Richard Buckminster Fuller

A mind never at rest always thinking of improving the lot of his fellow man: this is Buckminster Fuller. His one aim in life is to remake the world by obtaining in every phase of living "the maximum net performance output per gross energy input."

He has developed a science and philosophy, Energetic Geometry, by which industrialization can serve the most people at the least possible cost.

At various times, he has been editor of Fortune, editor of a technological survey for Chrysler, head mechanical engineer to the Board of Economic Warfare, a special assistant to the Deputy Administrator of the Foreign Economic Administration, inventor of a new kind of map projection, inventor of cars and prefabricated bathrooms; but his prime interest is housing. Recently, he has been a visiting critic at North Carolina State, Massachusetts Institute of Technology, and is presently at Yale. He was a visiting lecturer at the School of Fine Arts last year on the invitation of the Architectural Society, and he will lecture again this year.

Mr. Fuller does not claim to be an architect. He is an engineer, or as he likes to term himself, "a comprehensive designer." He is the personification of his Energetic Geometry, exploding with ideas, just as his great circles. Here is an article from his soon to be released book.

FINE ARTS EDITOR

INDUSTRIAL LOGISTICS AND DESIGN STRATEGY

Copyrighted: RICHARD BUCKMINSTER FULLER
Illustrated: PROFESSOR DUNCAN R. STUART,
of North Carolina State College.

WITH minimum overall investment of technical-advantage-resources, i.e. of controlled energy, either as chemical "materials" or as "work," the problem is to develop a universal and integral structural system:

(a) Capable of sustained enclosure and controlled isolation of conditions favorable to man's activities ranging in magnitude from single family dwellings to major industries;

(b) Capable of withstanding all probable stresses and providing all positional advantage requirements;

(c) Capable of supporting appropriate mechanisms for valving all locally impinging random or periodic energy environment receipts into preferred patterns complementary to man and machine processes;

(d) Capable of elective omnidirectional penetrations.

From the working postulates of ENERGETIC GEOMETRY:

The tetrahedron (four faceted structure) is minimum and therefore basic structural system; all structure is a transformative phase or complex of tetrahedroxel transformations.

All polyhedra may be subdivided into component tetrahedra, but no tetrahedron may be subdivided into component polyhedra of less than four faces.

Tetrahedra are seemingly unique in that they may be turned inside out and pass through zerophases of other transformations. (Fig. 1.)

A *triangle* (truss) is a tetrahedron of zerophase altitude. (Fig. 2.)

A *line* is a tetrahedron of zerophase base.

A *point* is a tetrahedron of combined zerophase of both altitude and base. (Fig. 1a.)

In addition to its four facets a tetrahedron has four vertexes and six edges. Its edges may be "straight," i.e. chordal "invisible" arcing, (small segments of arcs of large radius) or "visible" arcs (larger segments of arcs of smaller radius). See Fig. 4 below.

The regular six-chord-edged tetrahedron encloses (defines) the *minimum volume with the most surface* of all "geometric" polyhedra or structural systems;

Whereas sphere encloses (defines) *most volume with least surface* and the minimum sphere defining structure is the regular -six-great-circle-arc-edged tetrahedron of 109° 28′ central angles and 120° surface as there may be no *absolute* division of energetic universe into "isolated" or non-communicatable parts, there is no *absolute enclosed surf*ace or *absolutely enclosed* volume; therefore no true or absolutely defined simultaneous surface "sphere" integrity. Therefore a sphere is a polyhedron of invisible plurality of trussed facets (trussed because all polygons are reduceable to triangles or trusses and are further irreduceable and trusses. are therefore basic polygons—as per Fig. 6). Infinite polyhedron is infinitely faceted by basic trusses.

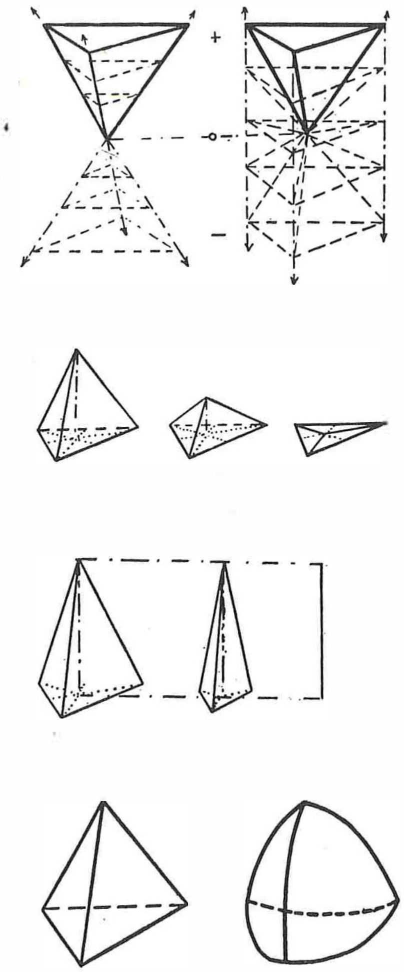
When stressed with *high relative internal pressure* all polyhedra tend to transform toward defining the maximum volume with the minimum surface i.e. toward the spherical convex-arc edge tetrahedra (the basketball and baseball are tetra structured).

When stressed by *high relative external* pressure structures tend to transform toward enclosing the minimum volume with the most surface, i.e. toward the chordal or concave tetrahedron (the symmetric collapsed baseball). The "regular" planar bound tetrahedron is the zerophase between the convex tetrahedron, i.e. the spherical tetrahedron, and the concave tetrahedron, i.e. the four webbed interaction between the six exterior edges of the tetrahedron and its center of gravity.

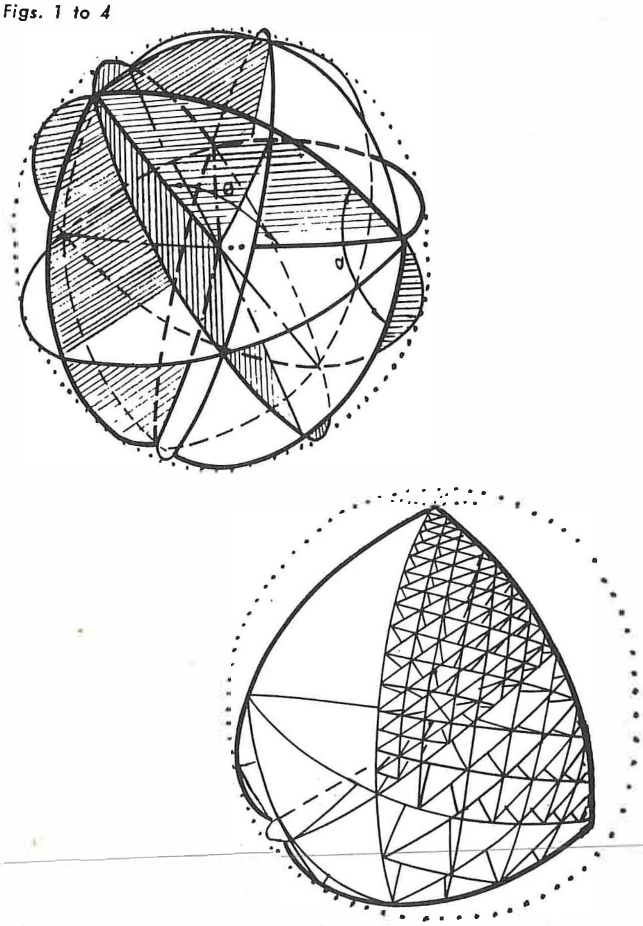
Great circle arcs represent the shortest lines between points on the surface of a sphere and great circle segment chords represent *the* shortest distance between two surface points on the surface of a sphere, therefore the great circle arcs represent limit structural transformative tendency of outward surface tensing by internal pressures and great circle segment chords represent the limit structural optimum for axii of compression resisting columns opposing external pressure by surface spreading. (We assume that pneumatic bags are not permitted as solutions of the problem as they prohibit omnidirectional penetrations and provide no local resistance against high impact.)

We are seeking a structure impervious not only to extreme differential between internal and external pressure dominances, but also to highly concentrated internal or *external loads* or *impact forces—yet permitting omnidirectionally effective controlled penetrability.*

Chordal edged tetrahedronal structures best resist external forces and their vertexes best resist concentrated loads, while arc edged tetrahedra best resist internal pressures and their surface arc vertexes best resist concentrated internal pressures and impact forces, yet both permit omnidirectionally valved penetrations. However, as the number of trussed faces of symmetric polyhedra are increased from the chordal and arc structural tetrahedra, through the heirarchy of great circle arc and chord trussed "solids"—i.e. the octahedron (8) and the icosahedron (20), the number of vertexes and edges increase providing more and dispersed structural interactions for resisting concentrated loads from more directions and also more and shorter chords, thus providing increasingly favorable slenderness ratios for the component compres-



Figs. 1 to 4



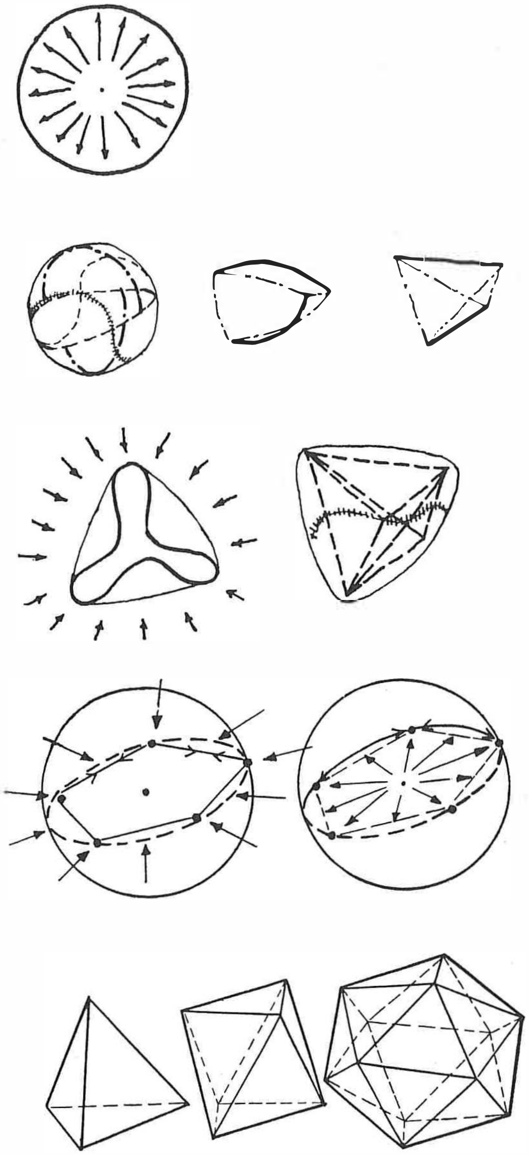
Figs. 5 & 6

sion columns (Fig. 11). As the number of external truss facets of polyhedra are increased the more nearly does the chordal (or compression) structure approach congruence with the arc or tension structured sphere. *The icosahedron has the highest number of identical and symmetric surface truss facets of all great circle defined polyhedra, providing 20 faces, 12 vertexes and 30 edges.* (Fig. 11) It is seen that if a further approach to the congruence of all-trussed chordal polyhedra with arc structured spheres can be accomplished, not only will the vertexes and trussed facets (or penetration points) multiply, providing increased advantage in more directions against concentrated loads and more directions of penetration, as well as ever greater numbers of ever shorter compression columns to share the load—to be realized progressively with more economical slenderness ratios and sections, but also a condition will be rapidly approached when both the chord and arc lengths and spherical surface angles and their chordal facet angles (see Fig. 12) become "practically" indistinguishable and the polyhedron's surface becomes indistinguishable from the sphere.

It was discovered that a 3-way great circle grid may symmetrically subdivide the trussed facets of the icosahedron. (See Figs. 6 and 12) This is what is designated as a *3-way grid geodesic structure*. Its frequency of modular subdivision of edge (Fig. 12) of the icosahedron's facets may be multiplied at will, once the spherical trigonometry rates of change of central and surface angle subdivisions have been solved.

This is the essence of the geodesic structures. At an edge frequency of 16 modules, the arc and chord tend to "indistinguishable" differences of dimension. However, as the number of truss facets increase, the convex vertexial interactions approach a zero altitude condition, which, though ideal for tension or internal pressure, tends to allow concentrated external loads to push the convex chordal vertexes inside out,—i.e. to a concave condition, whereafter the continuing concentrated external pressure will be resisted by tension increase in omni-surface direction,—as a rubber ball draws on its skin as it resists punching in and gains reaction and spring back, (causing bounce). To avoid in-pushing by localized external pressures in high frequency truss-faceted polyhedra, involute phase structuring is employed in which every other vertex is insprung and is thus resisted by more acute angled vertexes; as a result the original sphere is shrunken in radius to allow its skin to yield in all directions and the inwardly positioned vertexes are now in the surface of an inside sphere and the outer vertexes in an outside, but shrunken radius, sphere, both concentric spheres being therefore trussed to one another. This is similar to the skin of a pineapple or various nut skins. When frequency and diameter of spheres (or hemispheres or any portion of spheres desired) are further increased the relatively short trussing of the involute structure, which has neither exterior or interior surface chording but only *inward* and *outward* connectors, is converted into two completely surface trussed and intertrussed concentric polyhedra by trussing together all the outer vertexes and

(Continued on p. 24.)



Figs. 7 to 11

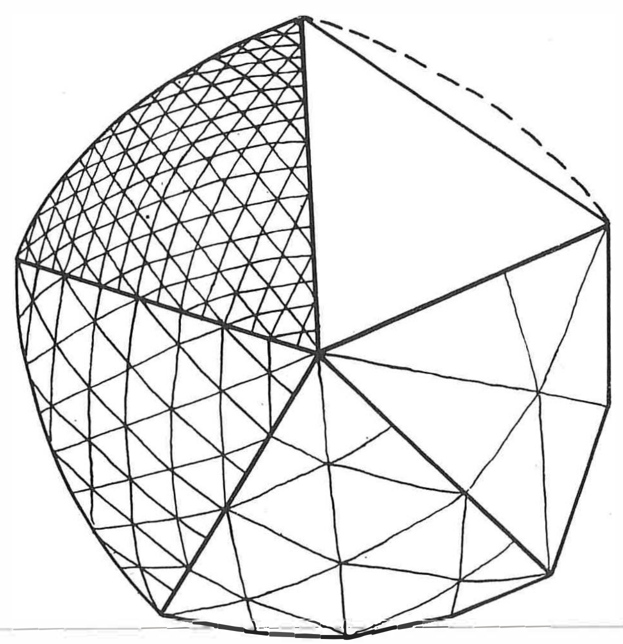


Fig. 12

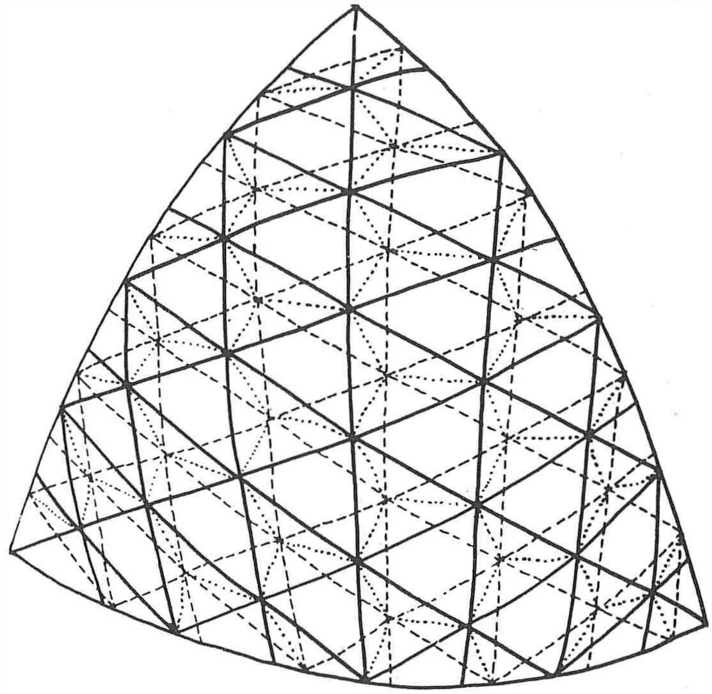
Industrial Logistics...

(Continued from p. 12.)

all the inner vertexes respectively, thus providing short columns and light sections and small openings by maintaining vertexial acuteness of angle and comprehensive tension at leverage advantage of radial depth over its enclosed compression circling.

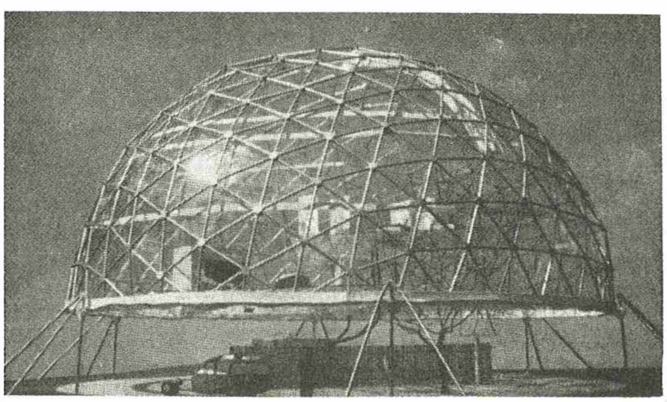
This design freedom of frequency increase makes possible the realization of structures whose components may be provided by a variety of light and short dimensioned materials whose interstices may be skinned in with a variety of components of mill standard dimensions—of transparent, translucent or opaque — or breathing or screening characteristics, as originally required and with minimum investment.

Despite a superficial aspect of "over determination" characterizing the sixfold chordal interaction of 3-way grid geodesic systems it is discovered through energetic geometry experiment that these six vector convergences represent 2 sets of three each belonging respectively to the central angles of positive and negative tetrahedra (as per Fig. 1a) opposing their respective inward and outward involutions and evolutions at each vertex and therefore that a 3-way geodesic grid consists of two sets of structural systems at opposite tendency interaction congruent at each vertex only (single bond) and therefore nonredundant, but on the contrary—in minimum universal jointed stability at proximity to zerophase omnidirectional convergence and divergence and zerophase of component convexity and concavity, i.e. in *stable and minimal omnidirectional equilibrium.*



Three-way geodesic grid. Fully trussed structures.

This theory is the basis for the miraculous **trusswork of** his geodesic domes, which have many varied applications where any unobstructed floor space is required.



This is a model showing how housing units can be set inside a dome. It was on display at the Museum of Modern Art last month.
Alan Borg

This "weatherbreak" unit was erected by two men in 25 minutes on Baffin Island in the Arctic. It has been tested to wind velocity of up to 120 milesper hour,without any flapping noise of the canvas.
Fuller Research Foundation
Canadian Division

GEODESIC STRUCTURE CLASSIFICATION   First Letter of Name ____ Type Number ____ Item Number ______

NAME   FUNCTION   PLACE   DATE

STRUCTURAL STRATEGY
- Topological Type: Tetra ____, Octa ____, Icosa ____, Eniniconta ____, Octet ____.
- ____ Frequency (V): regular ____, alternate ____, turbine ____. Secondary V ____. Tertiary V ____.
- Continous Compression ____, Discon't Comp ____, Differentiated Comp-Tension ____.
- Skin: rigid ____, tensed ____, primary ____, secondary ____.
- Skin: domical ____, vault ____, flat ____, hyperbolic-parabola ____.
- Sub-Assemblies: Vertex/Hexpent ____, Edge/Diamond ____, Face/Triangle ____, Pole/Strut ____.
- Bond: single ____, double ____, triple ____. - Climbable ____.
- Spheres: single ____, 1½/involute ____, double/evolute ____, triple ____, truss type ____.
- Topology, numbers of: Edges ____, Faces ____, Vertexes ____.

DIMENSIONS
- Linear ____ Ft. Diameter, Floor area ____ sq. ft. Average module ____ inches.
- Volume installed ____ cubic feet, Volume packaged ____ cu. ft.

	Chemistry	lbs.	yrs	Anchors: nos. ____
TOTAL: WGT ____ lbs; LONGEVITY ____ yrs — PRIMARY MATERIALS AND THEIR WEIGHTS — NUMBERS OF TYPES PARTS				
- Structure	____	____	____	pounds ____
- Skin, exterior	____	____	____	chemistry ____
- Skin, interior	____	____	____	disposability ____

Types (T), Parts (P): Special equator pieces ____T, ____P; doors ____T, ____P; windows ____T, ____P; ventilators ____T, ____P.
Chem (C), lbs, Longev (yrs) each above: ____C, ____lb, ____yr; ____C, ____lb, ____yr; ____C, ____lb, ____yr; ____C, ____lb, ____yr.

Required PERFORMANCE Limits
- Airliftable Method
  - external as whole assembly, open ____, folded ____.
  - external as partial assembly
  - internal as parts
- Field tools: special ____ lbs, ____ cu. ft; standard ____ lbs, ____ cu. ft.
- Max. Loads
  - distributed
    - wind ____ mph. Total lift ____
    - snow ____ lbs per sq. ft. Lift per anchor ____ lbs.
  - concentrated in structure: psi tension ____, psi compression ____.
  - shock, interior/exterior differential ____ psi
- Valves
  - Service openings: personnel ____, vehicle ____.
  - Energy Environment Controls

	type,	KWH max	min		type	K.W.H. max	min
- illumination	____	____	____	Air change	____	____	____
- heating	____	____	____	Dust	____	____	____
- cooling	____	____	____	Insect	____	____	____
- humidity	____	____	____	Marauders	____	____	____

ENVIRO-CONTROLS: Optical ____, Aural ____, Olfactoral ____, Tactile ____, Hazard: internal ____, external ____.
PHYSICAL CONTROLS: Electrolysis ____, Dielectrics ____, Wave fatigue ____, Radiations ____, Creep deform ____, lightning ____.

MAN HOURS	SCIENTIFIC	SKILLED	SEMI-SKILLED	NON-SKILLED
- Laboratory (non-repeating)	____	____	____	____
- Tooling (non-repeating)	____	____	____	____
- Factory (repeating)	____	____	____	____
- Field (repeating)	____	____	____	____
- Maintenance (repeating)	____	____	____	____

COST
- Pre-prototype $ ____
- Prototype $ ____
- Tooling $ ____
- Soft tool reproduction unit $ ____
- Hard tool reproduction unit $ ____
- Annual servicing by factory $ ____

RATIOS
- Installed vs. Packaged compression ____
- Field man hours ____ per cu. ft., ____ per sq. ft. Floor
- Pounds ____ " " " ____ " " " "
- Maintenance ____ " " " ____ " " " "
- Dollars $ ____ " " " ____ " " " "
- Dollars $ ____ per lb. structure, $ ____ per cu. ft. structure per year including: amortization, maintenance, control.
- K.W.H. per cu. ft. controlled environment at max. enviro-hostility ____.

DESIGNED BY   PRIMARY CONSULTANTS
ASSOCIATES   PRIMARY ENGINEERS
CUSTOMER'S ARCHITECT   CUSTOMER'S ENGINEER
CUSTOMER   MAIN SUBCONTRACTORS
PRODUCED BY   INSTALLED BY
PHOTOGRAPHED BY   PUBLISHED BY
IS PERMISSION REQUIRED TO REPRINT