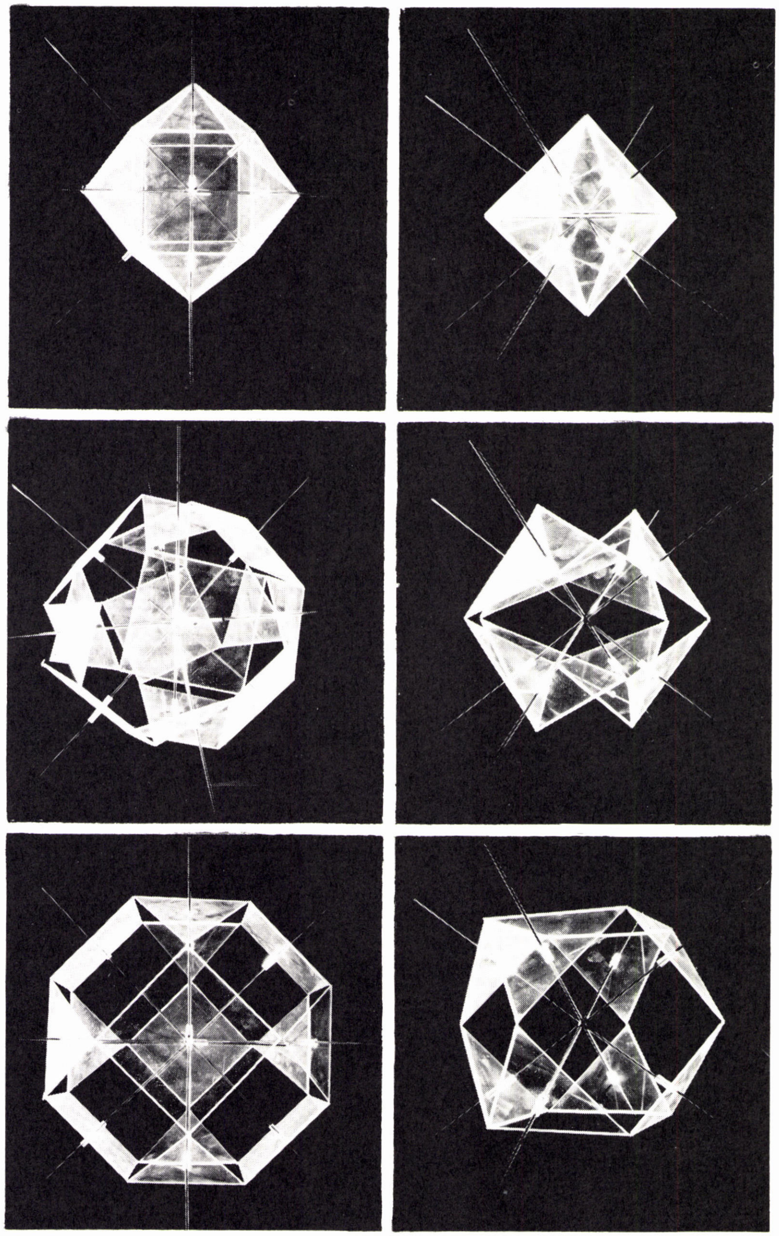
Figure 6

In a manner similar to Figures 5 and 6 we find that the Snub Dodecahedron occupies an in-between position in these transformations. First, as indicated in Figure 5 it lies between Icosahedron and Truncated Dodecahedron and similarly between Dodecahedron and Truncated Icosahedron. The same relationship to the *dual* exists as in the case of Figure 6. We see, as well, that the Snub Dodecahedron occurs between the Icosadodecahedron and the Lesser Rhombicosidodecahedron. These three Figures, 5, 6, and 7 complete the transformations which allow us to move from any one of the polyhedra initially shown to any of the others, with the exception of the two Greater Rhombic forms. Figure 8 which follows accounts for the transformation encompassing these.



THE SNUB DODECAHEDRON TRANSFORMATIONS

Figure 7



Photographs of working models

Here we show the beginnings of an infinite series of possible transformations starting with Cube. We have chosen to show these transformations in terms of the developed surfaces of the various polyhedra. In each case the polyhedron defined in the left-hand branch of the sequence is the one arising from the type of transformation involved with rotating the faces about their centers only. The polyhedron defined in the right-hand branch is the one obtained by using both center of faces and edge as the transformative method. We see then that beginning with Cube the left-hand branch leads first to Cuboctahedron and the right-hand branch leads to Truncated Octahedron. In the latter case the Snub Cube appears at an intermediate point. If we continue the first mentioned half of this series, we find that the Cuboctahedron's left-hand branch leads to the Lesser Rhombicuboctahedron with an intermediate stage of Snub Cube, and its right-hand branch leads to a form which might best be described as a Truncated Rhombic Dodecahedron. In a similar fashion, using the Truncated Octahedron as our point of departure, we see a left-hand branch which leads to a polyhedron which we see defined with a triangle-hexagon mosiac pattern with the initial squares interspersed within it. The eight hexagons of this pattern are related to the eight triangle faces of the Octahedron, the 24 triangles to the edges of the Octahedron, and the six squares to the vertices of the Octahedron. The right-hand branch of this transformation leads from Truncated Octahedron to a polyhedron whose developed surface is essentially a hexagon mosaic with interspersed squares. It bears essentially the same relationship to Octahedron as the previous one. Each one of the four polyhedra thus defined in turn lead to pairs of polyhedra and this process may be continued indefinitely. One of such pairs is shown growing out of successive left-hand branches taken from the Truncated Octahedron. We see here two mosaic patterns in which a heavy line has defined the part that is common to both. In the first instance the portion of the mosaic outside of the heavy line is composed of triangles and squares which when joined lead to the involute polyhedron shown at the upper right. The lower mosaic pattern has octagons substituted for the triangles and squares previously discussed and this leads to the polyhedron shown in the lower right. This polyhedron is the Greater Rhombicuboctahedron. In a like manner by employing the Dodecahedron as our initial point we arrive at a similar pattern in a sequence which we show in the lower left-hand portion of this illustration. The upper, and more complex of these shows the involute polyhedron resulting from the upper mosaic pattern and the lower illustration shows that with substitution of the Dodecagon face, we have generated the Greater Rhombicosidodecahedron. We see similar patterns to these latter items in the mosaics of Figure 2; in which we see the Dodecagon-Square-Hexagon Mosaic contained within the Hexagon-Triangle-Square Mosaic. In a like manner in Figure 13 the lower portion of the illustration describes this phenomenon as a transformative fact as well.

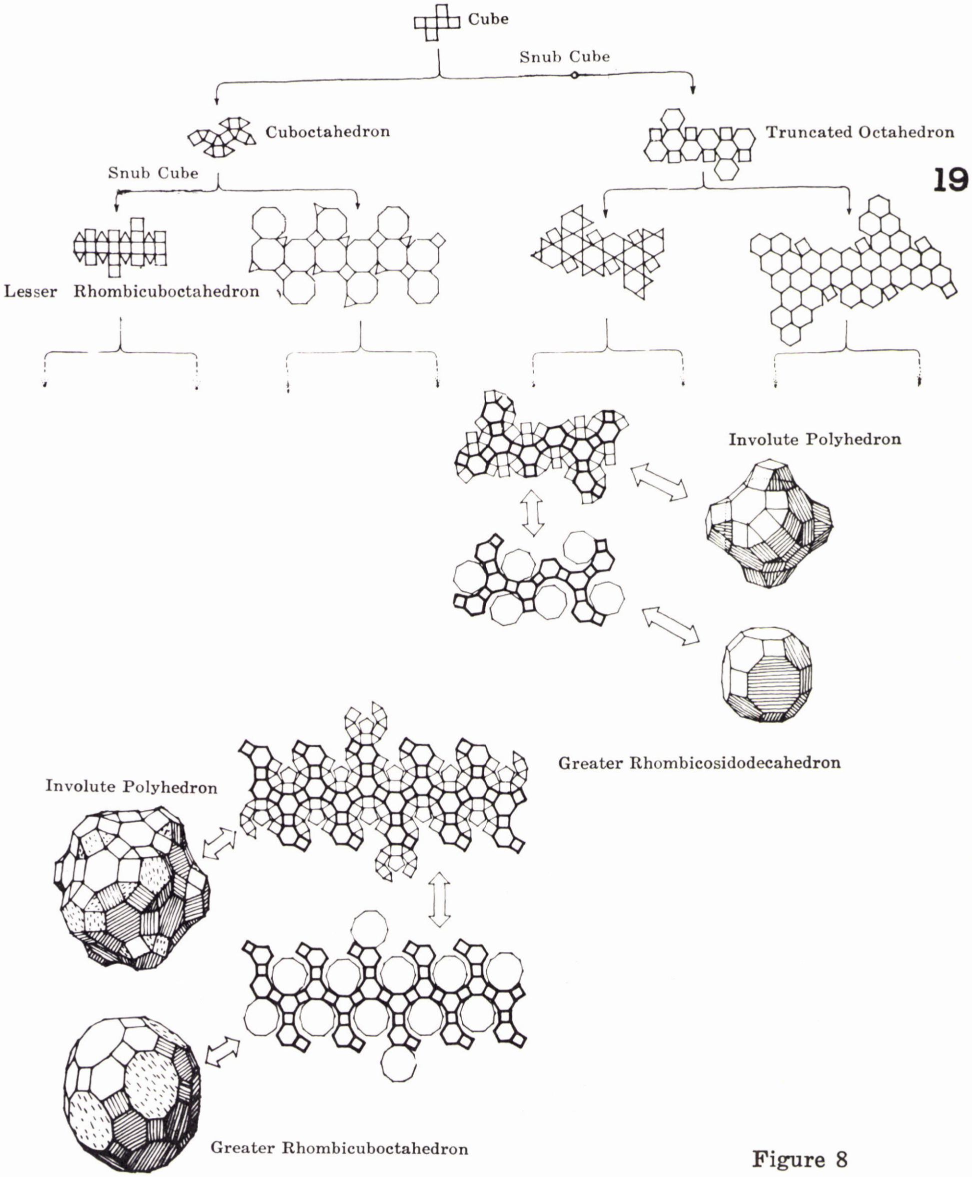
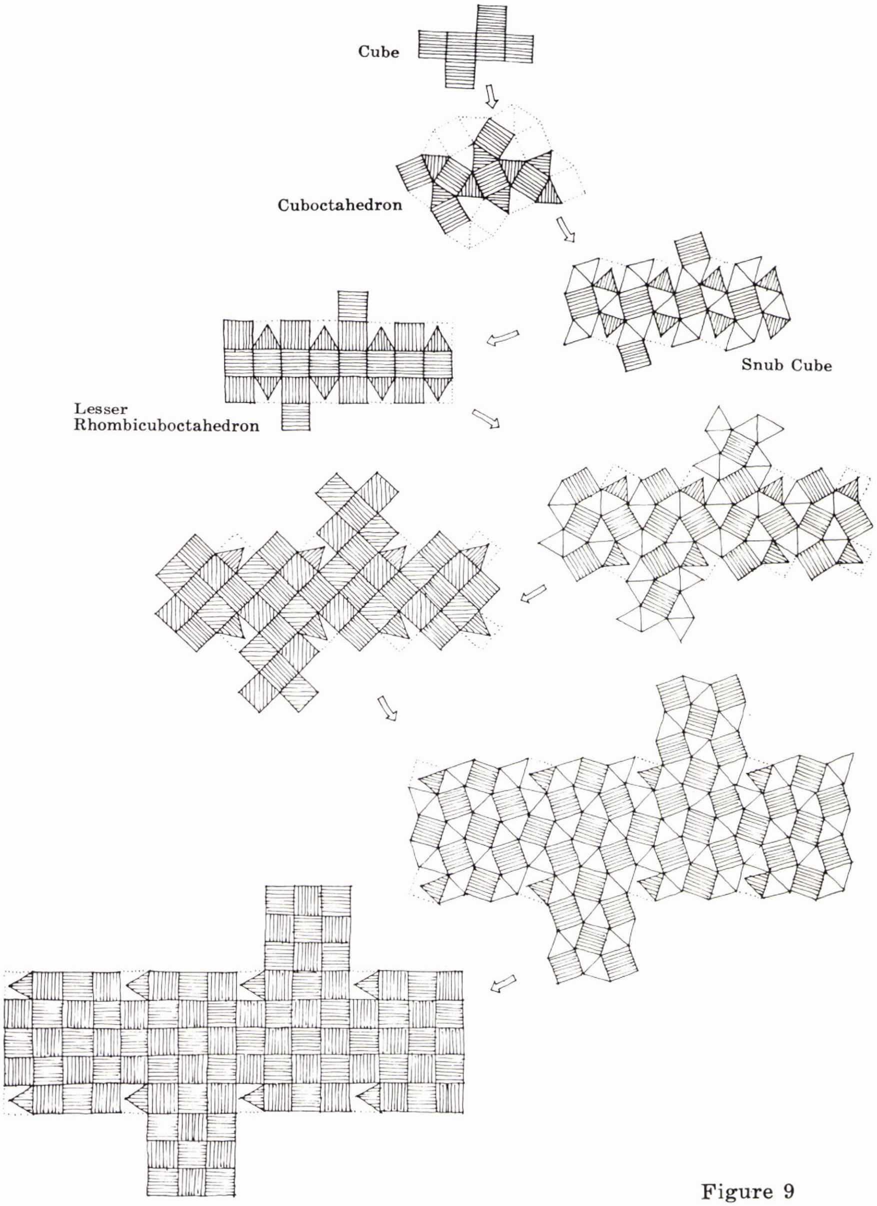

Cube
Snub Cube
Cuboctahedron
Truncated Octahedron
Snub Cube
Lesser Rhombicuboctahedron
Involute Polyhedron
Greater Rhombicosidodecahedron
Involute Polyhedron
Greater Rhombicuboctahedron

Figure 8

In this figure we show in greater detail a portion of the transformative story suggested in Figure 8. This one successively takes the left-hand branch of sequences; that of transformations by face alone, and shows the subsequent journey, including the in-between stages. We begin with Cube, then Cuboctahedron. This is followed by Snub Cube as intermediate stage, then the last of the semi-regular polyhedra obtainable in this series, the Lesser Rhombicuboctahedron. These transformations go on to more complex figures and in each case the in-between stage is a kind of snub form. It is noted that all of the end points with the exception of Cuboctahedron may be viewed as portions of Square Mosaics in which certain squares have been converted to triangles. In a like manner the in-between stages are Triangle-Square Mosaics in which certain of the squares have been converted to triangles.



Cube
Cuboctahedron
Snub Cube
Lesser
Rhombicuboctahedron

Figure 9

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This figure shows in greater detail the results of continuously taking the left-hand branch of the diagram shown in Figure 8. That is, the transformations involving the use of both face and edge. Here, starting with Cube we obtain first an intermediate stage which is Snub Cube and then our first end point, the Truncated Octahedron. This is the last of the semi-regular polyhedra obtainable in this series. If we continue the transformations we can see that in a manner analogous to Figure 9, all of the end points may be thought of as portions of Hexagon Mosaics in which certain of the hexagons have been converted to squares. All of the in-between stages may be viewed as portions of Hexagon-Triangle Mosaics in which certain of the hexagons have been converted to squares.

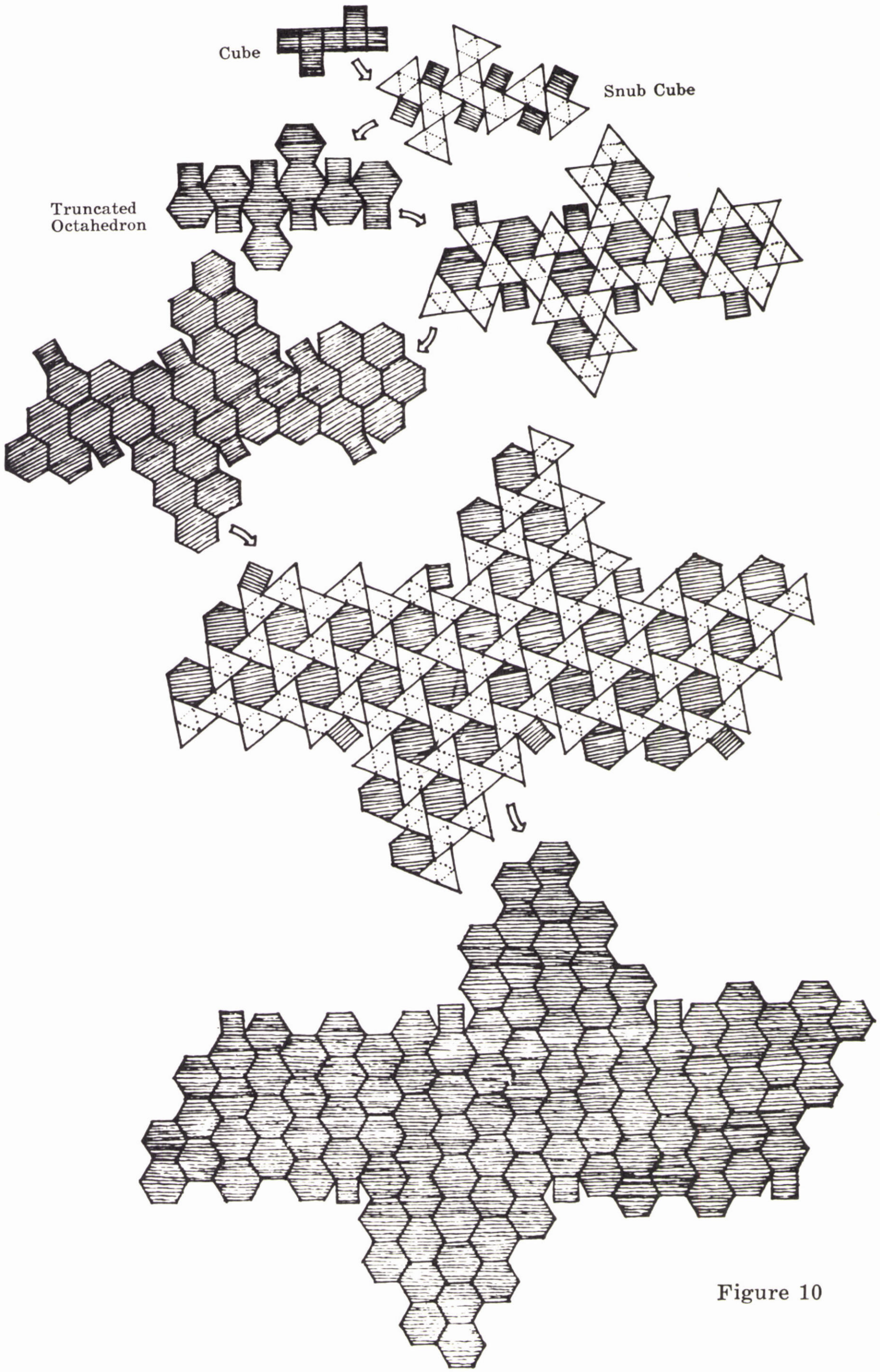
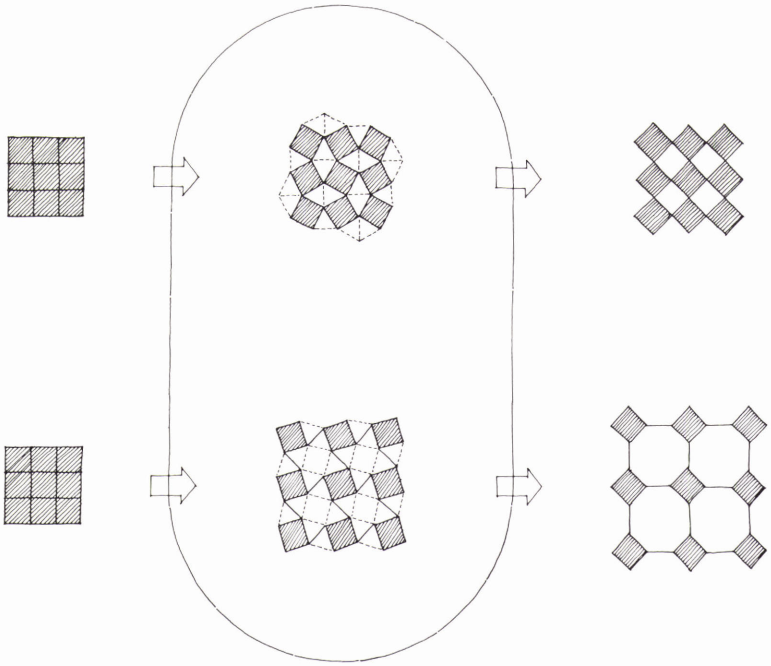


Figure 10

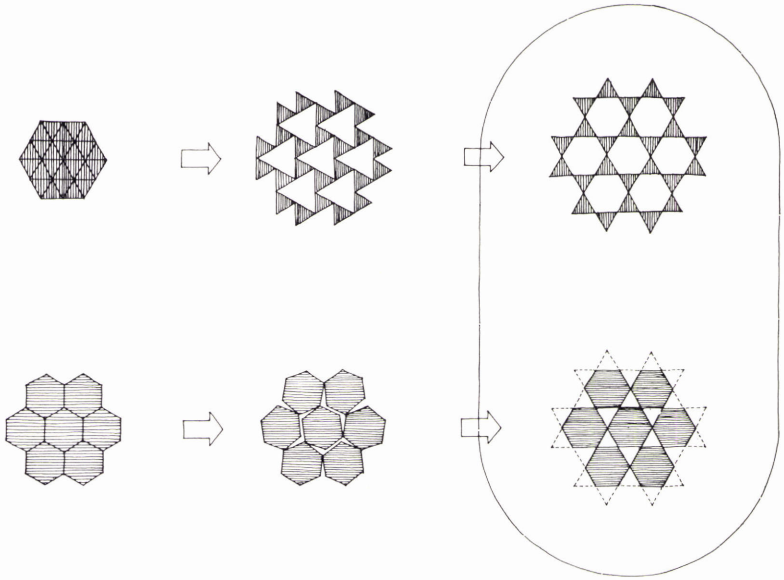
In a manner similar to the previous figures we now show our transformative process with respect to Mosaics and it is seen that they transform in a manner quite similar to that of the polyhedra. In this figure we show the basic types of transformations of the Square Mosaic. In the upper illustration we see a transformation by center of face alone which, at an intermediate stage, gives rise to the Triangle-Square Mosaic. This terminates in the checker-board Square Mosaic shown at the right. The lower portion of this figure describes a square transformation using the interposed edge. It is seen that the intermediate stage in this instance also is the Triangle-Square Mosaic with alternating squares being implied rather than explicitly present. This transformation leads ultimately to the Octagon-Square Mosaic shown at the right. In a manner similar to the polyhedra this expansion by edge leads to a truncated version of the mosaic pattern which has the same dual properties as in the case of the truncated polyhedra. That is to say the dual of the square mosaic is another square mosaic and we see its truncated version appearing in the lower right illustration as the Octagon-Square Mosaic.



THE REGULAR MOSAIC TRANSFORMATIONS—GROUP 1

Figure 11

Here we see the two remaining regular mosaics and their transformations. In the upper instance we see the Triangle Mosaic transforming through the pattern shown in the center leading ultimately to the Hexagon-Mosaic pattern seen at the right. Below this the Hexagon Mosaic transforms through the pattern in the lower center resulting again in the Hexagon-Triangle Mosaic. In the upper instance, the triangles are *solid*, the hexagon voids, and in the lower instance the converse is true.

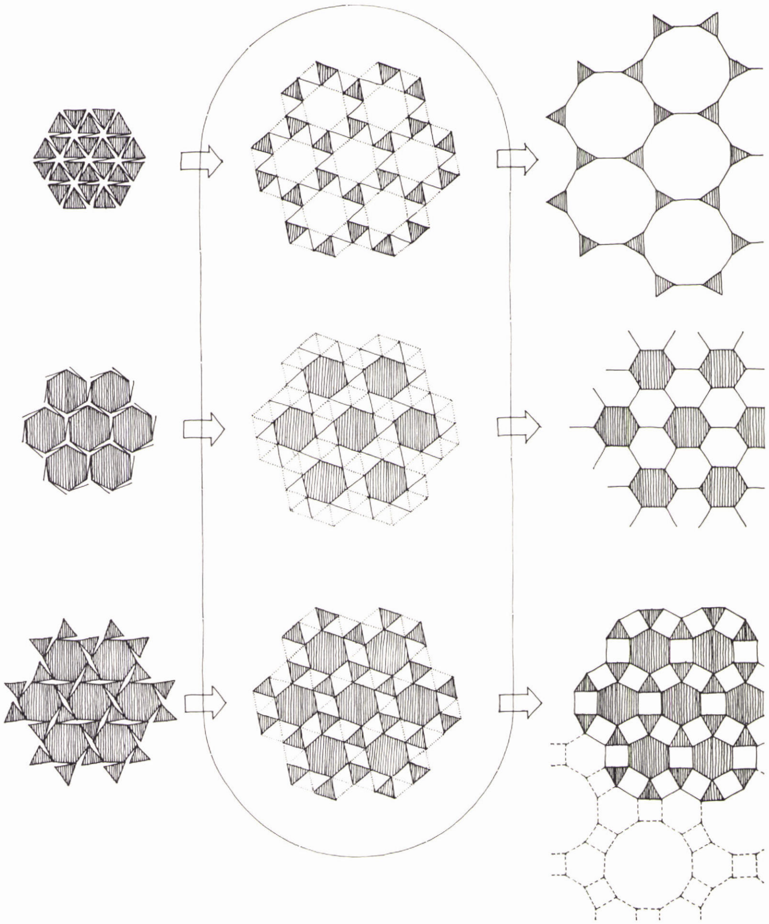


THE REGULAR MOSAIC TRANSFORMATIONS—GROUP 2

Figure 12

26

Here we show the final transformations which encompass the remaining mosaic patterns. In the upper instance we see a Triangle Mosaic which has just begun to transform. In the center we see its intermediate stage which is the Hexagon-Triangle Mosaic. This ultimately leads to the Dodecagon-Triangle Mosaic seen at the right. In the middle band we see, in a similar fashion, the Hexagon Mosaic transforming to the same Hexagon-Triangle Mosaic and ultimately the Hexagonal *checkerboard* Mosaic seen at the right. It is noted that these two bear the same relationships to the topological dual as in the previous illustration, i.e., the dual of the Hexagon Mosaic is the Triangle Mosaic and conversely. In the lower illustration the Triangle-Hexagon Mosaic transforms to the more complex Triangle-Hexagon Mosaic in the center which in turn leads to the Triangle-Square-Hexagon Mosaic at the right. The latter is seen to contain within it the Dodecagon-Square-Hexagon Mosaic.



THE REGULAR MOSAIC TRANSFORMATIONS, GROUP 2

(The lower transformation is based on the semi-regular triangle-hexagon mosaic)

Figure 13

There are other avenues to be pursued in these matters—and some glimpses down them are now possible. One such glimpse is suggested by the obvious transformative relationships seen between the Mosaics and the Polyhedra. The behavior patterns in these two and three dimensional worlds leads one to hope that some fascinating images may develop from the possibility of extending these ideas into the impalpable worlds of higher dimensionalities.

Still other possibilities remain to be investigated in the realm of the three dimensional transformations. The question of the transformation while polyhedra are in *closest packing* remains unanswered. One such possibility has been under preliminary investigation by the author—and the evidence developed suggests some fruitful avenues of further investigation.

In all of the transformations we have shown, we have terminated our *inward* phase of the transformation at the *minimum* polyhedral surface. If we allow ourself the freedom of permitting the faces to inter-penetrate one another by continuing the *inward* transformation, it is clear that we should, at some stage, find all of the so-called *Star Polyhedra* generated as resultant volumes. Just how and where these polyhedra would be generated in such transformations remains an unanswered question.

Many difficult questions remain unanswered with regard to the two and three dimensional transformations after they have expanded beyond the Regular or Semi-Regular stages.

In any event, we are certain that it can be said that our transformative story — incomplete as it may be — has brought together into a single package a number of packages which, until now, have remained unaccountably separate.

SOME THOUGHTS ON DESIGN EDUCATION

Vernon Shogren

Vernon Shogren is an Assistant Professor of Architecture in the

DESIGN IS THE PROCESS OF SHAPING CONTENT BY THE MOLD OF FORM.

CONTENT IS THE CONDITION OF FACT, GIVEN OR CHOSEN.

FORM IS THE SET OF DECISIONS WHICH BRINGS ORDER TO CONTENT.

CONTENT ORIGINATES AND FORM RESPONDS, BEGINNING A PROCESS OF ACTION AND REACTION TO THE ULTIMATE RESULTANT.

THE REALITY OF DESIGN IS IN CONTENT; THE REALITY OF THE DESIGNER IS IN FORM.

CONTENT WITHOUT FORM IS CHAOS; FORM WITHOUT CONTENT IS MEANINGLESS.

THE ORDER AND SEQUENCE OF CONTENT IS:

1	A Name	Subject
2	A Function	Use
3	A Situation	Place
4	A Means	Medium
5	A Mechanism	Method
6	A Resultant	Solution

THE ORDER AND SEQUENCE OF FORM IS:

1	What is to be done?	Objective
2	How is it to be done?	Direction
3	What is it to look like?	Appearance

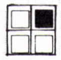
AN EXAMINATION OF THE DESIGN PROCESS FROM SUBJECT TO SOLUTION IS ONE OF **SYNTHESIS**: AN EXAMINATION OF THE DESIGN PROCESS FROM SOLUTION TO SUBJECT IS ONE OF **ANALYSIS**.

ANALYSIS:

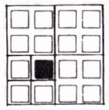
A *Solution* to a problem in design exists in a sea of possibilities.

However, this *Solution*, in actuality is chosen from those valid possibilities which exist:

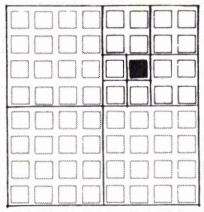
within a specific *Method*



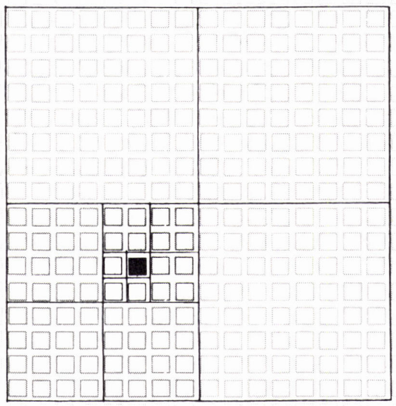
of using a specific *Medium*



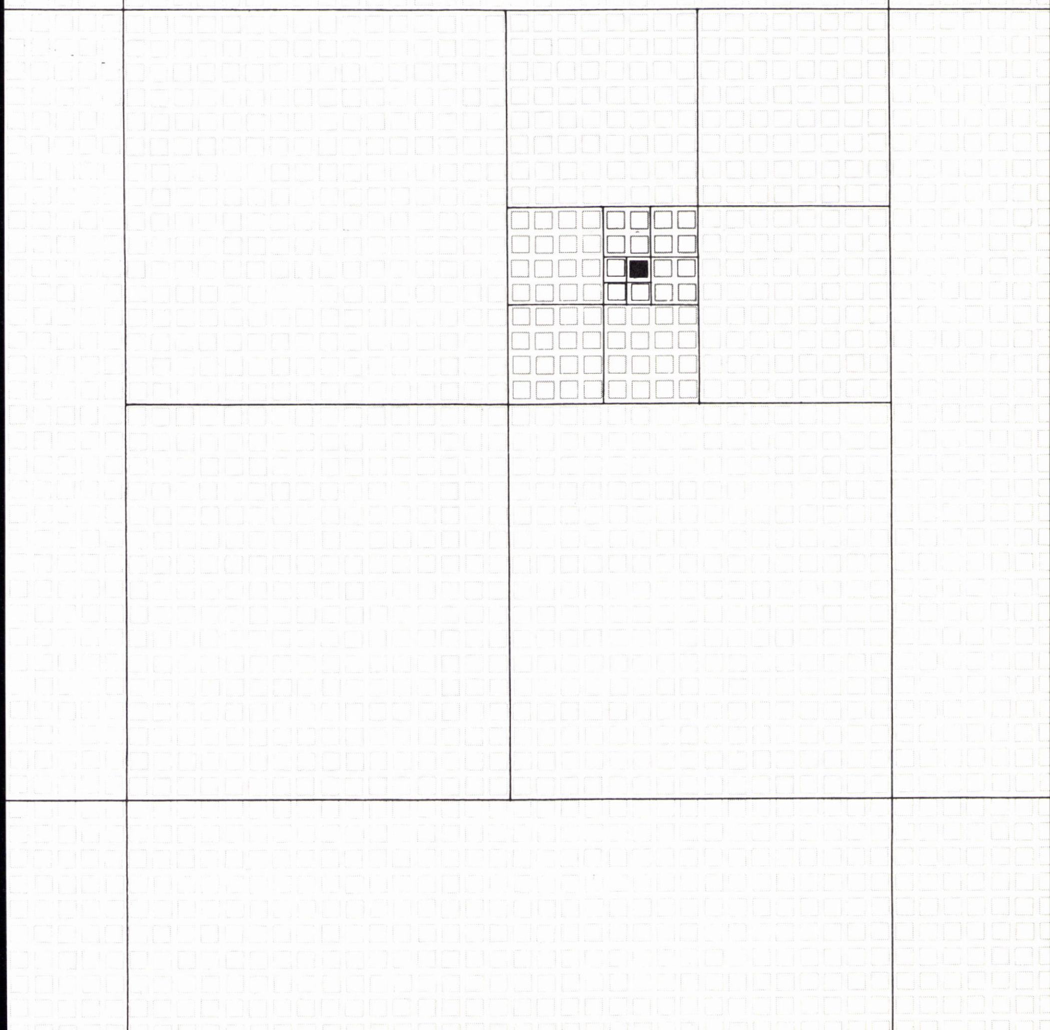
at a specific *Place*



for a specific *Use*

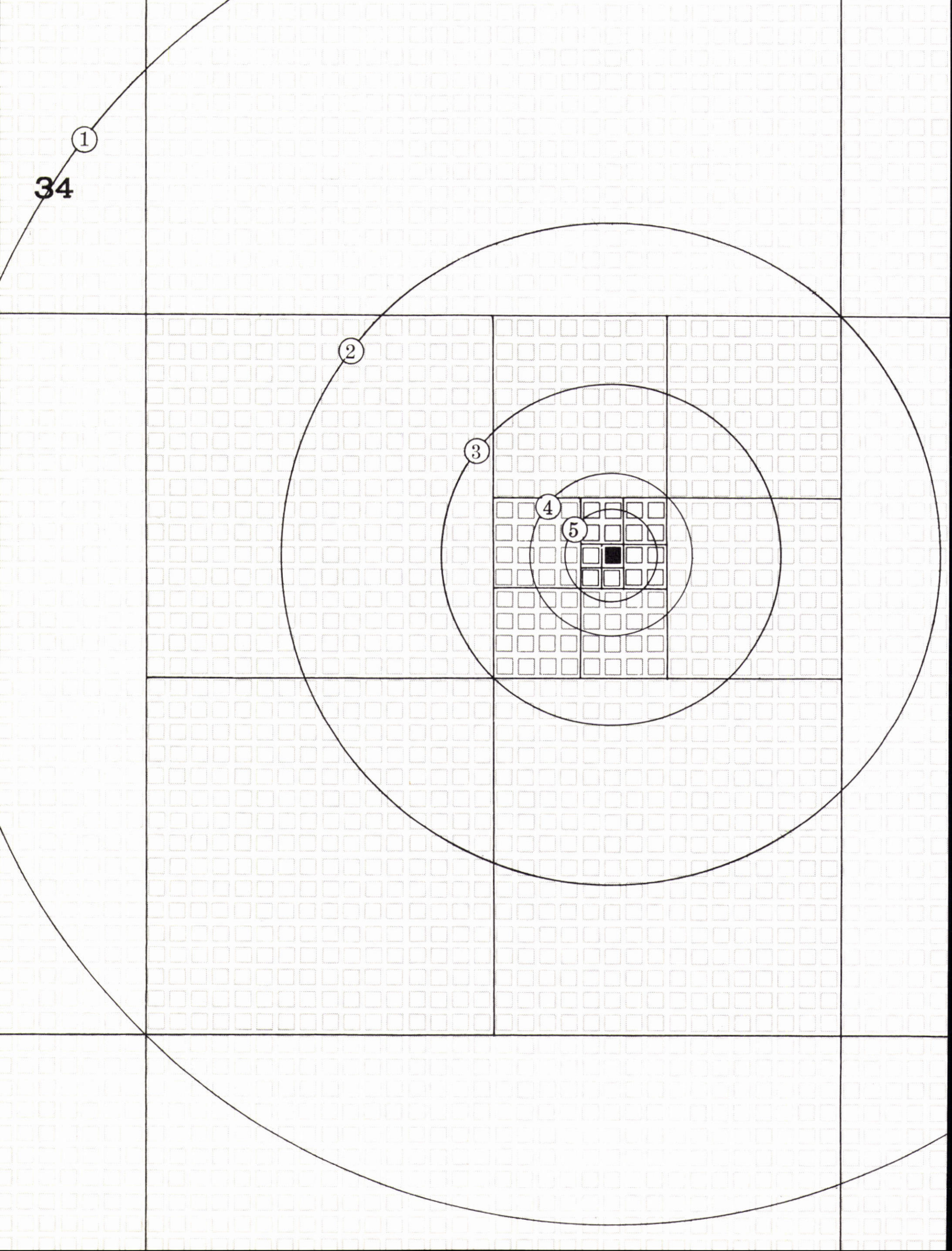


And a specific *Subject*—which itself is located on another sea of possibilities.

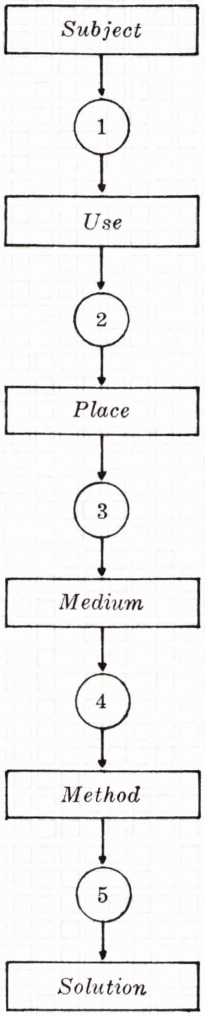


SYNTHESIS:

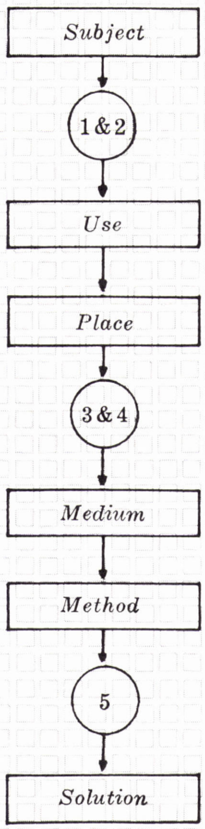
We can assume that these choices carry out a *Pattern of Intention*—(here represented by concentric circles), and that each choice was made, in turn, so as to fall as close as possible to the center of that pattern.



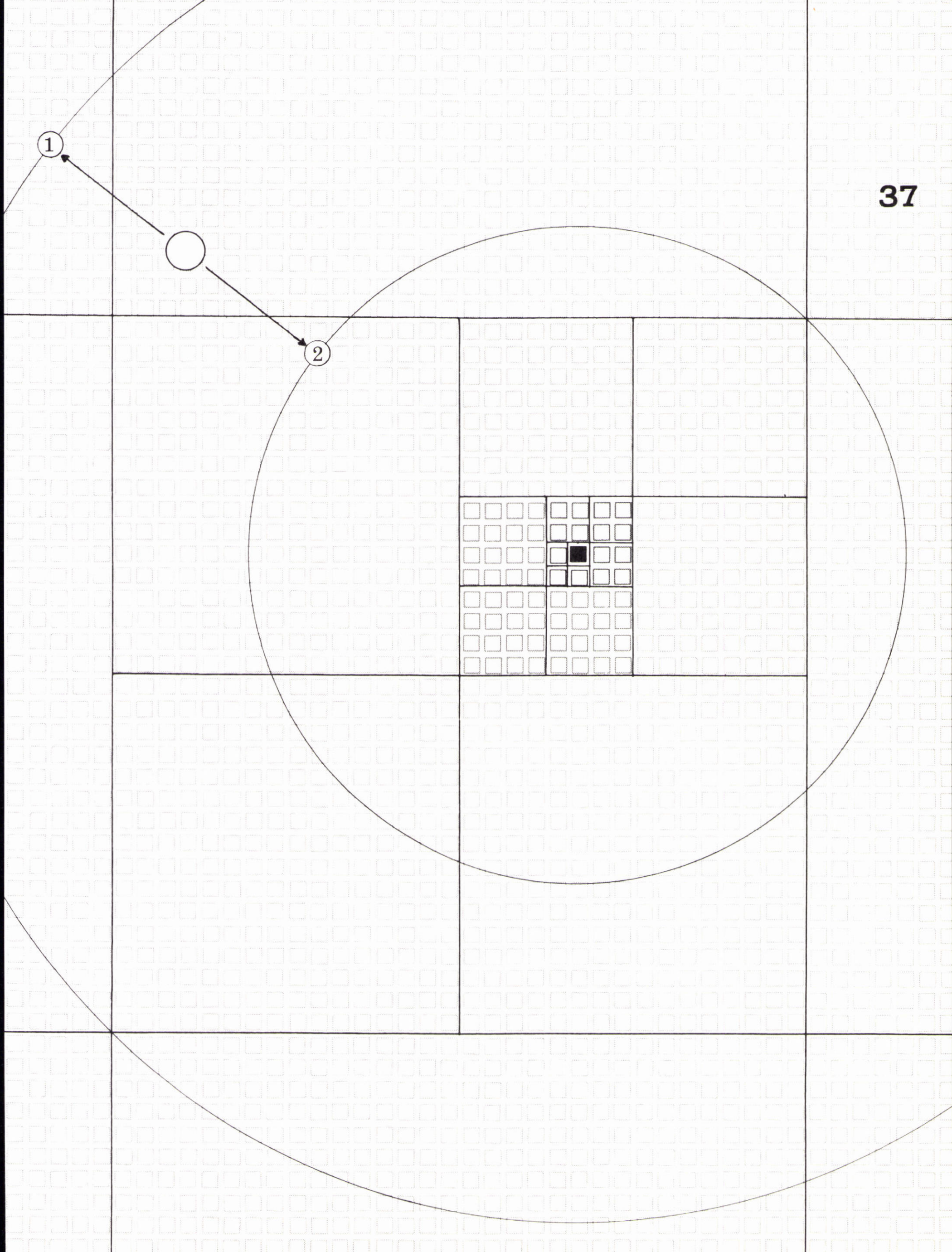
In another form, this pattern would appear as here illustrated



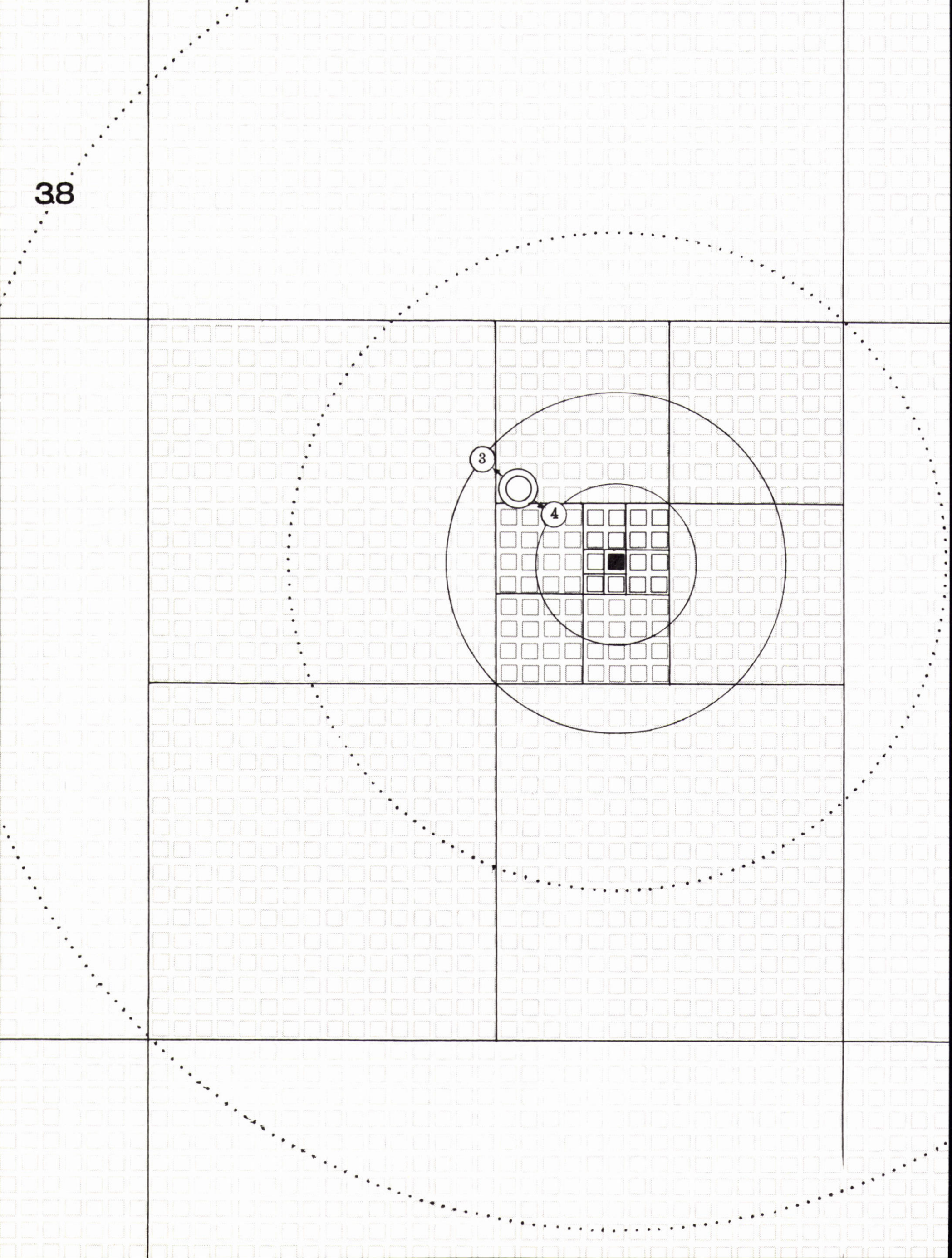
However, the choices of *Use* and *Place*, and the choices of *Medium* and *Method*, are rarely separable. This fact allows us to simplify the graph by consolidating boundaries 1 and 2, and boundaries 3 and 4, as follows:



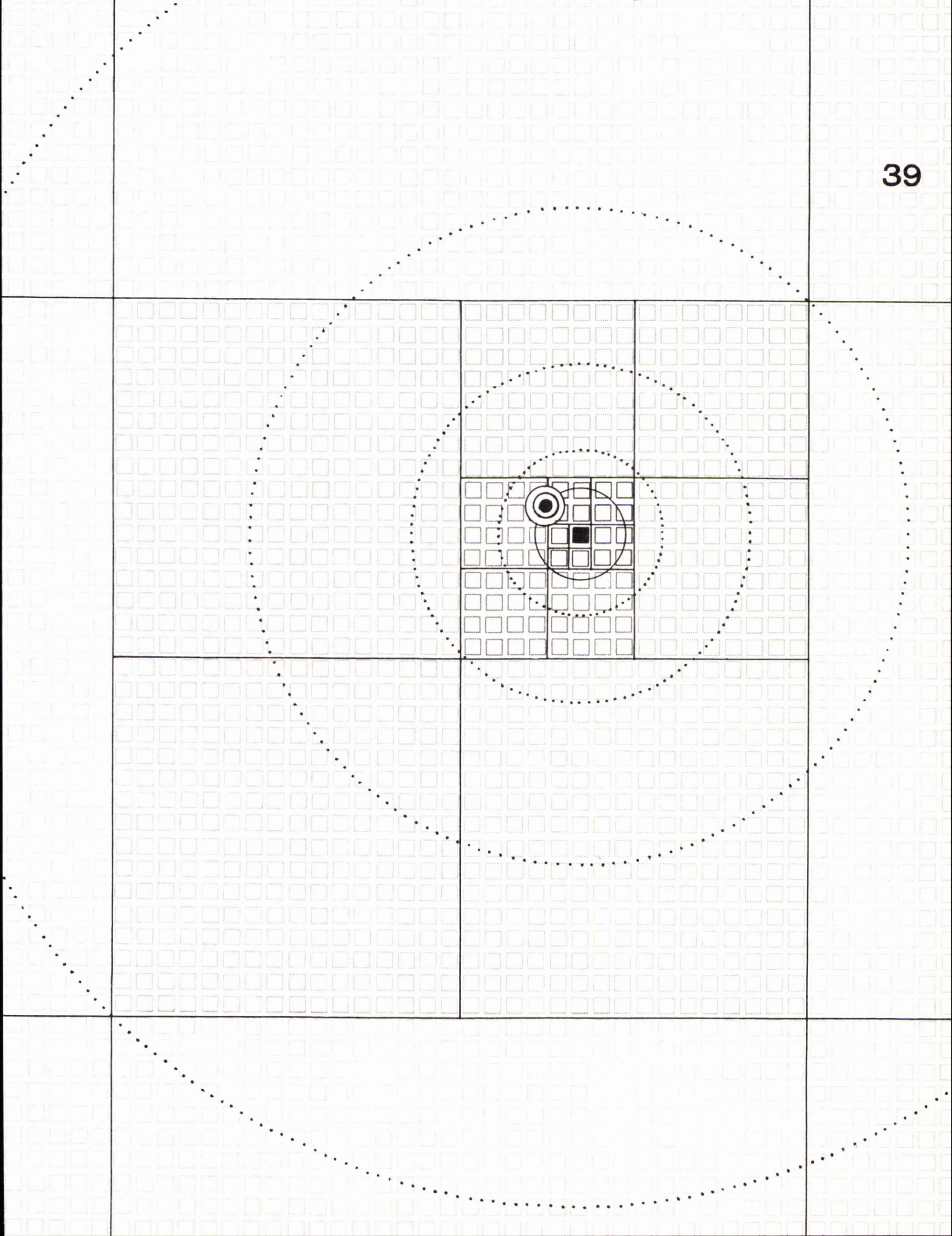
The first task in a problem of design, is to establish the boundary 1 & 2. This could vary in size from a maximum of 1 to a minimum of 2, depending on the clarity of *Use*. This composite circle we could call the **Objective**—Symbolized as ◯



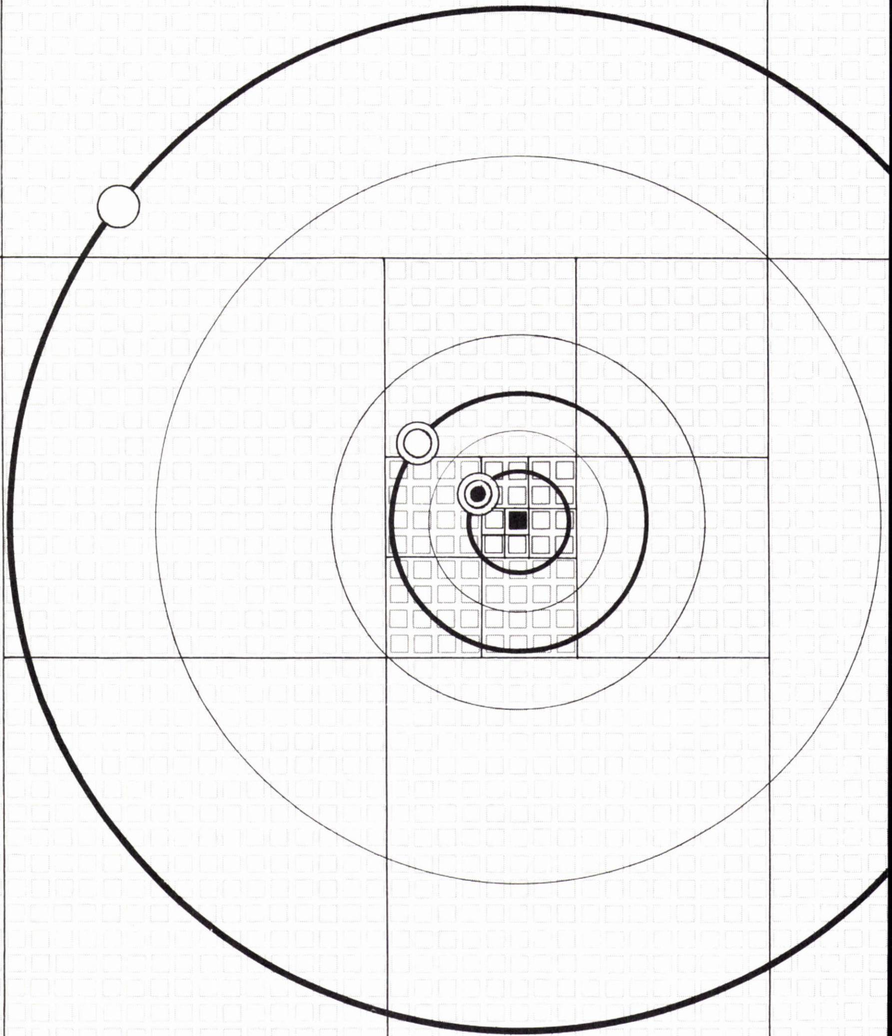
Having selected a *Use* and *Place* with the aid of **Objective**, the next task is to establish boundary 3 & 4. This also could vary from 3 to 4, depending on the clarity of *Medium*. This composite circle we could call the **Direction**—Symbolized as ◎

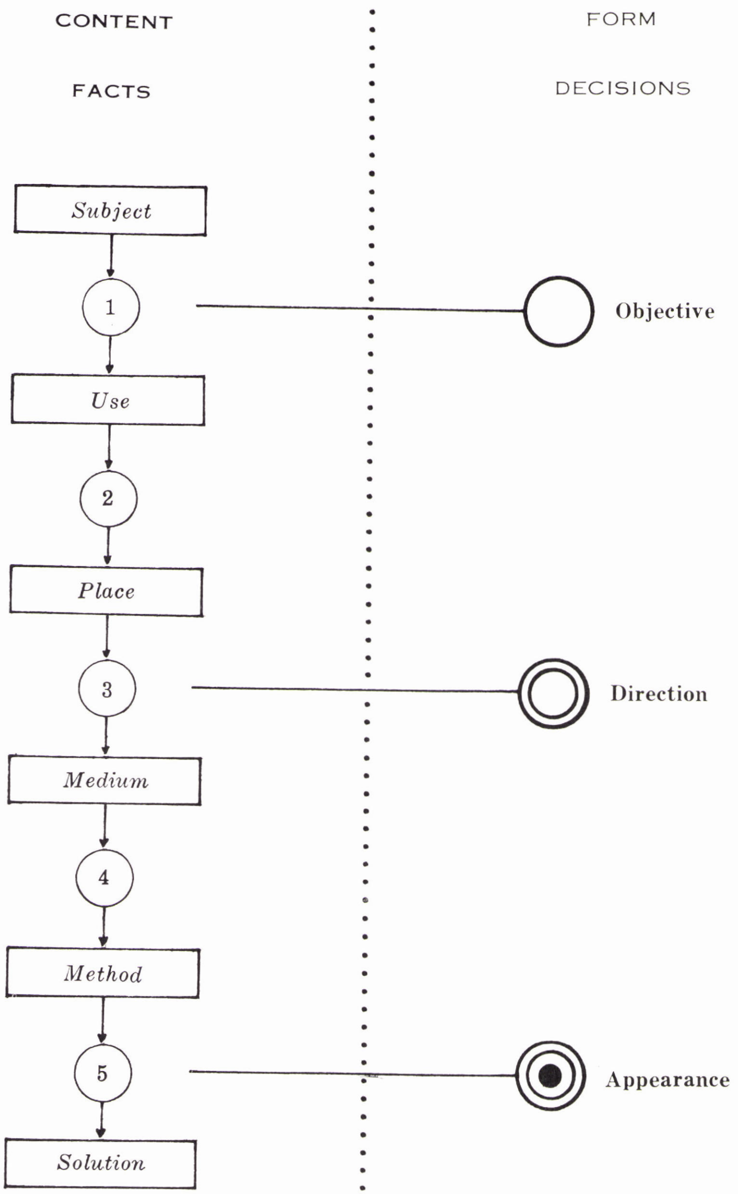


Having selected a *Medium* and *Method,* by the aid of a **Direction**, our final task is to locate boundary 5. This circle is concentric with previous ones and includes those valid possibilities within the chosen *Method.* The *Solution* will be found in its center. This circle we could call **Appearance**—Symbolized as ◎



Accepting an average difficulty in early clarification of *Use* and *Medium*, the pattern would appear as here illustrated. As on a bull's-eye, the boundaries would proceed inward as an orderly and progressive sequence, retaining their concentricity and enabling us to locate the *Solution* as nearly as possible in the center of our initial **Objective.**




CONTENT
FORM
FACTS
DECISIONS
Subject
1
Objective
Use
2
Place
3
Direction
Medium
4
Method
5
Appearance
Solution

This is the first of two letters that appear in this article—this one directed to the editor during the summer of 1962, and the other directed to the students in the form of an open letter. The editor of The Publication, feeling that these pieces represent an attempt to solve a difficult problem, has, therefore, made no attempt to revise or rewrite.

July 24, 1962

Dear Werner,

I will try to set down a few of my current thoughts on design education, as you requested.

When discussing problems of this kind, it's easy to fall into a pattern of glib generalities. I'm afraid I am not immune to this pitfall. However, that is precisely what we should be working to avoid.

I think we are agreed that the relative success of the first year lies in the fact that problems are dealt with specifically, in their own terms, and consequently dealt with adequately. The thing that is important, in this regard, is that problems be dealt with in such a way as to *avoid isolation from context*—spotlighting, rather than surgical removal. From this fundamental spotlighting approach flows the curriculum ideas I set down before—continuing the process to fifth year. This is very important, because the bounce-back reaction to suggestions such as this always is: "After you solve the pieces, how do you put them together again?" The answer, of course, is that the problem is never taken apart, but the scope of the spotlight increases year by year. The rest is assumed. I emphasize this because it is a common reaction from both students and faculty. It is usually followed by the other solution—the "background" solution. "Give the student the required background, and if he is any good he will do something with it."

As you are probably aware, there are two general approaches to teaching, both of which have strong adherents. The first is the "background" approach, and is suited to mass delivery; the second, individual. Schools of architecture have traditionally been set up on the second—individual—approach, assuming that judgment formation was the more important aspect of an architect's training. Now, because of technological problems you are familiar with, that system is being seriously challenged. The reaction is, as always, the opposite—program the works, as a unit. To me, at least, this is unrealistic. A vast quantity of unrelated information, learned (?) out of context with a problem, is valueless.

Cannot the two be combined? If schools (and faculty) were willing, would it not be possible to spotlight areas, give intensive and complete information dealing with the area in question, and then deal with that information in a thorough, exhaustive way? There is no need to cover all air-conditioning systems; one problem dealing with this area in a realistic manner would give insight into the *process*, and that is what is important. Perhaps it would be better to write specs for a picnic table one has actually designed than spend a year on generalities.

How does this relate—. Exactly this. What I was writing before was aimed at curriculum as well as students. I will carry that on. The system of spotlighting depends on adequate information dealing with the area or areas under study. This must come from research, of course, but mainly from faculty— which means a good deal of investigation and preparation on their part—far more than they would have available at their fingertips, regardless of experience. On the student's part, it means the obligation to absorb this information, and make it a working part of his vocabulary for the problem at hand.

The student must have the information, and he must learn how to make *objective decision* (so far as possible) with this information. There is a paradox involved here: "We are most ourselves when behind a mask." Likes and dislikes, when volunteered a priori, are almost invariably inaccurate. Subjective decisions followed as a fetish turn into inanely objective (valueless) decisions. Decisions based on the question "What *should* be?" will always (in the end) be subjective, but if the question is answered honestly, will be honestly subjective.

These two aspects of the problem are, to my mind, the critical ones. The first—thoroughness, is dealt with by the *scope* of the area under study (curriculum). The second, objectivity, by a flood of information in depth, combined with scope—which, by being narrow, forces depth or nothing.

A few European medical schools are experimenting with a new approach to the teaching of medicine. Instead of a prior indoctrination in textbooks and dissecting rooms, they begin immediately on human beings, their objective. The first years involve a progression from simple first aid to cuts and bruises, minor ailments, assisting at operations, etc. From the beginning they are required to put knowledge to work, and a lack of accompanying study means disaster. It appears to work.

As you know, a distorted parallel of this has been tried in architecture (I.T.T., Taliesin) but always failed because of an obsession of one kind or another (I.T.T.—materials and workmanship, Taliesin—Mr. Wright). Faculty, then, as well as students, must learn to be objective. In other words, not what they like, or know, or can do, but what is *needed*—at any certain time. We cannot ask of others what we are not willing to try to do ourselves.

Next, how does all this rambling relate to the very real problems of a confused third year student at the School of Design: somehow, someway, the problems that an architect is expected to solve must be brought down to earth. In my opinion, the day is gone when we can settle the issue with a grandiloquent wave of the hand, "If he is good he will, if not he won't." *Architects are in trouble today, because they can't compete with facts—that is, sell "art" in place of facts.* This is not due to lack of available information, but to a lack of willingness—perhaps ignorance of how to assimilate and draw conclusions from that information. The form-giver of today is a designer-technician. This is what five years of architectural education should provide. He must also be a man of some taste and sensitivity, and that is what a strong department of painting and sculpture should provide. But as far as I am concerned, that is the end of the matter. We do not find buildings condemned because they are too honest, simple or forthright—but because they are cliche'-ridden, trashy, and vulgar—always in an attempt to be "art," or "give some interest," or such phrases of the vernacular. This is the image of architecture we have been perpetuating, both in client's and student's minds, and is the reason, above all others, for bad and confused work in school.

The student must have:

1. A program he can cope with, dependent on year. (No bad houses, to better, to good, to excellent.)
2. Realistic information—given and/or self-gained—on the areas with which he is expected to deal.
3. An absolute intolerance of any failure to deal with that information sensibly and—realistically (objectively).

By information, I mean to use the word in its widest possible sense. A given site, for example, is information. It has width, depth, contour, orientation, location, etc., etc. It must be accepted or altered, but it cannot be ignored. An all-steel house is information which must be assimilated and used, or the problem becomes another one. Information, to be used effectively, must be absorbed to the point of becoming second nature to the problem. This brings up a problem of methodology, in how to reach the required condition. If a third year student is asked to design a children's hospital, for example, for a given client and site, with desirable area, space, character, etc. *all at once*—he will invariably compromise important aspects because of the immense scope of the problem. Important areas of information will be ignored, or given cursory attention, which is worse. Perhaps it is necessary, after a problem is stated, to examine each of the areas of information—hospital for *children,* owner, site, environment, technical aspects, etc. in *another context,* returning to the main objective only after the conditions are understood. Would this really take longer, or be more laborious? My own observations on the human intellect (including my own) lead me to think that we do not function best when we hit problems head on, and push tenaciously in a single direction. This is a prejudice sold to us by the Reader's Digest. For some reason, when we know too well where we are going, we always arrive back at the same point—nowhere, or at best a well-trodden field. The mind is a devious instrument, and must be tricked and cajoled into functioning—otherwise the wheels turn but the gears aren't engaged.

Understanding the problem—digesting the information—then becomes the prerequisite to an adequate solution. When that is achieved, a solution comes quickly, if it is to come at all. This business of "building up" a solution from sketches to refinement in a single line of development (or "idea") leaves much to be desired. It's too easy to get sabotaged with prejudice or clever tricks, often secondary to the main purpose.

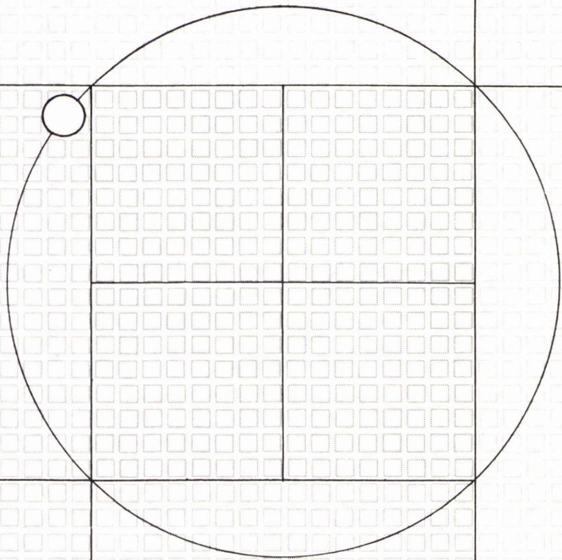
Another way to encourage objectivity in an architectural problem is to study the different aspects of a *single* solution—separately. For example, an office building studied without a ground plane, or as a frame, or as a circulatory organism. These must be attacked not as means to an end, but as ends in themselves—*perfect* in their way and ignoring other considerations. Side by side, they might well suggest a completely new solution, quite different than a collection of parts hung together. However, when this is attempted within the framework of a set parti, shoe-horning becomes the order of the day from the start. The type of study described above can proceed on any temporary solution, knowing full well that the final one will be very different.

The final suggestion I would make is a very mundane one—drawing ten times as much as is now customary. Most students have the misconception that there is no point in drawing until they have an idea. I say that ideas follow drawing, not precede. Designers think with their eyes, and they think of one thing at a time, like it or not. Drawing is by far the best way to assimiliate information—and by drawing I do not mean aimless, meaningless scrawls and "sketches." I mean carefully controlled, accurate *studies* of conditions to be coped with. The time for "sketches" is (perhaps) at the very beginning, and just before the final solution is decided. This, again, cannot be left to the self-discipline of the student alone, but must be supplemented with program (assigned) requirements.

I can see where much of what I have been suggesting will be interpreted as tyrannical. Where is the "freedom of expression"—where is the "art in architecture"? I think it worth pointing out that nothing limits *how* problems are solved—simply that they *be solved.* Art, if it is genuine and significant, involves understanding and discipline. It depends further on *individual* understanding, and *individual* involvement. In fact, one could go so far as to say that all art is the *expression* (statement) *of individual understanding.* Second-hand understanding, second-hand statements are worthless. "Freedom of expression" in solving a problem superficially attacked and inadequately understood is certain to fail on both technological and artistic standards.

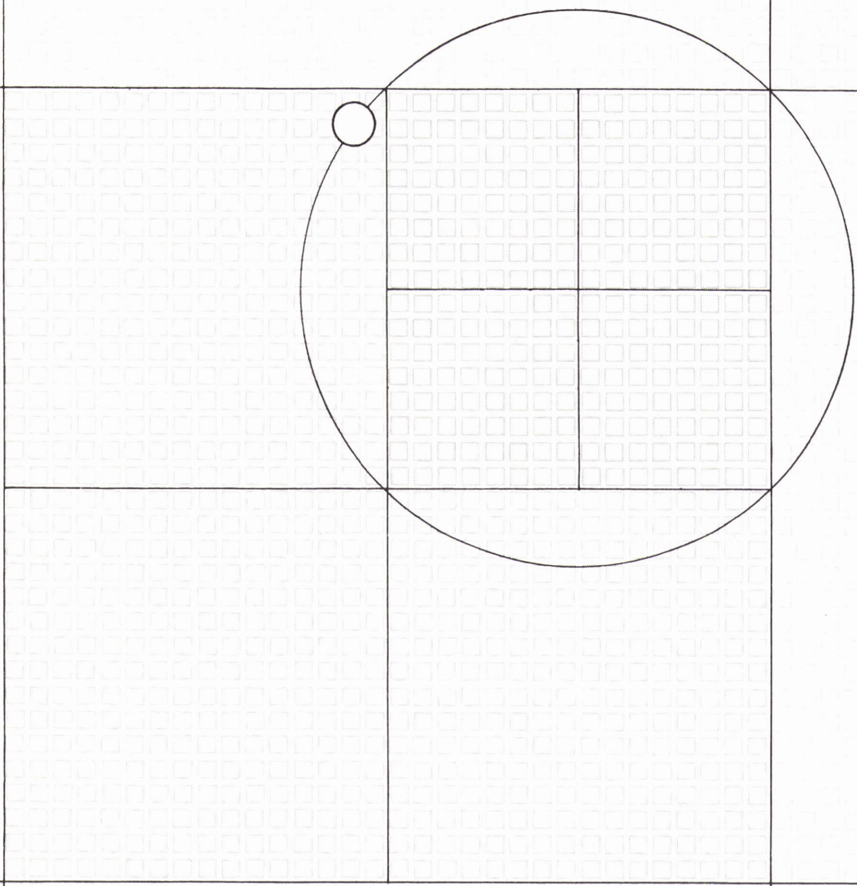
Power of judgement is the critical faculty a school of architecture should be striving to develop. Spoon-feeding unrelated facts and formulas will not accomplish this—only the exercise of judgement in solving realistic problems. Scale, that is, size, has nothing to do with it. Only *involvement* will do—and the kind of involvement (problem) a student can see and understand with the faculties he brings with him from his past experience-patterns. We have all had enough ethereal monkey-business on what is good and bad, right and wrong—in this solution or that one. The time has come for faculty to realize that a student solution either solves the problems or doesn't (and in what degree), and it doesn't matter in the least whether they would solve it the same way or not. It is also time for students to stop playing games behind walls of ignorance (kept well chinked) and approach the solution of architectural problems as a craftsman does the laying of a brick wall. He is not an artist, and he probably never will be, but at least he can learn to solve problems adequately.

At the beginning of this article, a design solution was analyzed in its theoretical aspect; it would be useful to consider it now from the practical aspect. It is obvious that our thought patterns do not have the ordered simplicity of theory. This is not due to a weakness of theory, but to weaknesses within ourselves. One of those weaknesses is the tendency to over-simplify.

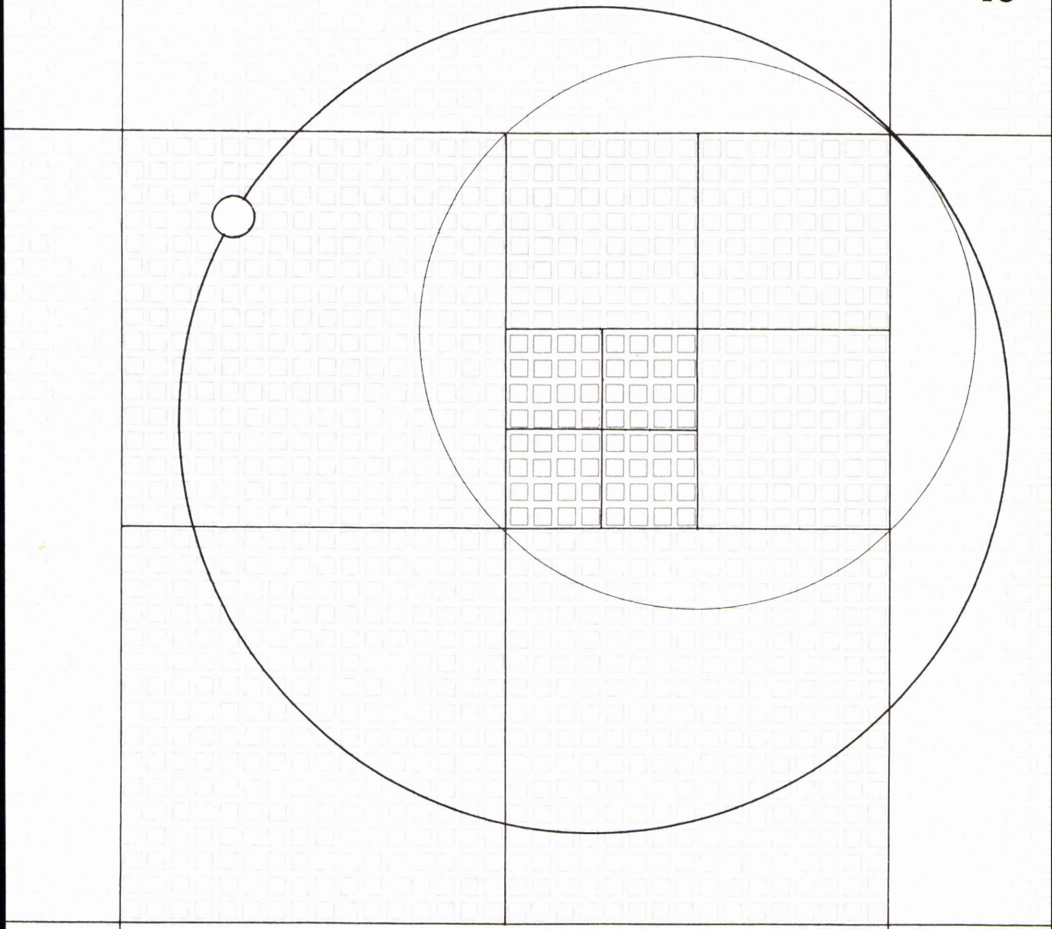


Over-simplification can be due to lack of thought or to prejudice. In either case, it has the effect of nullifying itself by putting off the decision until later, or of producing choices which appear quite arbitrary.

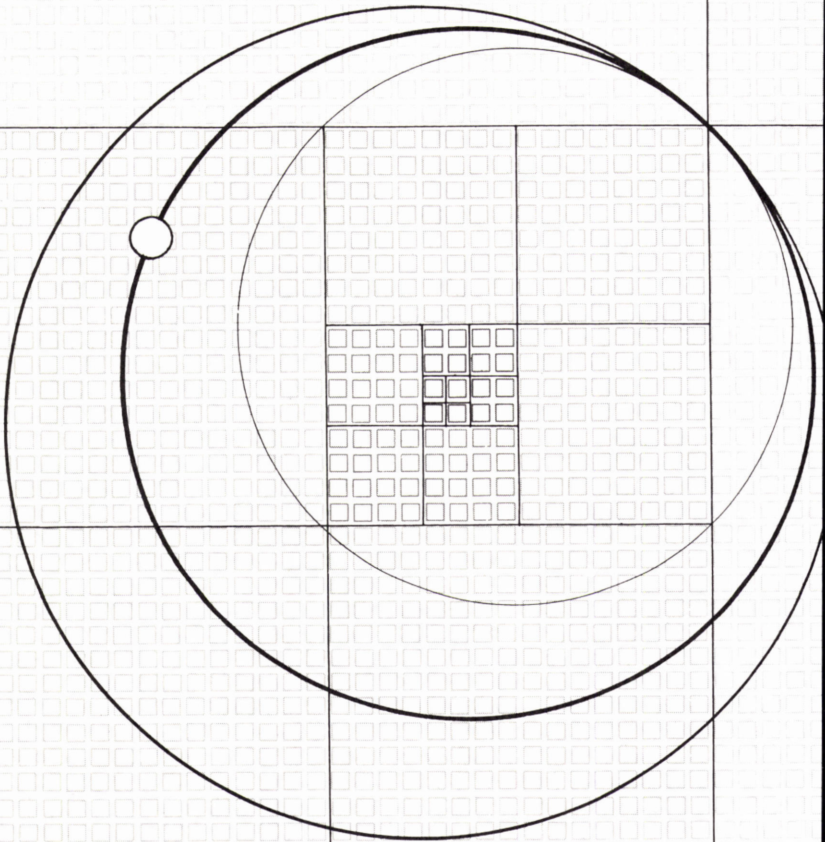
In the case below, the choice as to *Place* must now be made. However, all are equally located in relation to the center. Evidently the choice doesn't matter, which seems unlikely.



If the choice of place does matter, if there is any preference whatsoever, a mistake in original thinking is indicated. The original **Objective,** could be reconsidered and recentered on the basis of newly discovered fact, the choice of *Place.*



However, we can see that we are in the same dilemma in the choice of *Medium*. There seems no alternative but to return to a thoughtful consideration of **Objective,** which would have saved a lot of time if it had been done in the first place, but even now, it will speed up the process.



The intention of this article is to analyze and discuss three basic questions:

1. *Why* you are here?
2. *What* are your goals here?
3. *How* can you help yourself in achieving those goals?

1. Why?

When you enrolled in the School of Design, you did so with the intention of becoming a Product Designer or an Architect. Your vision of what these were, and what they did, was probably vague; but you had seen products and gardens, and buildings, and you were convinced this was for you. Very soon, however, you discovered that *doing* these things, along with drawing, painting, and sculpting, was not enough. You were not only expected to do them, but to *use* them. In fact, *using* these abilities soon became so important that doing them was almost taken for granted. This may have stimulated, bored, or shocked you, but it explains why you are here and not learning directly by working for a product designer, or an architect. It is for this purpose that the School of Design, along with all similar schools, was established. You are here to acquire abilities, and to learn how to use those abilities.

2. What?

If you are here, then, not only to learn how to do things, but to learn how to use those things, the question is not why, but for what? You are told that you should use your newly acquired abilities to "make a significant statement," to "express an idea," to "create a work of art." But these instructions do not answer the questions: What is significant? What is an idea? What is art? So long as you cannot answer these questions, you cannot use your abilities to achieve the objectives they urge. What if you were told that the answers to these questions must come, in the final analysis, from yourself: that they will be as big or as small as you are, as wise or as foolish as you are, both now and in the future. What if you were told, further, that you are not here to create works of art, but to learn *how* to create works of art if you should ever become capable of conceiving them. Art is involved in the communication of the human spirit. Communication needs language, and you are learning that language. You are not here to achieve, but to learn how to achieve. You are not here to succeed, but to acquire the tools for success. You must fail by definition, or else there is no point in your being here at all. This is the difference between a school and a factory.

Your goal, in the School of Design, is to learn how to achieve objectives which you set for yourself. It is not important, for now, whether those goals are significant, or even whether they are original. But it is important that you accept them as your own, and try with all your resources of energy and ability to achieve them. Your ultimate aim is to be able to fulfill your own private vision of what should be, and to be able to ignore styles, trends, and opinions of others. *Your goal is to become independent—independent of fact, independent of theory, independent of criticism.*

3. How?

To achieve all this, you may say, is incredible and impossible. Perhaps so, but what of that? If it is good and desirable, then any step toward reaching it is good and desirable. If it is a worthy goal, then it is never too soon to begin the journey. Let's begin at the beginning.

To become independent of fact, is to know and understand fact. If we are ignorant of fact, we are dependent; it directs us, rather than we directing it. In order to control and direct fact—in other words, to use it for our purposes—we must be more than simply aware of its existence. It must be part of our understanding, of our being, so that we can cut through its superficial appearance and understand its nature. We then become its equal, and use it with respect and effect. We must learn to recognize it in all its disguises, and deal with it directly, or we will end up frustrated and defeated. Most important of all, we must never confuse fact with opinion, just as we must never confuse opinion with fact.

Fact is what should be; opinion is what could be. Fact is independent of individuality; opinion is dependent on individuality. Fact justifies itself; opinion must justify itself.

The practical effects of an acceptance of fact are to prevent waste—waste of effort, of time, of energy. We can then utilize these resources to concentrate on those problems which fact does not determine These are many and complex; and are usually more than enough to occupy one's attention if they are to be dealt with adequately.

In school, you can gain some practical effect by the simple process of assuming things to be facts, whether they are or not. For example, if you are asked to design a house, you may simply assume that a house is what Mr. Wright said it was, "A refuge from a hostile, man-made environment." (Actually, it probably isn't any more, but that is beside the point). If you are honest with yourself and the problem, you will undoubtedly come up with a very different solution than he did, because times have changed. Perhaps the best way to talk about refuge in our day is not in terms of horizontal or vertical shelter, but in terms of isolation—even from nature, if need be. The main thing is, it gives you a point of departure (temporary fact) which allows you to focus on developing a sequence of consequences, in logical and consistent order. If you could do this satisfactorily, then you could develop any other point of departure, one of which, one day, may be your own if you are wise and observant enough. The only important thing to remember, in what I have suggested here, is *to be aware of what you are doing*. In other words, don't kid yourself about what is fact and opinion in actuality, but use such assumptions as are outlined above as a device, like a perspective chart.

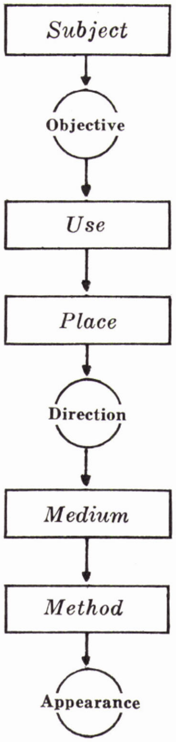
Usually, the limiting of problems to manageable proportion is dealt with by your instructor. However, if this is not done, then you should take it upon yourself to do it. It is more important for you to do one thing well than do a dozen badly. In the next heading, a system of proportioning what you can reasonably expect yourself to do is suggested, by year.

Theory and Criticism

These two are lumped together because they are part and parcel of the same thing. Theory tells us what we should do, and criticism tells us what we have done—in terms of what we tried to do. It is a cycle which completes itself, and which often takes the student on such a merry-go-round ride he doesn't know where he is, much less where he got on, or where he should get off. Let us examine closely what theory and criticism actually do.

We will assume first a problem, or subject in this case, a house. Our first task is to formulate an objective of what a house is, within the entire range of architectural problems around us. This, then, is our first decision, and it becomes our essential purpose in everything we do subsequently to fulfill this objective.

We must then consider information as to use (client) and place (site). When this is thoroughly digested, we can make our second big decision, which involves not only our overall objective but an actual *way* of achieving it. It is a mental image, which suggests a relative scale and use pattern, and a general functioning system. There is no detail as yet, all is fuzzy, but the basic configuration, shape, and circulatory system are decided. [For example, Mr. Wright might have said, "My concept of a refuge (etc.) is one which has a dominant feeling of horizontal shelter with a central (heavy) core rooted in the earth, with space directed to the four points of the compass."] In the light of this decision, we return again to information, this time in medium (materials) and method. Our second decision, or direction should suggest good and bad media to use in carrying it out, and these in turn will suggest good and bad methods for using them. (These are not arbitrary decisions.) Finally, we mold the medium, by means of a method, and by a decision as to appearance into our solution.



Is this actually how buildings are designed? Of course not; the human brain works much more rapidly, and certainly not in such an orderly sequence. An analysis such as this is but a visual translation of what occurs. It is useful however, to know what occurs in order to retrace our steps when there is a breakdown.

Fact justifies itself, but opinion must be justified. This is done by theory, or by practice, or both. We can try to convince ourselves (and others) that an opinion is sound by constructing a logical system around it, or by putting it into real form, and then await judgement. Both are as sound or unsound as the original opinion, certainly no more so. In other words, there is no real difference in outcome, whether theory is advanced by a verbal argument or a product argument. However, product arguments are easier to prove or disprove, so eventually verbal arguments are translated into product arguments, in order to settle things.

The mistake that most students make, however, is in accepting the actual form of the product argument as the end in itself. Actually, it is an irrelevant form, one of many possible forms which could be used for the purpose, and has to do only with the particular characteristics of the designer who did it. Arguments presented by products (or buildings) can only be understood if we penetrate beyond the simple appearance of those products. Also, and most important, only when theories are dealt with directly, and understood, are we free to accept or reject them.

The surest way to be a slave to theory is to ignore it.

It should be obvious to most of you that it is impossible to comprehend the significance of an effect unless we understand its cause. True, we can evaluate it, in an elemental way. We can draw some conclusion, let us say, from looking at a meteor crater. It's big, the trees are down in a strange pattern, and it's elliptical in shape. But it does not assume its true meaning, its actual awesome power, until we understand what caused it. Nor could we duplicate it until we knew this.

Theories are as big or as small as the people who originate them. They can be simply rationalizations for weakness, prejudice, or incompetence; or they can be explanations of fundamental principles which apply to a whole field of problems and people. In either case, knowledge of the theories which motivate is much more important than knowledge of results of those theories. You can do nothing with results but imitate them, or use them to further understanding of the theory which is behind them.

Criticism is the process of observation which keeps us on the straight and narrow from theory to product. It also evaluates, in a comparative sense, our decisions against abstract decisions (what is to what could be), but always against the framework of previous decisions. This implies a definite sequence from beginning to end which must be followed, or criticism breaks down completely. In other words, we can only judge where we are if we know where we came from and where we are heading. Criticism on any other basis is pointless and absurd.

The first thing we must know, in any given problem, is, of course, the subject of the problem.

Problem: A house

Next, we must set a general compass heading, a general objective for our future effort.

Objective: A house is a refuge from a hostile environment

How do we arrive at this objective? It has to do with time and value, in other words it is current fact or opinion as to value, significance, importance, use—in our time. Our values may be set by economics, mass opinion, philosophers, or artists—or all of these. *Analytical* criticism, the kind you encounter in classroom work, does not bother with it. It is rather *evaluating* criticism that debates this subject; The kind you encounter in juries, where the actual *way* of doing things is ignored in order to deal with *what* you did, what it means in terms of how it will work, and whether that is good or bad (or whether we can't decide). In other words analytical criticism, which traces the competence and accuracy in translating an idea into a product, should be confined to class activity; and juries should be involved in debating worth and value. (The jury educates, while the instructor trains.)

The next step, after we have set our objective, is to become acquainted with two of the facts we must deal with—the use (or client) and place (environment or site). A mere nodding acquaintance is not enough—it must be thorough and complete, until you are familiar with every whim and vagary of this pair, and that means, for designers, drawing and analyzing. The familiarization must be complete enough to give you total freedom in the next step, or you will be in trouble.

We then have our second big decision—the creation of a direction, or mental image of *how* the objective is to be implemented. This will necessarily be indistinct, for we don't yet know what the product is to be made of, or how it is to be put together. But it will set a *specific* direction, (or an exact compass bearing), in terms of overall function and configuration. The more specific, exact, and complete it is, of course, the more useful it will be in making decisions about medium (material), structure, appearance, form, texture, color, etc.

This is the designer's only real act of creation. He does not create objectives—they are created for him by the society in which he lives. In this area, he is an interpretive artist, similar to a pianist. His objectives will be as accurate as his ability to see through the trivial and superficial, and his humility in rising above his own preferences or prejudices, as the case might be. He cannot afford the luxury of interpreting the world as he would like to see it (which usually means to fit himself) but as it *will be, inevitably.* His obligation, then, is to guide and control this development as best he can. If he does not do this, he will be useless, or at best harmless, to the society in which he lives.

Abstract

Abstract can be both verb and noun, and they don't mean quite the same thing. For example, you may hear a manner of working described as either *abstraction* or *abstractive.* The first means that the problem is reduced to its theoretical essence, or unrelated to application; while the second means the problem is being approached within a different context from the one it will finally take. This gives rise to a great deal of confusion, especially from those who dislike the idea of anything being abstract.

The first year problems, for example, are really abstracted problems. They are real enough, and are not reduced to a theoretical essence in any way whatever. They are familiar problems which designers face every day, but are considered in a different context than the familiar one. The main purpose behind this abstractive plan is to free the student from preconceptions and prejudices as to what this and that look like. As a result, he does far better work than he probably will later, when he faces the same problem in the context he knows so much—too much—better. This is obvious enough to be apparent to anyone, and yet students apparently do not recognize it and take advantage of it. It is a familiar sight to see a fourth year student working on a sculpture, while beside him a first year student is producing something similar but infinitely superior. The fourth year student is busy producing *Art,* while the first year student is "just solving a problem." I have never yet seen a student who failed to get tied into knots whenever he thought he was engaged in something "important", or "significant," "art" or "architecture." But, you will say "when do we emerge into reality?" My answer is this: five years is time enough, more than enough, "Reality" as it euphemistically is called, is around us always, dull and tedious as ever. I can see no reason why you are so eager to become dull and tedious yourselves.

Perhaps, as stated before, you are not capable of formulating sage objectives, or even of creating brilliant directions. That *is,* in my opinion to face reality. But you can remove some of the sting of that fact by marshalling what resources you *do* have. What are those? Yourself, you, as an individual creation who thinks, feels and responds differently than any other creature in this world. The one and only chance of your ever achieving anything in the area of art requires that it come from you and you alone.

Abstractive thinking is an excellent way to find out things about yourself, and your genuine thoughts and feelings. You can't fake, copy, imitate—or work as a draftsman for your instructor—here. It would be much better for you to assume anything in the way of objectives and directions, on your problems, and decide to carry them out in the spirit of your current painting or sculpture project, for example, than to try to work in an emotional vacuum. Unless your projects are rooted in your own personal self, they are really "unrelated to reality." You would then be learning as an apprentice to ideas, emotions and desires that have nothing to do with you at all and that's a slow way to learn, besides being tiresome.

Of course, abstractive thinking works both ways. The fourth year student mentioned above might find it profitable to work out his version of "A Rainstorm in the Himalyas," in wood, using the material properly of course and not imitatively. Or perhaps, a "House for an elderly couple" in sheet bronze. The point is, anything, *anything at all* that will force you to become personally involved in your work, is better than nothing.

It is conceivable, for example, that it might become habitual for you to make decisions in design in the manner of your latest painting, and that you would make decisions in painting the way your design was going. Contradictory? Not at all. We are, at any certain time, determined as to how we will react subconsciously. Better to make a conscious effort to harness this fact, than to be battling it underground. If you try, in a design problem, to resist your most natural way of responding, you will inevitably wrench and distort the result, for it will be artificial. This, of course, does not give you license to discard logic. I am talking about a *way* of working, not what you actually do. If you look back at paintings you have done over several years, you will recognize both how rapidly you change, and how characteristically you solved these—relatively free—problems at any certain time.

As for abstraction itself, it is also useful, but more for purposes of discipline than productivity. An objective, or direction which is placed in abstract form, whether in words or symbols, serves as a convenient shorthand reference, in case you forget what you are trying to do. Also, the effort required to reduce a direction to, say, five words, forces you to think deep and long. You are bound to be much clearer about the exact direction you wish to take, and thus are able to make accurate decisions about how to get there.

A DESIGN SCHOOL IS AN INSTITUTION WHICH TEACHES A STUDENT HOW TO DESIGN. 59

IT DOES NOT AND CANNOT TEACH A STUDENT HOW TO DESIGN BUT SIMPLY HOW TO THINK. IT CAN SHOW HIM HOW TO ANALYZE AND BRING ORDER TO CONTENT THROUGH FORUM, BY THE PROCESS OF FORCING HIM TO DO THIS HIMSELF, AT THE LEVEL OF HIS TRAINING.

A DESIGN SCHOOL SHOULD GRADE ITS PROBLEMS FROM ELEMENTARY TO COMPLEX (OR SMALL TO LARGE) BY YEAR.

THERE IS NO SUCH THING AS AN ELEMENTARY DESIGN PROBLEM; THERE ARE ONLY UNREALISTIC DESIGN PROBLEMS. A BAD BUS SHELTER IS AS EASY TO DO AS A BAD CITY.

A DESIGN SCHOOL SHOULD BE JUDGED BY THE RESULTS OF STUDENT EFFORTS.

IF THERE WERE VALID CRITERIA, HELD GENERALLY EITHER BY THE SCHOOLS OR PROFESSIONS, FOR SUCH JUDGEMENT, THIS WOULD BE TRUE; BUT SINCE NEARLY ALL SUCH JUDGEMENTS ARE ON THE SUPERFICIAL BASIS OF APPEARANCE, IT IS NOT. SCHOOLS AND PROFESSIONAL OFFICES HAVE ENTIRELY DIFFERENT OBJECTIVES—ONE IS EDUCATION AND THE OTHER A PRODUCT. WE SHOULD NOT FORGET THIS.

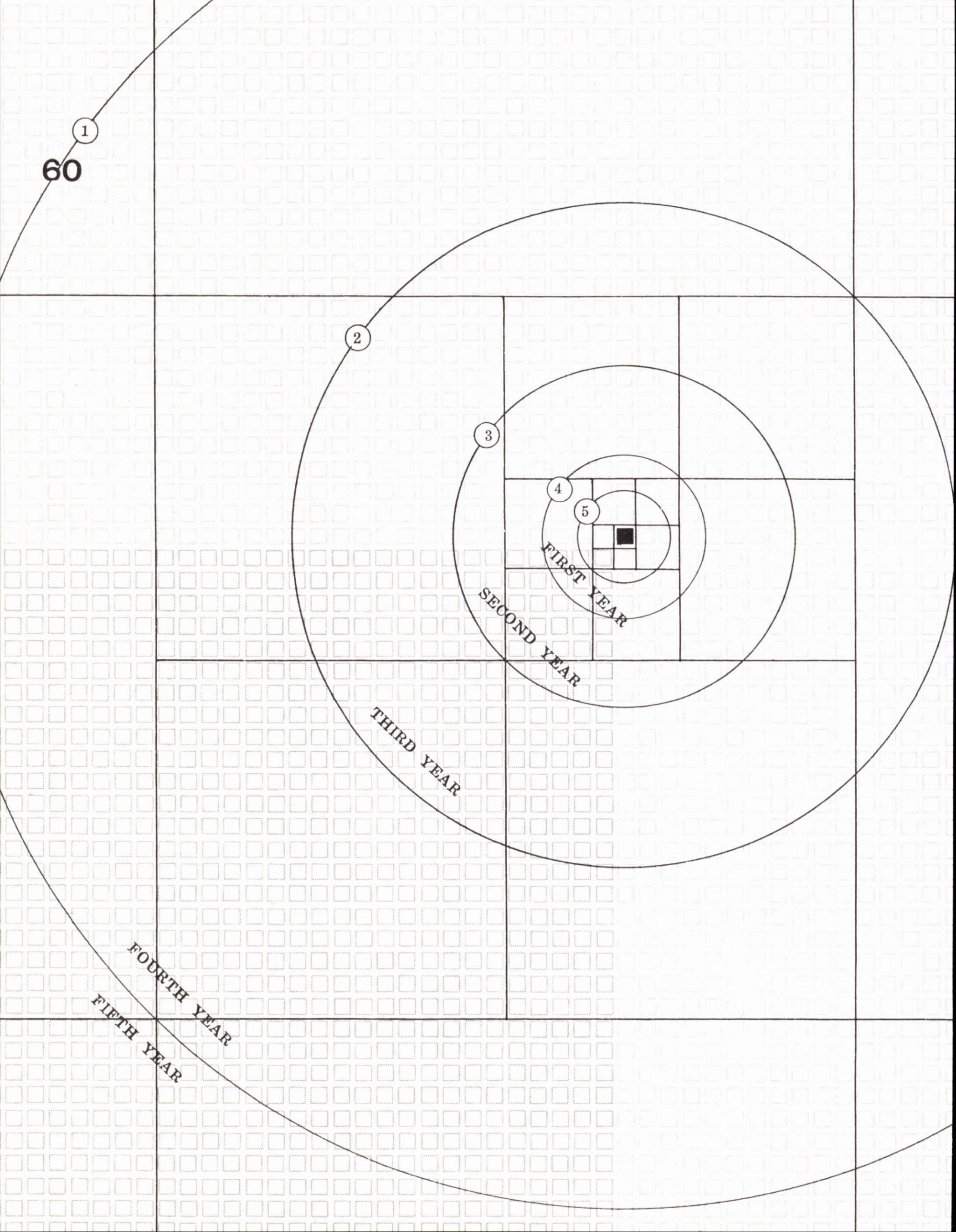
A DESIGN SCHOOL SHOULD GIVE THE STUDENT MORE FREEDOM THAN HE WOULD ENCOUNTER IN PRACTICE, IN ORDER TO ENCOURAGE CREATIVITY.

FECUNDITY OF FORM IDEAS AND CREATIVITY ARE NOT THE SAME THING, AS THE CRITICAL AREA OF REALISTIC JUDGEMENT IS LACKING. REAL SOLUTIONS COME FROM REAL CIRCUMSTANCES; THERE IS NO SUCH THING AS A GENERAL SOLUTION TO A PROBLEM.

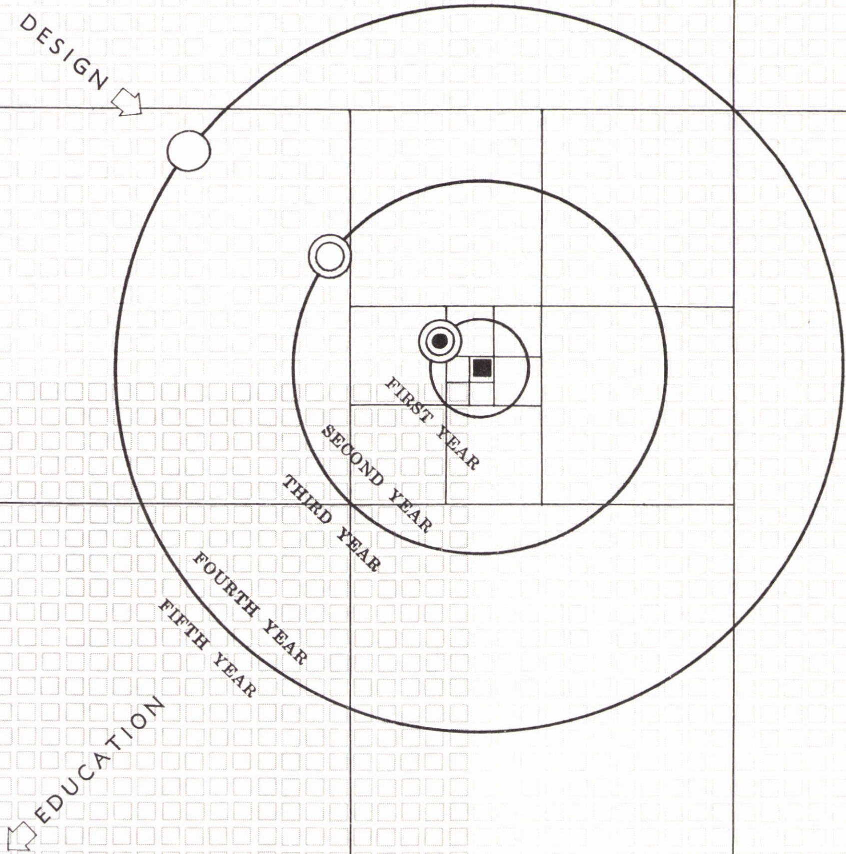
A DESIGN SCHOOL MUST GIVE A THOROUGH GROUNDING IN EACH OF THE ARCHITYPICAL PROBLEMS OF THE DAY.

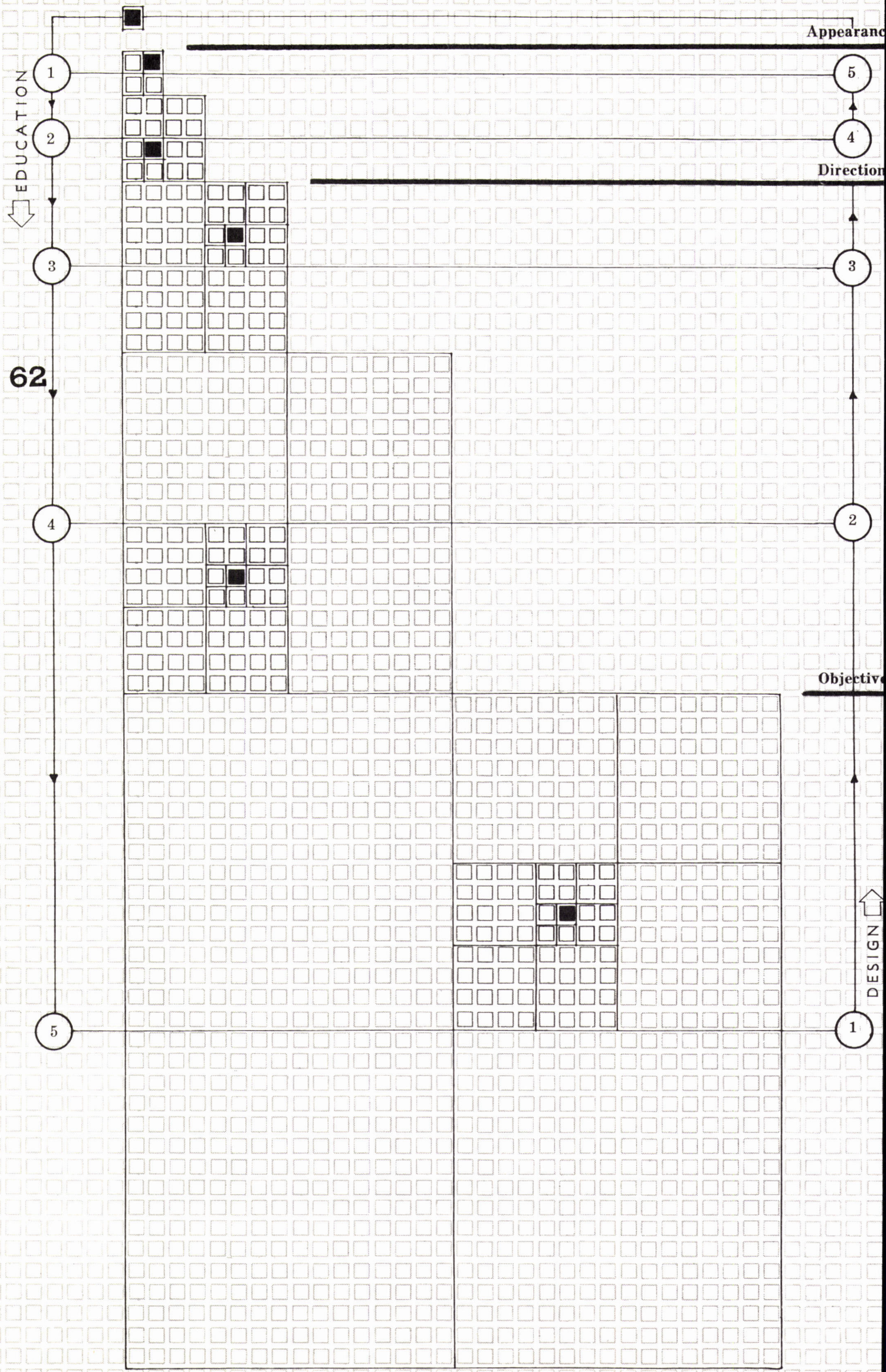
TO STUDY TYPE PROBLEMS, AS IF THOSE PROBLEMS WERE GOING TO BE THE SAME WHEN THE STUDENT IS IN PRACTICE, IS NOT VERY REALISTIC. THE STUDENT OF TODAY SHOULD BE TRAINED TO HANDLE THE PROBLEMS OF TOMORROW—NOT TODAY; THIS CAN BE ACCOMPLISHED ONLY BY TRAINING HIM TO THINK ACCURATELY, EFFECTIVELY, REALISTICALLY, AND INDEPENDENTLY. THE PROBLEM IS IRRELEVANT.

The natural order for design is from the outside in; and for education from the inside out. Each boundary of fact (*Subject, Use, Place, Medium, Method*) here shown is equivalent when isolated, but when placed in the design picture, becomes increasingly difficult due to its distance from the center.



However, the accumulation of facts is of no value unless converted to knowledge, and knowledge is acquired by putting facts to work in carrying out decisions. The critical area in design education, then, is in making those decisions which a designer must make, and practice in carrying them to completion.

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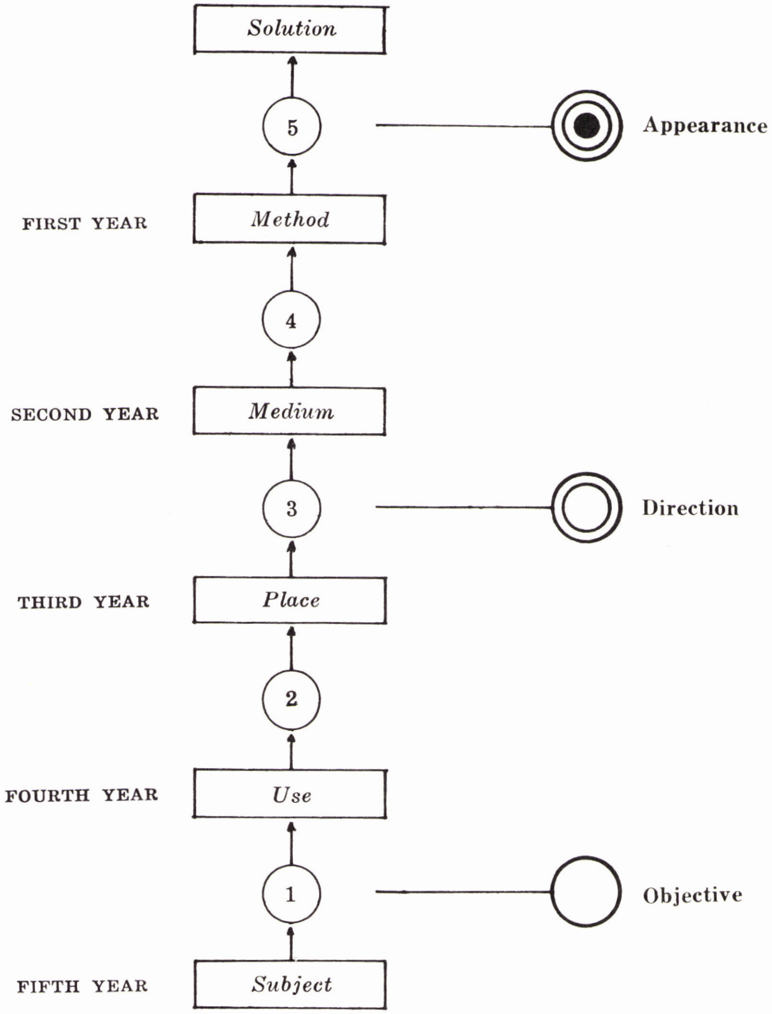
Solution
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Method
4
SECOND YEAR
Medium
3
Direction
THIRD YEAR
Place
2
FOURTH YEAR
Use
1
Objective
FIFTH YEAR
Subject

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Polyhedral and Mosaic Transformations; DUNCAN STUART. Finger Movies; JAMES POSEY.

PHOTOGRAPHS

Transformation Working Models; RALPH MILLS.

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COVER

The tetrahedron to octahedron transformation

INSIDE COVER

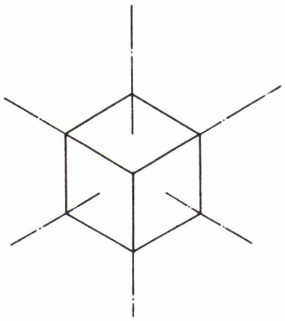
The octahedron to tetrahedron transformation

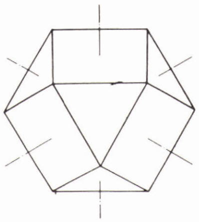
We have included six "finger movies" to more fully describe the nature of our idea of transformations. Three of them are operable in a front-to-back order, the other three back to front.

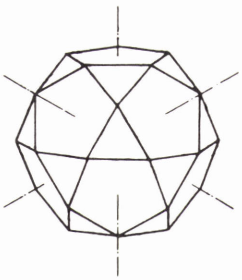
The first of these sequences identified by the letter (A) begins with the Octahedron and transforms subsequently through Icosahedron (the eighth drawing) and then to the sixteenth drawing, the Cuboctahedron. At this point we change our facial rotation pattern from the triangular faces to the square faces and continue the transformation until, at the final drawing, we have generated the Cube. It is interesting to note that all of the end points in this transformation are combinable in various ways as space fillers. In the first instance the Octahedron and the Cuboctahedron may be joined in closest packing to fill all space and in the second instance the Cube by itself will accomplish the same task. On the other hand, the Icosahedron which is not a space filler occurs as an intermediate point in the transformation.

The second series, identified by the letter (B) describes two transformations. First, beginning with the Truncated Tetrahedron, we transform by edge and face through the Icosahedron to the Tetrahedron —then, the Tetrahedron transforms, by face alone, through no intermediate-stage polyhedron and terminates with the Octahedron.

The third sequence identified by the letter (C) begins with the intermediate stage Icosahedron which we saw in connection with sequences A and B. This form transforms, with no intermediate poly-





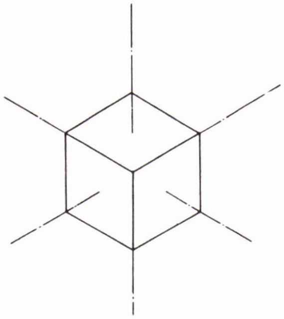


hedron to the Icosadodecahedron. When the Icosadodecahedron is achieved, we change our rotation pattern from the triangular faces to the pentagonal faces and continue our transformation with the end result being the Dodecahedron. In the latter half of this sequence we note also that no intermediate regular or semi-regular polyhedron results.

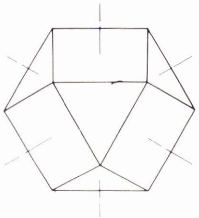
Now turning to the back-to-front transformations, the first of these identified by the letter (D), shows the Cube to Truncated Octahedron transformation. This is one involving transformation by faces and edges simultaneously. It is noted that the ninth drawing shows the Snub Cube occurring as an intermediate stage. This transformation continues to maximum, at which time the Truncated Octahedron results.

The second sequence of this group, identified by the letter (E), is one which begins with the Cuboctahedron and transforms until at the ninth drawing again we see the Snub Cube. In case of sequence D we saw this Snub Cube defined only by the square faces and certain edges connected them. In this case we see the same Snub Cube defined by the same square faces but also the eight triangles of the Octahedron. The resulting diamond-shaped apertures form the remaining triangles of the network. This transformation continues and at maximum the Lesser Rhombicuboctahedron results. As we continue onward, we move in reverse order through Snub Cube and terminate with Cuboctahedron.

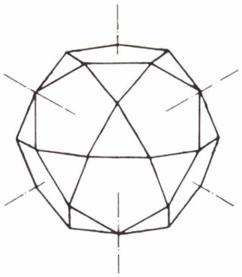
The final sequence, identified by the letter (F). is that of the transformation which is involved with the Icosadodecahedron and Lesser Rhombicosidodecahedron. We begin with Icosadodecahedron and at the eighth drawing the Snub Dodecahedron is found. We can see a close similarity between this transformation and the previous one. The difference being, that now we are using pentagons and triangles rather than squares and triangles.



CUBE



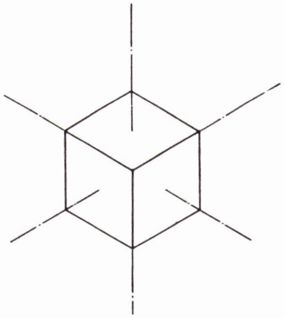
CUBOCTAHEDRON



ICOSADODECAHEDRON

This transformation continues until at maximum stage the Lesser Rhombicosidodecahedron results.

Although we do not have space to show them in this article, all of the polyhedra shown in Figure 1 may be generated through processes similar to those we have shown. By an analogous method in a two-dimensional domain we may generate all of the regular and semi-regular mosaics. It is interesting to note, however, that though we may transform any polyhedron into any other by this method, the same is not true of the two-dimensional case of the mosaic. The mosaics based on two-way symmetries (i.e., square) may not be transformed into those with three-way symmetries (i.e., triangles or hexagons). If we conceive of the mosaics as being surface phenomena of highly transformed polyhedra, such transformations can take place. Figures 8 and 9 show such a transformation.



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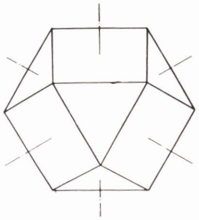
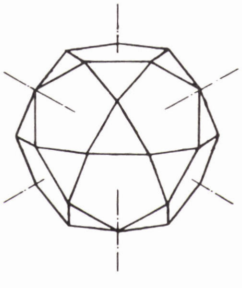
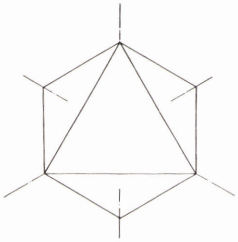


CUBOCTAHEDRON



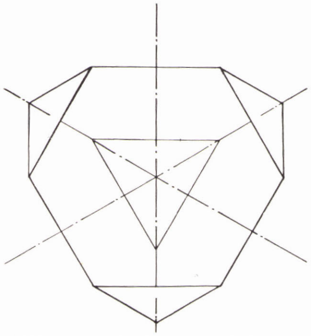
ICOSADODECAHEDRON

A



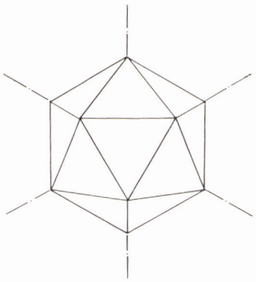
OCTAHEDRON

B

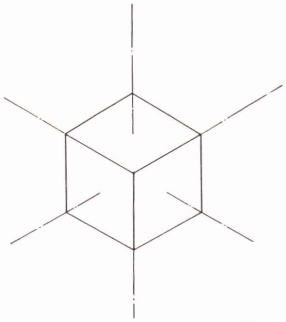


TRUNCATED TETRAHEDRON

C



ICOSAHEDRON



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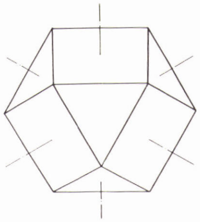
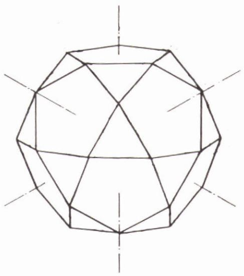
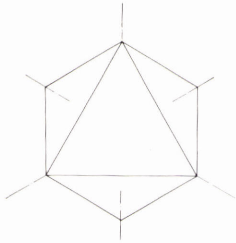
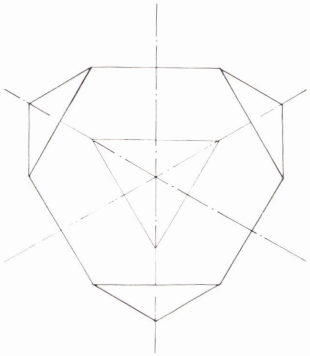


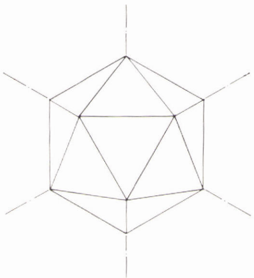
CUBOCTA

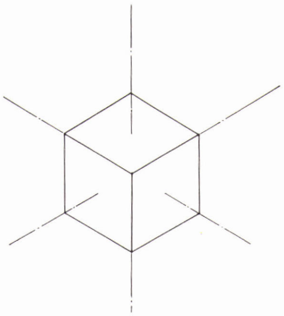


ICOSADODECA









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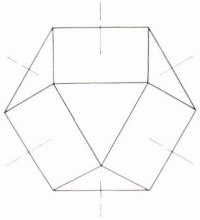
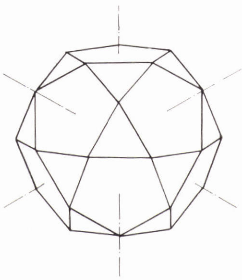


CUBO



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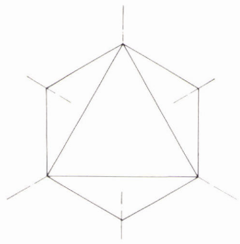

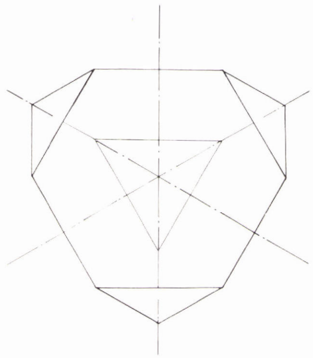

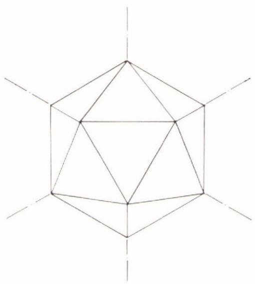

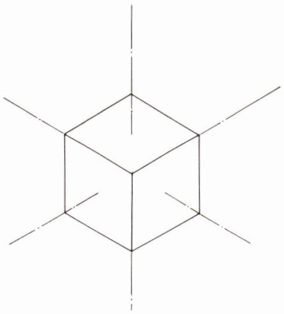

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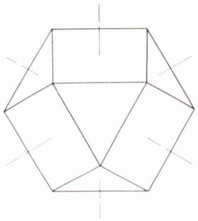

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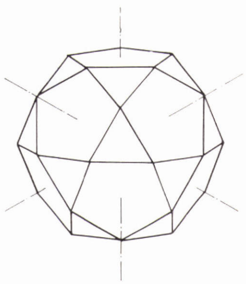

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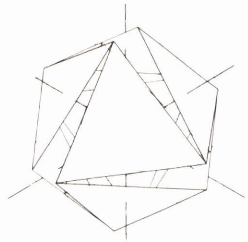

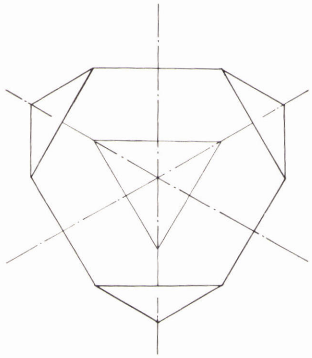

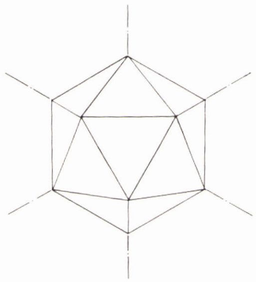

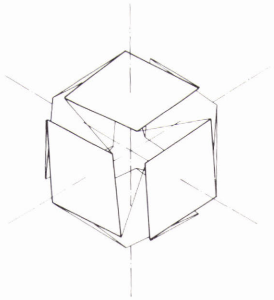

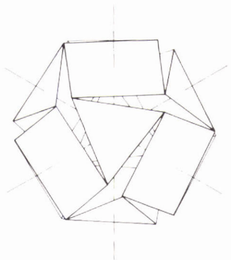

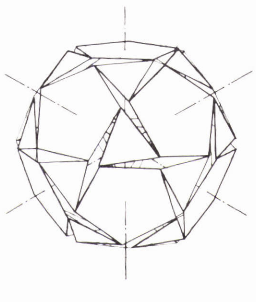

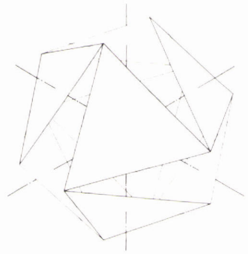

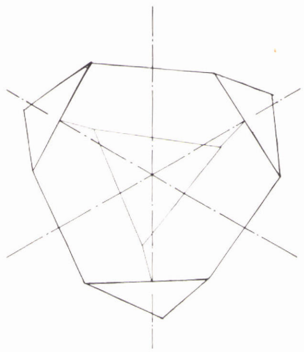

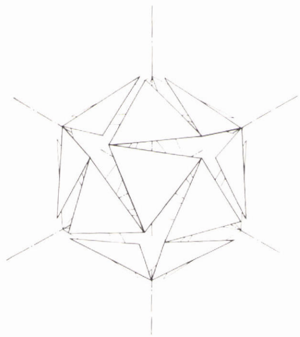

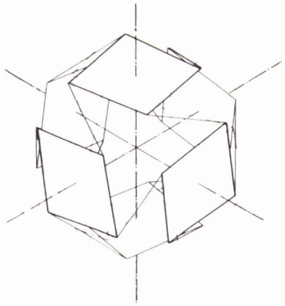

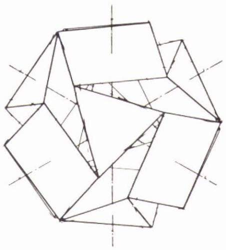

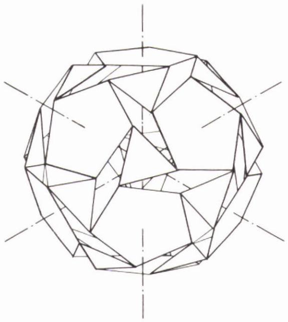

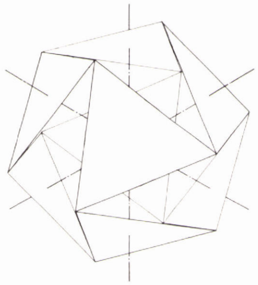

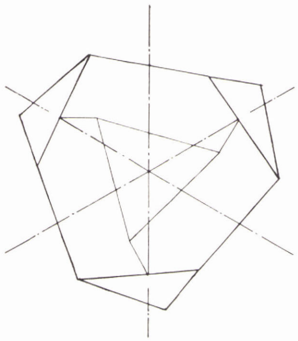

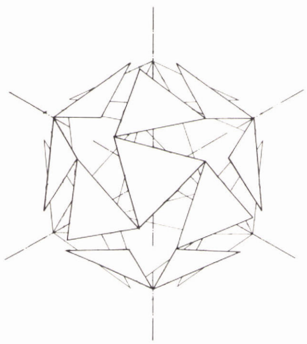

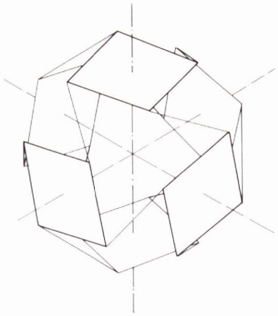

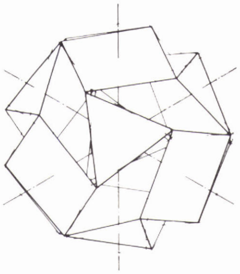

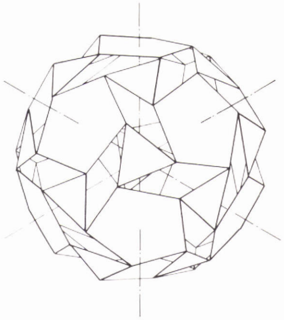

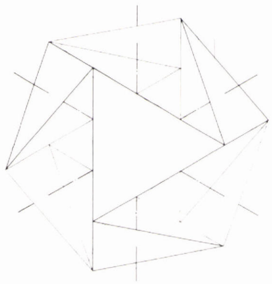

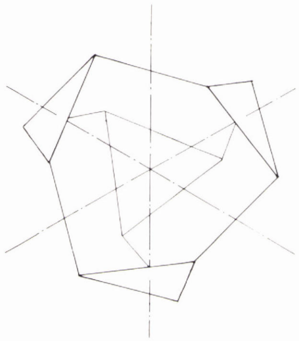

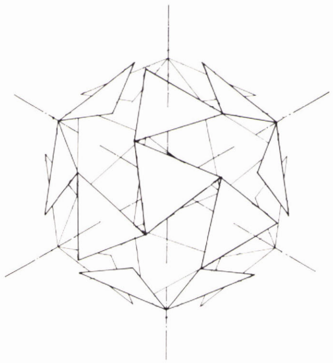

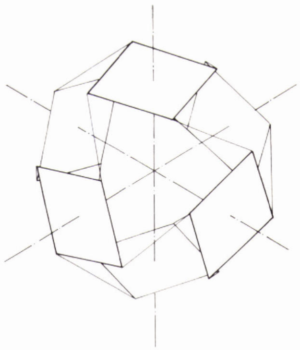

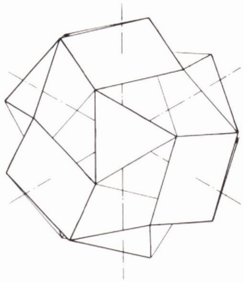

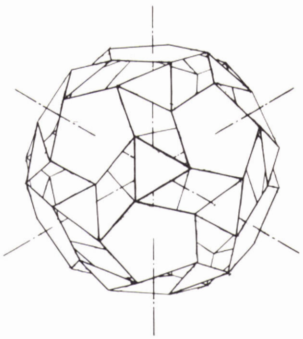

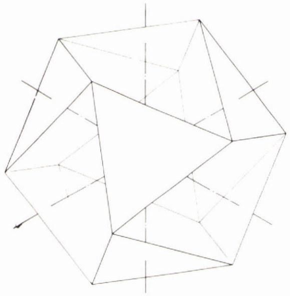

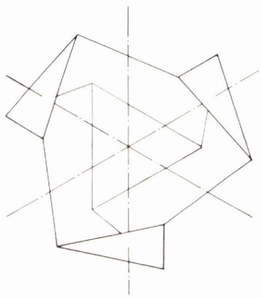

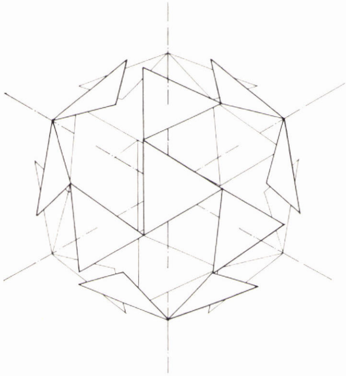

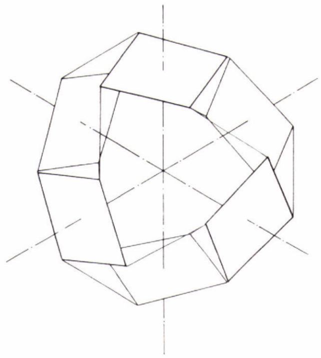

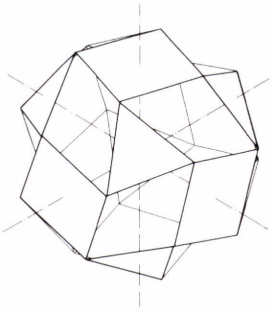

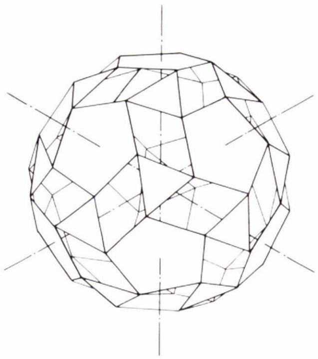

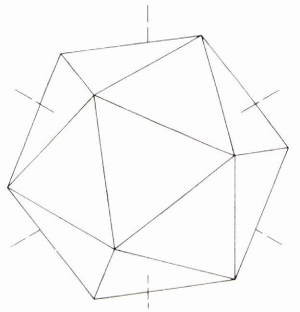

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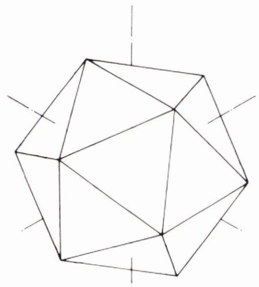

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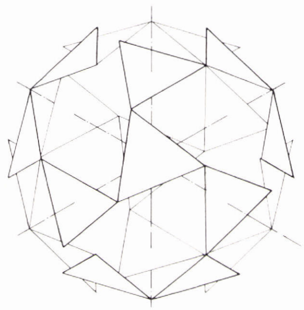

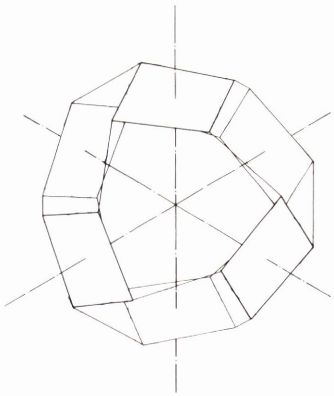

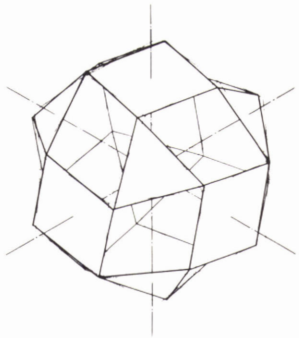

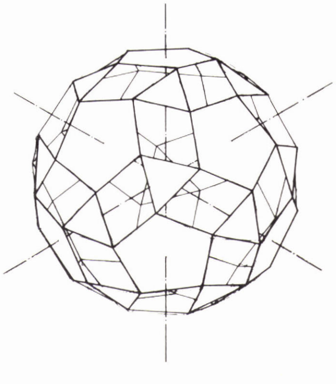

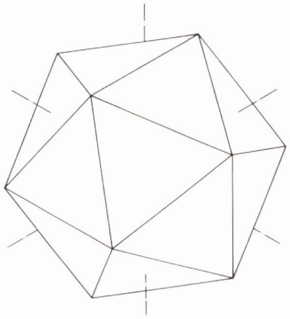

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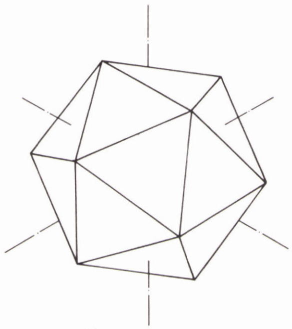

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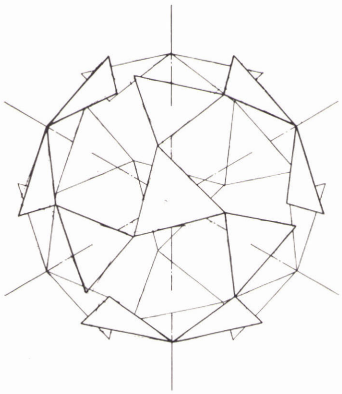

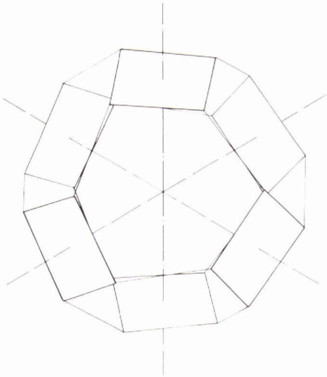

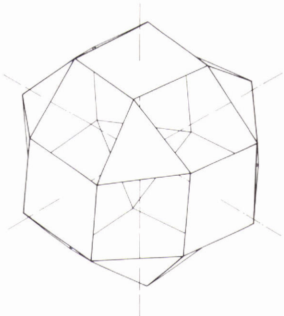

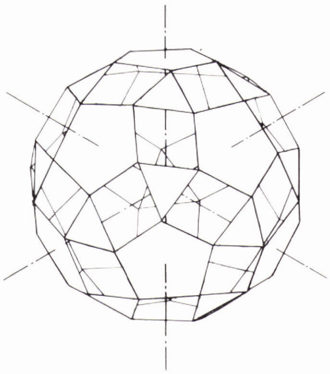

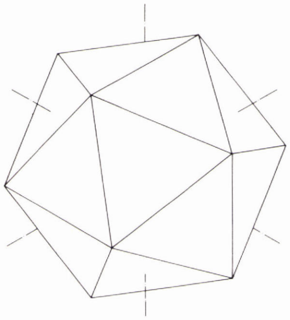

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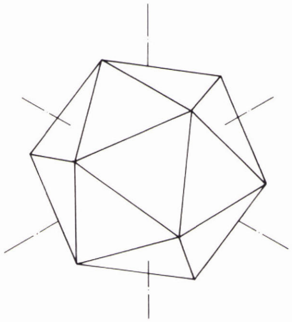

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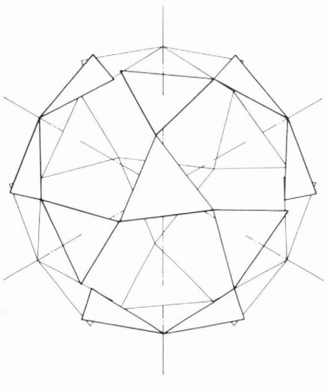

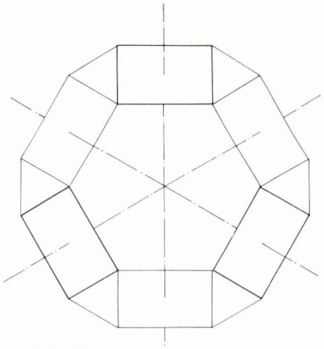

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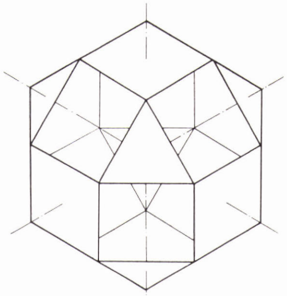

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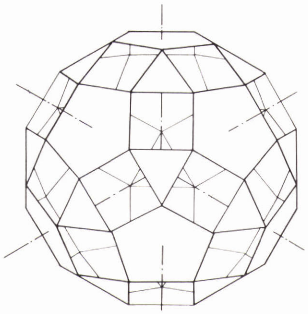

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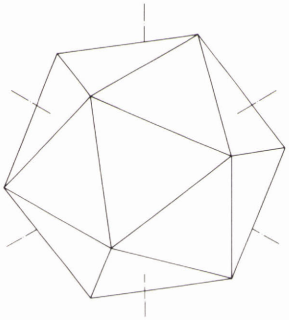

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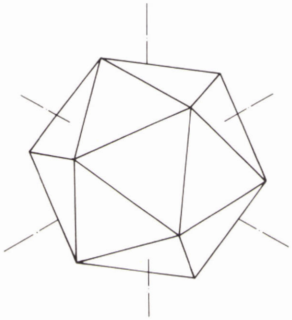

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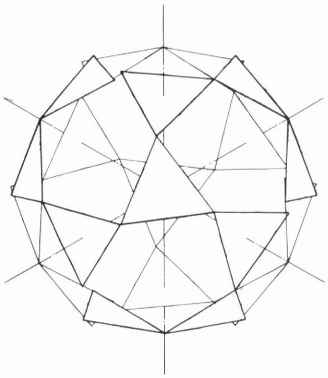

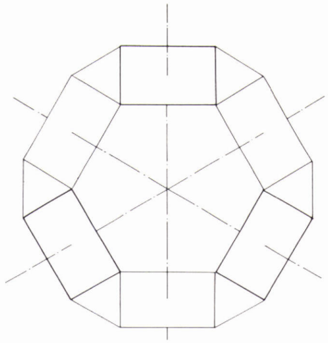

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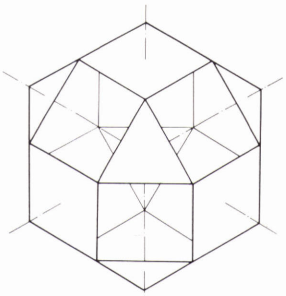

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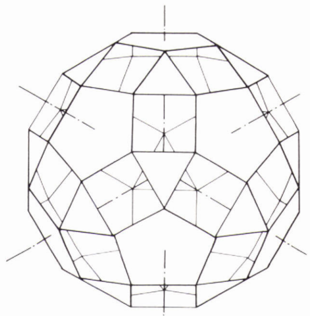

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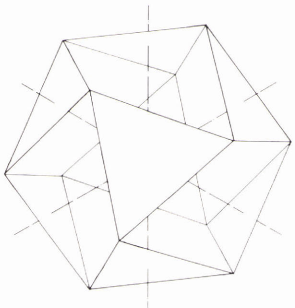

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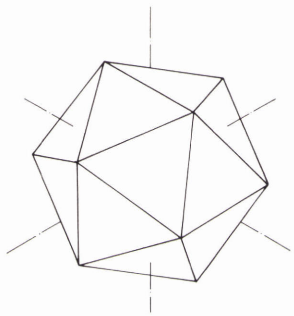

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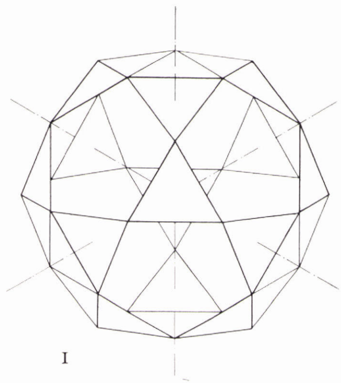

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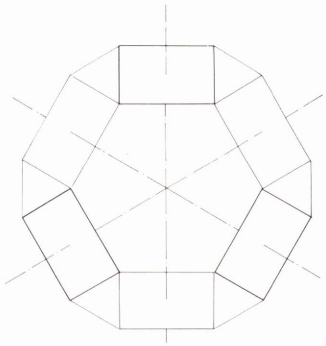

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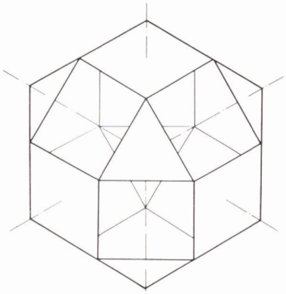

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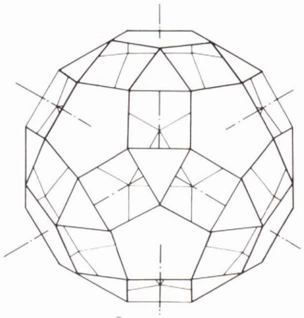

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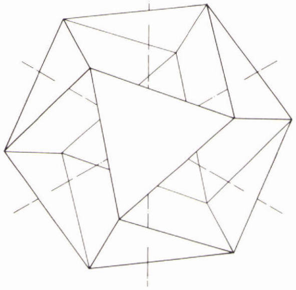

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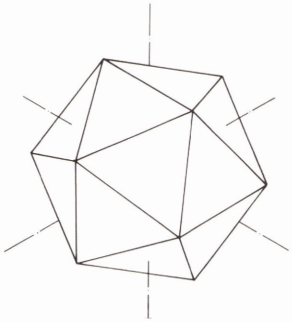

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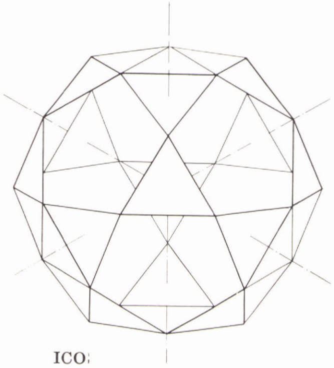

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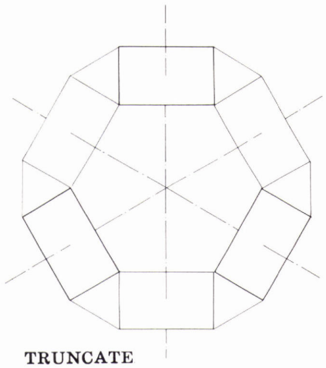

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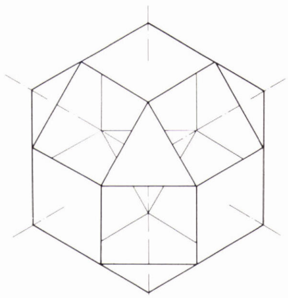

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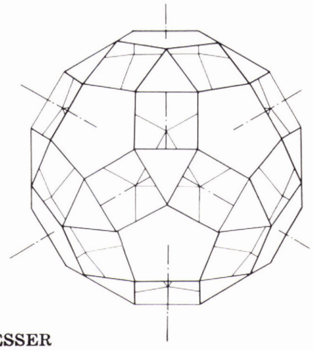

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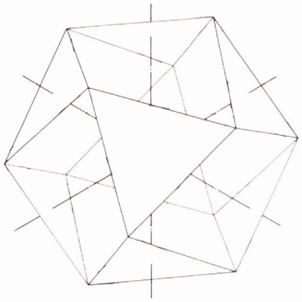

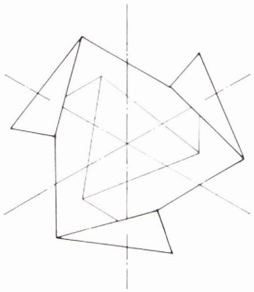

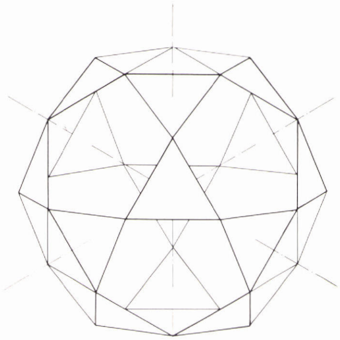

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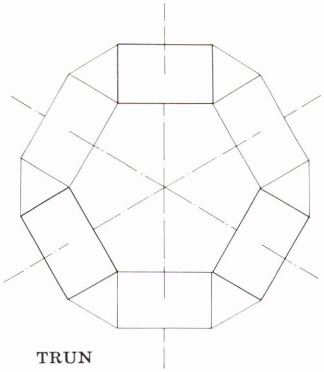

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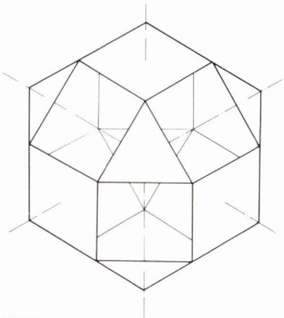

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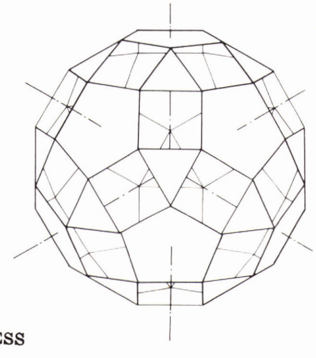

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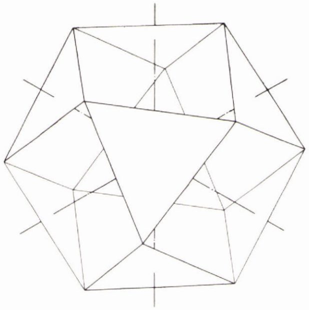

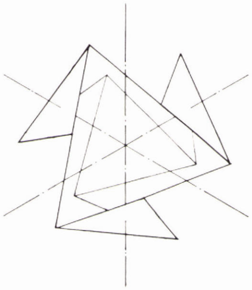

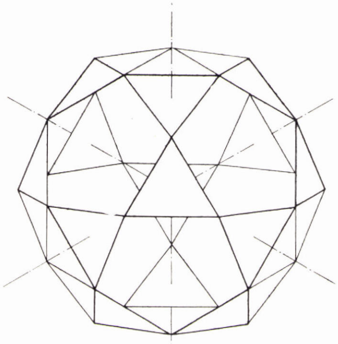

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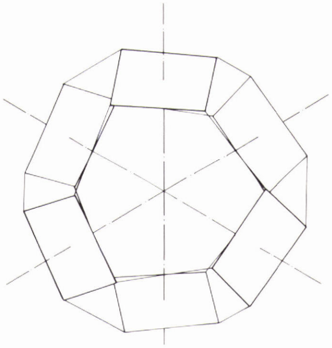

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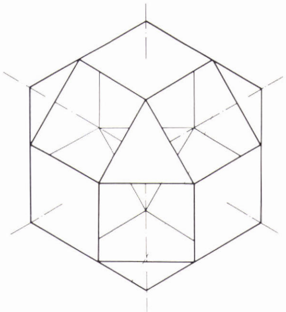

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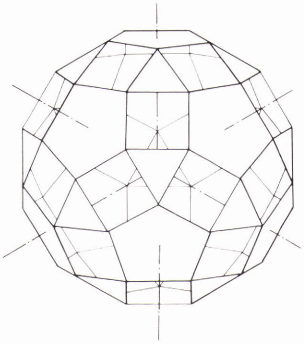

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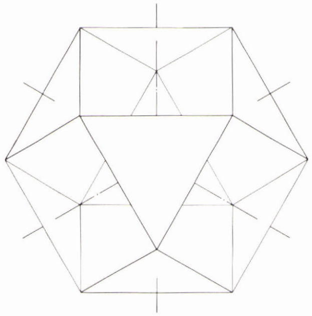

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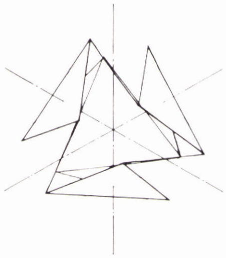

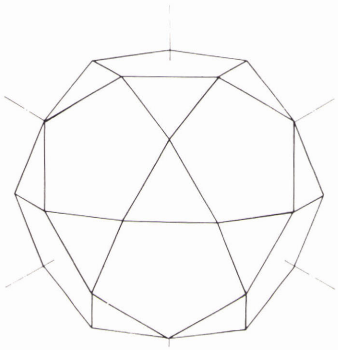

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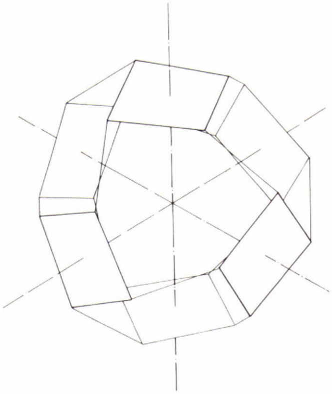

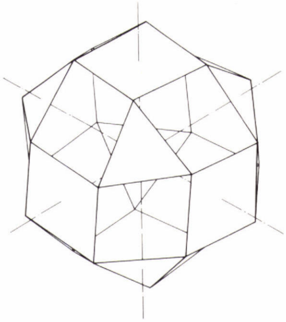

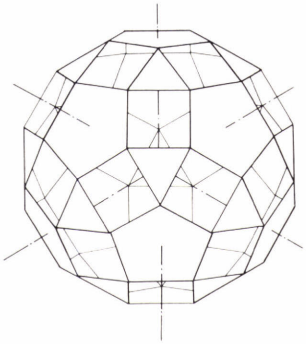

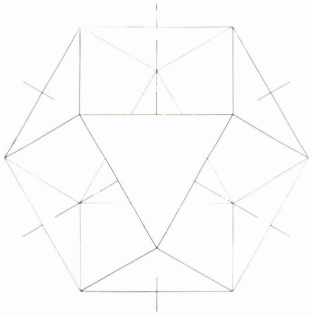

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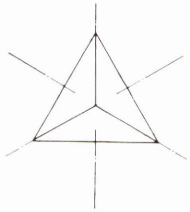

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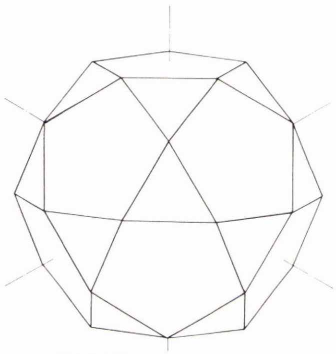

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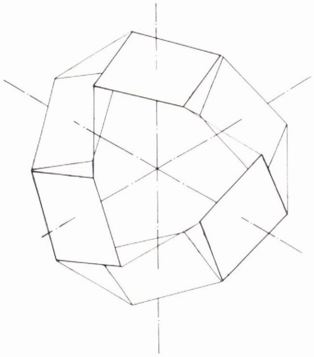

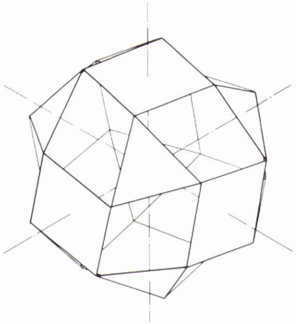

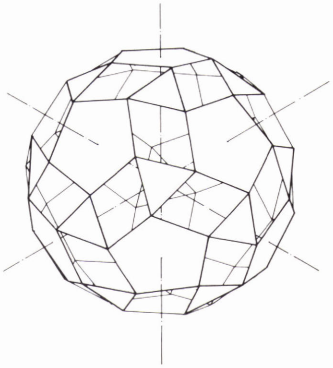

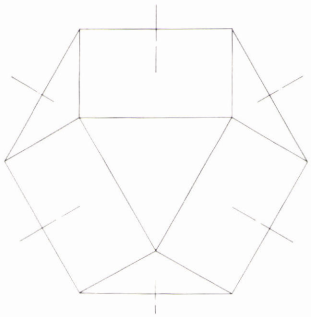

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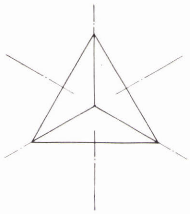

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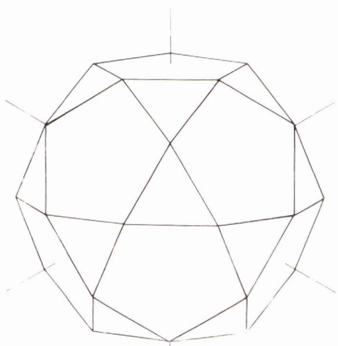

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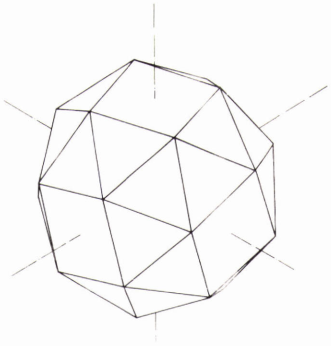

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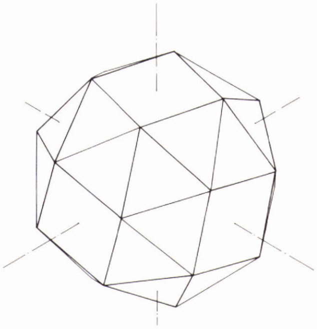

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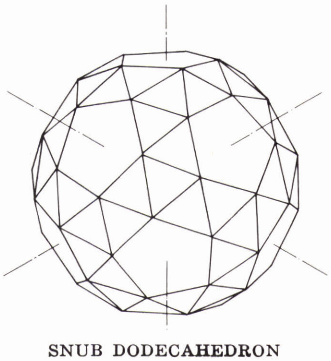

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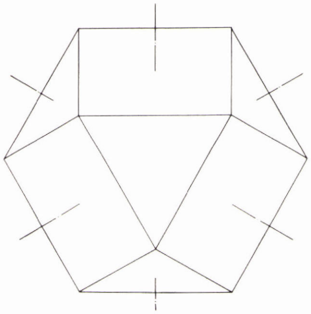

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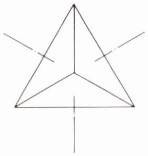

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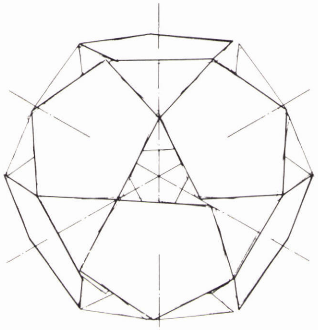

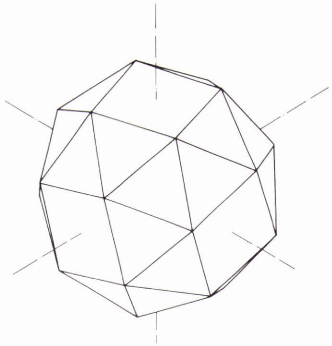

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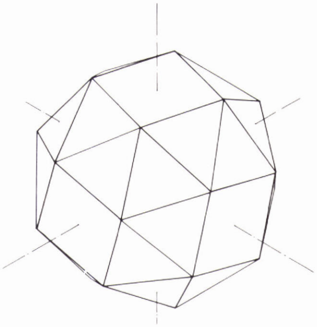

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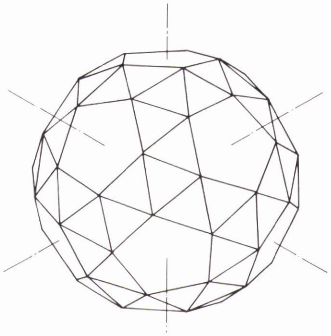

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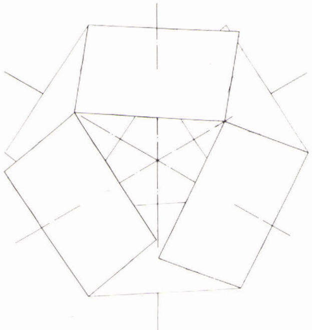

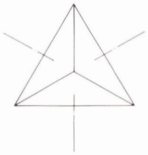

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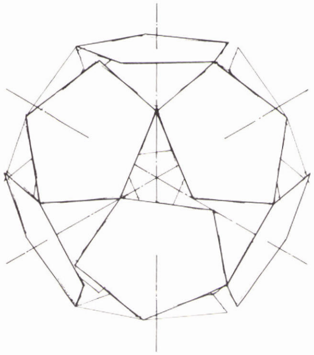

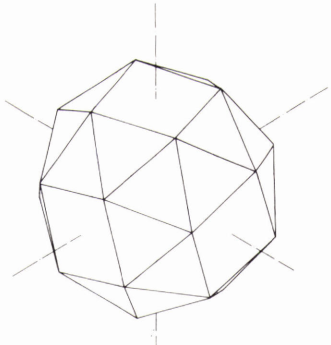

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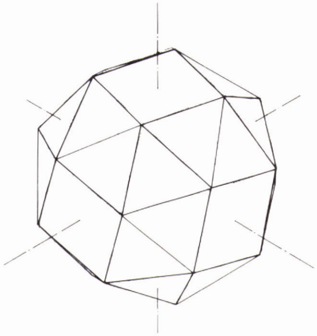

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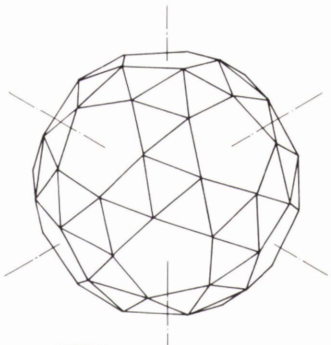

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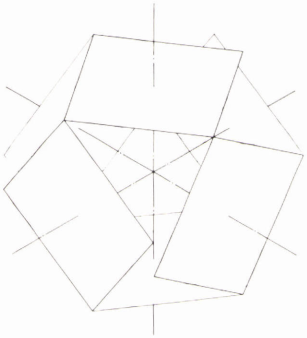

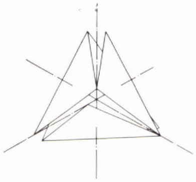

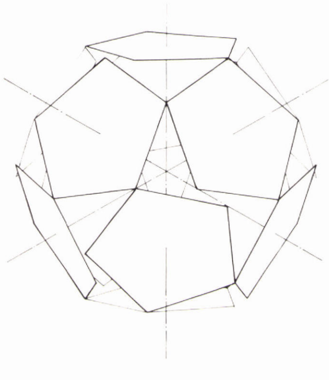

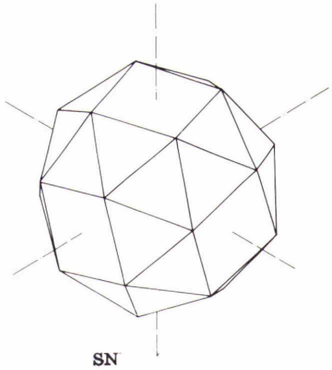

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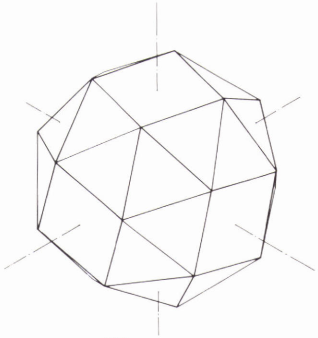

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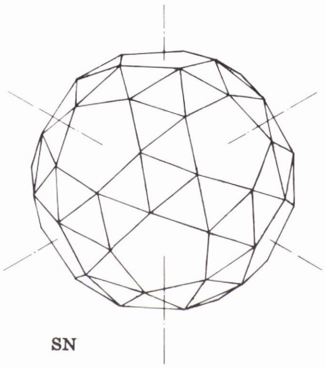

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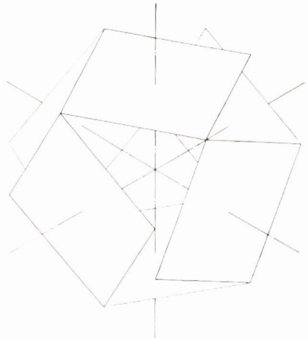

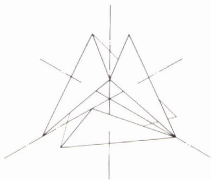

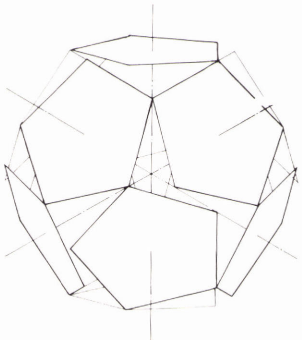

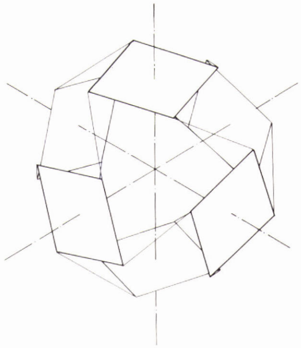

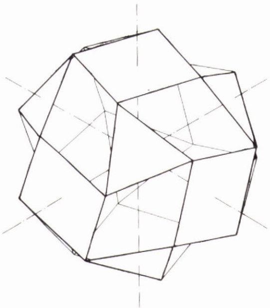

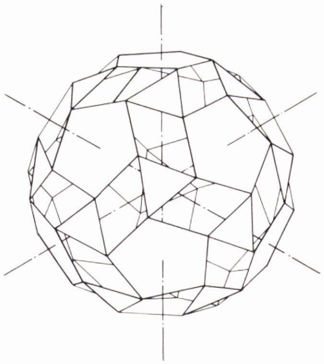

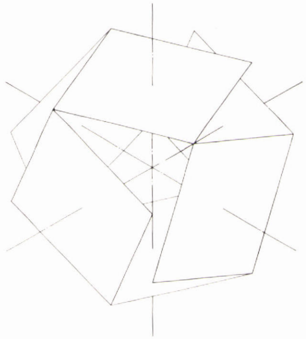

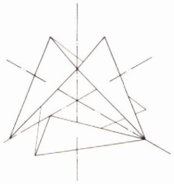

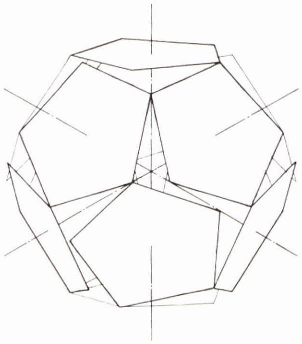

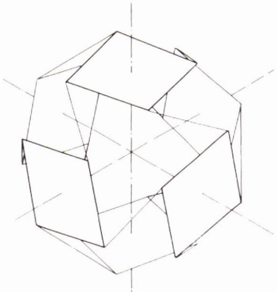

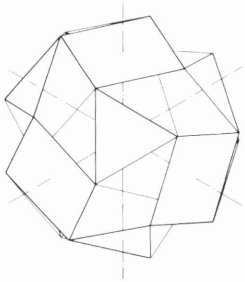

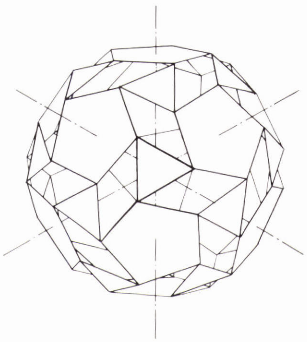

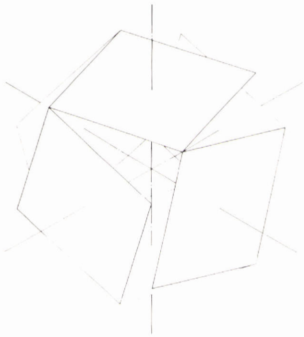

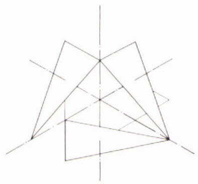

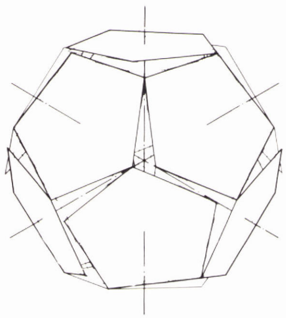

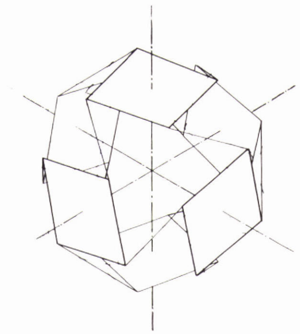

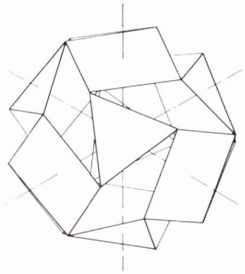

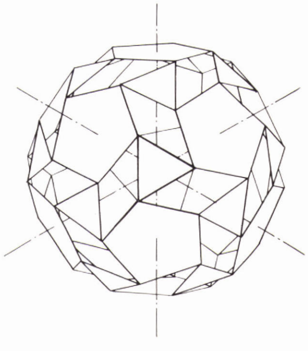

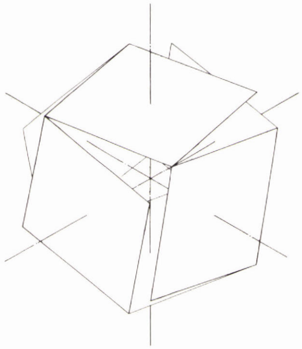

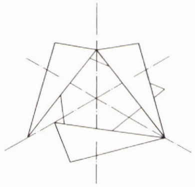

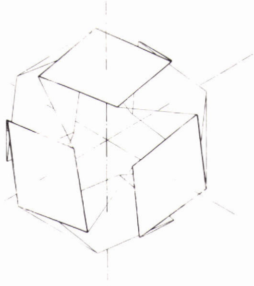

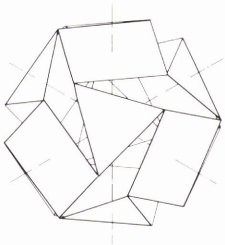

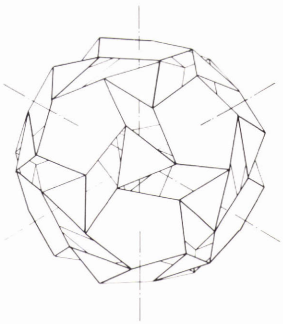

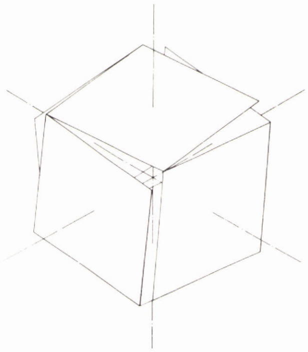

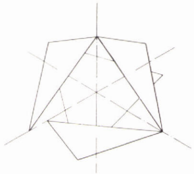

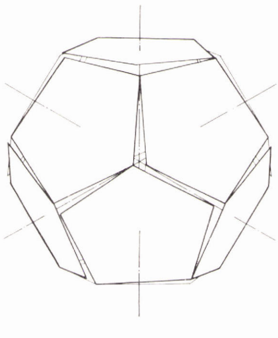

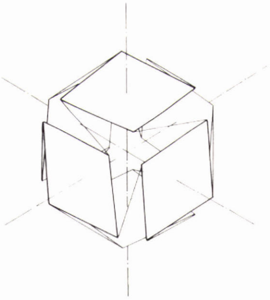

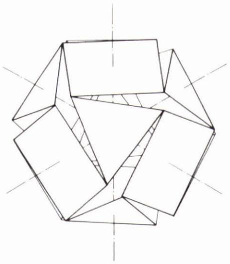

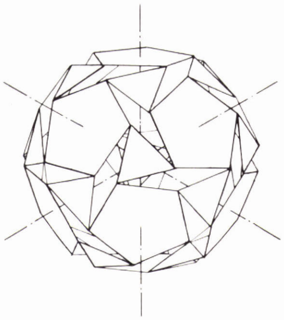

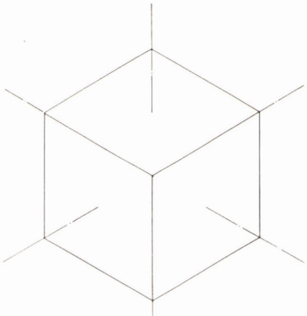

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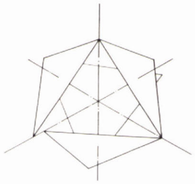

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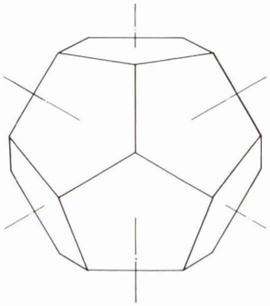

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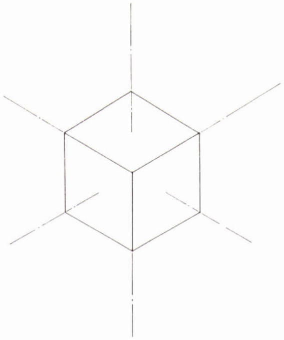

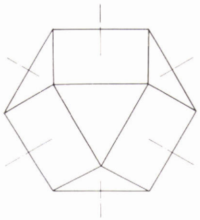

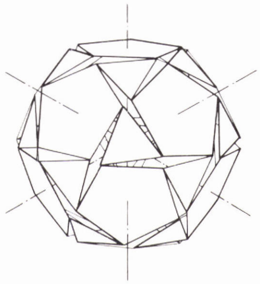

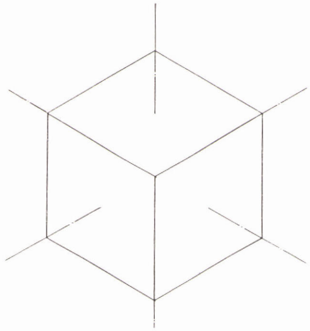

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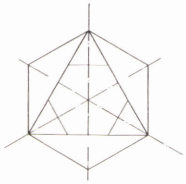

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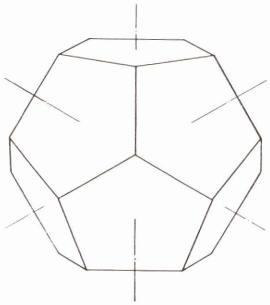

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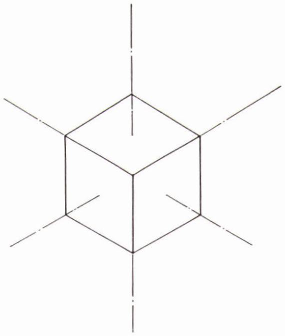

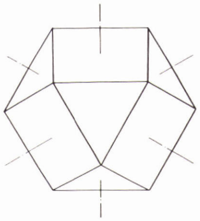

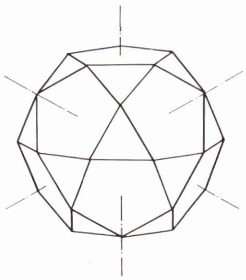

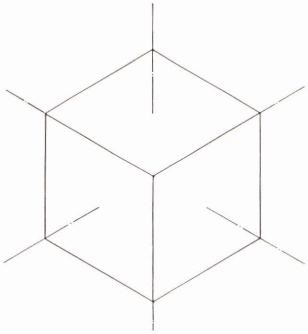

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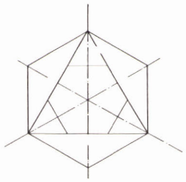

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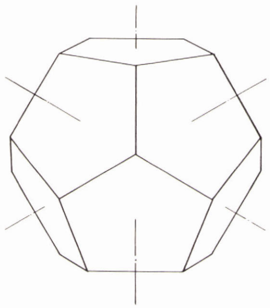

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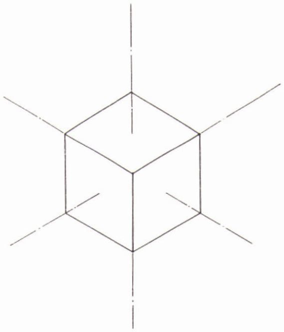

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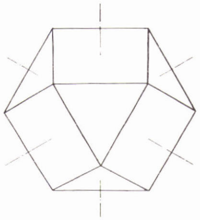

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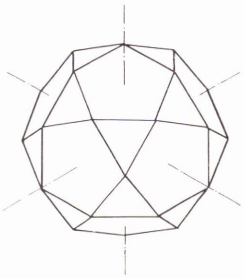

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