GYORGY KEPES

INTRODUCTION

Expelled from the smaller, friendlier world in which previous centuries of men moved with confidence born of familiarity, we are today compelled to cope with an expanded scale of events in a big, alien, redefined world. In order to live freely and fully in our new world, we have to learn to map its strange vistas, to discern in them harmonious structures appreciable by our visual sensibilities, and to arrange our lives in conformity with the new perspectives.

So far, we have failed to live up to the twentieth-century challenge. Science has opened immense new vistas to us, but we have failed to utilize our new technology fully or to share it wisely. We shrink from accepting the deeper and richer sense of life, uniquely inherent in our twentieth-century world, that is sometimes touched upon in the best moments of our best artists. We have not yet found our places in this broadened world.

We should realize that our failure was caused, in truth, by the blinders that we have put around our eyes, hearts, and minds. Sometimes ignorance, sometimes inertia, but mostly fear that we may be forced into giving up vested interests has kept us from pooling our knowledge, feelings, and power, and has thus prevented us from finding our potential twentieth-century selves.

Most persons who work in cultural and scientific fields recognize that the past century and a half has brought a fragmentation of experience, an explosion of knowledge into many self-contained disciplines, each with a wildly growing and increasingly private language. The infant Macaulay thought that he knew everything worth knowing. He did not—although a Macaulay, he was nonetheless an infant—but in his day this accomplishment was still conceivable. Today, it is manifestly impossible. And the accelerating spiral of knowledge, with its concomitant centrifugal thrust, is driving us apart. Clearly, our sense of a cohesive world is endangered by a crisis in communication. We are lost in a new scale of existence, with once-familiar relations uprooted, and habits and purposes displaced.

If we recognize and meet the challenge of our stage of history, we can live fully and sanely in contemporary terms, without danger of cultural impoverishment. We need, therefore, to find new centripetal forces that can hold our common understanding together and realize for us the spirit of our times.

We now speak many different dialects, to be sure, but these are dialects of the same basic language. We can communicate—that is, combine and reinforce our knowledge with that of other men—by stimulating the circulation of ideas and feelings, finding channels of communication that can interconnect our disciplines and enable us to see our world as a connected whole. G. G. Simpson, the paleontologist, has commented that, as organic evolution was brought about by interbreeding, so our further cultural evolution today will come about through broadscale "interthinking."

There must be feedback to our central scale of values from the new vistas that confront us in the scientific, technological fields. Our senses need to bridge these vistas and catch their meanings, their human overtones and undertones. Using our extraordinary vision, we can fashion such bridges.

Vision is a fundamental aspect of human insight. It is central in shaping our physical, spatial environment, in grasping the new aspects of nature revealed by modern science, and above all in the experience of artists, who heighten our perception of the joys and sorrows of life. Artists are living seismographs, as it were, with a special sensitivity to the human condition. They record our conflicts and hopes; and their immediate and direct response to the sensuous qualities of the world helps us to establish an entente with the living present.

As the twentieth century has grown older, most of our artists have recoiled upon themselves. They lack orientation in the total contemporary world, which, if they but knew it, holds as much promise as it does menace. Their honest response has been to scream their isolation. In frantic retreat, many of them have adopted a scorched-earth policy and burned their most valuable cultural belongings. Cornered and confused in a "horror of lost self," as the poet Robert Lowell puts it, some of them advertise brutality as vitality and intellectual cowardice as existential self-justification.

Artists today come together in small groups in great cities. There, in little circles that shut out the rest of the world, initiates share one another's images. They generate illusory spontaneity, but miss the possible vital, deep dialogue with contemporary intellectual and technological reality. It is unfashionable today, if not taboo, for artists to think and act on the broad terms of cultural and social ideals. No doubt, moralizing in art can lead to creative suicide, just as market-policed and state-policed art can lead to the murder of artistic honesty. But the other extreme—lack of intellectual curiosity and rejection of commitment—leads to emaciation of artistic values.

It seems that the overwhelming task of creating the new scale of modern science has used up some of our most vital intellectual and emotional equipment. When a vital part in a complex machine is worn out or out of adjustment, it is wiser to stop the mechanism than to grind on to destruction. Engineers, in such a case, devise arrangements that ensure orderly shutdown when a part gives way. It may be that what our cultural life is now experiencing is such a "failure to safety," as the engineers call it. Our artists may thus have served us by preventing disaster.

Nevertheless, emotional return to the archaic, ancestral cave is an obvious failure to function in contemporary terms—however necessary. Let us not mistake this temporary standstill for a genuine answer to our deeper long-range needs. We cannot renounce the dimensions of the twentieth century—the new vistas, the scientific triumphs—because they were bought with human distress. We may suffer from exposure to the new scale, but it is necessary for us to go ahead and meet its challenge.

Only complete acceptance of the world which is being born can make our lives genuinely acceptable. Such acceptance implies, above all, two concrete tasks. One, in every field of human endeavor we must advance to the furthest frontiers of knowledge possible today. Two, we must combine and intercommunicate all such knowledge so that we may gain the sense of *structure,* the power to see our world as an interconnected whole.

Structure, in its basic sense, is the created unity of the parts and joints of entities. It is a pattern of dynamic cohesion in which noun and verb, *form* and *to form,* are coexistent and interchangeable; of interacting forces perceived as a single spatio-temporal entity.

It is no quibble to separate the notion of structure from such related concepts as order, form, organized complexity, whole, system, or *Gestalt.* Each historical era seeks and needs a central model of understanding. Structure seems central to our time—the unique substance of our vision.

The most powerful imaginative vision is structure-oriented. As old connections crumble away, inevitably our creative efforts seek out new ordering principles to replace the old. In different fields, for different reasons, the new ordering relations are being accepted as fundamental. Scientists, for example, have come to recognize that the key properties of different materials are determined according to the way in which atoms, the basic building units of nature, are arrayed and the way in which they are joined

together, rather than, as once assumed, according to the elemental stuff of the material. The differences among solid, liquid, and gaseous states are explained by the patterning of their atoms, the relative closeness of their molecules.

From inorganic structures to plants and animals, from the movements of animals to their social behavior patterns and to human relations, structure is central. A dramatic focus of structure awareness has been reached through understanding of the molecular structure underlying the genetic mechanism of living forms. Inherent in the spiral structure of the complex molecule DNA is the ability to reproduce itself. Thus, a built-in program of growth and development is provided for an infinite variety of unfolding structures of living forms.

Structure is also central to our understanding of our ways of understanding. Studies of our perceptual and cognitive processes by *Gestalt* psychologists show that psychological events do not occur through the accumulation of individual elements of sense data but through the coordinated functioning of clearly patterned networks of sensation determined by structural laws. Investigations into the nature of language show that the structural properties of languages have far-reaching effects on ways of thinking. "For my part," says Bertrand Russell, "I believe that partly by means of the study of syntax, we can arrive at considerable knowledge concerning the structure of the world."* For the structure of a person's thought processes is based on the complex structure of his language, which offers him certain categories and denies him certain others. Complementing the mathematical and logical study of language, such complex tools as high-speed computers help to shed light on the various structural inter-relations of the nerve centers.

Creative exploration in the arts has yielded significant parallels with scientific investigation. The early twentieth-century painters who were still hoping and trying to embrace the complete vista of contemporary conditions looked for structural principles in art. Instead of aiming at an illusionary rendering of what they could see around them, they invented images and patterns. Clear, unmodulated surfaces, abstract shapes, and simple, basic colors devoid of emotional overtones were used as building blocks. "True architecture," wrote Juan Gris, a thoughtful pioneering painter of this period, "cannot be broken up into different pieces, each of which is autonomous and exists alone. A fragment of architecture will be no more than an odd, mutilated object that ceases to exist when it is removed from the one place where it belongs. Construction, then, is merely the imitation of architecture. The technique of painting is flat, colored architecture, and not construction. It is based on the relations between colors and the form that contains them."** This passionate involvement with image-building process had its great ancestor in Cézanne, many of whose successors built consistent, legible pictorial structures from the direct data of inner sensibility.

The most impressive manifestation of this interest is seen in contemporary architecture and engineering. Pier Luigi Nervi, whose work has almost symbolic significance in this context, has observed that the ever-increasing size of contemporary buildings has brought the problem of structure to the forefront. Structure has assumed such formal importance as to become the central feature of architectural design. In structural architecture, the forces of compression, tension, moment, and shear become a clearly legible

**An Inquiry into Meaning and Truth*, p. 438.

**"On the Possibilities of Painting," *Trans-Atlantic Review*, Paris, vol. I, p. 482.

pattern of stress and just as clearly legible a pattern of neutralization of stress—visible and comprehensible, demonstrative of the properties of the materials with which the forms are executed.

The editor of these volumes has a long-standing, stubborn belief that, all signs to the contrary notwithstanding, we may build, from our rich, many-faceted range of structural knowledge, a structure of structures, a new sense of interdependence between knowledge and feeling—and thus a keener and more profound awareness of our own time. Led by this conviction, he has conducted seminars at the Massachusetts Institute of Technology for fifteen years, with the participation of scientists, architects, and artists. It was hoped that students might gain confidence that they could combine and reinforce their knowledge with the knowledge of other fields by stimulating the circulation of ideas and feelings, finding channels of communication that interconnect disciplines, and suggesting the interconnectedness of the world as a whole.

The volumes of this series have grown out of those seminars. The contributors include some of the original participants and others whose papers have been written especially for these books.

The present volume consists of two parts: the first is concerned with the scientific approach to structure and structuring processes in nature; the second with the structures and structural principles found in man-made forms, especially in artistic communication and expression.

Three scientific essays form the first part. The first two essays deal with structural laws in inorganic nature. The third examines the role of the exterior world in the structuring of our interior world, of our thoughts and perceptions. All suggest the new and immensely rich resources of images that we can derive from our present knowledge of the world and of the minds of men.

The papers in the second part of the volume develop this suggestion further. They demonstrate how our new insight into structure can be adapted to provide keys, metaphors, that illuminate new vistas and adumbrate new solutions to the problems faced in creating our technical and artistic environment.

The first essay, by Lancelot Whyte, gives a synoptic view of the structural principles operating on the many levels of our physical world. Whyte emphasizes the close structural interconnections of the basic building blocks of our universe. He points out that we are moving away from the classical science of simplicity toward a modern science of ordered complexity: we are replacing the older concept of atomism with the newer concept of structure—structure that is not a rigid scaffolding for a schematized reality, but an aspect of the morphologic process.

One observation by Whyte underlines the significance that his remarks about our current knowledge of the physical world can have for all of us. He describes the crisis of the physicist working on the frontiers of science. For him, the physical world has become complex and abstract. Its visual content, which first impelled him to explore and explain, has become faded and has lost its original strength and inspiration. Whyte maintains that, if he were to return to the three-dimensional world of human eyes and hands and seek anew to interpret its everyday forms, fresh insights would be obtained and his disillusionment dispelled. The physicist's crisis bears upon the whole scope of this volume, for science and art share the problem of vision, in its deeper and creative aspects. The immediate data of vision are continually looked upon afresh wherever they are to be reorganized in a higher context.

Cyril Smith, in the second paper, examines a more limited aspect of the physical world in which structural patterns have a more prominent and obvious meaning. Smith examines the same structures at different microscopic levels, and reveals the complex inter-relationships of structure at different levels of existence. He leads the reader from the microscopic level of crystal patterns to the level of structural organizations visible to the naked eye. Particularly significant is his discussion of pattern matching, of congruence in structure from one level to the next. This discussion has importance for the creative arts, for it points to a possible correspondence between the structural patterns of the physical world and structural needs of the human mind.

The contribution of the psychologist Richard Held deals with the most recent investigations of the relationships between objects of the outside world and their projected inner images. We open our eyes and look out on the world of objects, shut them and blot out the scene. We walk among and between things in the world and gain different perspectives on them. How, why, and when we can find correspondences between the objects and their "effigies," as Held calls them, is basic to our understanding. What structural correspondences we can discern between the outer and the inner world is fundamental to the manipulation of our environment and also to our inner richness. It is assumed that some kind of order among the stimuli coming from the environment must be reserved in the retinal image. What the nature of this order is and the way it is translated into inner images plays a significant role in furthering our understanding of our relationship to our environment.

The second part of the volume is concerned with the arts in the broadest sense. Each essay suggests ways in which our understanding of structure in nature can guide us in creating forms—whether of design, such as buildings and cities, or of communicative expression, such as paintings and sculptures.

The essay by Bronowski is a thoughtful introduction to this section. It examines the correspondences and analogies to be found in every age between the scientific image and the artistic vision of the physical world.

"Conceptuality of Fundamental Structures," by Buckminster Fuller, provides an inspiring bridge between our comprehension of the structural principles of nature and the potential application of this knowledge to creation of man-made forms.

The next five essays all deal with man's building activities as he structures the physical environment around him. In his "Structure, Construction, and Tectonics," Eduard Sekler analyzes and clarifies our use of these key terms, which recur in the subsequent essays.

The two short papers by Luigi Nervi examine the vital link between the designer's knowledge of physical processes and his own creativity. The creative man involved in the shaping of physical forms must have a deep respect for the nature of his material and for the structural pattern that this material dictates. Nervi's essays emphasize the importance of the interplay between imagination and the cold facts of task and material if the designer is to arrive at new, authentic solutions of form problems.

The essays by Nervi, the Smithsons, and Maki and Ohtaka are concerned in differing degrees with the structuring of our environment, and are progressive in breadth of scope. Nervi deals with individual forms, such as buildings and bridges; the Smithsons, in "On Building toward the Community Structure," with the redevelopment of Sheffield University, in which the basic task is to organize large-scale units in relation to one another; Maki and Ohtaka, in "Collective Form," with gigantic cityscapes

beyond the present scope of our imagination. The latter two essays, dealing with community and metropolitan organization, embody concepts of utmost importance today. The increasing magnitude and complexity of entities to be structured is the newest and most challenging problem of twentieth-century design.

The last five papers deal with problems of structure in communication and artistic expression. I. A. Richards is directly concerned with structure in linguistic communication; he points out that language structure has assumed sociological importance as an educational tool.

Structure and communication—this "key-and-lock combination," as Richards puts it—are also the subjects of H. L. C. Jaffé's essay "Syntactic Structure in the Visual Arts." Jaffé makes clear that abstraction and concern with structural problems in painting of the last eighty years have been prompted essentially by a will to communicate. He also points out that many contemporary artists reject a structural approach. He concludes that the concept of painting as a semantic system, or language, is really a "pre-eminently social" concept, because "language and communication are closely linked to the contact of man with his fellow human being."

Max Bill, like Nervi and Jaffé, discusses the structural approach in the visual arts, and points out how the order of natural forms and natural law inspires the creative imagination. To Bill, structure is dynamic; uniformity and invention "manifest themselves [in art] as rhythm . . . a work of art grows out of the general structure by means of a rhythmic order." This statement is significant: in contrast to other approaches, it suggests a common structural basis for both external nature and the processes of human perception.

If Jaffé and Bill share a high regard for nature's structural laws as nourishment for art, Richard Lippold represents a dissenting voice. He shows that the importance of structure is by no means self-evident to all contemporary artists, for some of whom the intellectual turmoil of this century has destroyed it. Noting the rapidity with which modern science demolishes its theories, he maintains that the only approach to nature left to art is the illusion afforded us by our senses and feelings. Despite this playful evasion and the sophisticated manner in which Lippold divests structure of reality, his essay contains a clear and significant truth: ordinary appearances *are* illusion, not the concrete reality we once thought.

The concluding essay touches upon the central theme of this volume: the correspondence between the structural characteristics of natural and artistic forms. In her "Concrete Painting as Structural Painting," Margit Staber seeks a definition of structure that enables us to formulate this conjunction of scientific and artistic, of rational and aesthetic. She finds a suitable modern definition in the biological writings of Wolfgang Wieser: " 'Structure' should be understood to mean a network of relationships of elements or of elementary processes. Structures appear wherever elements combine into a meaningful whole whose arrangement follows definite laws. The wholeness in which we discover and examine structures we call a 'system.' Thus, there are inorganic, organic, sociological, and technical systems . . ." To these, Staber would add aesthetic systems.

Those central images and concepts which provide the key to man's inner world, and thus to the way in which he organizes the outer world around him, are different for different stages of history.

To the Greeks, form was essential—form and matter. Upon chaotic matter, God or man imposed a marvelous intelligence, creating form. The Greek universe was smaller than ours, shaped in accordance

with the perceptual limits of the naked human senses. Human ingenuity could stretch those limits—but not far. There was not room enough for a thing to have more than one matter or more than one form.

The universe we know today stretches endlessly beyond the reach of our unaided senses. The same "thing" has one type of organization on the level at which we examine it with our eyes and hold it in our hand, and another type of organization at the level of nuclear mechanics. In between, there are many intermediate levels, each as real as the next. The key modern concept of structure encompasses arrangements on all these levels and many, many more.

The world as a set of structural systems does not divide into the two territories of scientific knowledge and artistic vision. Rather, both our scientific understanding and our artistic grasp of the physical world exist within a common structure of motivation, communication, and knowledge. Every step toward the mutual enrichment of art and science brings us closer to full realization of our own potentials.

To reach what we all hope for, to become worthy of an environment worth living in, we must do what we can to bring our outer and our inner worlds together—renew the ancient marriage of art and science, art and nature. To rely solely on one area of our knowledge may lead us into blind alleys. Let us heed the warning given us by John Milton in *Areopagitica,* 1644:

"We boast our light, but if we look not wisely on the sun itself, it smites us into darkness . . . The light which we have gained was given us, not to be ever starting on, but by it to discover onward things more remote from our knowledge."

MAX BILL STRUCTURE AS ART? ART AS STRUCTURE?

One can consider art to be essentially identifiable as invention. The invention of means of expression; the first thrust into realms which contain as yet unknown aesthetic and formal possibilities.

That is the sense in which art presupposes something novel. The newness of the idea, newness of the themes, newness of the form. This kind of newness can be achieved in two ways: (a) in an individual way—which has its origin in the intellectual and psychological make-up of the artist; (b) in a more general way—which bases itself on experimenting with objective possibilities of form. In an extreme case (a) will lead to 'art informel' or to a neo-dadaistic combination of materials; (b) leads to structure. On the one hand: materials in their "natural" condition, individually interpreted. On the other: tectonic laws which ultimately are schematically applied in a uniform distribution.

Even though amorphous material can be considered to possess an inner configuration—a structure of its own—in its natural condition, we can eliminate this kind of structure from our consideration, for as an inherent structure it is not accessible to aesthetic or visual arguments, either in painting or in sculpture.

Tectonic laws are altogether different. They are accessible to aesthetic arguments for they are principally laws of order, and in the end art = order. In other words, art is neither a surrogate for nature, nor for individuality, nor for spontaneity. And where it appears as such, it is art only insofar as it informs the surrogate with order and form. Because order is so characteristic of art, art begins to rely for order on the tectonic laws.

Now the question arises as to what a tectonic law, a law of order, as we know it in science, means with respect to art. That is, where does structure end and art begin?

Let us start with the extreme case: a plane is covered with a uniform distribution in the sense in which this is understood in statistics; or a uniform network extends into space. This is an order which could be uniformly extended without end. Such an order we here call a structure. In a work of art, however, this structure has its limits, either in space or on the plane. Here we have the basis for an aesthetic argument in the sense that a choice has to be made: the possible, aesthetically feasible extension of the structure. Actually it is only through this choice to limit the arbitrarily extensible structure on the basis of verifiable arguments that a discernible principle of order becomes comprehensible.

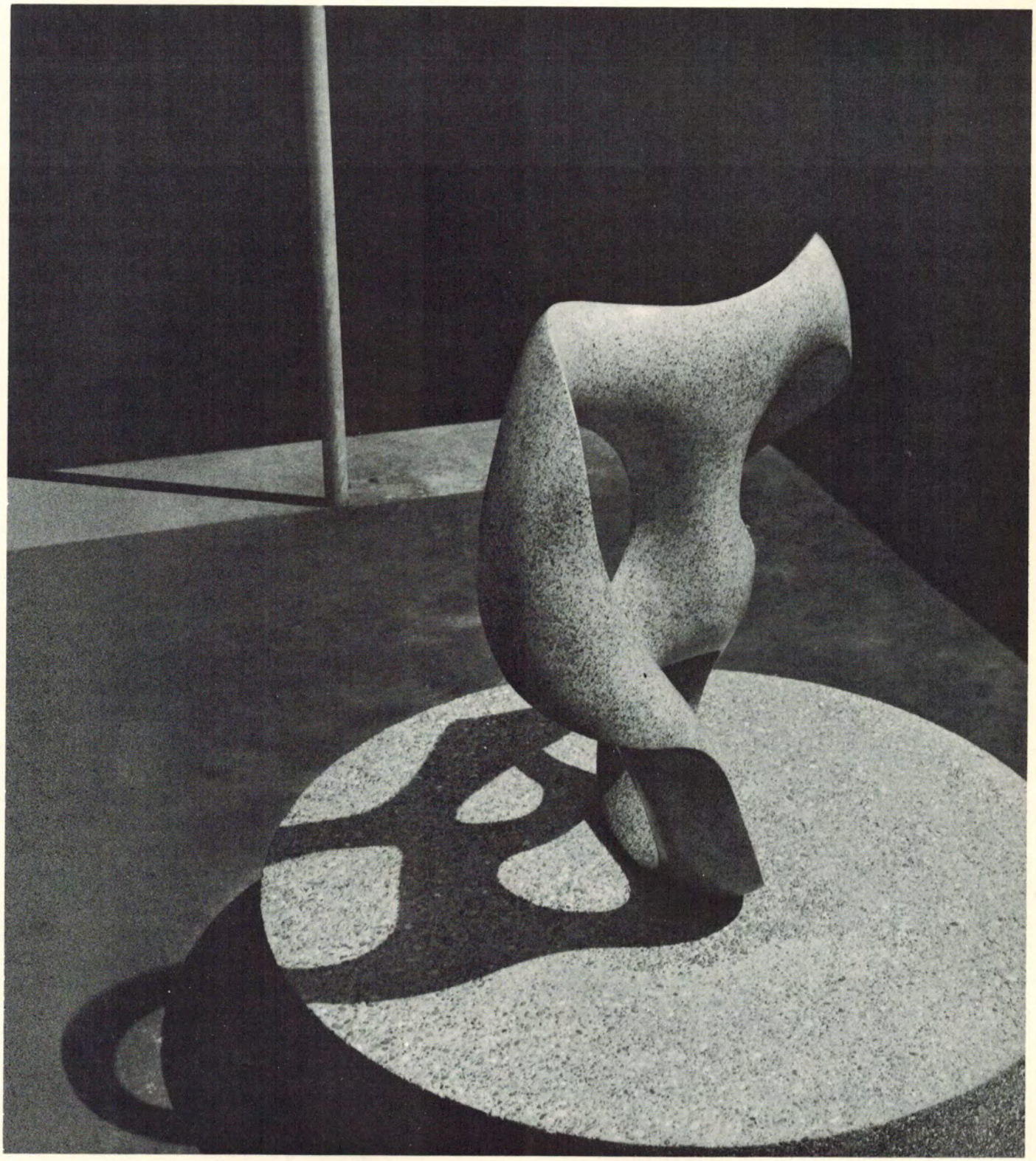
But is a choice, or the setting of limits, sufficient for the creation of a work of art? This question arises mainly because, since the radical attempt to dispense with all individualistic stylistic expression beginning with Mondrian, no reduction can be extreme enough. This also arises because the aesthetic information offered by the means of expression is dwindling sharply: *neither locatable nor measurable, neither expressing nor indicating an order:* producing a neuter with aesthetic pretensions. The aesthetic quality is beginning to withdraw into the most extreme reductions, into the most extreme objectivity, culminating ultimately in the negation of newness and of invention.

But invention always presupposes the discovery of new problems. The discovery of these new problems is individually determined. Art is unthinkable without the effort of the individual. Order on the other hand is impossible without an objectifying structure.

This means that art can originate only when and because individual expression and personal invention subsume themselves under the principle of order of the structure and derive from it a new lawfulness and new formal possibilities.

Such lawfulness and such inventions manifest themselves as rhythm in an individual case. Rhythm transforms the structure into form; i.e. the special form of a work of art grows out of the general structure by means of a rhythmic order.

Max Bill. *Rhythm in Space*, 1947–48.



R. BUCKMINSTER FULLER

CONCEPTUALITY OF FUNDAMENTAL STRUCTURES

What do we mean by the word structure? I have pondered on it a great deal and have decided to define "structure" literally from a descriptive consideration of its natural occurrence—for instance, its occurrence in chemical elements—for the family of chemical elements and their most complex agglomerations as super star galaxies are alike fundamental structures. It is clear in the results of modern scientific experiment that structures are not *things*.

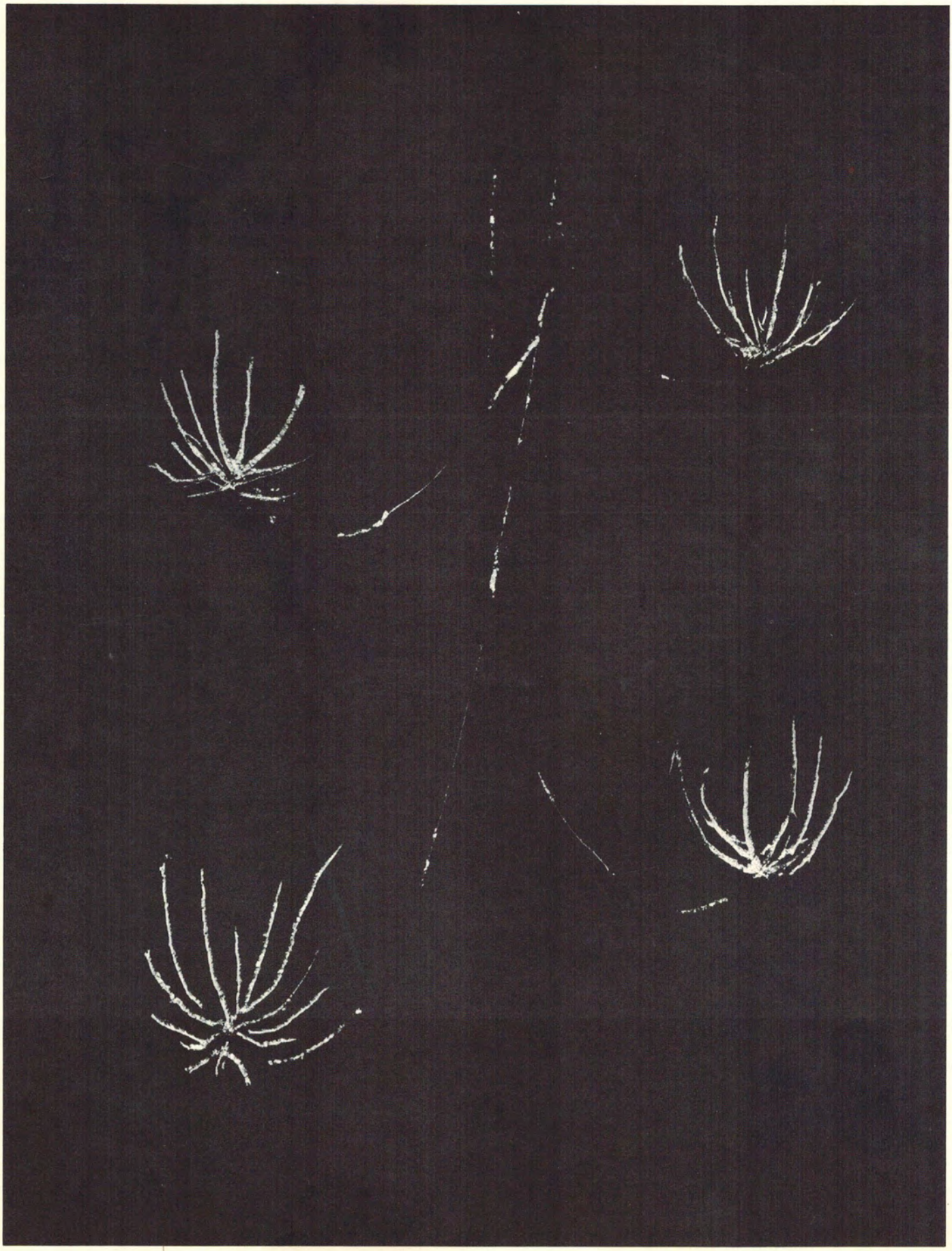
We might define structures descriptively as *patterns of inherently regenerative constellar association of energy events*. That sounds intricate and obscure at first so perhaps I had better explain what I mean by each of the terms. For instance by *inherent* I mean behavior *principles* discovered by man always to be reliably operative in universe under a given set of circumstances. I use the term *regenerative* because in an all-motion universe (which Einstein posited and the physicists in due course found to hold true), all the patterns of the universe are continually but non-simultaneously affecting all the other patterns of universe in varying degrees and are continually reduplicating themselves in unique local configurations. These patterns (Fig. 1) may be described as *constellar* because their component events stand dynamically together like star groupings, and any event patternings which become locally regenerative are constellar patterns. It is a tendency of patterns either to repeat themselves locally or for their parts to separate-out to join severally or singly with other patterns or to form new constellations.

All the forces operative in universe result in a complex progression of most comfortable (i.e. least effort) arrangements in which the macro-medio-micro star events stand together here and there as locally regenerative patterns. I call these spontaneously regenerative local constellations basic structures since they appear to be universally and inherently recurrent. This definition of structure holds true all the way from whole non-simultaneous universe through all the lesser local and inherently regenerative pattern differentiations down to the atom and its nuclear subassemblies.

It is interesting in considering the meaning of structure, to think of the redefinitions emerging annually at the Massachusetts Institute of Technology in respect to fundamental phenomena. Every February the Institute exhibits, in the main entry hall on Massachusetts Avenue, a collection of self-definitions by the various academic departments. This is done so that the prospective students for the coming year (it is enrollment time at mid-years) may consider what the Institute has to offer. The Physics Department, the Chemistry Department, the Mathematics Department and so on, all make statements about their particular concerns. They must say what they have to offer to the prospective students in a way that is both comprehensible and of high integrity of scientific meaning. Casual suggestions of the nature of the work will not suffice. Thus, annually each department has found it necessary to re-examine its inexorably evoluting disciplines and where appropriate to redefine its subject. Since each year both man's art and science of communication have improved, I have found it interesting to note how for instance the Physics Department at the Massachusetts Institute of Technology redefines itself as the years go on.

There has been such a rapid evolution in the sciences that what for instance the Physics Department said it was concerned with in 1912 was not what it professed in 1922. In 1912 (before M.I.T. moved to the Charles River in Cambridge) it was concerned with *mechanics* in general, optics, and so forth, and a phenomenon called electricity was newly included as an appendix. By 1922 science was overwhelmed with the newly discovered world of electron behaviors and the Physics Department said publicly that physics was primarily concerned with electronics. Physics in 1950 at the same Institute was described as being concerned almost entirely with the nucleus of the atom.

Fig. 1. Four non-simultaneous rocket bursts with visually overlapping patterns. Their four stars constitute the four vertices of a tetrahedron—the fundamental quantum of universe's structuring. There is a tetrahedronal structural *interrelationship* between (1) *the day before yesterday*, (2) *yesterday*, (3) *today*, and (4) *tomorrow*. Though we speak of them as "the four balls in the air"—maintained there successively by a juggler using five balls to do his trick—they are not the same balls and the four are never in the same positions; nonetheless there are always, and only, six fundamental interrelationships between "the four balls in the air", i.e., ab, ac, ad, bc, bd, cd; a, b, c, d, are non-simultaneous events. Universe structures most frequently consist of the physical *interrelationship* of *non-simultaneous events*. Because of the fundamental non-simultaneity of universal structuring, a single, simultaneous, static model of universe is inherently both "nonexistent", conceptually impossible", as well as "unnecessary". Ergo, *universe does not have a shape*. Do not waste your time, as man has been doing for ages, trying to think of a unit shape "outside of which there must be something", or "within which, at center, there must be a smaller something". All the words in the dictionary do not make one sentence; all the words cannot be simultaneously considered, *yet* each of the words is valid as a tool of communication; and some words combine in a structure of meaning.



The Department of Mathematics at M.I.T. which embraces the fundamental communication systems of all the sciences, is also the most generalized of scientific disciplines. The last time I wrote down its annual statement of self-definition was in 1953. This definition hasn't altered much since then. Mathematics, which is both the most comprehensive and abstract of the sciences, tends to evolve less rapidly than physics or chemistry. Mathematics generalizes all sciences and all other sciences must use it.

M.I.T.'s Department of Mathematics' self definition of 1953 said: "Mathematics, which most people think of as the science of number, is, in fact, *the science of structure and pattern in general*." It went on, for another hundred words or so, but that was the opening sentence. This definition of mathematics as "the science of structure and pattern in general" agrees comfortably with my definition of the word "structure"—structure is not a "thing"—it is not "solid."

Now you know what I mean by structures as the inherently regenerative local constellar subpatternings of universe. Since by my own definition *universe is the historically synchronous aggregate of all men's consciously apprehended and communicated* (to self or others) *experiences* and since the experiences are each finite but non-simultaneous, universe is a non-simultaneous yet dynamically synchronous structure, which is unitarily non-conceptual as of any one moment, yet as an aggregate of finites is sum totally finite. Thus we realize that finite structures are mostly non-conceptual in any momentary sense though certain local structures in universe are momentarily conceptual such for instance as the continually transforming historical aggregate of men's experiences packaged together in the words "planet earth." This may be a difficult introduction to the subject of structures but it sets the stage for further thought searching on a subject whose heretofore illusory "static solidness" has completely misled human thought and occasioned the last century's discoveries of science to be perversely surprising information seemingly to be dealt with only by geniuses.

Let us see how our definition of structure applies to architecture. I often hear it said in our technical schools, and by the public, that architects build buildings out of materials. I point out to architectural students that they do not do that at all. That kind of definition dates back to the era of men's thinking of matter as solid. I tell architectural students that what they do is to organize the assemblage of *visible modular structures out of subvisible modular structures*. Nature itself, at the chemical level, does the prime structuring. If the patterning attempted by the architect is not inherently associative within the local regenerative dynamics of chemical structure, his buildings will collapse. The kinds of spans man builds, the sizes of his columns, and the ways in which, in the end, man must enclose space, are governed by the fundamental principles of structuring preconceived in a priori structuring laws of nature. The principles governing structure not only prescribe what man can put together, but they are operative at the molecular level, at the atomic level and at the nuclear level. They are also operative in each of man's life cells and throughout principles of structure in the starry heavens. They are universal, they are purely mathematical, weightless.

Now, in order to understand universal structure one must consider the fundamental coordinating system employed by nature. It occurred to me a half century ago that nature might have a coordinating system of her own—which might not be the same system as that which man has arbitrarily invented, adopted and applied to his measuring of nature. It also occurred to me that nature probably did not have separate departments of physics, chemistry, biology, mathematics and sociology, etc. In formulating the quadrillions of bubbles per second in the waters of Niagara Falls, nature has no time in which to refer her structural formulation decisions to bureaucratic conventions of department heads of academic categorical states.

To implement the invention of the calculus, man has used the XYZ coordinate system formalized by Descartes out of the Greek's 90 degree symmetrical cross "tree" of three supposedly straight and supposedly continuous "infinite lines." We have learned to reason only in terms of these experimentally demonstrated fallacial suppositions and only in three dimensions: of width (X), breadth (Y), and depth (Z). But width, breadth and depth do not include consideration of how hot a local structural event may be nor how long it has been there nor how much it weighs. There are a lot of other aspects of Nature which the ghostly Greek kind of geometry did not accommodate, as for instance, the experimental information that two actions cannot take place through the same point at the same time—i.e. two lines cannot run simultaneously through the same point. In the Greek's three-dimensional conceptionings, 90 degree perpendicularity and non-parallelism to a plane already established were essential to qualification as a new dimension. Thus in the development of the XYZ coordinate system, we have found only three unique 90 degree line convergences in a common "point." All our analytical geometry, and the technically difficult structures we build with it, are translated through the XYZ coordinate system. The calculus is used to

Fig. 2. Identical radius, spherical agglomerations in closest packing. The comprehensive coordination of nature's most economical, most comfortable structural interrelationships employs 60° *association* and *disassociation,* which provides an omni-rational interrelationship accounting system—which if arbitrarily accounted on a 90° "three-dimensional basis" becomes inherently irrational.

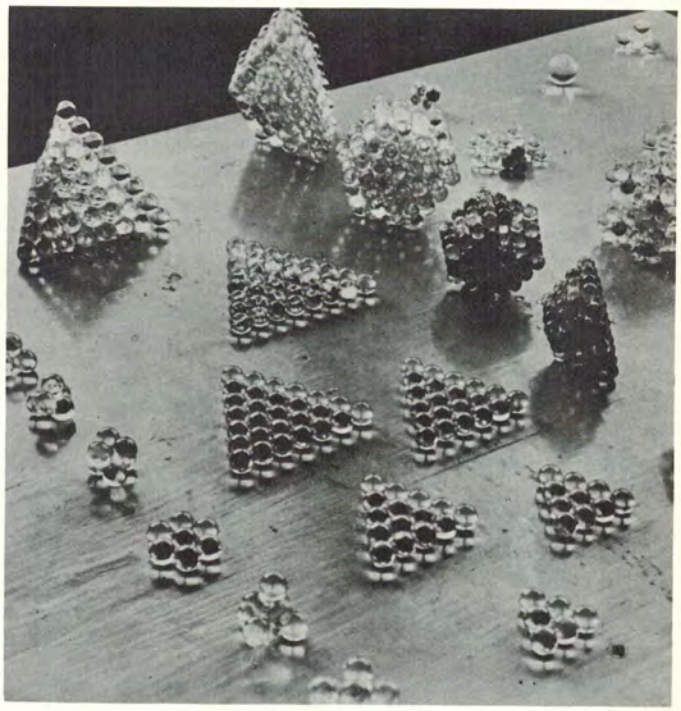


Fig. 3. Vector equilibrium, i.e., a structural system in which the radial vectors and the circumferential vectors are of equal magnitude; ergo the tendency to *explode* or to *contract* is in equilibrium; either *could* but neither *does,* unless something is added or subtracted to change the dynamic balance. Equilibrium is a "dangerous" condition because—due to entropy—something is always about to be added or subtracted to change the balance. When an airplane *stalls* it is in equilibrium. The vector equilibrium consists of four symmetrically interdisposed planes. These four planes are parallel to the four unique, symmetrically interdisposed planes of the regular tetrahedron. The vector equilibrium shown in the picture is subpatterned with a two-fold, modular frequency, edge and radius subdivision. Both *radial* and *circumferential* frequencies, of modular subdivision of the *vector equilibrium* are always, everywhere, equal, in both magnitude and number. The *volume* of the *vector* equilibrium is always *twenty times frequency to the third power,* written as $20\ v^3$. The vector equilibrium is also known as an isotropic vector matrix. The vertices of the vector equilibrium of any frequency are always congruent with spheres of equal radius in "closest packing" (see figure 2, in which the fourth row of spheres, in closest packing, show vector equilibrium models of two, three and four frequencies, respectively). The *number of the vertices* in the vector equilibrium, which are always the same as the *number of the spheres* in omni-symmetrical, closest packing, are always: *frequency to the second power times ten plus two*—written as $10\ v^2 + 2$.

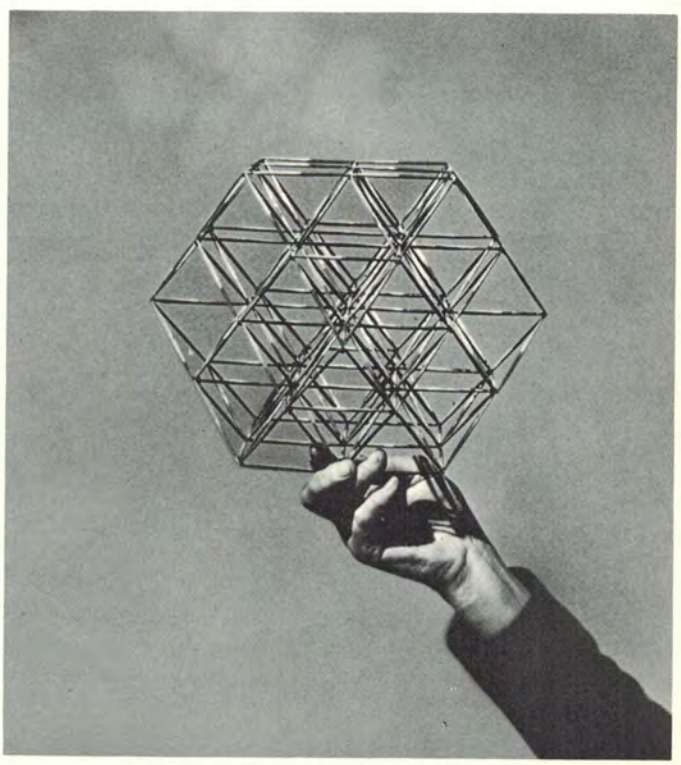


Fig. 4a. This structure was made at Washington University, St. Louis, in 1953 under my invention and design instruction. You may possibly be looking at the prototype of the structural principles that we may use in sending history's first (little) *scientific dwelling* to the moon. As you see, all the structural members are tightly bundled together in parallel so that they may be transported in minimum volume within a rocket capsule. The parallel-strut bundles of light-weight magnesium alloy consist of sets of three, fastened together at one end with ball joints clustering them in tripods. Each set is like a camera tripod with three tubular magnesium legs. Each set has ball joints at the tripod *head*. All the tripods' *feet* are also fastened together with ball joints in clusters of five and six tubular-tripod feet per ball joint. We have a little mast coming out of the top of each tripod. This mast is pushed out automatically by a piston in a cylinder mounted in each tripod *head*. We put 200 pounds of gas pressure inside the cylinder and the gas pressure, when triggered by a lanyard, will push the masts of all the tripods outwardly from each of the tripod heads. The pushed-out masts each have three tension members leading to their respective tripod's feet. As the masts are pushed out by the 200 pound pressure the tension members pull the legs of the tripods outwardly from one another. The tripods all open wide with their ball joint feet fastened together in hexagons and pentagons. There is a triangular net of aircraft cable in a regular geodesic "star" spherical grid that restrains the tripod legs from moving any further outwardly from one another than is necessary to form a symmetrical *geodesic dome* or *sphere*, which can be done in 45 seconds.

4a

Fig. 4b. The students pull the lanyard, unleashing the pressured gas to transform the flying seed pod's parallel arrangement strut assembly into a geodesic one-third sphere.

4b

Fig. 4c. Flying seed pod in opened condition: adequate for heavy stressing, yet the 100 pound structure encloses three car space.

4c

figure the relative acceleration curves in the drag tank pattern tests for a ship like the *Queen Mary*. Then the points along the curves are graphically accommodated by translation through analytical geometry, and geometrical identification of the relative positions of the various points in a three-dimensional grid cube of XYZ coordinates.

By 1913 I saw that man had come to regard the three-dimensional coordinate system as exclusively fundamental. But, I thought that while the XYZ coordination served useful purposes it might also be possible that nature had some other quite superior, rational and comprehensive kind of coordinate system. This occurred to me because the XYZ coordinate system inherently requires recognition of such irrationalities as *pi* and the paradoxial recognition that we cannot finitely subdivide the circumference of a finite circle by its radius. There are a great many irrational numbers occurring as "fundamental" constants in the mathematical coordination between mutually remote scientific disciplines which I thought might be the consequence of our arbitrary use of the XYZ coordinate system. Chemistry seemed to laugh at our coordinate awkwardness as nature contrived all of our physical "matter" entirely out of rational, whole integer simplexes.

If the XYZ, 90 degree coordinate system were not the one employed by nature, then the awkward roughness of the XYZ's irrational constants would be understandable. This was made evident to me while I was in the Navy. Looking back at the wake of my ship one day in 1917, I became interested in its beautiful white path. I said to myself, "That path is white because of the different refractions of light by the bubbles of water—H_2O (not $H_{pi}O$). The bubbles are beautiful little spheres. I wonder how many bubbles I am looking at stretching miles astern?"

I began to make calculations of how many bubbles there were per cubic foot of water. I began to find that in calculating the ship's white wake I was dealing in quintillions to the fourth power times quintillions to the fourth power or some such fantastically absurd number of bubbles. And nature was making those bubbles in sublimely swift ease!

Any time one looks carefully at a bubble, one is impressed with the beauty of its structure, its beautiful sphericity glinting with the colors of the spectrum. It is ephemeral—elegantly conceived, beautifully manufactured and readily broken.

Inasmuch as the kind of mathematics I had learned of in school required the use of the XYZ coordinate system and the necessity of employing *pi* in calculating the spheres, I wondered "to how many decimal places does nature carry out *pi* before she decides that the computation can't be concluded?" Next I wondered, "to how many arbitrary decimal places does nature carry out the transcendental irrational before she decides to say it's a bad job and call it off?" If nature uses *pi* she has to do what we call *fudging* of her design which means improvising, compromisingly. I thought sympathetically of nature's having to make all those myriad frustrated decisions each time she made a bubble. I didn't see how she managed to formulate the wake of every ship while managing the rest of the universe if she had to make all those decisions. So I said to myself, "I don't think nature uses *pi*. I think she has some other mathematical way of coordinating her undertakings."

It seemed preposterous to go on trying to force nature to explain herself through our awkward XYZ coordinate system. Recital of this 1917 event will have given you a close-up on what I am convinced must be the mental reorientation necessary to comprehension of the principles governing structures.

The most economical spherical agglomerations, i.e., "the closest packing of spheres," we now find to hold the mathematical clues to the principles of coordination governing natural structure—governing the dynamic, vectorial geometry of the atomic nucleus as well as of the atoms themselves. Over and over again we are confronted by nature obviously formulating her structures with beautiful spherical agglomerations (Fig. 2). This began to interest me very much. I found that spheres coordinate, not in 90 degreeness, but in 60 degreeness. Just take three billiard balls and you will find that they *pack* beautifully into a triangle. If you arrange four of them on the billiard table in a square they tend to be restless and to roll around on each other and if compacted to a condition of stability they form a 60 degree angled diamond shape made of two stable triangles.

The physicists find that spheres always form omni-triangulated structures in their closest packing. The frequency phenomena studied in quantum mechanics are all predicated upon agglomerations of spheres of given—i.e., known—radii. All the coordinating is done in spheres of given sizes whose radii are subdivided finitely in modular wave lengths of discrete frequencies. Furthermore, spheres of given sizes are always compacted in omni-triangulation of 60 degreeness, so that six spheres pack most tightly around one sphere on a billiard table and twelve spheres around one in omni-directional compacting. Additional rings of spheres may be tightly compacted around the sphere on the billiard table as symmetrical hexagon patterns and additional layers may be

added omni-directionally around one nuclear sphere in symmetrical vector equilibrium growth. The number of spheres in the successively enclosing shells are 12, 42, 92, 162, 252 and so on, which calculates as *ten* times the *frequency* (of radial or circumferential modular subdivisions) to the second power, plus two.

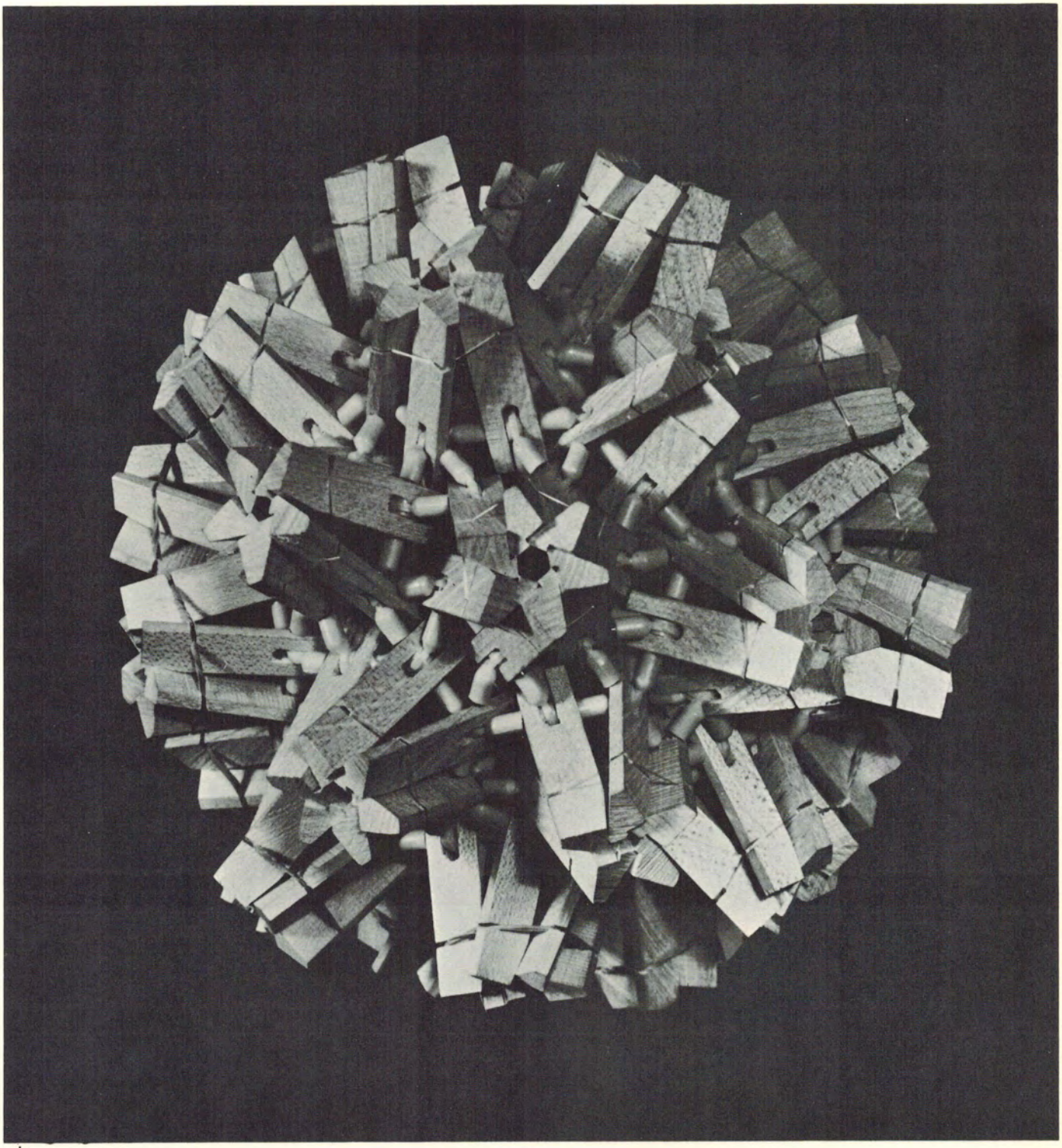
If we accept 60 degreeness we find that instead of getting only four right triangles around a point in a plane, or eight cubes around a point in space, we get six 60 degree angles about the point in the plane, and 20 tetrahedra around one point in space. Furthermore the circumferential modular frequency of planar or omni-directional patterning will always be in one-to-one correspondence with the radial frequencies of modular subdividing. When we do this, we find we have made a model of the spontaneously coordinate structure which nature actually uses (Fig. 3).

In demonstrating this to yourself, remember that the eight cubes around one point in space represent the three dimensions of 90 degreeness. However, when dealing with the 60 degree coordination of tetrahedra, which are the volumes bound by the planes of four edge-joined triangles, you will find that you can get fourth power or "four-dimensional" accommodation of space around a point as computed in the terms of linear module frequency of either radius or circumference of the pattern system (which also is to say that linear and angular accelerations are in one-to-one correspondence). You can get twenty tetrahedra around one point, $2^4 + 2^2 = 20$. Anyone using the tetrahedral concept in coordinating geometry and arithmetic would find that four-dimensionality is not an inconceivable or nonconceptual mystery but a very simple, modelable and rational relationship arrived at by closest packing together of equi-volume tetrahedra around one point.

Late in the nineteenth century the organic chemists led by van't Hoff, discovered that all organic chemistry is tetrahedrally configured. In all the structuring we know of in organic chemistry—plastics or gasolines or what-have-you—the atoms form molecules by little tetrahedral arrangements: tetrahedra point-to-point (univalent), tetrahedra edge-to-edge (bivalent), tetrahedra face-to-face (trivalent), or congruent tetrahedra (quadrivalent). These are the primary bondings. The range goes from C (carbon), which is relatively light, to C_4 (carbonaceous diamond), which is quadrivalent: four points of the tetrahedra are congruent with one another.

After X-ray diffraction in 1932, Linus Pauling, who received the Nobel Prize for his pioneering exploration of

Fig. 4d. The principle of structural dynamics of the Washington University, St. Louis, moon structure, the flying seed pod, and its logistic pattern transformability, are doubly interesting because they have turned out to be also the same structural, self-realization system employed by a class of microcosmic structures—the protein shells of all the different types of viruses. About three and one half years ago molecular biologists in England and their colleagues in America, working in teams, were trying to discover the structural characteristics of the protein shells of the viruses with X-ray diffraction photographic analysis. These virus scientists discovered that the viruses' protein shells were all some type of spherical geodesic structure. Having previously seen published pictures of my geodesic structures they corresponded with me and I was able to give them the mathematics and show them how and why these structures occur and behave as they do. They have now found the polio virus structure, pictured here, to be the same structure as the "possible moon structure". The polio virus, instead of having the tripods on the outside and the clusters of five and six feet on the inside, has the five- and six-way jointings outside and the tripods or three-ways on the inside. The pictured model of the protein shell of the polio virus was made by Dr. Donald L. D. Caspar, nuclear physicist, Director of the Children's Cancer Research of the Boston Children's Hospital, Boston, a colleague of the English virological team at Cavendish Laboratory. The number of "humps" or structural clusters of five or six prismatic sectioned struts of the protein shells of the virus follows my law of $10\,v^2 + 2$.



4d