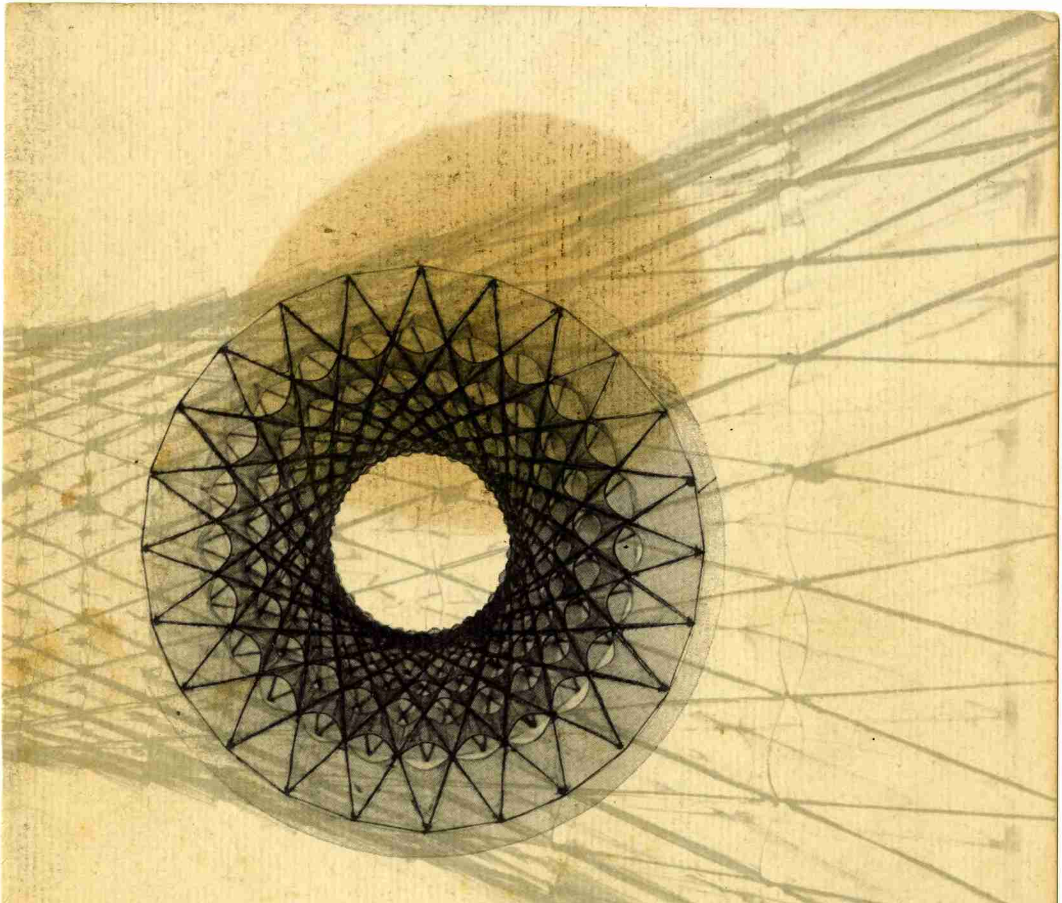

STUDENT PUBLICATIONS OF THE SCHOOL OF DESIGN
NORTH CAROLINA STATE COLLEGE
RALEIGH, NORTH CAROLINA

Benjamin B. Taylor

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THE COVER of this issue is a photograph of a faceted model of a hyperboloid of one sheet. This model was designed for aerodynamic wind tunnel test in conjunction with the investigation of double curved surfaces now being conducted by the fifth year class of architecture. (Photograph by Ralph Mills).

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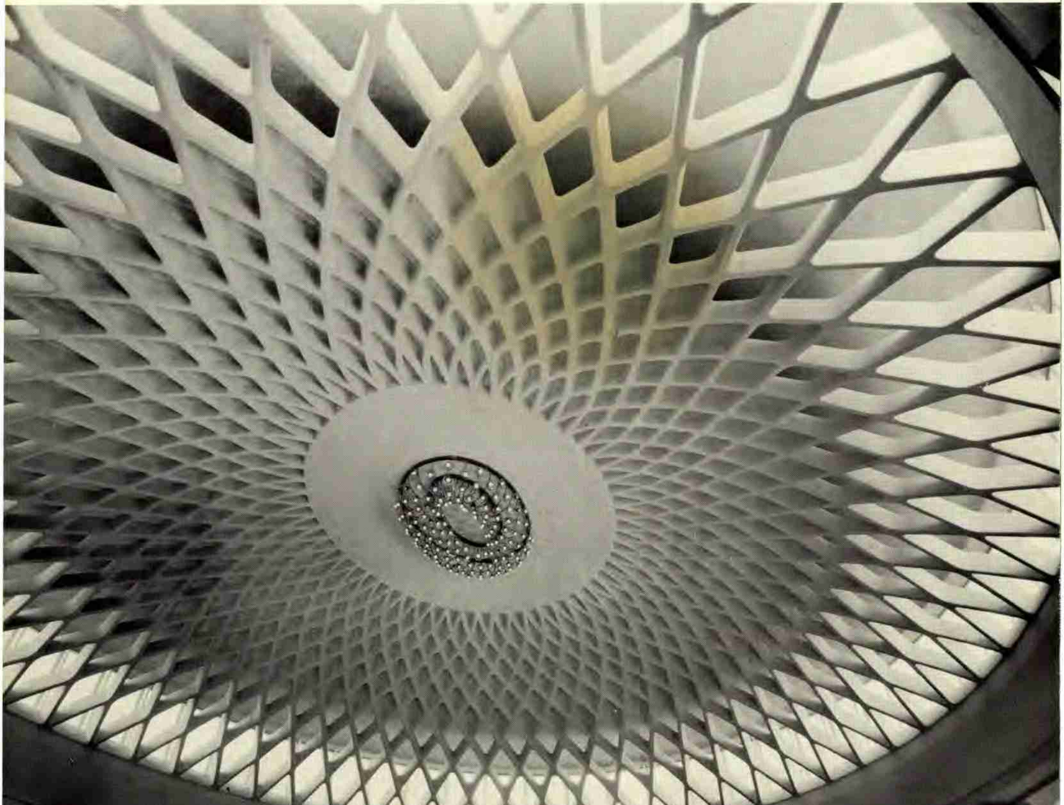
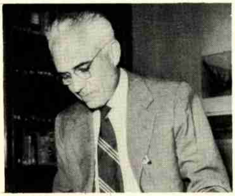


photographs courtesy of the *Architectural Forum*

Pier Luigi Nervi

CONSIDERATIONS FOR A CURRICULUM



Recently when the School of Design decided to make some curriculum changes they formed a committee to present various questions to selected educators, scientists, philosophers, engineers, etc. in an effort to obtain broad opinions as to what one should consider before establishing these changes. Of the answers received, we particularly felt that the following paper by Italian engineer Nervi was constructive as well as interesting.

A program for a graduate School of Architecture should depend upon the answers to the following three questions:

1. What ideas and ends will building construction be directed toward in the future?
2. What "*forma mentis*" (mental attitude) is necessary to understand such ideals and ends?
3. What is the best educational system to develop this "*forma mentis*"?

In order to understand the laws of the physical world, humanity is unquestionably being directed toward a scientific-technical attitude, both for the idealistic wish of knowledge and for the knowing use of energy, materials, and production. Each scientific development represents an *established* truth taken out of our hands.

Each technical improvement is a step forward toward the integration of the *type-solution* (prototype) with existing physical laws which are valid and constant in their time and place. Large bridges, airplanes, vehicles, fast boats, and mechanical solutions clearly show the type-solutions toward which they are definitely directed, or those they will reach after some period of time.

It is interesting to see that in the social fields we are also leaning toward a more truthful humanity that is based upon people with equal rights and equivalent standards of living. The false, unnatural caste systems and the hereditary supremacy of only a few families can now be considered as ended forever. With them also disappear the impressive estates and the great palaces that were typical expressions of the architecture of the past.

We also have to consider the *type-solutions,* as parts of an increasing number of formal bases into which the most free technical solutions are being assimilated. This is clearly shown if we observe the influence that the streamlined forms of airplanes and fast vehicles have had over slow vehicles and even objects for domestic and common use.

It is very difficult to explain why the most technically perfect forms, closely conforming to physical laws, are, with few exceptions, satisfactory to our aesthetic taste. It is undeniable that a well designed machine, a large bridge, a perfect static structure

Translated from the Italian

(all of them products of static and dynamic equilibrium) satisfy our aesthetic sensibility. This sense of beauty does not come from a rational, intellectual fact; it is evidently of an irrational nature similar to that produced by masterpieces which can also be appreciated by laymen. Similarly, a well planned layout, a well balanced building which expresses its function, etc., satisfies our aesthetic sense. Both socially and economically, building construction has taken stride—a stride which will be increased in the future.

These brief premises show that the architecture of tomorrow will be directed toward more *truthful solutions* through the progressive diffusion of the scientific-technical ability, the social, economic, and structural problems and their relationships to the character of *type-solutions.* With this spirit architecture will find its aesthetic ideal. But, to conceive and carry out works in accordance with such criteria it is necessary that a "*forma mentis*" be based on the following conditions:

1. A clear understanding of the pure harmony of the laws of the physical world, particularly those regulating the equilibrium of forces and the resistance of materials.
2. An intellectual sincerity in order to objectively clarify the essential factors of each problem and to solve according to static, economic, social, and constructional laws.
3. An abandonment of the imitations of the solutions of the past.
4. A vast knowledge of the social and economic planning problems.

It is fundamental to observe that the architect must possess the ability to spontaneously recognize the essential elements of each problem. Instead of being a specialist, the architect must be able to assign and coordinate the different works of the specialists with an exact perception of the limitations and possibilities of each individual technique. His activity is similar to that of an orchestra conductor who, without using the specific ability of each musician, must evaluate what he can receive from their combined abilities and instruments. This should illustrate how complex and difficult the task of a modern architect is and how vast his cultural background must be. This indicates that the character of the architect must essentially be conceptual and generalized rather than detailed and particularized, since the latter belongs more to the specialized professions.

As for the architect's cultural background, the advanced studies should be directed toward clarifying general concepts while minimizing the formalsistic developments of exact quantitative evaluations. This factor in the architect's professional education would be clearer if we would consider how he should use structural statics for some of the most natural, modern architectural expressions such as stadiums, exhibition halls, railway stations, hangars, harbors, factories, etc.

To design a resistant structure, to define its scheme and its proper dimensions, one uses only *intuitive statics* and approximate formulas that are easier to use than the very complex ones. Most often developments if used in the period of conception, contradict themselves, and also at that time their use requires such a considerable amount of time that it prevents the designer from producing comparative solutions. Besides, each statically complex structure has to be solved through calculation for verification.

The heart of the matter is developing an educational system which will give the student an intuitive knowledge of statics and the mastery of an approximate method of calculation. The problem is very difficult and depends upon the answer to this question: Is it possible to acquire intuition of statics and the control of an approximate method of calculation without going through the complex study of the construction sciences with mathematical sciences as is now being done in the graduation engineering schools? In other words, is it possible to acquire the proper understanding of the functioning of a hyperstatic system, its different elementary systems, etc. and to make possible its quantitative evaluation, without completely developing the entire theory of elastic systems and its relation to higher mathematics?

It is clear that if we accept this as a fact, it will be necessary to introduce into the architectural school such subjects as higher mathematics, physics, rational mechanics, and construction sciences as a level at least equal to the ones existing in the very best engineering schools. If this happened, the amplitude and difficulties of the study of architecture would be practically insuperable, added to the impossibility of relating mental approaches so different as the analytic-mathematical of the deeply theoretical research and the synthetic-intuitive one characteristic of architectural creations.

I believe that an effort should be made to organize a program where the structural field is directed toward the conceptual understanding of the phenomena of statics and the use of quickly and simply approximated formulas sufficient to give the first measurement of the resistant elements of a structure. I think that if starting from a solid base of elementary statics (composition and decomposition of forces, general equilibrium of a system, behavior of materials affected by loads, indeterminate static system) it would be possible, through the use of models, analysis and critical interpretations of complex structures and examples of practical exercises, to arrive at an intimate understanding of a complex hyperstatic structure, and to ultimately be able to determine in advance the hyperstatic unknown of its division determined static systems.

The final step in calculating a fixed-end arch can be reduced to the elementary principle of a three hinged arch if based upon intuitive considerations, and one can approximately determine the points of the curve of pressure in the key and bases. Every hyperstatic system, when understood and interpreted in its fundamental way of resistance, allows a preliminary evaluation of all the data of the unknowns that can later be solved by a system of known equations. In more complex cases it is also possible to decompose a hyperstatic system into a determined static system with the intuitive evaluation of the reciprocal influence of importance.

I particularly consider the use and study of graphic statics as being important in the understanding and analysis of resistant systems. Graphic statics shows the play of forces and their composition and decomposition much better than the analytical method. I am glad to have been able to check the practicability of this approach for structural problems through several decades of constant work, and the extensive exact calculations carried out by me and my collaborators have never fundamentally changed from the initial hypotheses.

We can have the same approach for the other related fields of architecture, such as heating and ventilation, air conditioning, hydraulic engineering, mechanics, lighting, etc. Subjects of primary importance are those related to the profession such as the History of Architecture, Freehand Drawing, and Architectual Composition which are, more or less, considered from an aesthetic point of view.

What aspects of the architecture of tomorrow (without formal ties with that of the past) will have to be studied? The past has also had very pure, *truthful* solutions related to subjects and materials of their times such as the Greek Temples or the Gothic Cathedrals. Truth is lost when the architectural substance is lost in pursuit of formal aspects; it reduces the style of a period to a few decorative elements applied to completely different organisms.

I believe that the study of the History of Architecture should be directed so as to emphasize only the art of building construction which although common in essence, it is sometimes different in form, as is found in the stone structure of a Gothic Cathedral or in a well balanced reinforced concrete structure. The beauty of a work is obtained by the harmonic composition of the equilibrium of action and reaction, the relationship of columns, of surfaces, and of colors that can come from an unlimited number of schemes —all determined by the distributive and static characteristics of the individual architectural problems and not related to predetermined methods or forms.

It is possible to see that the expressiveness of an artistic manifestation is directly influenced by the unconscious mood of the author through whom it reflects the atmosphere in which he lives.

In summarizing, I believe that a good solution to the difficult problem of teaching in schools of architecture is to make evident a creativity which is based on the limitations and potentials of the various disciplines, I would say that it is worthwhile, after developing the various disciplines, to devote a year to a comprehensive design, assisted by the Professors of the coalescent fields such as Architectural Composition, Techniques of Construction, Technical Installations, etc., in a way that will allow the student to acquire the ability of extemporaneous coordination, and the reciprocal subordination of the essential elements of an architectural work.

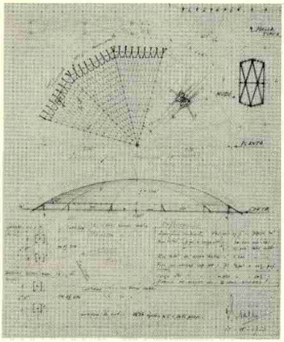
I consider it also very important to limit the study of drawing to its truthful function as the indispensable representative medium of a reality which is completely independent of the qualities of the drawings themselves.

The main mistake of the architecture of the first decades of the twentieth century was that of confusing drawings with architecture. It was thought that an architectural event (reality of form, volume, equilibrium of forces, composition and distribution of spaces, accomplishment of economic and social laws, etc.) was only the happy and harmonious play of lines on a sheet of paper.

Atilio Gallo, from Buenos Aires, is a structural engineer who has calculated and built many long span thin shell structures in Argentina.

Atilio Gallo

INTRODUCTION TO THIN SHELLS



In the structural field which deals with long span bridges we have found that reinforced concrete structures, because of their excessive weight, cannot efficiently compete with the relatively light, economical metallic structures. Some prestressed concrete bridges have reached a high degree of development; but still they are unable to rival the ones constructed of metal.

In the structural field which deals with light shelters composed of long spans, the highly specialized field of reinforced concrete reached an unprecedented level when, in 1925, Dr. Ing. Dischinger introduced us to the thin shell concept and illustrated its maximum expression in the Leipzig Market. The great spans and the economy of material that was obtained with the Zeiss-Dywidag system allowed thin shell concrete structures to advantageously compete with metallic structure; for certainly, some of these projects, such as Dischinger's span of 800 feet, tend to make this system one of the wonders of our time.

In order to appreciate the success of reinforced concrete in the field of light shelters, despite its inherent excessive weight, we must mention two things that Dischinger introduced into the science of construction: the *membrane,* and the new form we call the *thin shell,* whose properties have yet to be analyzed.

A new path has been open to architects and engineers with the application of membranes to such materials as

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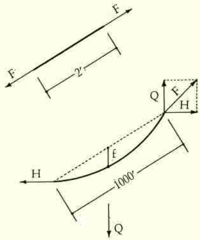

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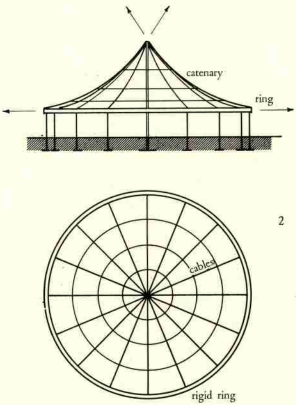

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light metals, fabrics, and plastics; for the conditions of our time require us to cover maximum areas with a minimum of supports. Although we now have a great deal of experience in the application of prestressed concrete to large span shelters, I see no theoretical barriers to prevent the application of the continuous membrane or lattice-skin concepts to other materials that are better suited toward solving the problem than reinforced concrete.

THE NETWORK

Let us consider a string which is two feet long. Can we stretch it so that it takes a perfectly straight line? Yes; there is not any difficulty (figure 1). Now can we repeat this same test if the string is 1000 feet long? Certainly not; for the string's own weight, when stretched, introduces a transversal stress which leads to a known curve: the catenary.

If we increased the tension *F*, the deflection *f* decreases until the string reaches its maximum resistance. It fails before reaching a deflection of zero. If we want to maintain our string in equilibrium it will be necessary to join it to two fixed points and to keep our stress constant.

Application:

a. Now let us rotate a flexible cable around a central column and fixing it in sixteen different positions as in figure 2. The column will take all of the load and the ring will maintain all the horizontal stresses in equilibrium. The cables will take a catenary curve which will be connected by concentric rings composed of cables of a smaller resistance. We now have a surface as a reticular structure which can be covered with a very light skin. It can only absorb tensile stresses. Its equilibrium is obtained by securing its reinforced edge to certain very well defined points. Study will show that there are an infinite number of shapes that this type of structure can adapt itself to.

THE MEMBRANE

If we take a network and successively increase the number of meshes per unit of surface area while simultaneously decreasing the weight of each string, we will have a web

Drawings prepared for publication by Raymond F. Stainback and Thomas Harrison.

with the same structural features of a net work; and, if the meshes of the web are infinitely small, we will have a structure which is called a membrane, a skin, or a film.

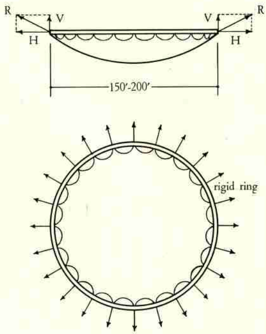
Membranes are structures with a very small thickness relative to their surface areas. They are extremely flexible and can only resist tensile stresses. In nature we find an infinite number of membranes such as a drop of water or the skin of an apple. Examples of artificial ones can be found in a sheet of paper, the silk of a parachute, the envelope of a dirigible, a plastic tablecloth, or a nylon stocking.

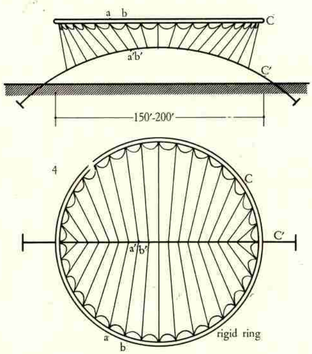
Application:

a. If we cover a ring with a membrane and hold it tight against the rigid edge we will obtain a flat suface of limited dimensions. Suppose that a sailcloth covers a ring which measures 150 feet in diameter as in figure 3. If a simultaneous tensile stress is applied at the ring to every point of the membrane, we will be able to reduce the sailcloth's deflection to a minimum, which is compatible with its resistance. At its central part the surface will be a catenoid of revolution, while at the edge the surface will be undulated because of the pertubations that appear as a result of the concentrated stresses from the reactions of the ties. The rigid ring will be submitted to a series of radial stresses ***H*** translated into annular compression. The vertical components *V* will be balanced by the cloth's own weight and by possible live loads. Disproportioned live loads, however, will produce tensile failures in the membrane.

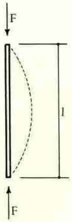
This structure is highly economical (its cost reduces as the deflection *f* increases); but, having its concavity upwards, it presents the unavoidable problem of drainage. It is possible, however, to devise several solutions to overcome this problem by employing the appropriate surfaces.

In figure 4 a very simple idea is represented, that of keeping the circular plan and the rigid ring on a horizontal plane. The surface is originated by joining a corresponding point with straight lines from the horizontal ring *ab* and from a convenient curve *C' a'b'*. The structure is thus formed by a cable *C'* whose stress can be regulated, and a membrane, as in the previous example. The rigid ring is now under different stresses than those indicated in figure 3; but we will not discuss the problem here. We will





leave to the reader the task of applying the same system to rectangular plans, 150 feet by 200 feet, with diagonal cables.



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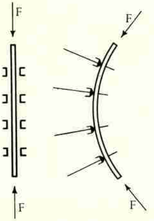
THE LATTICE WORK

Let us now compress a steel rod (figure 5) with a stress F proportional to its section. If the rod is short, its axis will remain a straight line. If the rod is greater than a certain length, we will see the rod curving and producing the known buckling ratio of l/r. How is it possible to avoid such deformation while keeping the same compression F and at the same time increasing its length l. Obviously, it can be done by employing lateral supports at convenient intervals. The axis will then keep its original features whether it is straight or curved (figure 6).



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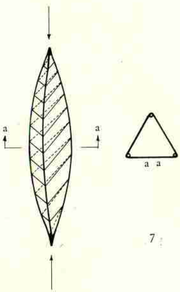
Application:

a. **It is possible to build a column with three longitudinal rods (figure 7) with a helicoidal wire welded to them at established distances. Despite the small section of the rods, the equilibrium is secured by the rational location of these elements. By analogy we can build a lattice with longitudinal rods under compression with transversal rods to overcome the buckling. The equilibrium will be secured if the lattice is developed on a cylindrical surface which follows the directrices and generatrices (figure 8) when the section of the rods is proportional to the exterior stresses. The fact that the lattice is developed as a cylindrical surface gives stiffness to the element which is a quality that is not present in flat lattices or isolated rods.**

If we compress the generatrices of the cylindrical surface (figure 9) we again obtain a state of instability; thus a double curved surface is required to stand compressive stresses from both directions.

b. **In figure 10 we have a structure with a circular plan developed on a spherical cap and subject to symmetrical stresses at the joints. If the lattice is spherical and the angle is less than 51° 50', all the lattice bars will be compressed[1]. In this structure we are able to absorb all the**



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1. The number of bars will be large enough to allow the use of straight bars between the joints; although, for clarity, we have shown only a few bars in figure 10.

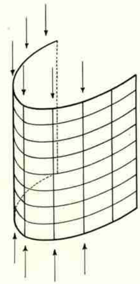
horizontal components from the support reactions by the use of a tension ring. At each support we will have vertical reactions. The section and the moment of inertia of each bar will have to be calculated proportional to the loads and diameter of the cap at its base; for too great an l/r ratio will be present if we go beyond certain limits. If we consider a non-symmetrical load, such as wind pressure, the lattice is subject to internal stresses which will tend to deform the lattice (figure 11) and thus the entire structure. By correcting this with diagonal tension bars we will have the structure which is known as the "Schwedler Dome."

c. For practical reasons it is often necessary to cover spaces with rectangular plans. By applying the same principles that we have already discussed we obtain the structures shown in figures 12 and 13. The surface of figure 13 is generated by a curved line *a* that moves parallel to itself on the curved line *b*. In both cases the structures have to be reinforced at their edges by other elements known as diaphrams or edge beams so as to transmit the loads to the supports. Despite their apparent simplicity these structures are very complicated, however, they do allow us to obtain large spans with great economy of material for each bar is working at the maximum efficiency that the section and material employed allow without danger of buckling effects. The internal stresses are either all tension or compression, but never flexure, provided the loads are always applied at the joints.

d. The structure of a rigid dirgible is a lattice work of double curvature[2]. The builders of the *Zeppelin* approached it as a surface to be developed by transversal rigid rings to which longitudinal beams could be connected. The rigidity of each joint was acquired by using many diagonal tie wires. If we regard that form as a space structure, we can build its surface as a triangulated lattice with its double curvature providing the required rigidity (figure14).

A greater resistance to dynamic loads is given by using the longitudinal axis as a position from which radial wires evolve on planes acting as the diaphrams of the cylindrical surfaces (figure 15), which we have already discussed.

2. Their construction will be resumed as soon as the structural concept is simplified.



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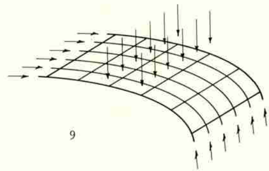

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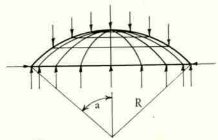

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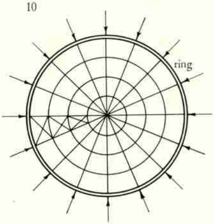
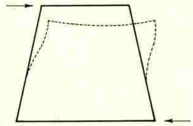


This is very clear if we see how a ring is deformable by two opposed radial forces (figure 16) but becomes more rigid by introducing radial tension wires.

THE THIN SHELL

If we take a curved lattice surface and increase the number of nets per unit of surface and simultaneously reduce the section of the bars, we will obtain a continuous structure with the same static properties of the so-called "thin shells." This name is derived from the small thickness of the shell relative to its other dimensions, however, thin shells are never as thin as pure membranes. The difference between thin shells and membranes is that thin shells are able to resist tension and compression while the latter are only able to resist tension. Despite their small thickness, thin shells are often able to stand some concentrated loads on reduced surfaces that would otherwise cause failures in membrane structures.



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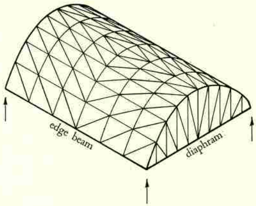
Similar to lattice works, there is no rule of thumb to the design of thin shells. As an orientation we can say that a thin shell has a thickness t in an almost constant ratio with its radius of curvature R as the resistance increases with the increase of its curvature. Thus the ratio of t/R will be within these limits:

$$\frac{1}{100} > \frac{t}{R} > \frac{1}{1000}.$$

Greater thicknesses do not belong to this type of structure, and smaller thicknesses belong to membranes[3].

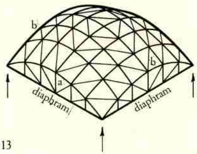


The materials that are available for thin shell construction lead us to select certain proportions as being the most convenient for the fulfillment of practical aims. Thus we can say for a thin shell of double curvature that its t/R is:

for *reinforced concrete* ---- $\frac{1}{100} < \frac{t}{R} < \frac{1}{250}$

for *duraluminum* ---- $\frac{1}{300} < \frac{t}{R} < \frac{1}{800}$

for *steel* ---- $\frac{1}{500} < \frac{t}{R} < \frac{1}{1000}$



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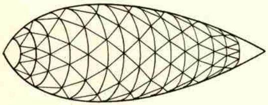
3. Lord Raleigh has obtained membranes of a thickness of one micron whose t/R could reach 1/100,000,000.



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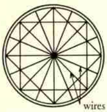

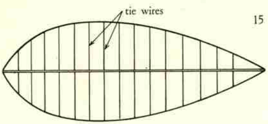

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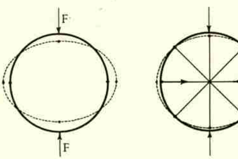

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The determination of thickness based upon the radius of curvature, dimensions, position of supports, and exterior stresses is a problem that can be solved only by a specialist applying the proper mathematical theories for the interpretation of such phenomena as statics, elasticity, and strength of materials.. In many cases the mathematical solution of the problem is impossible; therefore, the designer often has to be guided solely by empirical data. As an example of the influence of the form on the type of resistance developed by thin shells, we have compared a cylinder and a sphere of equal radius of curvature and thickness (figures 17 and 18) on the assumption that both are built with reinforced concrete and using a safety factor of three. In this example we see that the diaphram allows the cylinder to stand a load five times greater than the cylinder without the diaphram while the sphere is able to stand a load 200 times greater than the cylinder with the diaphram. We can also see the enormous resistance of the cylinder as a column:

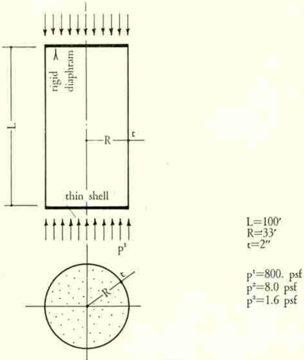
$$\frac{\text{800psf x pi x } 33^2}{\text{2 x pi x 33}} = \text{13,200 pounds per foot!}$$

Without its curvature, as a flat surface two inches thick and 100 feet high, the surface could stand only 500 pounds per foot which is only about one-fourth of its own weight.

These examples are very simple ones; in practice we frequently use sectors of cylinders or spheres which present edges, that when reinforced, often make the mathematical problem quite complex; however, this does not alter the major concept. Thin shells composed of a sector of a cylinder are well known in the field of long span structures (figure 19).

Frequently the question arises as to what is the largest span that a thin shell can reach with a given thickness. In a cylindrical structure similar to figure 19 there are other factors in addition to the span L and the thickness t that are pertinent to the design, such as the width B and the radius of curvature R and H; and, if we do not consider all of these, it is impossible to answer the question.

It is good to remember that when the desired span is so long that when applying ordinary rules the thickness t becomes too great (the appreciation of "great" is based upon weight related to economy) it is possible to adopt methods



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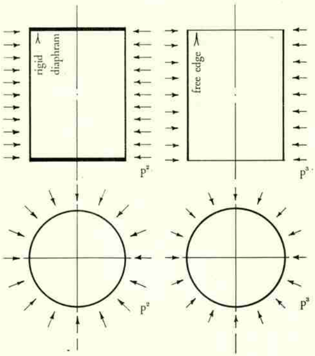


that are able to accomodate a higher moment of inertia, such as those shown in figure 20.

DOUBLE CURVATURE

Alexis Carrel said that "if Prometheus or Archimedes were to be resurrected at this moment, they undoubtedly would guess for what end such an unknown organism as an airplane had been created . . . as in the human organism it is necessary to find its aim in the structure."[4] We can say the same about all organisms; whether they are a product of nature or of man, their structure is exactly related to their aims. In a few words, "structure" means the organization of matter in view of a predetermined purpose. All structures posses a form as its external quality. Its image, we could say, has no relation with any aim beyond an abstract geometrical idea. Forms are products of the imagination, while structures are products of the study of the behavior of matter under impinging forces.

In this field the shells of double curvature are especially appropriate; for, if the resistance of very thin sheets depends upon its curvature, the double curvature becomes its maximum expression. We see in nature that shells are always of double curvature as a manifestation of nature's aim to always obtain the maximum effiiciency with the minimum amount of material.

There are an infinite number of surfaces of double curvature, and we have to apply several rules and a little imagination to create them; however, four procedures are known:

1. *Rotation* of a plane curve (generatrix) around a straight line (axis) on the same plane. They are known as *surfaces of revolution,* and they include the sphere; the circular, elliptical, or parabolic torus (figure 21); the paraboloid (figure 22); etc.
2. *Translation* of a plane curve (generatrix) parallel to itself resting on a curve (directrix) in another plane. They are known as surfaces of translation (figure 13), and their numbers are vast and not yet named.
3. *Transformation* of a plane curve (generatrix) similar to itself when rotating or translating. They are

4. *Reflections on Life*

known as *surfaces of similar sections*, and their numbers are even greater than those above, e. g., a cow's horn; a leaf of grass; or a groin vault without edge (figure 23) which is generated by a circumference of a variable radius resting on another of fixed radius while taking advantage of double symmetry; or the cloister vault without edge on a square plan (figure 24) where the directrix is a straight line, and the generatrix is a variable circumference.

4. *Projective transformation* of a surface onto another surface by using the methods of projective geometry. They are known as *projected surfaces*, e. g., the elipsoid of three different axis as a projected surface from the elipsoid of revolution. With this method it is possible to easily adopt a solution that has been studied under certain dimensions to others with differing dimensions while still maintaining the same criteria.[5]

Note: We will refer to surfaces of double curvature which are generated by straight lines in our discussion of *The Ruled Surface.*

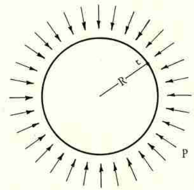
Application:

a. Figure 25 shows a continuous surface obtained by a diagonal eliptical directrix *A* and a variable eliptical generatrix *B* which is parallel to the other diagonal. The longitudinal and transversal sections are not actually eliptical; thus the surface can be referred to as an *informal elipsoid.*

b. A circular arch of variable radius moving on a fixed parabola gives us a surface which we can rotate twelve times to obtain the structure shown in figure 26. If this were to be built in reinforced concrete with a uniform thickness of three inches, we could obtain a structure of 120 feet in diameter.

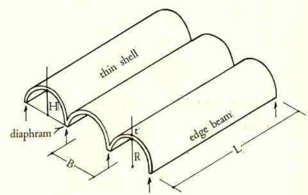
c. A double curved surface composed of a spherical cap and a waved surface whose sections with co-axial cylinders are analogous. By developing the cylindrical surfaces we obtain sinusoids of equal wave length but varying amplitude. These

5. Mathematically speaking, *projective transformation* includes the transformation discussed in the third procedure, but it is better to keep this classification for practical reasons.



18

R=33′
t=2″
p=1600 psf



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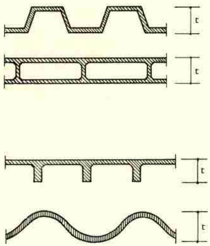
sinusoid lines (generatrices) move as a circular directrix as can be seen in figure 27.

One of the objections to the design of these structures is the apparent complicated calculations that are necessary to derive these relatively simple forms. It is convenient to remember that very few surfaces of double curvature can be mathematically analyzed and that approximate methods are generally used for most practical applications. We should not forget that the structural theory of the mushroom column and slab was non-existent at the time when its construction was very common. It usually happens that man's imagination poses problems that are only later analyzed by mathematicians. Their analysis, on the other hand, then allow new imaginative developments.



20

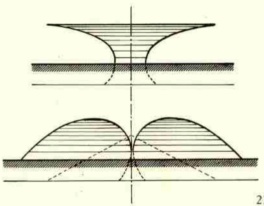
THE RULED SURFACE

All second degree surfaces have already been mathematically analyzed, while the analysis of surfaces of a higher degree, which we have designated as surfaces of double curvature, are almost unknown.

Among the second degree surfaces there are only two that can be generated by straight lines, and they are thus called *ruled surfaces*. They are the hyperboloid of one sheet and the hyperbolic paraboloid. Their geometrical properties are well known but their application as thin shells is extremely scarce. Special cases, such as the cone and cylinder, are often used because of their developable surfaces; but they are of simple curvature.

Below we are able to see four different ways of generating surfaces of double curvature by using straight line generatrices:

1. The straight line generatrix moves parallel to a plane and rests on any two curves or straight lines (directrices). If the directrices are two non-coplanar straight lines, a *hyperbolic paraboloid* is obtained; if the directrices are non-coplanar lines, one straight and the other curved, or if both directrices are different curves, *conoids* are generated. (A special case would be the helicoid that is generated when the generatrix is perpendicular to an axis and simultaneously rests on a twisted co-axial curve).



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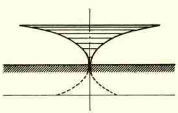

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2. The straight line generatrix moves touching three dual non-coplanar curves or straight lines. If the three directrices are straight lines, we will have the *hyperboloid of one sheet*. Surfaces arising from other cases have yet to be named. (A special case would be when the straight line generatrix rotates around a non-coplanar axis, thus obtaining a hyperboloid of a sheet of revolution).
3. The straight line maintained perpendicular to a curve which moves while resting on another curve or straight line.
4. A projected transformation of a ruled surface always gives another ruled surface.

No ruled surface can be developed as a plane without some deformation, and, because of this, they fall into the class of *anti-clastic surfaces.*

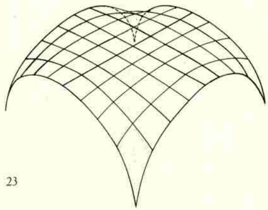
Application:

a. In figure 28 we have a structure which is formed by conoids, cones, and cylinders arranged so as to form a solid of equal resistance. Here the edges are subject to tensile stresses while the shell is almost completely under compression. A similar thing happens in barrel vault structures (figure 19) where all the conoids are different but can be derived by a projection from the central one. The fact that it is a ruled surface makes its construction relatively simple.
b. We have not considered the cases of the hyperbolic paraboloid and hyperboloid of one sheet as being known structures.

CONCLUSION

Networks, membranes, and thin shells are three cases from the same family of three dimensional structures. The common feature between them is their curvature or, to be more precise, the relationship between their thickness and radius of curvature t/r. For a constant thickness, the ratio $t/r = 0.005$ would designate a shell; a $t/r = .0001$ would designate a membrane; a $t/r = 0$ a plane; and a $t/r = 1$ a solid sphere with a radius t.

We have established the relationship $0.01 > t/r > 0.001$ as being the practical limits for the structural application to thin shells. If the shell is of variable curvature, this condi-



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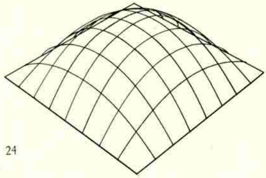

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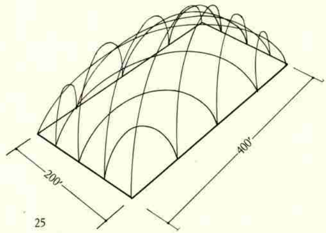

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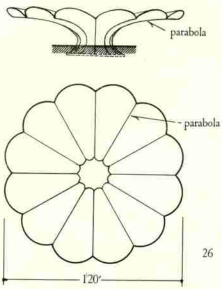

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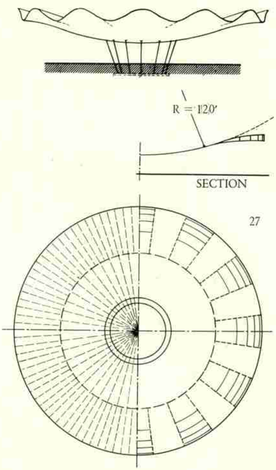


27

tion must be verified at every point. By acquiring the proper thickness, any curved surface can become a shell; for this is the way that a geometric form becomes a structure. The surface may be of uniform continuity as in the egg shell, or corrugated as in the scallop shell (*pecten maximus*), or latticed as some radiolarians (*aulonia*); but, in every case, the continuous internal stresses will exist.

The thin shell as used in construction was first introduced by specialized reinforced concrete engineers, however, the inherent properties of the thin shell do not necessarily confine its use exclusively to reinforced concrete. Shells can be built using almost any material, but one must remember that its thickness will be smaller the greater the resistance to tensile and compressive stresses. The particular advantage of reinforced concrete is its ability to be molded to take any form, while steel and aluminum are especially appropriate for curved lattices which use like bars and joints throughout. Timber allows us to build lattice skins using bars or lamellas, and, when it is laminated with glues or nails, it makes possible the construction of timber shells.

A barrel vault roof resting on two generatrices secured with tension bars is not a shell because it is not a three dimensional structure. Its internal stresses are parallel to a transverse plane, and, as such, it is considered a planar structure. A cylindrical vault, however, becomes a shell when diaphrams are added to each end so as to act as supporting elements and thereby avoiding the tension elements. Thus we find many shells that are combinations of various curved surfaces or curved and plane surfaces.

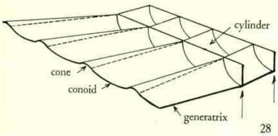
We have purposely omitted the three dimensional structures that are formed solely by planes; these are *polyhedral* forms (*tetrahedron, cube, etc.*), and they are very interesting and perhaps very useful; but they are not shells because of their lack of curvature. We can say, though, that they are to shells as a regular polygon is to its inscribed circumference; but each plane surface is a "plate," and it is statically different from a curved sheet.

We have said that it is the "form" that gives thin shells their characteristic rigidity; but how is this form determined? I can only answer that it is the task of the designer, for whom there is no rule. The form is created by the imagination in an effort to solve a certain architectural problem.

The designer's imagination is free; but it must be guided by his technical knowledge and the greater his knowledge, the greater his results. *Imagination,* which is the creation of mental images, should not be confused with *fantasy,* which is the creation of capricious fiction. Imagination flows logically and objectively as thoughts; fantasy is unreal and illusional.

When the form has been created by the designer it is the duty of the engineer to analize it as a structure in order to determine its characteristics for adaptation to materials and methods of construction. The duality form-structure is no more than the consideration of one unified problem under two different, but complimentary, viewpoints—one synthetic (design) and the other analytic (structure).

But is an analysis always possible? No; for the analysis depends on the technical and scientific knowledge of the engineer, and occasionally it is insufficient to analize some of the simplest forms created by the designer. In many cases, however, an estimation, although only approximated, can be highly sufficient. One must not forget that a calculation, regardless of the number of figures it contains, can be of no value if it is based on a hypothesis that is not related to reality. In the field of structural analysis, a mathematical background can be a very valuable tool if a correct estimation of the known coefficients is made before establishing the exact formulas for the calculation of the internal stresses and the external reactions.



28

In order to analize a structure, it is necessary to have a clear and logical understanding of the static problem as a whole along with a correct estimation of all the participating forces and elements. A very sharp and highly refined stress analysis is of less importance! For each new architectural problem, the designer creates a new form which is related to his experiences and intuition. The selected form requires a physical structure to bring it into reality and this must be obtained by a close collaboration between the architect and the engineer. This collaboration is successful only if the imagination of the architect is guided by a broad, although not necessarily a thorough, understanding of the problems in the technical field and only if the reasoning process of the enginner has deep foundations in the field of mechanics and is guided . . . by the imagination.

1 BEFORE 2

Roy Gussow

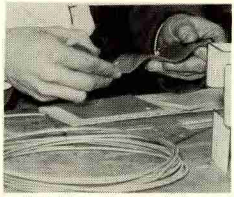
The photographs on the following pages are samples of work done by first year design students. As the captions will disclose, these are studies—"problems"—involving very specific elements with definite limitations. The choice of both elements and limitations have a purpose which is directly related to the general sequence of a developing creativity. They are not abitrarily selected. An attempt is made to isolate certain elements in order to study their interaction with the whole, to learn something about them singly before combining them with the many complexities usually involved in a composition. In other words, as much as possible, all elements in the arrangement are maintained as relative constants except for one. An example of this would be the problem of studying planes in three dimensional space. The volume itself retains its size, shape (cube or rectangular solid) and proportion. The material of which the planes are made is kept uniform and usually anonymous (white, neutral gray, or balsawood). Sometimes the size of the planes is kept uniform or, if modulated, they are done so within a modular system. The only element that is really manipulated is position—the placement of these planes within the volume to produce a particular space quality and interesting, efficient articulation of that volume. This is a scientific approach but with enough of the intuitive decision included to make it a balanced experience—an intellectual and emotional exercise. This problem can develop by gradually increasing the variables—such as first varying the character of the planes by utilizing different materials—then transforming the planes into volumes which can be visualized as complex planar structures; then incorporating certain structural requirements which would involve tension and compression in a realistic manner. Each selection brings with it some demand for concession. What the concession is, and whether the element is worth the concession, are questions which must be answered by every designer.

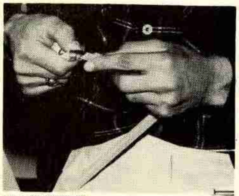
Most of the work in the first year follows this pattern—from experimentation to control. Application is only suggested since premature specialization brings about narrow viewpoints and impoverishes the experience of a developing personality. This is also the reason why the problems are treated objectively. It provides a broader background of experience to which the student can refer. A wall, floor, table, or garden pool, all become planes objectively and can, therefore, be more satisfactorily organized in relationship to its function.

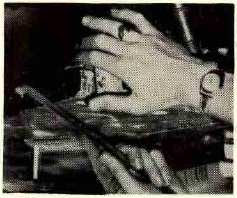
Perhaps it is because of its objectivity that this work is regarded as an art form, but the naivete which eliminates children's two and three dimensional communication from the category of aesthetic expression also prevents these problems from falling into the same category. The problems are not entities in themselves, but the manifestation of a process and a step in a series of elementary studies.

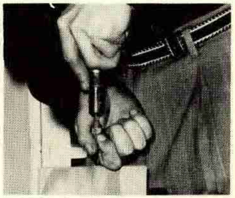
The progress of the student is evaluated neither in terms of quality nor of production, but what is considered of utmost importance are the attitudes developed. Techniques are fundamental, but creative stimulus and desire for expression form the incentive to learn techniques. They are a means to an end, not the end in itself. The student must learn for himself through his own efforts. He does not study tradition, but instead analyzes the principles and factors which affected tradition.

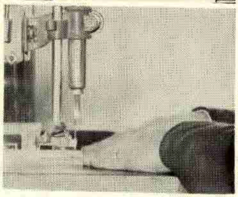
The purpose of this approach to design education (and it might well include education in general) is to train and develop a responsiveness to the world, an awareness of the quality of all things—ordinary and extraordinary, the structure of a pebble, the craters on the moon; to develop the courage to approach problems on one's own initiative; and find equilibrium within one's self and with society.

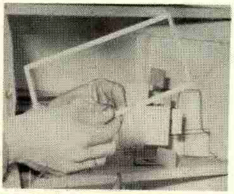




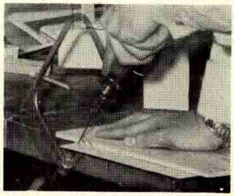


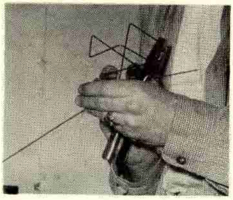


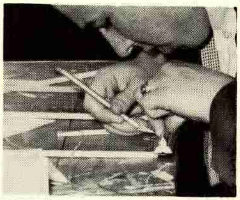


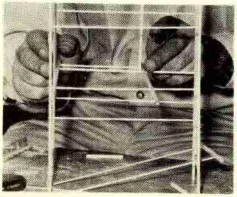


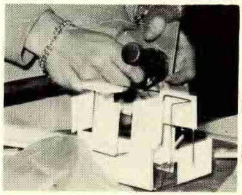
Man
Machine
Materials
the habit of learning
by
DOING

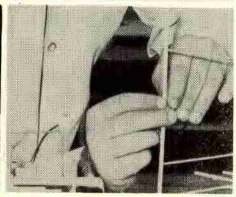


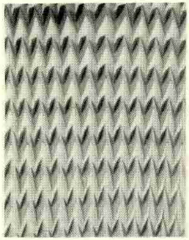
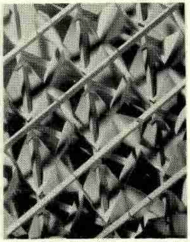
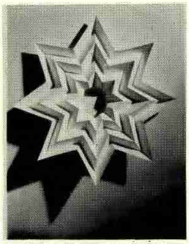
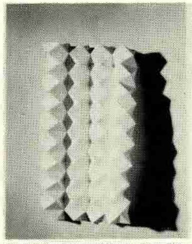


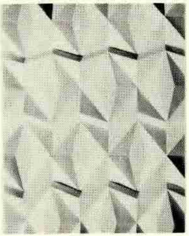
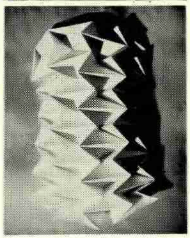
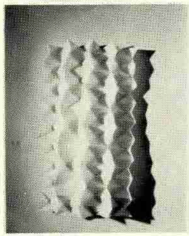




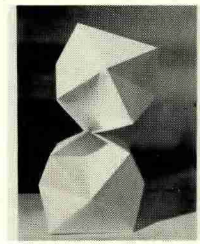


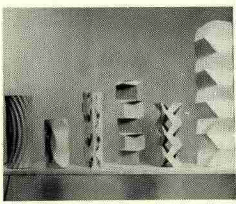
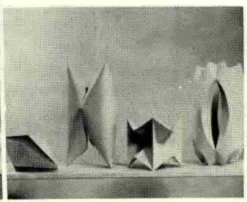
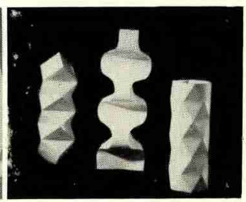


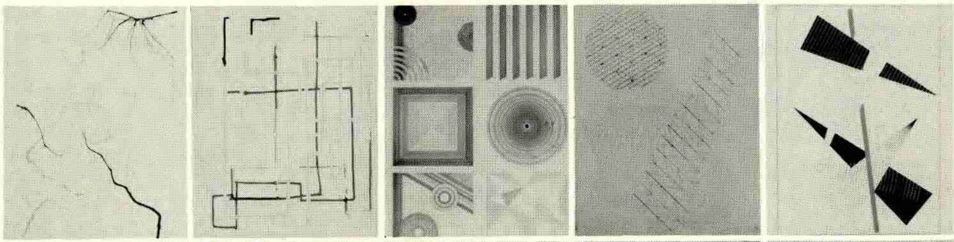
to discover and express the structural qualities of a sheet material—paper
not a direct application but a demonstration of these qualities
No glue or fasteners of any sort
ABOVE—limited to a planar relationship
BELOW and RIGHT—Form or enclosure of mass

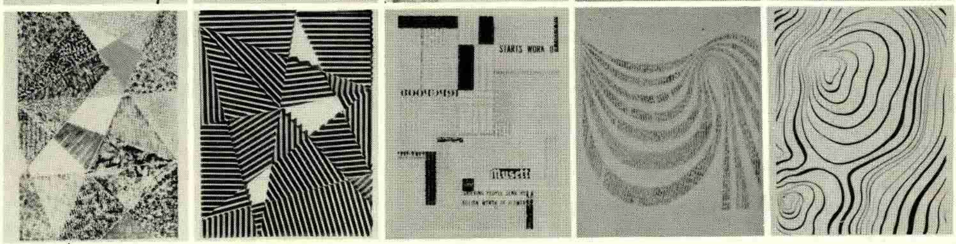


Line quality—articulate area
use of gravity and interaction between surface
and liquid paint—colors optional
LEFT—free
RIGHT—geometric organization

line quality
exploit ruling pen and drafting tools
LEFT—complete freedom in six equal areas
RIGHT TWO—planes in space, transparency, overlapping penetration

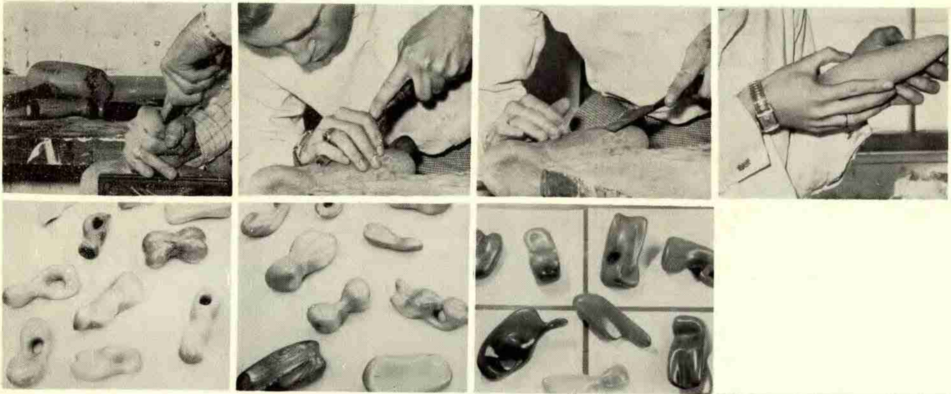




plastic use of texture and value
transparency, overlapping, dual image
LEFT—ink and various methods of handling
RIGHT—actual light, even texture, change

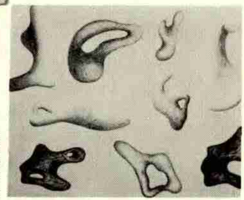
light reception, corrugated cardboard
plastic use of texture and value
typography as texture
value (light and dark) affected by line
space relationship within the characters
as well as between the lines
LEFT—planar
RIGHT—warped plane

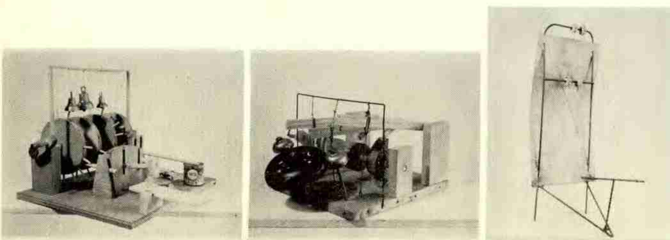
warp plane with
drawn line—ink,
pen or brush



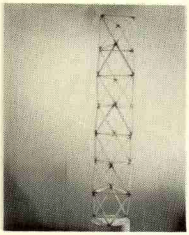
tactile
make a form which is pleasing only to the sense of touch,
material—maple, oak, poplar, pine, etc.
hand tools only, uniform finish—shellac—French polish, technique.
preconceived idea kept to minimum—develop form as you go,
examine with hands, fingers, arms, neck
Result—organic form, tactile satisfaction—visual satisfaction
bone-like, stone-like, anatomical quality, nature, the common
denonminator

Visual form
from tactile experience, develop
two dimensional forms using
texture and value
"Free" form with more conviction

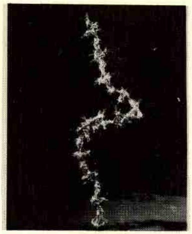




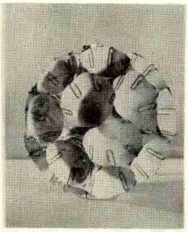
Rythmic Sound Machine
not a musical instrument
operator is only a source of
energy and can only control speed
exploit sound quality of materials
study of rythmn—primitive,
jazz, old and contemporary
classical. combine materials—
structure, mechanics craftsmanship



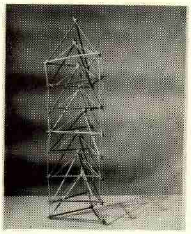
straws and
paper clips 56" h



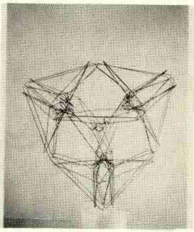
bobby pins and
rubber bands 16" h



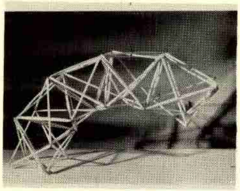
paper cups and
paper clips



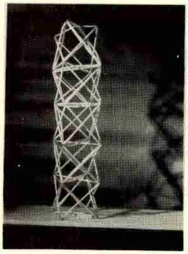
pick-up-sticks
and rubber bands
(discontinuous
compression)



coat hangers 30" h.

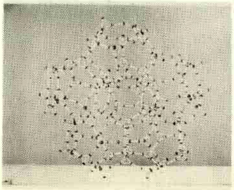


straws and paper clips
two superimposed columns
of tetrahedrons
a universal joint

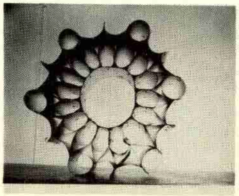


Found element structure
maximum of two different elements which have
been fabricated for some other purpose
discover and exploit the structural potential of
characteristics inherent in these elements
few or no alterations permitted
consider modular growth
start with simple rythmn, 1-1-1
build up more complex rythmns if necessary
1-2-1-2, 1-2-3-1-2-3, etc.

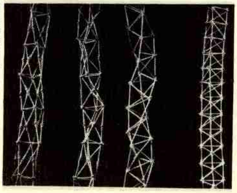
toothpicks and
sink washers 36" h
dodecahedron growth



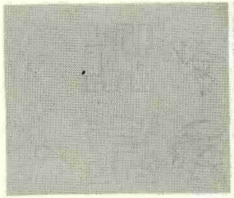
file cards and
paper clips
organic tubular structure

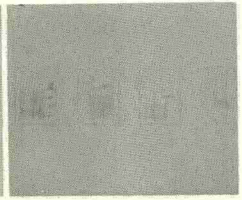


toothpicks and
rubber bands 30" h



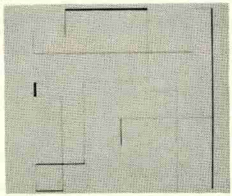
articulate three basic shapes with one continuous line the quality of articulation should reflect the shape that is being articulated

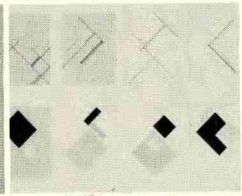




sequential composition each area composed separately and fit in as part of a series LEFT—horizontal and vertical lines, touching each other free of sides

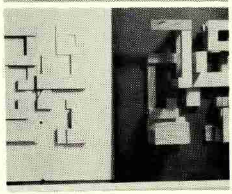
enlarge one shape vary line thickness to suggest depth

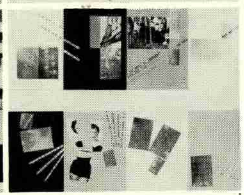




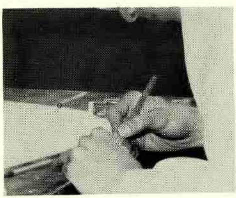
UPPER—lines parallel or perpendicular to each other, 45 degree angle from sides, touching each other and sides
LOWER—planes—same as above but free of each other and sides

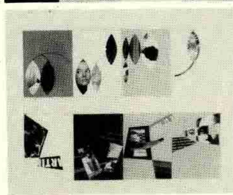
articulate area with planes—low relief not more than three thicknesses of illustration board—overlapping planes—positive and negative RIGHT—exaggerate third dimension—change planes to masses.



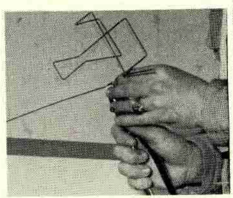


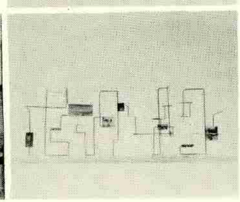
UPPER—planes touching each other, free of sides—parallel and perpendicular to sides, lines on angle and touching sides
LOWER—as above but planes not parallel or perpendicular to each other or sides
both use texture and value



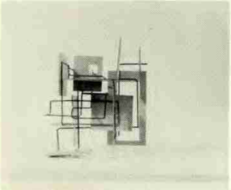


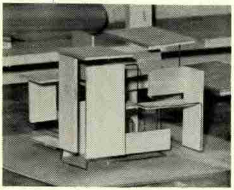
UPPER—curved lines and planes
LOWER—free combination of any or all limitations

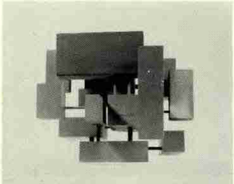


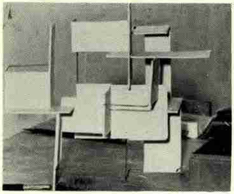


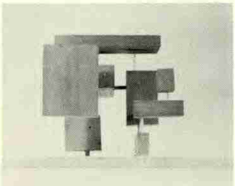
Ingenious combination of linear articulation of volume and above problems there are four separate linear structures—balanced separately or in combination with each other





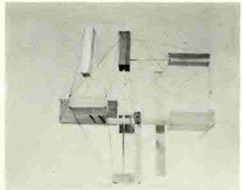


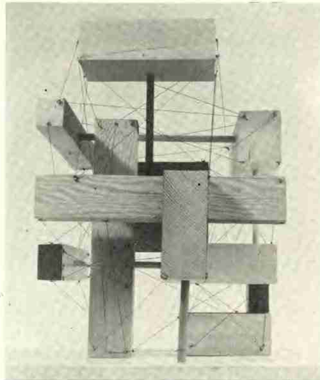




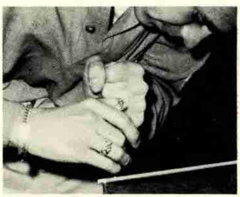
Planes in space
planar articulation of
volume, from linear
versions, 6-9″[3]

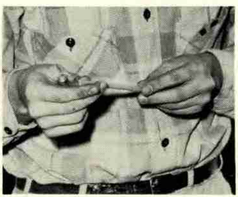
Masses in space
volume enlarged
planes changed to
masses, maintain
comparable space quality
and scale—12″—18″[3]

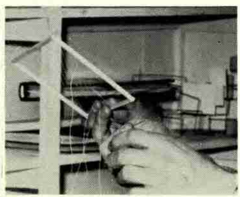


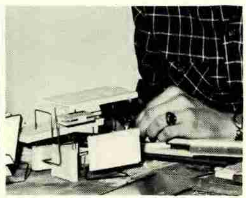


entire structure made as
rigid as possible with
tensile elements. First hand
experience and experimental
approach to statics

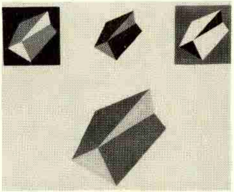




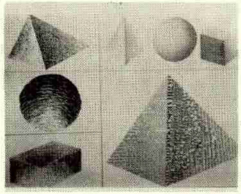




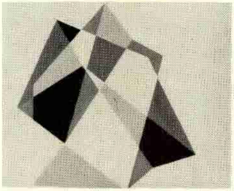
value study
black, white and grey
seven arbitrary points
connected to form
folded or warped plane
one enlarged and
expressed with three
hues—match value

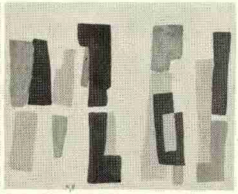


return to color **value**
vertical elements
arranged horizontally,
high value, accent
with low value



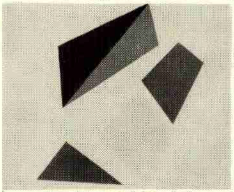
enlarged shape from
above superimposed on
itself—no color
limitation—achieve
maximum transparency

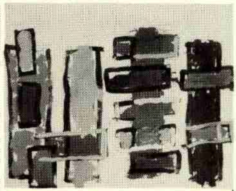




horizontal and vertical
elements arranged horizontally
and vertically—low
value, accent with high

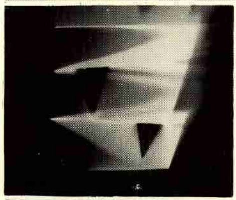
enlarge and explode
original form
no color limitation

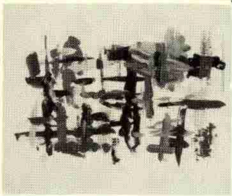




as above but use low
intensity accent with
high

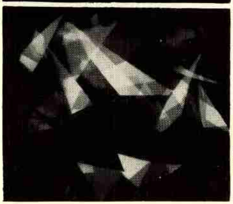
value study
photogram or cameraless
photograph—work
directly with light and
shadow—exploit black
white and extended
grey scale

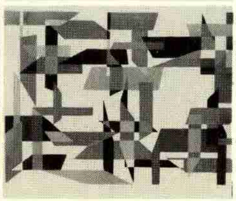


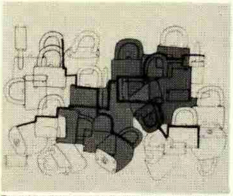


as above—combine
high value, high intensity
low value, low intensity
achieve maximum plasticity

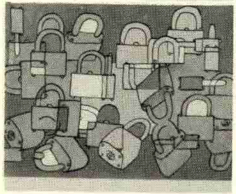
use of value or
shades to create
simple forms—use
ink, pencil and
typographical texture



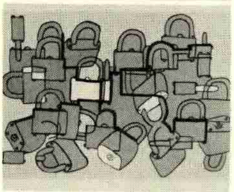




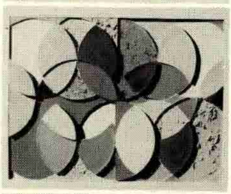
different views of
small simple object
jumbled first, then
ordered with
linear emphasis and
few large color areas



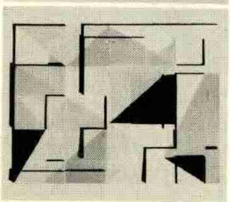
above, with solid
color areas—low
value, high intensity
accent with high
value



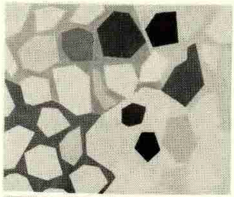
above; with linear
accent replaced
color variation



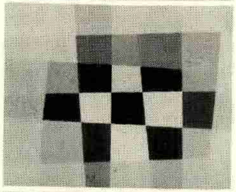
color plasticity used
to oppose dimension
of low relief. Low
plane of relief advance
with color intensity,
high plane, recede
RIGHT and LEFT
same problem



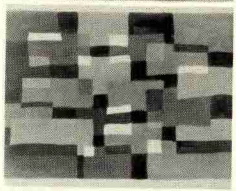
color plasticity used
to camouflage or
distort relief



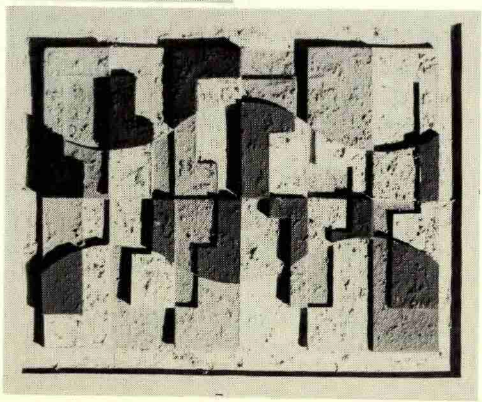
shape relationships
color changes with
background
positive and negative



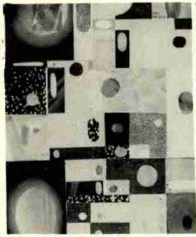
value, intensity
gradations radial
development



transparent overlapping
planes
low value, high intensity
accent with high value
high intensity

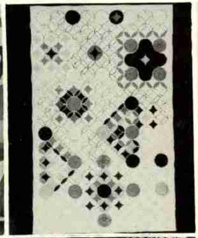


shapes within shapes
pasted colored paper
process allows
fast change

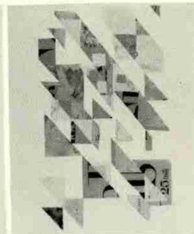


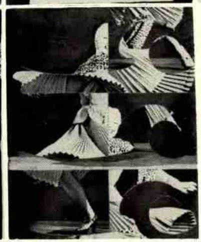
shapes within shapes
painted

work within grid
make use of inherent
order. rubber sink
mat



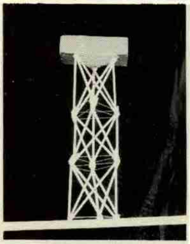
cut paper, color—shape study similar
to one on extreme left. after arrangement
is completed it is recut arbitrarily into
more or less regular interchangeable shapes·
shapes are lifted, a new order is formed



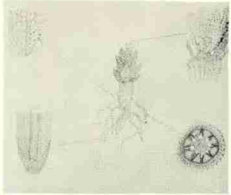


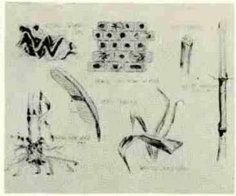
technique similar to last two above.
working with the subjective quality of a photograph
complete story as well as separate details are
presented with greater impact due to the more
dynamic relationships of forms

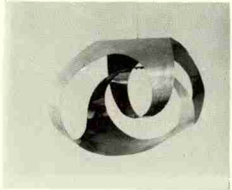
photomontage
natural elements placed in unnatural
surroundings also permits clearer
visual story telling and the use of
psychological implications

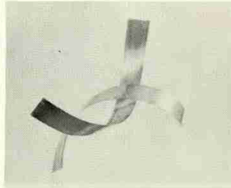


examine the use of
the warped plane as
a structural element
in nature
utlizing the qualities
of sheet metal develop
a visual, structural, three
dimensional form which will
reflect some aspect of the
research. can involve welding,
riveting or soldering.

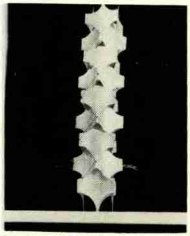


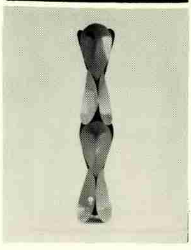


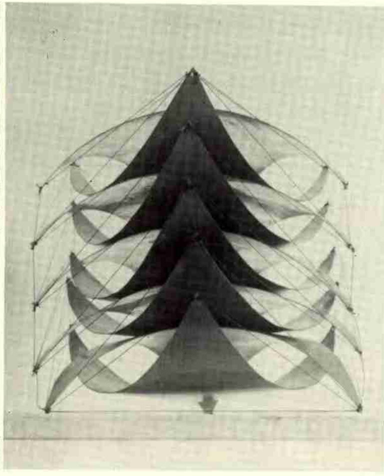




support a common
brick not less
than 16″ away
from table.
use minimum
drinking straws
and thread.
economy forces
structural efficiency

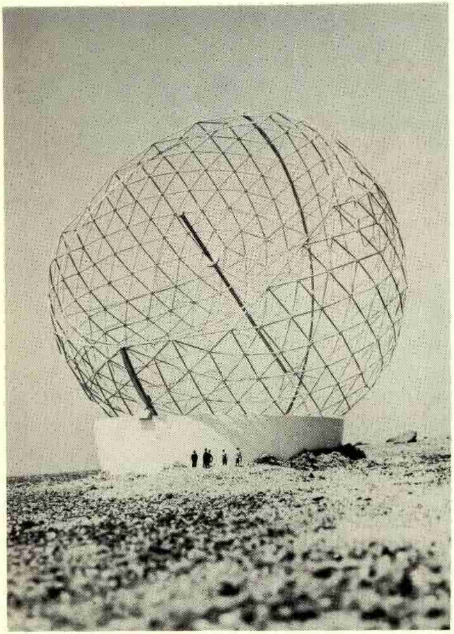






SKY-EYE

Margaret Lemle



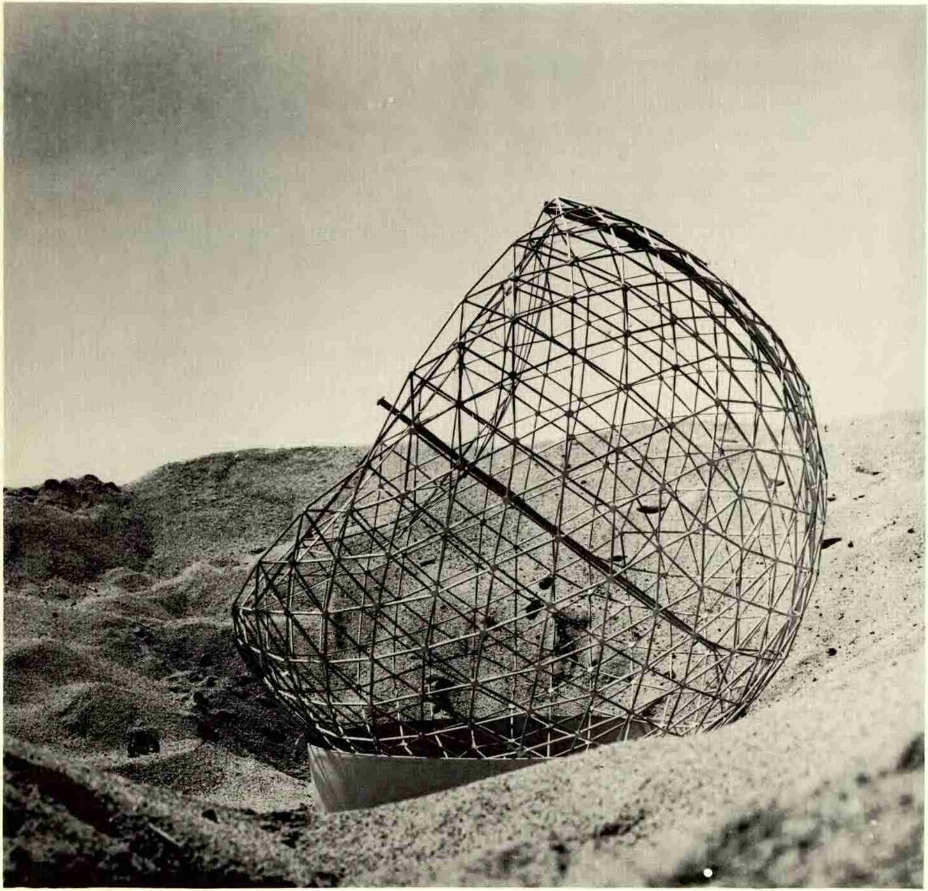
Miss Lemle is a member of the public relations department of Tulane University where the following project was undertaken in February of this year.

Our knowledge of outer space is contingent upon the development of instruments which can accurately receive the faint signals which issue from it. The most recently developed instrument for this kind of work is the radio telescope which is used by scientists today to conduct research on radio waves from outer space which originate in the action of hydrogen atoms. The waves, which make hissing noises, are caught on an open-work curved-mesh parabolic mirror and are amplified so they can be heard by human ears.

Because of the necessary size of the mirror, 250 feet in diameter, and because of the importance of its being aimed at the sky at all angles, a structure built to house it must be very strong, precise and light. Inasmuch as conventional types of mounting have become too heavy, inflexible, and expensive, Bucky Fuller and Jeffrey Lindsay, director of the Fuller Research Foundation in Canada, have supervised the construction by Tulane University architecture students of a model of a new mounting system. In Fuller's solution, the mirror, the largest ever built, would be housed in a $\frac{3}{4}$ sphere construction 300 feet in diameter, which would float in water as lightly as a pingpong ball in a finger bowl. With this floating suspension, the mirror could be turned mechanically with great precision to track automatically the changing position of any sky object.

The actual radio telescope based on the model would be one-fourth lighter, (weighing 75 tons including the mirror), and far more versatile than the conventional steel radio telescopes now in use. In addition, it would be approximately 50 per cent less expensive to build. The spherical supporting structure would be made up of 1,100 cigar-shaped hollow tubes, 28 feet in length, two feet in diameter and weighing 110 pounds apiece. The tubes would be made of glass-reinforced plastic and be joined by specially patented joints of stainless steel. A relatively small number of these tubes can displace enough water to provide the buoyancy necessary to support the whole structure.

If this solution proves successful, it will be a mounting design as revolutionary in concept as the instrument it supports.



Charles Eames and Jeffery Lindsay

Irwin Jones

ESTHETICS AND SURVIVAL


Bill Campbell

The author of this article, a resident of New York City, formerly attended Columbia College and is now a student of Architecture in the School of Design.

Laughter, that trait peculiar to human beings, can indicate at times, an attempt to brush aside the seriousness of an accusation, an unwillingness to face the obsolescence which is occurring in a particular set of concepts or ideals. It is perhaps this kind of laughter which occured recently when Bucky Fuller, when speaking to an audience, alluded to the insignificance and unimportance of the supposedly revolutionary ideals of esthetic refinement which we in this first half of the twentieth century have all been taught to accept. To challenge the idea that architects are distinguished from, and elevated above, the other workers in the building field by their intuitive knowlege of the refinements of form and proportion, and of the mysteries of 'space'; moreover, to insinuate that such a preoccupation on our part actually detracts from our social usefulness, is to jab deeply into our architectual egos. The self-conscious laugh that followed seems to reveal that we don't feel as secure in the value of our contributions as we might like.

Is it difficult to begin to understand why this insecurity is present in us once Bucky has given us glimpses of the full responsibility that is ours in assuming the task of design. We are shown that the field in which we must work has been expanded far beyond our normal areas of thought, both spatially and temporally. As designers, we can accept nothing less than the entire globe as the spatial complex in which our actions will have consequences. The near future will see this complex greatly expanded. We can accept nothing less than fifty years of the future as the practical temporal complex in which our actions bear consequences. Design in its most general conception becomes the distribution and apportionment of the energy available to us, the people of the world, both in the crystallized form of "matter" and in the forms of radiation. Design becomes a basic social necessity whose problems are not those of day dreams, but of ultimate reality because it deals directly with survival, a survival no longer threatened by nature, but by the tremendous tensions created by the energy differentials between the peoples of the world, differentials made operative by our newly-born world society. When Bucky shows us what designing must mean from now on, is it any wonder we laugh nervously and squirm a little as we think of our present preoccupation with developing a "personal style" of worrying about someone stealing our clever ideas, or of being accused of having stolen someone else's.

Few of us can help being struck by the fundamental validity of this analysis and feel its power in the implications it holds for our future actions. But this problem of esthetics, so important in our present thought and seemingly neglected in this new thought, still holds us back. This was, after all, the noblest phase of the study and practice of architecture, the reason we were studying to be architects rather than engineers. What about esthetics?

To begin by comparing my (or anybody else's) subjective reactions to a Fuller dome and a house by Frank Lloyd Wright would defeat the purpose of this article. It would be accepting the widely held premise that esthetics is essentially a problem of refined subjective reactions which a few lucky people are blessed with while the rest of the masses must forever remain incapable of real esthetic enjoyment. It is, on the contrary, the thesis of this article that esthetic experience is an integral part of every activity, that esthetic value must be judged according to the same criteria as any scientific theory and practical action; that no person, above all the artist, can withdraw from social and intellectual responsibility by claiming a god-given faculty. Esthetic experience is as closely woven with the whole of our life as any other experience.

In trying to discover the operation of the esthetic faculty, a very important phase of esthetic experience which we cannot overlook is that which many mathematicians and scientists claim they have. When a well worked out experiment, or a new, powerful mathematical deduction is made, very often it is called "beautiful." This leads us to suspect that that which is esthetic is not confined to the fine arts, the applied arts, or even science, but is really a quite basic satisfaction which can be derived from all sorts of experience. It is something which is a part of all actions, all thought and so is very deeply important to all of us.

In order to talk about esthetic experience, it seems we have to first consider some of our fundamental conceptions of all experience. Any group of ideas about the world must eventually accept a basic value which determines the validity and worth of all subsidiary actions and thoughts. This value will determine the nature of reality for the people who accept it. Most systems of belief, for example, accept some notion of a god, or a deity, or a mystical principle as their starting point, and develop a concept of reality and of valid action and thought from that. Many people shall continue to do this in the future, and ultimately there is no way of proving this principle wrong or inaccurate. This is a volitional acceptance and not subject to any rational discussion or judgment. However, the people who do accept a god as reality must live in "this world" and suffer with the rest of us; they must eventually accept the fact that the thoughts and actions valid in a god-reality are essentially irrelevant to the occurences of "this world." The other basic value we can accept is one which includes as valid actions and thoughts none but those dealing entirely with "this world," namely, human survival. Reality becomes a series of problems the solution of which is necessary for survival. It is ultimately described purely in terms of sensation, of what we feel, see, hear, taste, and smell. There is a great deal of evidence gathered by psychologists, anthropologists, and sociologists to support the latter value. A person believing in a god-reality, however, would have no logical compulsion to accept these findings; neither would they have a logical right to use them. The ultimate difference in the two values is the eventual amount of physical and mental pain suffered by people in "this world."

This fundamental distinction in values will undoubtedly be attacked as a kind of extremism by those who wish to hang on to some apparent emotional comfort offered by the god-reality while taking advantage of the scientific developments of the survival-reality, but then they must forever face the cultural gap which yawns between the technical and socio-political improvements of the last four-hundred years. They must give up any hope of closing this gap by other means than the catastrophic methods of totalitarianism.

If we accept survival as the fundamental value and reality, then we must adopt ways of looking at the world which are going to enable us to deal with reality, to survive. We cannot allow our ways of thinking and acting to obscure the problems we have to face. Unreal ways of thinking and acting are nothing less than fantasy of a potentially very dangerous kind. For example, many artists say that we can talk about esthetics as much as we like, but when it's all over, action is the only thing which accomplishes, which solves the problems. This type of sentiment contains the seeds of totalitarianism—too much talk, let's "do something." This is not to insinuate that anyone uttering such an idea is good material for the next S.S. troops or NKVD. But ways of thinking are transferred very rapidly from artistic activity to political activity and vice versa. The way we approach our problems is the real unity which exists between various fields of endeavor, rather than any comparability of specific contents or results. If a particular approach to problems exists in a man's most important field of activity, it's reasonable to assume it exists in others too, albeit not quite so obviously.

Action-thought is the tool of our survival. In order to work it must be able to gain control of our external circumstances through knowledge. Knowledge we have come to think to be primarily associated with the mind or what we normally understand to be thought, in and or itself. Experience, however, occurs only through action, and without experience, we could never have any contents or substance to knowledge. What the mind does supply, we might call procedure. It is only after experience in the form of various sensations given to us by action is organized and ordered into various relationships supplied by thought that we have knowledge with a survival value, knowledge of reality.

Knowledge is not concerned with "things" with "units" or particular sensations, but with relationships existing between various sensations. Our perceptions of sensations are chaos until organized. A familiar question in this respect is, "Is a penny round or elliptical?" When we look at the penny from the top it appears round, from an oblique angle, elliptical. What is the penny really like? This is a question we can't answer because there is no real penny in the sense of some absolute thing. "Penny" is a concept we use to express the relationships of several different types of sensations. Experience (action) shows that the sensations that we call "circular" and "elliptical" work together. It also shows that with these sensations go certain other sensations of touch, taste, temperature, etc. We also understand by "penny" the relationships this central group of sensations enters with other groups of sensations. We have learned that if we let the penny fall a certain sound results, that if we give it to the man across the counter he will give us a stick of gum, and so forth. The widespread and at times disastrous confusion regarding the "real nature" of a penny, what it "really" is above and beyond our senses, has occurred because in our language we use a sentence construction based on a subject and predicate, object-attribute relationship. In speech we say a penny has such and such a quality. This leads us to assume there must be some real penny apart from any sensations of it, to which we attribute qualities. Philosophers have tried to prove the existence of unicorns by saying that if we can talk about the unicorn being white, there must be a unicorn. They have said that atheists admit the existence of God by the very fact they use the word "God" in a sentence. Such assertions confuse words with so-called "real things," rather than realizing that words stand not for things but possible and actual relationships. If we agree that we can learn about the world only through information supplied us by our senses, *which we must if we wish to have knowledge of survival value,* there is no possible way of making any logical inference from these sensory data to real, absolute things. It must be realized that we can have knowledge only *through* relationships and not *of* things.

The whole point of this discussion has been to show that the basic process needed for knowledge and survival is one of ordering sensations into relationships. This process is the logical origin of every word, every concept, every thought. It's success or failure means survival or no survival. This organization, this ordering of relationships can be seen to affect our deepest feelings of security.

All intelligent action is essentially an ordering of sense impressions into coherent relationships. This is true of writing, painting, composing, building, scientific research, lobbying, truck driving, shepherding, or what have you. Obviously, the complexity of the relationships varies among activities. Science and art are distinguished from practical fields such as politics and truck driving mainly by the fact that they are consciously concerned with developing relationships. On the other hand, we must distinguish science and art by the content of their investigations, and not by their ultimate purpose or their method. Their ultimate purpose is the same as that of any other activity: the organization of sensation. Their methods which now seem to be so opposite, the one involving hypotheses and deduction, the other intuition, will eventually be the same, inasmuch as intuition has been a substitute for a more reasonable approach which continues now because of tradition, because of lack of investigation and cooperation on the part of artists, and also because of the multiplicity of the factors involved. As for content, science and art differ in that science deals with the organization of organizations, with discovering the relationships existing between subsidiary relationships which we call concepts and things; while art deals directly with the ordering of sensations. This last must be modified because at present there is only one field of art which deals directly with the ordering of sensation, and that is music. Most estheticians have looked at music as something apart from the other arts. Music seems to be purer than the plastic arts or poetry. This difference can be explained on the basis that music organizes pure sensations of sounds, while poetry and plastic art have essentially dealt with secondary organizations, of words in one case, and images of "things" in the other.

Inasmuch as the problem facing the plastic arts has changed from one of organizing secondary organizations to that of directly organizing visual sense impressions, the difference can be illustrated by very briefly tracing the history of art. (The ideas presented are developed in great detail and with great force by Charles Biederman in his book, "Arts As Evolution of Visual Knowledge.") Up to the Renaissance, plastic art had its vital development in the field of sculpture. The purpose of sculpture was not as we are told today to create a pleasing relationship of volumes, but to accurately copy the three-dimensional forms of nature. Greek sculpture was an attempt to put into concrete marble that set of visual relationships which we refer to by the sounds "human body." The Romans further developed sculpture, concreting the group of visual relationships called "Hadrian" or some such specific group. At the time of the Renaissance, the technical problems of sculpture had been completely solved and its limitations were such that it could no longer serve in the attempt to crystallize new groups of visual relationships. The contents of art changed from the three-dimensional forms to the *visual image* of nature, and painting became the vital medium. Here too, the problem was to order a complicated field of blurred and fragmentary, ever-changing groups of sense onto a two-dimensional surface. We never see as part of our actual sensory experience anything which approaches the coherence and order of a painting. It was indeed an exciting and challenging task to take brush and oil paints and crystallize our ephemeral visual sense impressions. This was a problem closely connected with understanding reality in a time when geniuses like Galileo and Kepler were transforming our confused sense impressions of "things" and their changes in space and time into a grand, completely mechanical, predictable scheme.

The position of painting as a useful medium was suddenly changed when in 1839 an artist of the realistic school named Daguèrre gave up his old handicraft tools of paint and brush to invent a machine called the camera which could do with unheard of accuracy and speed what men had spent long, long hours doing before. The camera has forced a revolution in art. Whereas before art dealt with the ordering of visual images which entered into groups of sensations called "things," from now on art must deal in a primary ordering of the sense impressions of color, line, light and dark. Plastic art is now capable of the same degree of purity as music. Painting is no longer a vital medium because we have a machine to give order to visual images. Art must now deal with the problems of directly organizing the fundamental visual sensations which we understand in four dimensions, not two. Piet Mondrian was the last great painter. He exhausted the possibilities of a flat canvas . His paintings became simpler and simpler because he was no longer dealing with a picture of anything but approaching the three-dimensional problem of the canvas itself.

We have seen that knowledge is organization of sense data, that to survive all our activity must strive for knowledge. It has been suggested that science, art and practical activity, shall we call it business, vary only in degree of consciousness of the process of ordering, and in content, but not in purpose or method. *Esthetic value of any* *activity is due to the sense of power and security created by the development of a series of relationships which aid in dealing with reality, with survival.* Esthetic value cannot be cultivated in and of itself. It is a result of any activity which successfully deals with reality. The esthetic satisfaction of a mathematician or an accountant need no longer surprise us. Mathematics, for instance, is the purest form of "science" in that it deals, not with the relationships of "things" but with all possible types of quantitative relationships. "Art" and "science" must be in quotes because we shall soon realize them to be capable of having the same knowledge value, and be subject to the same intellectual and social responsibility. "Science," meaning "knowledge," will include every activity.

The designer of buildings can no longer accept the existing social, economic, functional and structural patterns as they are. He can no longer indulge in whimsical fantastic pattern-making, be merely an exterior-interior decorator, but must be able to investigate with the rigor of the scientist, those relationships in all relevant phases of experience which will make it possible to deal with reality, with survival. Once he is able to do this, beauty will be part and parcel of every joint as well as of the whole structure.

Because we become aware of structures through visual impressions, we cannot jump to the conclusion that architecture primarily concerns the organization of these visual impressions. Architecture deals with the relationship of stresses which occur in gravity-defying structures. Inasmuch as stresses are relationships between crystallizations of energy which reflect light, they must have a visual aspect. Ideally this aspect should correspond exactly with the pattern of stresses.

How can an architect presume to add value to a building by changing the visual proportions of structural members? "The architect must not be a slave of structure," it is said. This is similar to saying, "The architect must not be a slave to reality." Implicit in these statements is the idea of a split between human personality and "material things." We, as people differ from structures and "material things" only in organization, in the types of relationships between our parts. We can try to escape reality, but we will succeed only in obscuring our knowledge and our ultimate chances of survival. Actually, the architect is a slave to structure only when he doesn't understand it or uses it inefficiently. He is free when he has found its most workable relationships. It is also said that the architect must "express" structure rather than expose it. It is hard to see what other visual relationships can better reveal the pattern of forces in a structure than those which result from the members of an accurately-designed structure itself. To "express" a structure in other than this way is to create an inefficient economic or structural relationship and a visual fantasy.

What is the only possible justification of these alterations of the proportions of various elements? The only reason offered by those who practice this kind of estheticism is, "I like it." What validity can this have? What can a so-called "modern" architect who argues in this way say to a person who likes Grecian columns stuck on the outside of buildings? Is there really any difference between the classic columns around the government buildings in Washington, D. C., and the WF columns around

Mies' apartments in Chicago? As long as only justification of an action is, "I like it," there is no logical obligation on another person's part to accept it.

Esthetically satisfying buildings will result only when a building becomes a series of the realest, the most efficient social, economic, and structural relationships.

But isn't architecture concerned rather with space, with human emotions? Pietro Belluschi has said about architects, "Our immediate task it seems to me is to show our concern for the emotional needs of our clients and to show them that we are not reluctant nor unable to impart richness to the background of their lives, or to provide the kind of emotional fullness which played such an important role in the great periods of the past." Building must indeed show concern for emotional needs, and perhaps of all spheres of activity it is peculiarly able to do so because of its necessity and intimacy in our everyday lives. But what are our emotional needs? Emotionally, we have not been able to face the realities of the twentieth century. We feel in the same way our great-grandfathers did while having to deal with H-bombs and totalitarianisms. Is architecture fulfilling emotional needs if it encourages fantasy and escape from reality; if in an age of urbanism and collective living, the ideal house is one deep in the woods overlooking a quiet lake; if in an age of light metals, plastics, and mass production, the ideal house is made of stone and wood; if in an age when people work in man-made surroundings and deal with man-made problems, travel greater distances more often, the ideal house "grows from the land" and "communes with nature?" The ideal house of today's architecture does not help people to deal emotionally with today's reality but rather keeps them dependent on a set of ideals long since out of gear with reality.

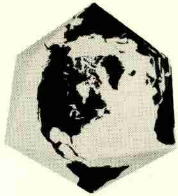
Just as we can no longer think in terms of "things," we can no longer have emotional attachments to things, specific things such as texture and materials, particular places, particular items of art, music, furniture, clothing; specific ways of doing things; because particulars must and shall change and they change more rapidly now than ever before. To remain emotionally dependent on particulars is to be sure of continued emotional insecurity. We must find new emotional security in people individually and collectively. We can't impair the development in building of our knowledge for survival by insisting on particular things to which we have emotional attachments, nor can the architect continue to be the agent of such a process.

I've been trying to suggest that the discovery of relationships among sense data is the process necessary for knowledge, that can aid our survival; that esthetic value and satisfaction is due to the sense of power and security resulting from such knowledge; that it is only by accepting the ultimate value of survival, these conclusions as to esthetic value which follow from it, and the actions implicit in the whole, that the great gap between emotions and the results of thought can be bridged.

The assumption, which I have tended to make, that we will ever be willing to give up our fantasies, is, I imagine, a little tinged with fantasy itself. The obstacles to be overcome by the plan of action implicit in this analysis are tremendous and so it can constitute only a direction to follow, to my mind, the only logical direction.

FLUID GEOGRAPHY

A primer for the airocean world



Buckminster Fuller

It is a sailorman's credo that there is a generic difference between himself and a landlubber. While admitting that sailor blood sometimes may be trapped inland for several generations, he believes that it never loses its dynamic proclivities. Though landlubbers may frequent the seas by political appointment, tourist urge or commercial necessity, conscientiously memorizing nautical language and techniques, the sailorman believes that they are fated to wear these acquisitions only as paraphernalia, distinctly superimposed upon their static roots. He reasons, therefore, that while a Kansas Citian may get to have four stripes, that unless he has inherited seagoing corpuscles, he must remain strictly corny, not salty.

Irrespective of the validity of this credo, there exist fundamental differences between the practical requirements of the sailorman's and the landlubber's lives. By exigencies, sailors have come to be the only men of commerce dealing directly and daily with the mechanics of the stars. Confronted with large quantities of unknowns intervening between identified ports, they came early to rely upon instruments and skills of the intellect, upon scientific imagining. In principle, "blind flying" has been employed at sea for centuries. Without thinking of themselves as cosmogonists, sailors naturally develop a spontaneous cosmic viewpoint. They view the world for outside; they 'come upon' the land.

But not so the landlubber. Though half a millennium has passed since Copernicus and Galileo urged upon educated people that the heavens were not turning about the fixed earth, landsmen in general and even their rock mounted astronomers persist in "seeing' the sun 'set' and 'rise' in their personal lives.

Intending to help their children to grasp the 'very difficult' concept of total heavenly motion, the landlubber theoreticians have devised planetariums within their great cities. Instructed by this device, the children approach personal conviction of the ceaseless motion of the planetarium heavens, only to be thrown into lifelong confusion at the critical moment as the closing landlubber phrases come to their stimulated attention: 'Now the sun is rising again in the East, the lights are coming on, the machine stops, and we return you to New York' (to the 'practical' life in which the sun, as a handy gadget, still zooms around the contentedly static earth).

These are excerpts from an article which originally appeared in the American Neptune *in April, 1944.*

To the landsman 'the East' and 'the West' are places; to the sailorman they are directions in which he may move. To the sailorman entered upon the great Pacific, it is final proof of the landlubber's nonsense that the sun is not only forced to do this rising and setting act, but perversely to do so on the wrong stage. Viewed from the Pacific, the sun 'rises' from the Occident and 'sets' in the Orient.

By exigency, too, sailors constantly exercise their inherent dynamic sensibilities. The ceaseless universal motion of the sailorman's life persists in his brain, even when he is landed 'on the beach.' For hours and days after he has come in from the seas, his legs go on adjusting him to the slowly heaving motion of Fifth Avenue. It isn't hard to convince a sailor that the watery, grey-mist horizon toward which he may be sailing is rolling down to reveal the sun, or that his circular horizon segment of the moment is one little wet spot on a great sphere, ponderously rotating to obscure the sun to the westward. He sees everything in motion, from the slopping of the coffee in the pot to the peregrinations of the major magnitude stars. Amongst all these relative motions, the pole star alone seems to float motionless as the world's mooring buoy in the sky.

To the static-minded landsman, it is an insensible statistic that the moon is about 239,000 miles away from the earth. To the sailorman, it is a natural sensation that the moon-earth pull is so great as twice daily to be able to lift many feet aloft the thunderous tonnages of water upon which he sails. By measured reasoning he 'sees' the moon lifting the water as it circles after its rotating and orbiting mothership Earth. So fast is the orbiting that the sailor knows it is difficult to obtain an accurate navigational sight from the moon. However, to the static landsman, that moon seems to hang motionless as a luminous flat medallion in the periodically glimpsed scene.

To the landsman, a trip around the world means the conversion of a bank account or an Irish Sweepstakes prize into a procession of hotels; to the sailorman, it is the logical fulfillment of his work, punctuated by visits to 'the beach.'

While it seems that a preposterous case of rationality versus irrationality can be made in favor of the sailor, what is really being demonstrated here is the principle transcending identity with either the sailor or the landsman.

One common observation of an effect of that principle is 'Necessity is the mother of invention.' The sailor is much better acquainted with that trying dame than is the landsman, if for no other reason than because land activities generally are based on eight-hour workdays, after which the office and factory are shut down; whereas the sea can never be shut down. While physical laws persist both on land and sea, their slow articulation on the dry, crystalline land could be disregarded for two-thirds of the day. The landsman stables the horse, garages the car, or merely walks into his house and sits down. Inertia, unchallenged, promotes careless philosophy. Everyday the seafarer is exposed to three times the necessitous experiences, for even when off watch he is still in a dynamic environment. Moreover, the mutability of the liquid state and the proportions of tonnage and velocity to which the sailor is continuously exposed are many times those encountered on land. Thus by compounding of factors, technology advances far more rapidly at sea.

If we will remember that leverage, for instance, as a universal principle may be abstracted from immediate identity with sea gear for reapplication on the land, we can readily understand how the technical advantages gained on the sea gradually come to satisfy land emergencies. In the light of this technical leadership, we can understand why rule of the world derived from rule of the sea.

Frequency of technical emergency is accelerated to even greater extent in the gaseous state. Airmanship emergencies require the most exquisite of solutions. In short order aeronautical engineering has reapplied to its needs all of maritime technology. While the air technology may not as yet have taken complete leadership away from the technology of the sea in the pacing of man's affairs, it hastens inexorably to such predominance.

With the land as the bottom of the new unbroken air ocean, as so brilliantly taught by George T. Renner of the Civil Aeronautics Authority to elementary school America; with sailors, aviators, and landsmen all crossbreeding into a dynamic world citizenry; and with historical events accelerated from a frequency interval of centuries to intervals of hours, all men are, so to speak, now in the same boat and are necessitous among other items, of a precise means for seeing the world from the dynamic, cosmic, and comprehensive viewpoint.

The Dymaxion Airocean World Map, Student Publications of the School of Design Edition, was invented for this purpose, and while it is certain to be bettered by subsequent inventions, it is for the moment the most reliable comprehensive projection, in that it describes the earth's surface with the minimum total score of distortions from the many well-known geometrical processes inherent in translation of the angle and scale information from a spherical to flat surface.

This new projection makes possible the reassembly all on one plane of each and any of the continents in any of the arrangements in which they occur relative to one another on the globe as one explores successively the infinite number of great circle continuities.

Unblemished by the peripheral sinuses necessary, first, to the scoring open and, second, to the peeling of any solid, this projection is the joint result of a new mathematical discovery on the one hand and on the other of emancipation from the formal cartographic tyranny imposed by the poles.

The particular assembly of icosa triangles accompanying this article is not the only arrangement. There are many other arrangements which the reader may develop for himself. Each, by 'picture psychology' focuses attention on the central portion of its mass, yet retains all other factors in appropriate contributory status. Each of the arrangements is as important as the other, depending on the geographical location with which the individual has habitually been identified.

The sailor may ascertain by inspection the most advantageous courses to his many world ports from the tactical center of that watery workaday world. So far as he is concerned, the whole world is one ocean, one quarter of whose uneven bottom crops up through the surface in peaks and plateaus. When he comes in to the shore, he's coming in to the peak of a mountain range about five miles high, to our modern cosmic sailorman, coming in to an airfield in Tibet over the Himalayas is approximately the same sensation as coming in to Puerto Rico over the Antilles ranges rising abruptly 30,000 feet above the Nares Deep.

There are also many rearrangements of the map to emphasize whole continental masses. By means of these elective arrangements, our thinking may be realistically insinuated within the special geographical environment of the peoples of any one world area as predicated upon their own set of conditions directions and proximity to all the rest of the surrounding world. It is in this feature that we discover the dynamic leverage afforded our world appraisal by this device. No longer need the American continents, for instance, with only twelve per cent of the world's population, occupy relentlessly the central and non-distorted portion of the world map, assigning fifty-two per cent of the world's population to an insignificant, fragmented, and distorted Asiatic borderline position.

The sailorman's interest in world history relates only to the net difference in means of travel between component parts of his unit globe. All history 'pays off' to him in total sustainable knots. The shrinking dimensions of his world are computed in relative velocities.

We can see by experiment with this map why he laughs at the suggestion that 'East is East and West is West and never the twain shall meet,' for he sees that men as individuals have not only moved in the total course of time in all directions over the face of the earth, but *that they emigrated essentially out of one major pool of civilization,* which was Indo-China. Here East and West were originally one. From this one major pool there grew *two main spearheads* which we have come carelessly to identify as unrelated. This division into East and West occurred as the offshoots drew into diametric global positions in the course of their eventual encirclement of the earth. Growing out of the same unit mass of civilization, the eastbound and westbound spearheads progressively absorbed the lesser sources and their tendrils in Africa and South America, as well as the interweaving complex migrations.

The differences between the two spearheads existed only in the effects of environmental changes upon their cumulative technologies. The spearheads attained extreme diametric east-west remoteness in the period approximately called the Dark Ages.

The sailorman, alert to currents, can see the flows of history as the static historians have failed utterly to do. He sees how some people have turned adversities into technical advantages, how they have gradually reduced the limitations to their elected motions, and how they have in fact accelerated their movements.

Let us retrace on the new map the major civilization flows, in order to see more clearly the historical significance of our present dynamic world conditions.

Both major migrations appear as the gradual extensions of the horizon by successive generations. Because everything flows in the direction of least resistance, and because the heat to the south was too great and likewise the cold to the north, the least resistant directions were approximately east and west. The next extensions of the generations are directionally random because the geography is random, but they are extremely uniform in the unseen thermal latitudes.

Establishment of these two great world trendings was unplanned by any systematic organization of society. These divergent trends are the articulation of biological forces demonstrating progressive equilibrium everywhere throughout the universe. Their dynamic inter-relationship, as modified by the total geographic scene, determines our fate.

Springing jointly from the Indo-China area, the spearheads both start in an easterly direction, but split up at the Malayan tip.

One main stem grows in a general northeasterly direction along the islands close to the Chinese and Siberian coast, along the Aleutians and eventually down the coast to the Americas, with myriads of subsidiary spearheads penetrating inland from all along the main tendril. The nearer to the beginning of the main stem, the larger and more plentiful were the branches.

As offshoots to this first major spearhead coasting northeasterly, many tribes penetrated the Mongolian hinterland, passing westward to the north side of the enormous Himalaya ranges. The vastness of this region lost them for millenniums even to the point of seeming extinction so far as the people still remaining in the land of their origin were concerned. Historically, these lost migrants are not heard of again until in India, as the Mongols, called Moguls, they come over the mountians in the days of Ghengis Kahn to rule their sedentary forebears. During the course of the thousands of miles and thousands of years of the many separate inland trekings, the appearances of the individuals develop distinct and unique characteristics. Many demonstrate color evolution as a result of sustained changes in radiation conditions.

Many of these tribes reappear to the westward all the way from the Mediterranean to the Arctic Sea. They arrive in successive waves, for instance, as the Hellenes in Greece, and the Hungarians and Tartars along the Danube. Some of these tendrils double back toward the Pacific. Fragments of their more recent and vivid easterly motion have sometimes obscured from anthropologists the preponderently westward pattern of the early Asiatic migrations.

Somewhat similar technical evolution characterized all of these peoples wayfaring. They were constantly on the move because of the sharp changes of the northerly climate and vagaries of the sparse vegetation. Because of this mobility, they develop sheerest efficiency in their mobile living and hunting apparatus and in their survival routines. These wandering hordes, equipped for their inland migration with already efficient technologies won from the sea, subsequently devised portage efficiencies which enabled them to overpower the more easy-going southerly peoples as they encountered them.

Despite this impressive inland migration, the greatest mass of the easterly spearhead's main stem stayed near the sea and fished and farmed along the fertile shores of the many river mouths of the China coast, where their progeny still exist as a teeming marginal life.

Reeling our continuity backward millenniums to the original ancient pool of civilization in Indo-China, let us inspect the coursings of the second major spearhead.

This second spearhead, which broke off from the first at the Malayan tip, drifted out into the myriad islands intervening between China and Australia. Though part of this seaward drifting was by accident, part of it must have been attempted by choice and as such constituted considerably more daring than that demonstrated by the people who hugged the coast. The separation of the spearheads constituted a first-screening of psychological types. This psychological screening imposed by elective dealing with the dramatically presented problems of the unknown off shore deeps has been repeated constantly in subsequent history. For this reason sea history plays an important part in developing the psychological factors of modern problems.

Subsisting on the less fertile soil of the islands, and of necessity forced to wander from time to time, the people of the westerly spearhead learned to navigate or control their course of direction between the islands, to identify their chances with the favorable winds. Gradually they learned to make passage even with less favorable winds, by quartering down wind, and finally by right-angling. In time they developed techniques for sailing better than a-beam to the wind. From this broad reaching they learned to point up even closer toward the direction from which the force came. They discovered that they could challenge their fate successfully. Next they learned to translate this angular wind advantage into increased speeds. Out of this technical about-face accomplished by the island sailors of the Southwest Pacific grew the second major world migration, trending to girdle the world in a northwesterly direction. This second migration got underway in its ultimate direciton at an accelerating technical advantage over that of the northeasterly bound or number one spearhead.

Developing its technology at a slower pace, the major northeasterly spearhead came naturally and in due course to evolve the square-rigger out of its downwind sailing junk. The fore-and-aft rigs of the northwesterly bound spearhead evolved from the swift South Seas proa or doubled-ended outriggers and catamarans. This second spearhead having completed its U-turn and now westbound in the face of the prevailing winds, renegotiated the Malayan tip. It then worked westward along Indian Ocean shores until it reached the Persian Gulf.

How can we be so sure of all this? Because in marked contrast to the fragmentary character of man's land-evolved mechanics, dug up only from ruins, every one of the boats and sailing types evolved throughout these earliest historical motions of man are *still in use and may be found in operation today* under the very same rules of technical logic and thinking as characterized their slow invention in the very same environment and part of the world where they were created. It is not necessary to guess how these ancient technical developments were used and, therefore, what they implied. What is more, boats were able to carry larger cargoes of the components of civilization than could be carried overland by men or beast. Boats may be found in every phase of transition. Choosing at random we witness, for instance, the single log evoluting into the compound log raft bearing a straw thatched hut, or the hollowed-out hulls replaced by ribbed and stretched skin kayak evolving into the canvas-decked outrigged rowing shell, or the half-raft-half-hull sampans, or the portable American Indian canoes, or the round basket boats rolling down the banks of the Tigris and Euphrates Rivers. The dhow, demonstrating great advance in sailing technique, is today the work boat of the Persian Gulf. It is the same fore-and-aft rig with which man negotiated the westerly passage of the Indian Ocean.

In design, building technique, and materials, the dhow follows the practices of Biblical and pre-Biblical times. It can point up into the wind more closely than the best of the America's Cup Defender sloops, though the handling of a dhow's spars is most crude and difficult by comparison.

Beating up the Red Sea and negotiating the Arabian Desert in the first overland navigation by caravans, the dhow builders again fashioned the same kind of ships in the Mediterranean, where they appear as the early vessels of the Phoenicians.

The major westerly spearhead is here wedded with the Hellenese tendril from the faraway northeasterly spearhead, as the people of the Peloponnesus and Phoenicians clash and integrate. This marks the first important phase of our intimate history of civilization The conjunction of their respective advanced techniques, occurring under more favorable climatic conditions than those to which the Hellenes had been forced to accustom themselves, compounded to bring forth a civilization so distinctly in command of its environment as to provide the first large increments of time in which to demonstrate the arts, sports, and philosophy. The two Asiatic migrations and the seaborne spearheads are the mobile flanks to, and provide the leadership, for the progressively settling down population in their wake. The latter come to make up the great body of early Mediterranean population. This cross-breeding pool is what we call western civilization.

The fundamental difference between the Asiatic people and those of Western Europe and the Americas is intimately associated with these two fundamental histories of technical relationships to forces. While neither the major northeasterly nor the major northwesterly spearheads blindly opposed the forces, they respectively demonstrated diametric methods of using them. They demonstrated diametric attitudes toward life and death themselves—of ready commitment of self to death by the eastbound Asiatics and stubborn refusal of it by the Westerners. To the Asiatic, riding serenely downwind, often over the horizon never to return, it is logical and noble that life may suddenly be terminated. He does not question the forces, the omniscience of the deities. Any back-eddying on the downstream flow is ignoble. Hara-kiri will cancel the the ignominy.

The westernbound spearhead people of Europe and of the Americas in particular, were repeatedly shuttling to the windward and back, working the adverse force. The challenge provided by death has invoked amongst them the advancement of technology in general but in particular in medicine, resulting in marked extension of the life span. The unnaturalness of death to these people has caused its threat to outweigh ignorance and tradition in the vital emergencies and to admit science at the eleventh hour in a popular application, the extent of which has not been equalled in any other of its potentials.

It is sound scientific speculation that the Garden of Eden episode documents the first psychological difference between easterly and westerly faced peoples. Adoption unto himself by the individual of the deity's knowledge of the westbound civilization, illustrates this fundamental difference between flowing with forces and turning them by rationalization into multidirection advantage.

Both concepts are noble. One concept obtains immediate serenity by complete commitment to the sagacity of the Almighty, mysteriously bespoken by all events beyond the seeming control of this routine function. The other concept wins serenity by faith in the ultimate over-all sagacity which therefore assumes welfare of the many to be implicit in every adversity. It gains its nobility, however, by assuming personal responsibility to discover and nurture into realization the universal benefits which, though tendered by the Almighty, must be earned by truthful labor.

Reaching the Americas by the uphill route, the northwesterly spiral had acquired a myriad of technical advantages proportional to the multitude of adversities. This technically enhanced spearhead of society we have appropriately identified as the industrial. The American industrial Civilization has been likened to a salmon who insists upon climbing waterfalls in order to propagate. Now ages old, no logic could justify sudden cessation of that force-eating northwest trend.

Of course, east was to meet west. They met first in Greece and thereafter repeatedly as Vandals, Huns, etc. But they for the first time after having come completely around the world in the opposite directions to close the circle, when European voyagers met the American 'Indians'. Of course, westerly-bound was certain to go into the psychologically strange encounter under adverse conditions. Of course, westerly-working is ultimately certain to turn the impact of the major trend forces to advantage. Already westbound has pushed eastbound three-quarters of the way back.

These population and technology flows are implicit in the comprehensive concept of the world which the accompanying map dramatizes, and typify the big motions that the sailor comes naturally to comprehend and cogitate by realistic imagining faculties. He also sees the whole world, its waters and its atmospheres, its electrical properties, as a continuously and reliably operating mechanical system.

Long before the movies came along to provide Disney-like educationals, Rear Admiral Alfred Thayer Mahan, U.S.N., described for popular envisioning how the British sailormen had surreptitiously discovered that there was only 'one ocean,' near to whose center in the low forty latitudes around the Antarctic, there roared a made-to-order, one-way merry-go-round, to carry them swiftly eastward to the Orient, and from there swiftly eastward again into the Atlantic. Thus the English and Europeans logically spoke of China and India as the Far East.

Lieutenant Matthew Fountaine Maury, U.S.N., all without benefit of sympathy in his enterprise, but inspired by the cosmic eyes of the sailorman, made the preposterous proposal that the daily and regular log entries of the sea-captains about weather conditions, wind directions, current drifts, etc., be methodically reported into a central record, despite the fact that the data might be years in reaching headquarters. Silly, impossible, impractical, but Maury, gradually accumulated information, began to advise sea-captains that if in January they took one route and on 15 March another, they would reach their destination ahead of uninformed competitors. So impressively right did his predictions turn out to be that the United States then lent itself with vigor to his world measuring program, adding this dynamic newcomer to the early universal language of the green and red running lights, light houses, and bell buoys—all of them the common lanquage of the world sailormen. The collection of data and scientific forecasting urged by Maury has developed directly into today's forecasting meteorology which guides successful world flight.

However, in Maury's time the down-wind sailing advantages, which could have been popularly employed, never appealed to adversity-embracing northwest spiralers in North America. The Americans wanted to do it the hard way. Noting that the English had monopolized the easterly and down-wind sailing below the continental tips, Americans forwarded their great seagoing tonnages right up onto and across their continent. Thus the American railroads developed out of the ocean steamer technology. Seagoing technology went up on the land onto steel rail canals. By principle, they brought up onto the land their ship masts, yardarms, lifting tackle, as cranes and winches to build bridges and great buildings. It was this ability, demonstrated most dramatically by the American transcontinental railways, to transport unprecedented tonnages, formerly carried only on the water, that was recognized by Sir Halford McKinder, English political geographer, and subsequently by General Haushoffer, the German geopolitician, as tantamount to converting the dry lands to the function of oceans. This concept formed the nucleus of the present mechanized warfare and automatically precipitated a re-assortment of world economic and military factors.

As the industrial host of the northwest spiral populated the western American coast, it met direct flows of the easterly spearhead for the first time. Soon thereafter its into-the-wind sailing technology literally took the spearhead aloft to inaugurate the trans-oceanic service phases of the air age westward across the Pacific. The flying ships were heavier than air and therefore were born aloft entirely by energy control technology. Thus, once more they discounted the easiest-way technology whose balloons appeared centuries earlier on the China coast. Abandoning even motorized and directable lighter-than-air craft, the northwest spiral's airplane technology preferred to depend for its bouyancy one hundred per cent on projections of the intellect. Now proven far swifter, safer, and higher flying, this modern stratospheric sailorizing is demonstrating dramatically to the static-minded landsman that he is indeed living in an all motion dynamic universe. Here the real principle of isolationism demonstrated its own fallacy. Isolationism was something deeper; it was statcism, blind inertia. When you have a whole continent to yourself, thousands of hours away from others, you can play ostrich or any other game, year in and out, and you can falsely attribute your advantages to Santa Claus or any other cause and no one can deny the error. But if you want to play ostrich on Broadway, you are liable to get knocked over from behind.

Now as land and air navies grow rapidly, while colliding in cataclysmic demonstrations, the sailorman's viewpoint becomes ever more popularly cogent. And that viewpoint enchanced many-fold by new instruments and instantaneous, world-girdling communication, begins to see the spinning little world even more neatly. As yet somewhat ahead of popular comprehension, the modern sailor has investigated the higher reaches of the world's thin wrap of atmosphere. He now sees that not only does the Earth spin eastward, but that the water upon its surface, though displaying many a black-eddy, also spins eastward in net motion and at a greater velocity than the easterly spinning of the earth below it. Freer still of land obstacles, he finds that the atmosphere also spins in a net easterly direction at an even faster rate, and that the atmosphere's main flows circle primarily around the Arctic and Antarctic Circles, while its back-eddies articulate storm-breeding counter-spirals downward at the Poles, with a steadily flowing back undertow around the Earth's Equator known as the 'trade winds.'

Thus the sailorman discovers, to the surprise of the static-minded landsman, that the earth is not spinning in space under its own momentum at a slowly running-down speed, but discovers that forces are pulling the Earth around, the elements in their more plastic condition pluming forward to reveal the pull.

Thus also the sailorman discovers, to the surprise of the landsman, that it is only one-third the distance in the stratosphere from Kamchatka to Alaska as from Alaska to Kamchatka, provided one's plane can average two hundred miles per hour. He also discovers that a seventy-mile-an-hour dirgible could not make that stratosphere flight at all. He discovers that he was wiser than he knew in sticking to his intellect flying.

By flight in the stratosphere Arctic Circle, in present trans-oceanic equipment, it is quicker to go to Russia from Alaska via Greenland, and it is much quicker to go from Norway to Minneapolis via Siberia and Alaska than to back 'uphill' via Greenland. This is information that yesterday's practical people would have said was of no importance. It will certainly not be ten years before this is more important information to most people than the Pennsylvania Railroad timetable is now. Our new map has the ability to demonstrate relatively greater air distances by appropriate arrangement.

The sailor knows that the library globe is mounted in an azimuthal circle, and its polar axis is tipped only to demonstrate the theory of the earth's motion relative to the sun. Observing how complication is introduced to inadequately reveal a somewhat irrelevant fact, the twentieth-century sailor classifies this library as a pretty contraption, as beguiling and misleading as the planetarium in its ineffectiveness. Forced to deal ever more realistically with a spherical world, he found the globe was a miniature plaything, too small to provide him with important navigational data beyond the most sketchy plans of great voyages. A globe large enough to reveal working data on hazards and aids to navigation would lose any ship in its vast innards. Sailormen need both sectional charts and comprehensive maps.

Then, too, it became evident that one can never see the whole world at once by means of looking at the globe. One cannot see even half of it, due to the rapid increase of curvature tangential to the lines of perspective. The viewer, holding the picture in his brain, could spin the globe and piece together the imaginary continuity. A typical landlubber invention resigned to correct this shortcoming was recently exhibited in a New York City museum. This globe was big enough to permit the viewer to stand inside. The usual exterior surface data was inverted to the interior. However, unless one could see through the back of his head, vision was limited as before to less than one-half the surface. Though hailed by the intelligentsia, this item disgusted the sailor.

Preposterously distorted in its Polar Regions, Mercator's cylindrical map, tangential at the Equator, was none the less preferred by the sailor to the globe. He found Mercator's map could be unrolled to represent the whole world. So long as man's comings and goings were centered within the warm belt girdling the Earth at right angles to its axis, the Mercator map was a pretty satisfactory affair.

But as suddenly as cities were being wiped out by air bombings, there came upon the people the necessity for seeing the world vividly as have the eyes of the sailorman. Suddenly, that is, within actual months, people came to realize that they can girdle the planet in an infinite number of directions. The world had been surprising itself by coming in its own backdoors and down its own chimneys from every unlooked for direction. This called for a revolution in map-making and in cartographical principles such as history had never seen. A need had arisen for new methods of peeling data off the glove and for assembling the peeligs in such a manner as to gain useful knowledge of the spherical coursings.

While still imbued with the static pictures and the traditional thinking, people viewed the first appearance of the new maps as a novelty. Any inclination to comprehension of the relative merit of the different maps as a result of comprehension of the principles by which they were constructed was thrown into utter confusion by the welter of pedagogic terms: sinusoidal, conformal, azimuthal, gnomonic, orthographical systems, scared the layman away from making criticism of the appearance of Australia as a kidney bean three times the size of South America. Feeling the progressive urge to global comprehension, he produced a mass market for commercial globe manufacturing, but after a few swift inspections, they were relegated to decorative functions rather than to be his daily tools. Much more important to him were the newspaper maps of the daily war scenes.

Out of the newspapers and novelties, people are beginning to see that there are some interesting new angles and proportions. Unfortunately, most landlubber cartographers prefer to impress people with the difficulties and esthetics of their art rather than with implications of the dynamic geography of a world-industrializing people.

People are catching on that great circles constitute the spherical straight line and that there is an important continent at the Antarctic and not a jagged, icy fringe along the bottom of an east-west Mercator layout. This advance in popular awareness is despite the fact that the traditional suppliers of maps provided streamlined equatorial Mercator world maps for all the allied war offices and accessory bureaus, upon which maps the ocean distances between Greenland and England appear as greater than those between Tokyo and San Francisco.

People are learning that 'via the North Pole' is the shortest great circle distance from America's midst to the center of population of the world. But when people were told that Tarawa represented the first major gain in the direction of Tokyo, they were not well enough versed in their geography to realize that announcement that the Marines had taken the North Pole would have put the United States closer to Tokyo's center, and that the Marines were actually farther from Tokyo than Chicago is from London. And even those professional geographers and military tacticians who did know that these were the proportionate distances by great circle, have not, unless skilled in the dynamic sailorman's thinking, realized that in the terms of the air motions which twist the great circle courses all out of shape, the North Pole is a third nearer to Tokyo than Tarawa when full advantage is taken of atmospheric motions.

Because of this latter fact, it becomes obvious that the kind of map that static cartographers can produce can only partially educate the people, that is, up to the realistic great circle concept. All known traditional protection methods fall far short of providing a comprehensive, sectional cartographical device which may be mutably arranged in any direction in such a manner as to bring focus to bear on any of the dynamic interrelationships of the world's surface affairs.

One such sailorman's mid-twentieth century invention is the mutable map presented herewith. Unlike all known preceding projections, which represent transfers of spherical data to plane surfaces tangent the sphere only at one point, as in the case of the azimuthal or gnomonic projection methods, or only along one central line, as in the case of the Mercator, or only along one or two segmental arc lines, as in the conics, this projection is one in which the coincidence with the projected sphere occurs all along the complete boundary of each section of the projection, thus retaining the unique cartographical feature of being the only projection in which uniform great circle scale characterizes the logical terminal edge of each section to be projected, that scale being maintained intact after transfer from the sphere to the flat surface of the map.

Sailorwise, this new projection is made from the cosmic viewpoint, that is, the astronomical zenith and the center of the earth always remain respectively vertically above and below each and every point of the surface of the cartographic data. Not only is this true in its sperical arrangement but also in its planar projection into the sections of the comprehensive map.

Because the enclosing border scale cannot be elongated, distorted, or contracted and represents a great circle bent flat into a one-dimension line, the adjustment of the contained spherical surface segment to a plane surface segment must be satisfied by interior contraction of the data instead of by exterior stretching, as in all other methods of projection. Because of this feature, the several pieces, of course, fit neatly together, being the mutual sides of adjacent polygons and being separated by the same great circtle or straight line. Because the area of a circle increases as the square of its radius, the same error outwardly disposed must be distorted to four times greater extent than by inward disposition.

Benjamin B. Taylor

From the contents of recent issues of this magazine you have noticed that we have attempted to establish what we believe to be a valid relationship between the architect and his world community. You have also discovered that we have concerned ourselves with what we consider to be architectural developments beyond the problems of human shelter. Our aim for such a study is this: as the size of our community becomes progressively smaller through more effective intercourse brought on as a result of faster, more efficient communication, the sphere of our responsibilities becomes increasingly larger; so that we, as students, are no longer able to feel secure in dealing with isolated details designed to display our petty uniquenesses or peculiar styles. We prefer to think of ourselves as pattern-makers, as coordinators of the many activities which must be successfully integrated in order to achieve a harmonious product. And, moreover, we prefer to enlarge our scope of activities so that we may be able to intelligently deal with such things as crop rotation, radio telescopy as well as painting, landscaping, and, of course, the ever-present problem of man's shelter.

From these same contents you have further realized that our contributors have been individuals who are actively engaged in a variety of creative fields. They have been neither all students nor all practicing men. Our reason for such a selection is plain—we simply cannot afford to make occupational prejudices when we can learn from so many.

—THE EDITOR

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visitors to the school of design for the winter and spring terms:

BUCKMINSTER FULLER: *(Month of January) Comprehensive designer from New York conducting a problem with a group of architectural students and several open lectures.*

ROBERT ROYSTON: *(Month of April) Landscape architect from San Francisco (Eckbo, Royston, and Williams) conducting problems with advanced students in Landscape Architecture.*

ALEXANDER ARCHIPENKO: *(January 25, 26, 27) Sculptor from New York City conducting daily talks with students and one public lecture.*

HIDEO SASAKI: *(February 22, 23, 24) Assistant Professor of Landscape Architecture at Harvard University acting as visiting critic on special landscape problem.*

CHARLES EAMES: *(March 1) Industrial designer from Venice, California conducting seminars with students and one public lecture.*

FELIX SAMUELY: *(April 12 through 24) Consulting structural engineer from London, England acting as special structural consultant to fifth year students of Architecture.*

ROBERT LE RICOLAIS: *(April 18 through 21) Consulting structural engineer from Paris, France conducting seminars with students of the school.*

EDUARD SEKLER: *(April 1, 2, 3) Architect and city planner from Vienna, Austria conducting lectures on planning and seminars with students.*

RICHARD NEUTRA: *(April 22, 23) Architect from Los Angeles conducting a public lecture and informal talks with students.*

ROBERTO BURLE-MARX: *(May 15 through 24) Landscape architect from Rio de Janeiro, Brazil conducting a problem with advanced students in Landscape Architecture, a public lecture, and seminars.*