THE WORLD OF BUCKMINSTER FULLER
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THE WORLD OF BUCKMINSTER FULLER

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"To me no experience of childhood so reinforced self-confidence in one's own exploratory faculties as did geometry. Its inspiring effectiveness in winnowing out and evaluating a plurality of previously unknowns from a few given knowns, and its elegance of proof lead to further discovery and comprehension of a grand strategy for all problem solving."

This quote of Bucky Fuller from his recent book *Synergetics* (1975) is dedicated to the great geometer H. S. M. Coxeter. In addition to paying homage to Coxeter, Fuller gives us an inner glimpse, however brief and incomplete, of the motivating "vectors" that direct and drive R. Buckminster Fuller, a true genius of our time who yet seems to defy description.

The difficulty in writing a definitive statement about the work of Bucky Fuller is that you never know when to stop. Born in 1895, the man is eighty-three years old. He still tosses off brilliant hypotheses and insights; still circles the globe on a yearly nonstop basis; still numbs his listeners and disciples with the length, breadth, and height of his visions and with the scope of his global concern but indestructible optimism about humanity and its lot on this earth. When you try to write definitively about this man—a living legend in his day—he refuses to stay put. He's like quicksilver in motion. You just can't toss off blithely some pat statement about his being the Leonardo da Vinci of the twentieth century.

The man probably is known to most teachers of mathematics as the inventor of the geodesic dome (fig. 1). Alone this would

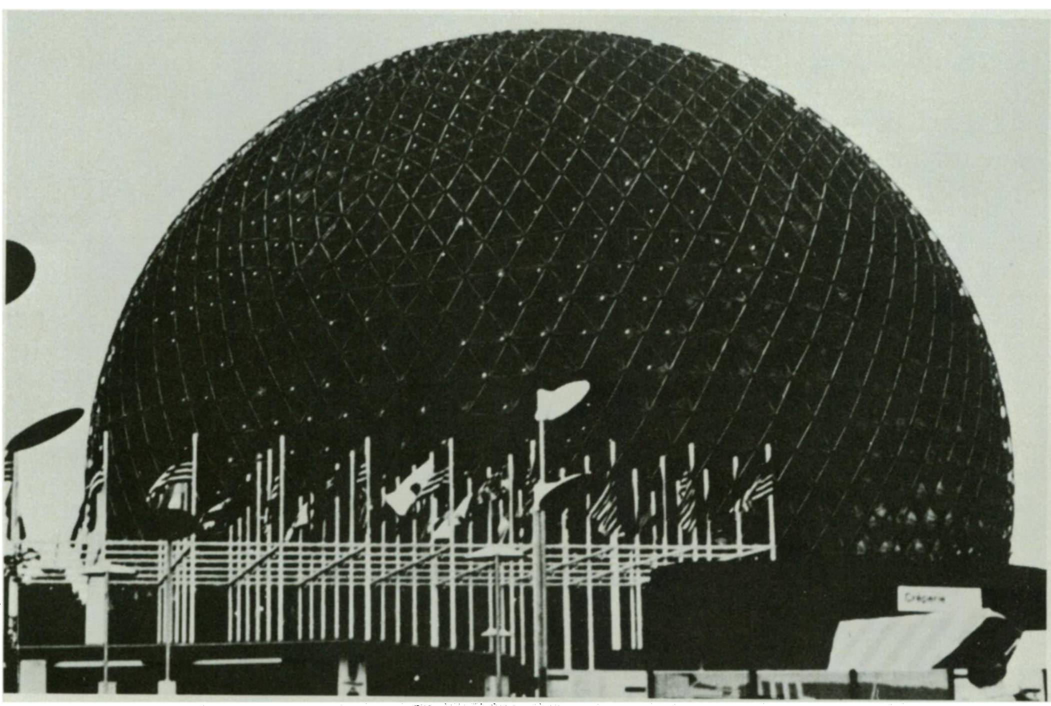

Fig. 1. A geodesic dome

be insufficient grounds for a statement made by more than one writer: it's not *whether* he'll get the Nobel prize, but *when* he'll be so recognized. In a world only lately preoccupied with problems—overpopulation, insufficient food, unpredictable drought, shortage of energy-producing resources—his preoccupation with solutions goes back forty years or more. Perhaps it is better merely to enumerate reasons why teachers of mathematics ought to know something more about this man.

> No experience of childhood so reinforced self-confidence in one's own exploratory faculties as did geometry.

Statements made by two writers are worthy of note with regard to the monumental achievements of Buckminster Fuller. Robert Marks, in the book *The Dymaxion World of Buckminster Fuller* (1973), has this to say in the preface: "It is a difficult matter to interpret Bucky. He has the genius's constant onrush of dream flow and dream logic. And it is graced with the quality now known, in cybernetic circles, as positive feedback—mirror multiplication of the information communicated. Each thought that Bucky expresses feeds back into his mind, there to generate families of fresher thoughts, broader in scope and more intense. . . ." Marks is poetically informative in this description of Fuller.

> Bucky has never been easy to understand—even by those best equipped to grasp his meanings, by those who know him best and love him most. The reason is both psychological and semantic. He overloads the channels of communication. He is ever ready to give too much of himself too spontaneously, too richly and too quickly. The simplest question may evoke from him a torrent of insights. And these insights he expresses in an incisive, private argot, a dialect resplendent with word coinages, hyphenated Latinisms and metaphoric tropes.
>
> Although his cardinal ideas have about them the skeletal simplicity we associate with the best of Greek thought, they sometimes come through to the casual listener as communicated cascades of ambiguities. And this often because there is simply so much. You would not expect to take in the first six books of Euclid at a single reading or hearing, nor without a reduction of the text language to an informal, conversational level. Yet, with Bucky, the near equivalent of such technical richness is offered untranslated, at each meeting. His conversation, thus, is always a subtle form of flattery for you. It implies that he believes you are at ease in all the areas of his talk, and that you can with equal agility go "second powering," "tetrahedroning," "inwardly-outwardly-to- and froing," or go bouncing on a four-dimensional pogo stick down the slopes of Parnassus. [Fuller and Marks 1973]

Although the book takes the reader up to the year 1960 and no farther, it is the best single source I know for Fuller fans. The pictures and drawings are stunning, and the writing style is graceful and lucid.

The comments of world-renowned architect Frank Lloyd Wright, on the occasion of the emergence of Fuller's book *Nine Chains to the Moon* (1938), throw additional light on our man Fuller:

> Buckminster Fuller—you are the most sensible man in New York—truly sensitive. Nature gave you antennae, long-range finders you have learned to use. I find almost all your prognosticating nearly right—much of it dead right, and I love you for the way you prognosticate. To address you directly will be a hell of a way of reviewing your book. I know, I should write all around you, take you apart, and put you together again to show—between the lines—how much bigger my own mind is than yours and how much smarter than you I can be with it and leave the essence of your thought untouched.
>
> But I couldn't do it if I would and I wouldn't if I could. To say that you have now a good style of your own in saying very important things is only admitting something unexpected. To say you are the most sensible man in New York isn't saying much for you—in that pack of caged fools. And everybody who knows you knows you are extraordinarily sensitive. . . .
>
> Faithfully, your admirer and friend, more power to you—you valuable "unit."
>
> (s) Frank Lloyd Wright
>
> Taliesen
> Spring Green, Wisconsin
> August 8th, 1938

Fundamental to an appreciation of the overall Fuller philosophy is his Dymaxion principle. It permeates much of what he did and is still doing today:

> In its simplest form, Fuller's Dymaxion concept is that rational action in a rational world, in every social and industrial operation, demands the most efficient overall performance per units of input. A Dymaxion structure, thus, would be one whose performance yielded the greatest possible efficiency in terms of the available technology. [Fuller and Marks, p. 4]

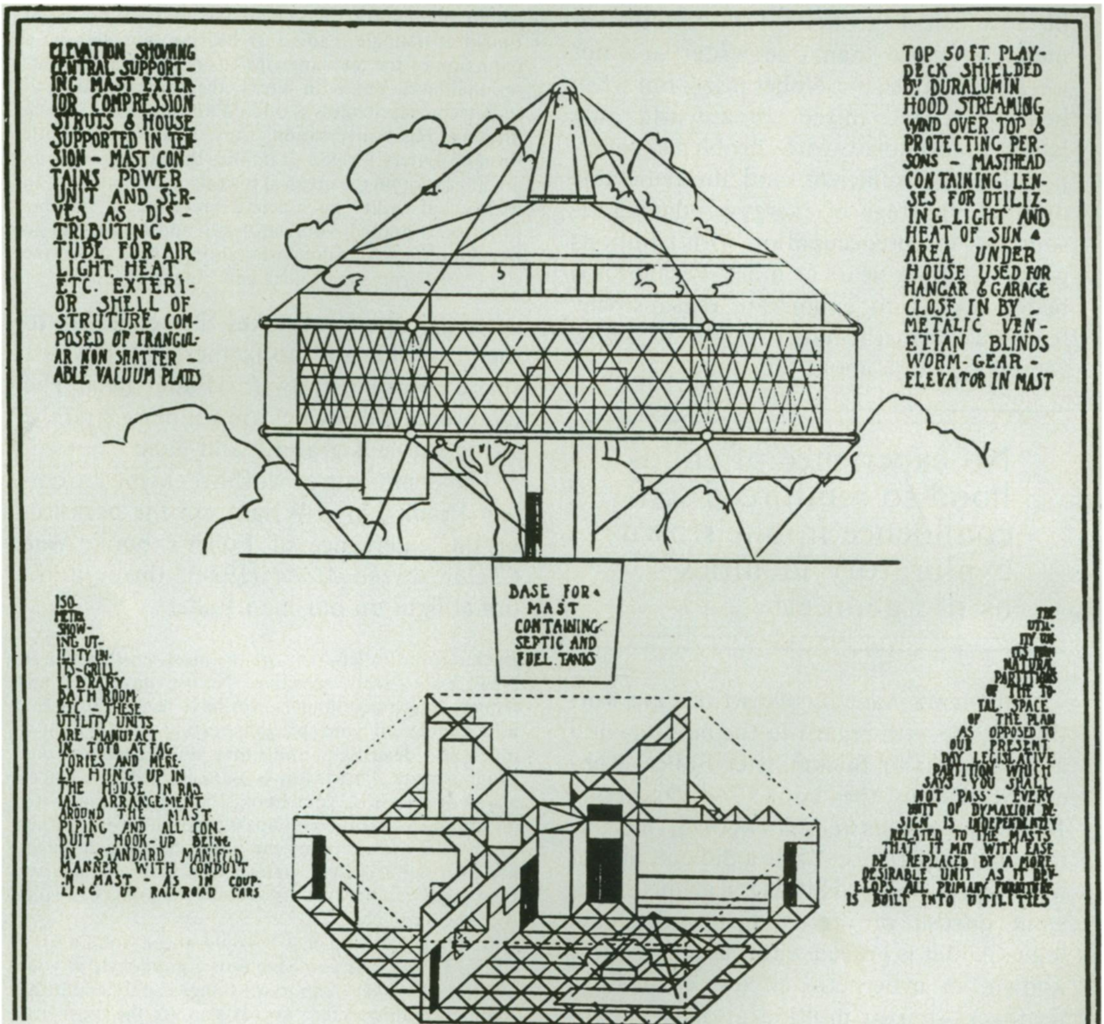

Fig. 2. Optimal-living-system house

The importance of the Dymaxion principle lies in the universality of its application to diverse problems. Fuller used it to advantage in such apparently unrelated structures as a self-contained, optimal-living-system house that hung from a pole (fig. 2), a new type of aerodynamic automobile (fig. 3), a new system of transformational map projection (fig. 4, used with permission), and of course, geodesic domes (fig. 1).

Just for the record, Fuller did *not* invent the geodesic dome; he pollinated and perfected it. The first dome was built in Germany (Jena) in 1922. It was constructed on the roof of the Carl Zeiss optical works and was built to house the planetarium projector invented by Dr. Walter Bauersfeld. Bauersfeld also designed the dome—the first thin-shell concrete structure ever made. Curiously, the dome was just incidental to the invention of his projector. What Fuller did with the original idea of

From the book, *The Dymaxion World of Buckminster Fuller*, by R. Buckminster Fuller and Robert Marks. Copyright © 1960 by R. Buckminster Fuller. Published by Anchor Press/Doubleday. All photographs courtesy of Buckminster Fuller. The photographs in figures 2, 3, 6, and 9 appear by courtesy of Buckminster Fuller.

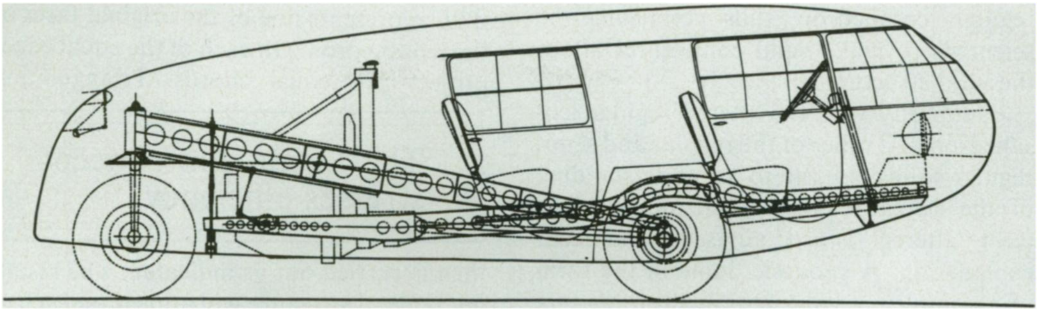

Fig. 3. Scale drawing of the Dymaxion car

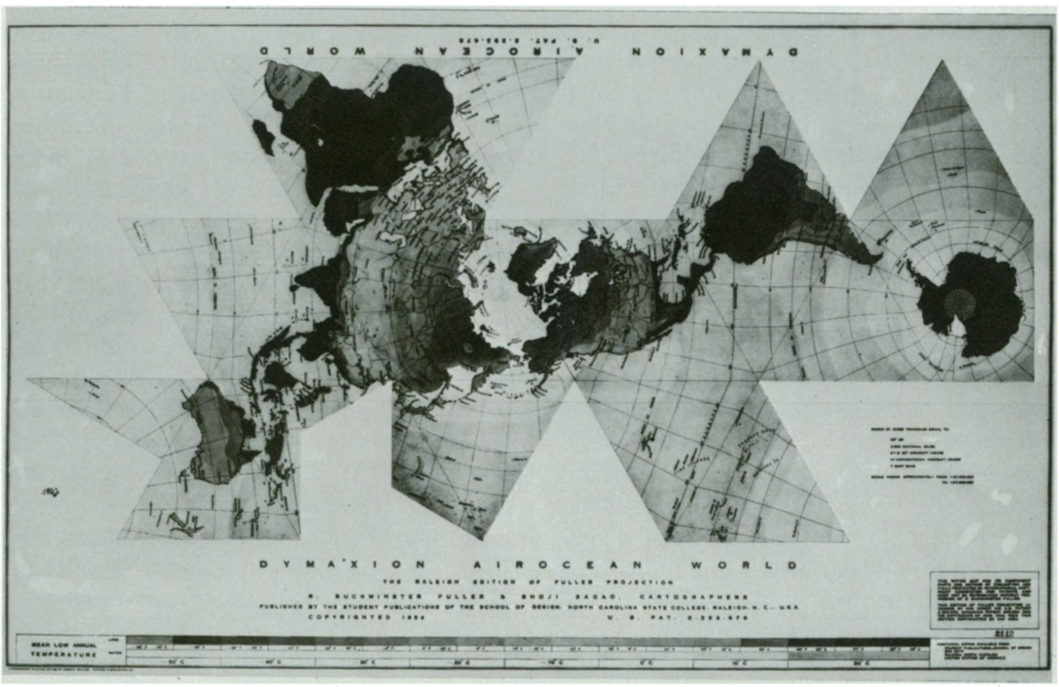

Fig. 4. World map on Dymaxion projection. © 1954, R. Buckminster Fuller.

the geodesic dome is, of course, completely his own.

Certain basic principles permeate the work of Fuller. It is here that the teacher of mathematics can latch onto intriguing ideas and materials often related to everyday teaching.

Plane and Solid Geometry

Regular solids constantly emerge in the work of Buckminster Fuller. This is fascinating since the Greeks studied much of their geometry in order to cast greater light on the five regular polyhedra. The virtual demise of the teaching of solid geometry in our training institutions and in secondary schools in the past decade—a crime, in the opinion of one teacher who has been at it for forty-four years—has resulted in the present generation of young teachers who are, at times, less than literate in this field. Sadly, so then are their students. The regular solid permeates the structure of such diverse fields as bacteriology, atomic structures, and architecture. With regard to just one of the applications of regular solids, Drs. Klug and Finck of Birbeck College, London, England, wrote to Fuller in June of 1959 confirming the fact that the polio virus had a structure quite like that of the regular icosahedron, thus permitting the scientists to make valid conjectures about the viral structure.

Familiarity with the altered regular icosahedron and other of the regular and semiregular solids is basic to an understanding of the structure of geodesic domes. The term "altered" is used advisedly and needs explanation. A geodesic dome in the form of a complete regular icosahedron (as in a radar dome) would have, for its vital statistics, thirty equal edges, twelve vertices, and twenty congruent equilateral triangles as faces. At each of the vertices would emanate five equal segments forming five equal face angles of the solid angle encountered. The sum of these face angles would be 300° (60° × 5). This merely affirms the fact that the sum of the face angles of a polyhedral angle in a convex solid is always less than 360°. (Incidentally, this fact also leads to the proof that there can be no more than five regular polyhedra!) In actual practice, geodesic domes are usually convenient, fractional parts of the complete geodesic sphere.

If large-scale domes were to be constructed according to the more classic statistics quoted above, the sheer dead weight of the components would snap the long struts required for support. Hence, the basic triangle involved—the essential face of the regular icosahedron—is normally subdivided into smaller units. In a two-frequency basic structure (fig. 5) triangle *ABC* represents one of the original faces of the icosahedron. On each of the equal edges project two equal chords. Triangulation

The Dymaxion concept stresses efficiency.

then is carried out as indicated. The resulting skeletal structure will appear on each of the twenty faces. In the geodesic dome that eventually would emerge, $\overline{AB}$, $\overline{BC}$, and $\overline{AC}$ would not even appear. Only the vertices would remain. Each of the substructures would mesh with its four neighbors. In a three-frequency dome, $\overline{DE}$ and the other original edges would be replaced by three chords. The number of such projected chords gives rise to the terms two-frequency, three-frequency, and so on. In a dome such as the one that appeared at Expo 67 in Canada (fig. 1), you might find that a sixteen-frequency dome would be involved. In essence, Fuller pioneered the invention of a triangulation device to construct a physical structure composed of linear elements that would approximate the desired curvilinear features of a sphere.

As may be shown, a sphere maximizes interior space with a minimum of exterior cover. But curved structures are difficult to fabricate and, when large, pose architectural design problems. Fuller's geodesic spheres and domes, being comprised of straight lines, of *lineal* triangles or polygons, are a synergetic, best-fit solution to the problem. From geodesic structures, phenomenal strength results. What is more, the physical elements (struts and braces) that are fastened together can be quite short; yet huge, even tremendous structures can be evolved. To cite one such building, not the largest in the world but massive nonetheless, the Union Tank Car Company had a dome 117 m in diameter and 35 m high constructed in Baton Rouge, Louisiana (fig. 6). In 1958 it was the largest dome of its type with a clear span (no columns or spanning girders). The structure was built as a roundhouse for the rebuilding of railroad cars. Clearly, the lack of any internal

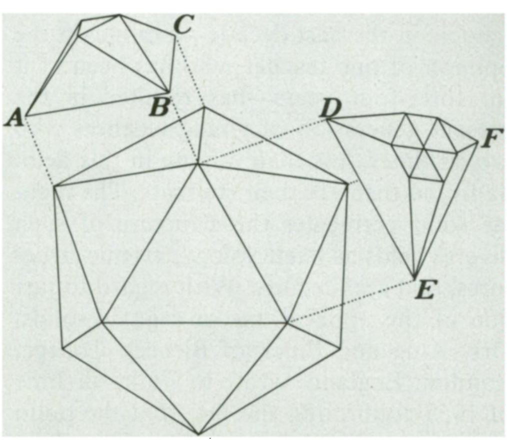

Fig. 5

supports was the building's strongest feature, permitting free movement, access, and ease of construction.

Fig. 6. A steel geodesic dome in Baton Rouge, Louisiana, 117 m in diameter, 35 m high

The precise calculation needed for the construction of the lengths of the struts in geodesic domes is formidable. Originally; Fuller and his assistants did all the needed work with trigonometry tables and mechanical desk calculators. Now these computations are programmed for computer solution, at a considerable saving in time and work.

Geodesic domes, then, truly owe both their diversity and multiplicity to the fertile genius of Bucky Fuller. Mathematically, Fuller had discovered that in "a network in which all points are equidistant from each other, all vectors are the same length, [and] the existing points are connected . . . to produce a symmetrical transforming series of concentric geometric enclosures. . . . These enclosures can be visualized as spheres within spheres, much as the universe is envisaged in Dante's *Divine Comedy*." (Fuller and Marks 1973, p. 45) Algebraically stated, this poetry reads

$$p = 2 + 2nf^2, \quad \text{where} \quad n = 1, 2, 3, 5.$$

That is, the number of points in the shell or outer layer of any symmetrical system p is two plus two times a given prime number from one to five, multiplied by the square of the system's edge frequency. Hence, all triangulated symmetric point systems are explained in terms of the first three primes and 1. Fuller's discovery would have pleased Dante as well as the Greeks.

As a personal note, before I got interested in the complexities of geodesic domes, I was quite confused by one particular element. Every teacher of mathematics knows that if six congruent equilateral triangles have one vertex in common, a regular hexagon emerges. Teachers also know that the elements (or sides) of a regular hexagon are coplanar. I would look at some of the pictures of complex geodesic structures and see what appeared to be congruent regular hexagons. If this were so, how could a "three-dimensionality" (Fuller is not the only one who can invent new words) result? In other words, how could such figures be coplanar and noncoplanar at the same time? If we place three congruent regular hexagons in juxtaposition, the resulting configuration is coplanar. Further ratiocination, however, revealed that you do not really see a true regular hexagon in such geodesic constructions. These "hexagons" are always subtle relatives of the regular hexagon, adjusted in such a manner that three-dimensionality can result.

Phenomenal strength results from geodesic structures.

Before we move on to other Fullerisms, I wish to interject another personal note. Buckminster Fuller is, at present, the god or guru of many of the so-called grassroots, back-to-the-earth aficionados in the United States. The geodesic dome has sprung up as a personal dwelling for many such people in diverse parts of the United States, particularly in the arid parts. There may be a reason for this (my source is that indispensable compendium of human knowledge, *The Last Whole Earth Catalog*). Geodesic domes, when fabricated from machine-made elements, are one thing. When smaller ones are hand-made by the hammer-and-saw method, errors, small as they may be at the outset, have a tendency to aggravate themselves and the builder when it rains—you might be better off if your name were Noah or you resided in the desert, where it rarely rains. Curiously, the old, traditional post-beam construction, verticals with horizontal roof supports, is still one of the easiest ways of achieving some protection from the elements. The moral, if there is one, may well be, It's not necessarily bad if it's old, and it certainly is not necessarily good if it's new. (Reformers of mathematics education, kindly note!)

Even a surface knowledge (pardon the pun!) of Fuller demands some understanding of what Fuller calls "tetrahedronizing." In the two-dimensional realm, certain sets of discrete points may be joined in such a manner that nothing but equilateral triangles emerge. With such a system, rigidity is assured, since the equilateral triangle is the fundamental building block of plane geometry. A quadrilateral, with its four components, has limited rigidity. It wiggles and wobbles unless diagonals are added for triangulation. If both diagonals are added, then bolted at their intersection, strength results. *Eight* triangles may be said to contribute to the support of the basic quadrilateral.

In a similar manner, the tetrahedron is the fundamental building block in three dimensions. The use of modern machinery makes the reproduction of identical components in a system quite simple. In two dimensions, from a building-block viewpoint, repeated equilateral triangles would be an ideal way of covering the plane. It used to bother me in my work in high school mathematics that repeated joinings of congruent, regular tetrahedra could not be used to completely fill space. We know that repeated cubes, such as baby's blocks, will fill three-dimensional space, but regular tetrahedra will not. The angle formed by adjoining faces of a regular tetrahedron contains 70° 31′ 44″ (I just happen to know that fact from solid geometry!). Since this value is not an integral divisor of 360°, space-filling in three dimensions is an impossibility with repeated regular tetrahedrons. However, when the regular tetrahedron is combined with the regular octahedron, most intriguing results ensue. Bucky called it the Fuller Octet Truss (F.O.T.).

In actuality, the geometric basis for the F.O.T. has been known for centuries. Nevertheless, give Fuller credit for making it an integral and necessary part of certain of his structures. The arithmetic basis for the marriage of the regular tetrahedron–regular octahedron rests in the values of the plane angles of adjacent faces of the tetrahedron-octahedron. Recall that the plane angle is the basic measure that indicates the angle at which two planes meet. It is formed by taking a point on the edge common to two intersecting planes and constructing perpendiculars, one lying in each plane. The measure of this angle is the angle at which these planes meet (fig. 7).

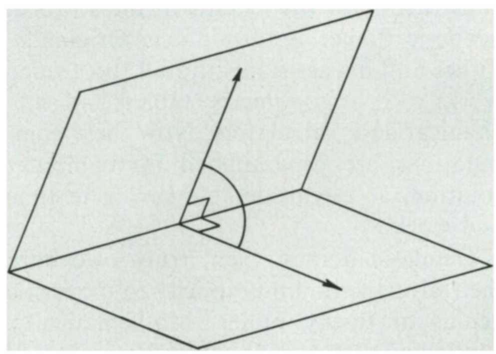

Fig. 7. A plane angle

The plane angle for the regular octahedron is 109° 28′ 16″ (A little Euclidean bird told me so.). Also, study figure 8. You will see that the sum of 109° 28′ 16″, 109° 28′ 16″, 70° 31′ 44″, and 70° 31′ 44″ is 360°, as, indeed, it must be. Actually, the calculation is nothing but a parallel to the well-known epigram, How come the seashore is always so close to the ocean?

It is Fuller's spatial discovery that repetitions of regular octahedrons and regular tetrahedrons will fill three-space that results in this specious bit of arithmetic and geometry. When equal struts are joined in the manner suggested by figure 8, a fantastically strong structure results. Fuller used this basic idea in the construction of the

Ford Rotunda Building in Dearborn, Michigan (1953). The construction of this particular dome seems to have given Bucky

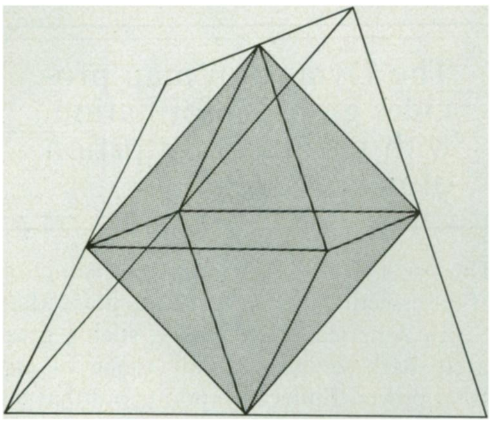

Fig. 8. An octahedron imbedded in a tetrahedron

Fuller particular pleasure. It just about fulfilled his prediction, made in 1927, that it would take a quarter of a century before certain of his principles would be accepted. He referred to his first customer as "Mr. Industry himself."

The Octet-Truss caused quite a furor when it was used in an exhibition at the Museum of Modern Art in New York in 1959. This particular construction was 30.5 m long, 10.7 m wide, and 1.2 m deep. The one-layered Octet-Truss (fig. 9) can be extended above, below, and in just about any direction whatever by judicious additions of struts. In essence, when a regular tetrahedron is affixed to each of the faces of a regular octahedron—they share certain of the linear components—new openings emerge for the addition of new layers of regular octahedrons. This is difficult to visualize and to draw, but quite simple if construction sets such as D-Stix or Geodestix are used. You'll have to combine rubber connectors to accommodate the complex nodes that arise, some of which require twelve struts.

Remarkable constructions can be designed with the Octet-Truss principle. The horizontal coverage suggested by figure 9 would make it possible to cover a tremendous flat space. What is not at all obvious—it requires that a different orientation of the Octet-Truss be observed—is the fact that proper repetitions of the unit will result in the formation of a regular tetrahedron. I can't do justice to this concept within the framework of this short article. All I can say is to look at pages 172 and 173 of the book by Marks and Fuller.

Cartography

No discussion of Fuller, however brief, could fail to mention his forays into cartography. He finds the Mercator projection, which still defaces the front walls of many of our schools, quite unsuited to the needs of the twentieth century. There are many versions of Fuller's Dymaxion map. (How he loves the word!) The original map, since superseded by other versions, was invented in 1943. It caused quite a stir when it appeared in *Life* magazine in the issue for

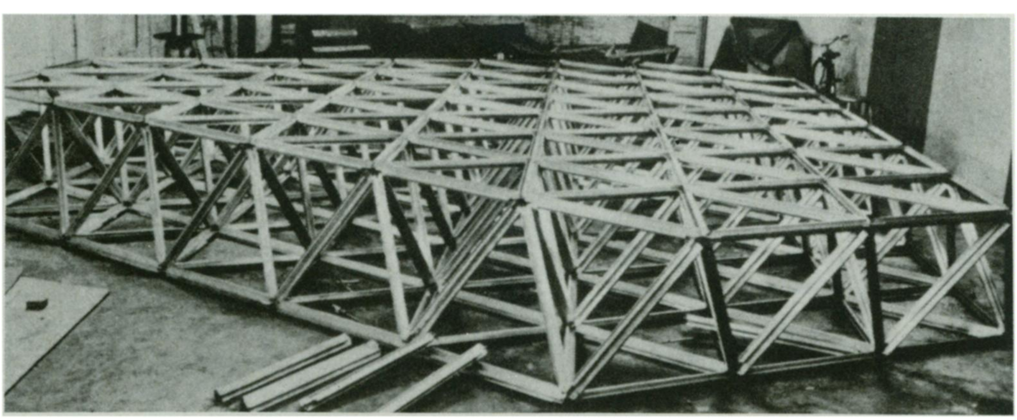

Fig. 9. Octahedron-tetrahedron ("Octet") truss consisting entirely of struts

March the 22nd, 1943. This issue is a collector's item. If you can get hold of it, treasure it. If you can get two, save one for me. The original Dymaxion map appears on page 152 of Marks's book. If the corners of a cube are lopped off, a cuboctahedron results (fig. 10). Fuller imagined that a sphere had been inscribed within this solid (Fuller and Marks 1973, p. 151). Boundaries of earth masses were projected on the faces of the solid—either equilateral triangles or squares. Judicious arrangements of the fourteen faces resulted in a highly accurate, two-dimensional picture of the relations of the land and sea measures. This picture is certainly more amenable to the construction of maps at a time when plane travel is such a common means of transportation.

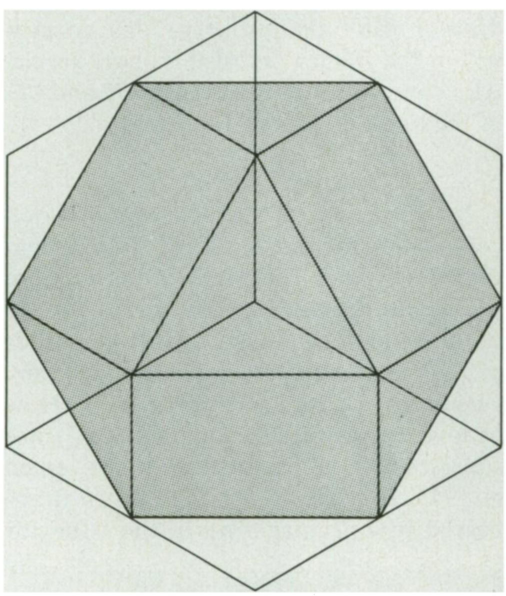

Fig. 10. A cuboctahedron

The Dymaxion map "... provides global information with negligible distortion of magnitudes," and "it is the only flat surface plot of the earth that presents all the true geographic scale areas in a single, comprehensive picture without any breaks in any of the continental contours, or any visible distortion of the relative shapes or sizes of these whole land masses." (Fuller and Marks 1973, p. 57)

On the original Dymaxion map it is possible to locate a Dymaxion equator—a great circle—that passes through Cape Kennedy, Florida, across the United States, through Cape Mendocino, California, thence completely around the globe.

The Dymaxion map provides global information with negligible distortion of magnitudes.

This great circle has the unusual distinction of intersecting no other land mass than North America. Importantly, such a great circle path violates no air space of any other power. Fuller also points out that the 50-50 point on the earth, Lat. 50° N., Long. 50° E., is in Russia at the foot of the Ural Mountains, where Russia, at the time the Marks original edition came out, maintained launching stations. This is the pole of a hemisphere that contains 93 percent of the earth's population. Thus, you can sense its importance in this era of rocketry and its intimations for world domination. (A copy of the Dymaxion map is seen in fig. 4 and can be constructed in polyhedron form or purchased from Fuller and Sadao, 32–37 Vernon Blvd., Long Island City, NY 11106.)

The world of Buckminster Fuller, which I have described here, takes us up to the year 1960. During the years 1960–1977 Fuller hasn't exactly been dormant. Peripatetic, octogenarian Fuller, a truly global figure (he used to carry three wrist-watches; one carried the local time, one carried the time where he was yesterday, and one carried the time where he would be tomorrow) is recognized as the genius he is all over the world. It was not always this way.

In June of 1972 plans were announced for the formation of the Design Science Institute. Guided by Fuller and under the leadership of Dr. Glenn A. Olds, president of Kent State University, this organization seeks to propagate the basic ideas and teachings of Fuller. Among its projects is the dissemination of Fuller's books, articles, researches, and activities on a world-wide basis for the good of humanity in general.

The most recent, the most ambitious of Fuller's many writings is *Synergetics—Explorations in the Geometry of Thinking* (1975). Norman Cousins of *Saturday Review* calls it "The Compleat Bucky." Arthur L. Loeb, a crystallographer from Harvard, in his introduction to Fuller's book, states, "Fuller's hope for the future lies in doing more with less." The book, a compendium really, cannot be read like a paperback novel. It must be absorbed in small doses. *Synergetics* seeks to summarize and appraise about fifty years of Fuller's work. If you would know about R. Buckminster Fuller's philosophy and his doings, this is the book to buy or borrow. (You may wish to borrow it; it costs about $25.)

In closing, I take the following story, again from *The Dymaxion World of Buckminster Fuller.* I repeat it word for word:

> He [Bucky] learned at an early age that the teachers lacked satisfactory answers to all the questions he had to ask. One day, for example, the geometry teacher attempted to explain the basic definitions. She put a point on the blackboard, then rubbed it out. "A point," she said, "does not exist—it has no dimensions." She then drew a line. "A line," she continued, "is made up of points but there are no lines." Bucky looked at her wide-eyed as she defined a plane in terms of parallel lines. His eyes opened wider when she announced that no planes exist. The final blow was her presentation of the cube. "A cube," she said, "is a solid stack of square planes whose edges are equal."
>
> "I have a question," Fuller said, raising his hand, "How long has the cube been there? How long is it going to be there? How much does it weigh? And what is its temperature?"

This all portends the emerging, brilliant, and practical mind of Buckminster Fuller. One might also recall the beautiful little poem of J. A. Linden's:

Points
Have no parts or joints.
How then can they combine
To form a line?

The answer? As Fuller himself states in the prefatory note to *Synergetics:* "Dare to be naive."

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Note: Ernest R. Ranucci died suddenly on 4 August 1975 at his summer home in Brookfield, Vermont. He was sixty-four. A professor of mathematics education at the State University of New York at Albany since 1965, Dr. Ranucci had previously been a faculty member at Newark State College, Newark, New Jersey. However, he was proudest of his more than eighteen years as a mathematics teacher at Weequahic High School, New Jersey. From 1955 to 1970 Dr. Ranucci was a member of the Commission on Mathematics of the College Entrance Examination Board. He was a participant at international meetings of mathematics educators in England and Hungary and was a popular speaker at local, state, regional, and national meetings of mathematics teachers.

There are over 130 articles that bear his name, as well as at least seven pamphlets. But first and foremost, Ernest Ranucci was an inspiring teacher. Students at SUNYA learned that you "took" Ranucci rather than Advanced Euclidean Geometry or Recent Advances in Mathematics—two of his most popular courses. His impact on teacher education in the more than twelve countries in which he lectured, taught demonstration classes, and "sold" imagination in mathematics teaching can not be measured, nor can the mark of inspiration he has left on so many of us.

Dr. Ranucci passed away shortly after the submission of this article. We are grateful to D. Thomas King, St. Paul Public Schools, St. Paul, Minnesota, for his efforts in preparing the article for publication.