Nov. 11, 1969 J. M. KOSTICK 3,477,188

MODULAR STRUCTURE

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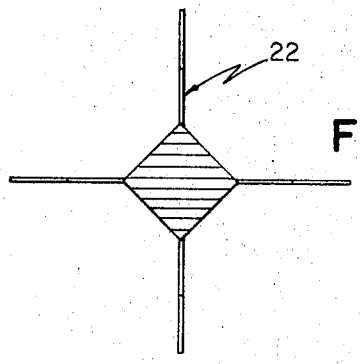


FIG 3

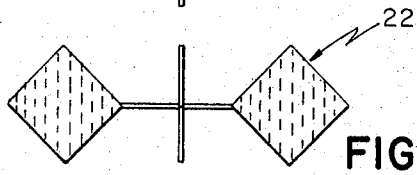
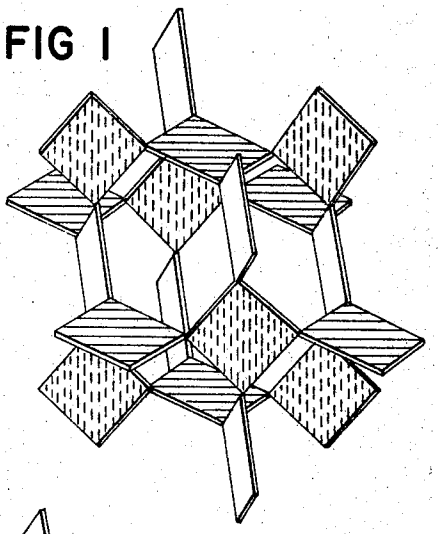


FIG 4

FIG 1



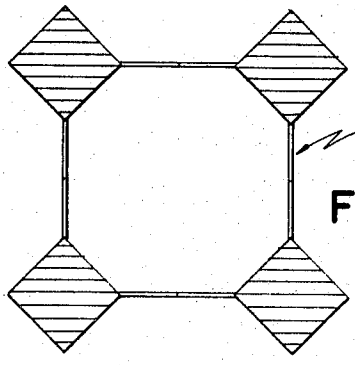


FIG 5

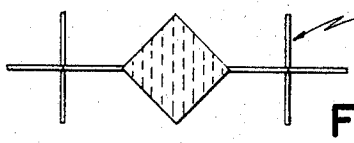


FIG 6

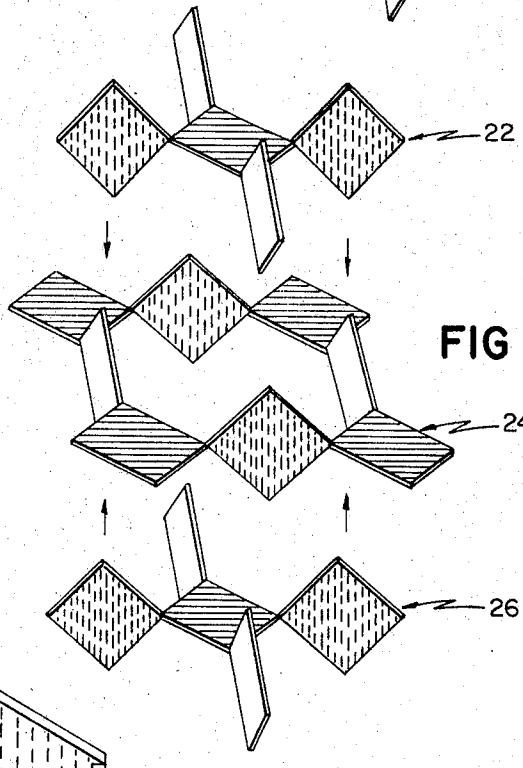


FIG 2

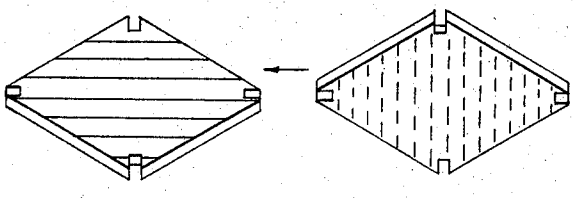


FIG 7

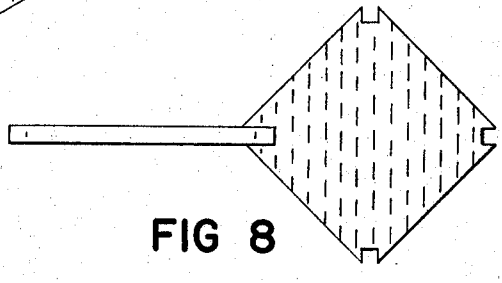


FIG 8

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FIG 9

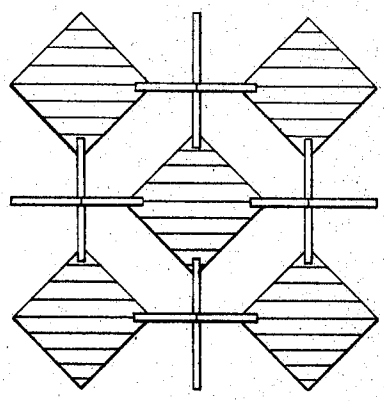
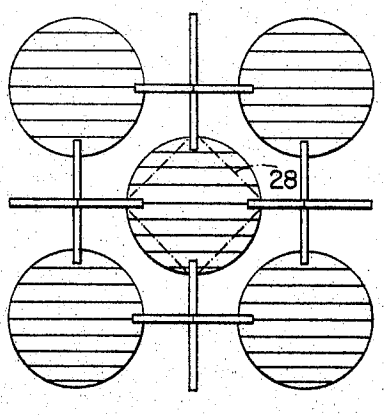


FIG 10



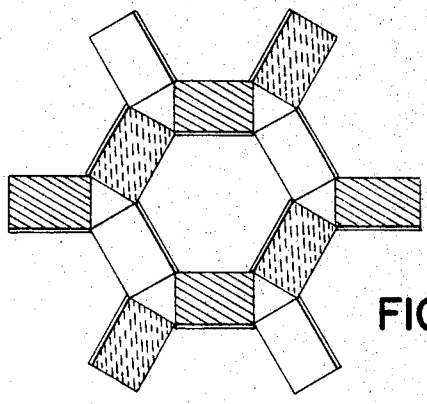


FIG 13

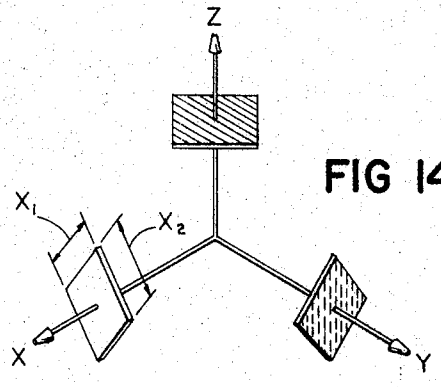


FIG 14

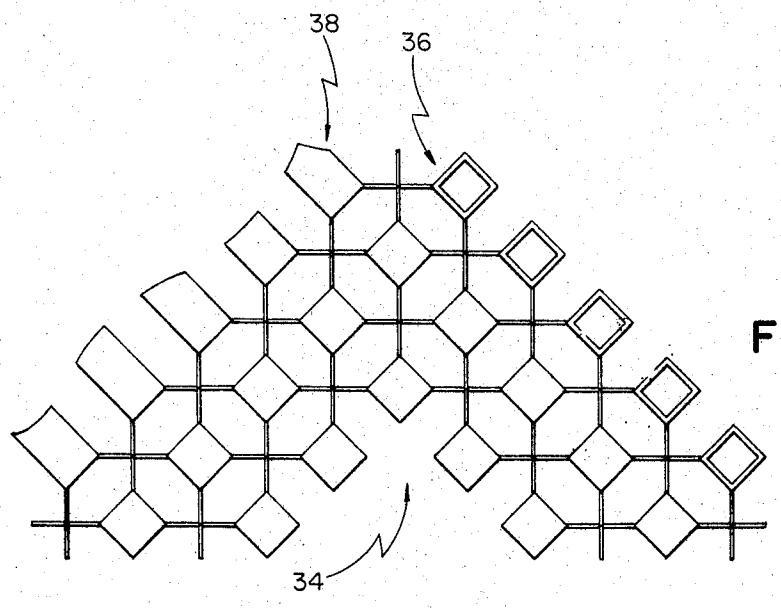


FIG 15

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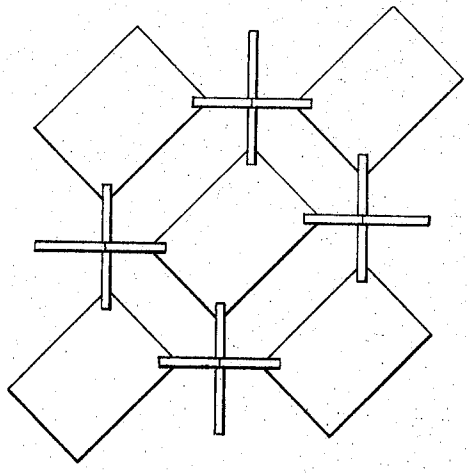


FIG 11

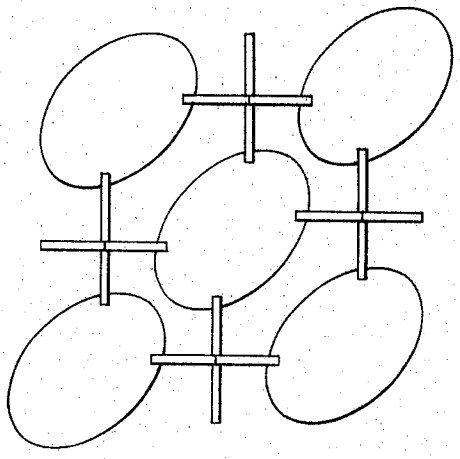


FIG 12

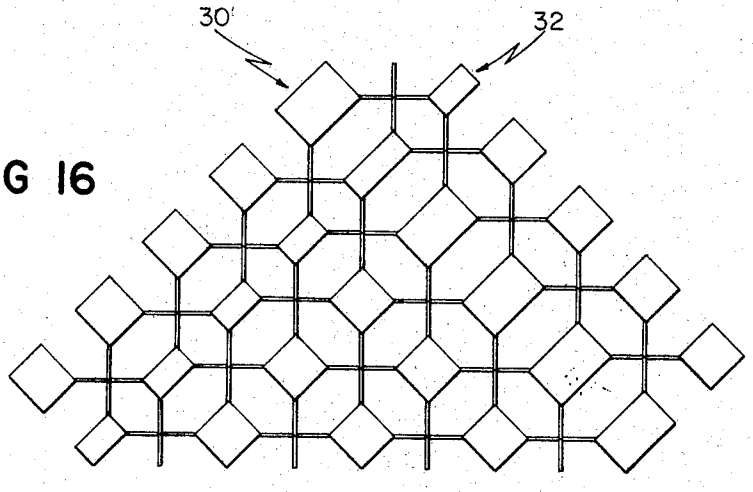


FIG 16

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3,477,188

MODULAR STRUCTURE

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Int. Cl. E04h 1/00, 14/00; E04c 2/42
U.S. Cl. 52—637 8 Claims

ABSTRACT OF THE DISCLOSURE

A modular structure for subdividing a volume into a three-dimensional lattice of similar contiguous cells. The structure may be constructed from sets of generally planar structural elements oriented parallel to three mutually orthogonal reference planes. In a preferred embodiment the resulting cells define tetraxi-decahedrons having six square structural faces and eight interposed hexagonal apertures.

MODULAR STRUCTURE

This invention relates to a structure for organizing volumes of space into similar contiguous cells.

One of the most common functions served by man-made structures is the subdivision of open space into contiguous compartments or cells. Space is often in short supply and man seeks to increase its utilization by subdividing it. The usual mode of subdivision is Cartesian; rectangular prisms are placed in adjacent proximity to form larger rectangular prisms. Street grids form rectangular city blocks from which arise box-like glass fronted office buildings the identical rectangular floors of which are divided into a multitude of similar rectangular cubicles furnished with desks and file cabinets full of rectangular drawers containing rectangular books and files made up of rectangular pages divided into yet smaller rectangular character locations.

Rectangular prisms are a useful and economical way of subdividing space, but they are not the only way of subdividing space. If used without variation they can produce a mind-numbing monotony. Variety and complexity of the visual environment is useful for its own sake. Growing plants and moving water are valued visual stimuli that contrast strongly with man's endless Cartesian grids. But man as well as nature can provide variety in the visual environment. Certain cities, including Washington and Paris, have eschewed the rectangular street grid with no evident loss of efficiency that would offset the improvement in visual experience. Other man-made structures such as Buckminster Fuller's geodesic domes and Moshe Safdie's Habitat '67 have proved that the unconventional organization of space need not imply loss of functional utility.

Visual variety is not the only objective; economics also imposes certain constraints upon practical structures for subdividing space. Because space is in short and generally decreasing supply the most practical methods of subdividing it are able to use it all. This is to say, whatever shape is chosen for the cell or module of subdivision it is often desirable that such shape be a "space-filler" capable of being stacked or juxtaposed in a three-dimensional array without unwanted interstices. Furthermore

it is advantageous for any such structure to be capable of cheap and rapid construction in quantity; other things being equal this favors those structures which require only a small number of different parts.

The principal object of the present invention is to provide a structure for subdividing a volume of space into an attractive and unusual space-filling lattice of similar contiguous cells. Another object is to provide such a structure that may be cheaply and conveniently fabricated from a very limited number (as low as one) of simple standardized elements. Another object is to provide such a structure that may be easily modified to elongate or contract the cells thereof along any of six non-parallel axes without changing the basic angular relationships of the component elements or the manner of joining them one to another. Yet another object is to provide such a srtucture which may be readily varied in appearance and function by variation in the inter-joint perimeters of the elements thereof without changing the basic angular relationships of the component elements or the manner of joining them one to another.

In a preferred embodiment of the invention there are featured three sets of similarly sized generally planar rectangular elements oriented parallel to three mutually orthogonal reference planes. Any given element not at the periphery of the structure is joined corner-to-corner to four adjacent elements all perpendicular to the given element. The adjacent elements at opposite corners of the given element are parallel, those at adjacent corners of the given element are perpendicular to each other.

Other objects, features, and advantages will appear from the following description of preferred embodiments of the invention taken together with the attached drawings in which:

FIG. 1 is a perspective view of one complete cell (and portions of adjacent cells) fabricated from eighteen identical square elements with the three orthogonal sets of elements differentiated by shading;

FIG. 2 is an exploded view of the cell shown in FIG. 1;

FIG. 3 is a top view of one of the two end caps of the cell shown in FIG. 2;

FIG. 4 is a side elevation of the same end cap;

FIG. 5 is a top view of the center ring portion of the cell shown in FIG. 2;

FIG. 6 is a side elevation of the same center ring;

FIG. 7 shows one method of joining adjacent elements of the structure;

FIG. 8 shows two elements joined by this method;

FIG. 9 is a top view of the cell shown in perspective in FIG. 1;

FIG. 10 is a similar top view of a variation of the same cell employing Z-plane elements with sides rounded out between the points of joining to produce a circular perimeter;

FIG. 11 is a side elevation of another variation of the same cell employing rectangular rather than square X-plane elements;

FIG. 12 is a further variation of the cell shown in FIG. 11 employing X-plane elements with sides modified between the points of joining to produce an elliptical perimeter.

FIG. 13 is another view of the cell shown in FIG. 1 and FIG. 9 taken in a direction normal to one of the eight hexagonal apertures thereof;

FIG. 14 shows three mutually orthogonal reference planes designated for convenience X, Y, and Z;

FIG. 15 is a side elevation of a typical lattice formed from a number of contiguous cells similar to that of FIG. 1 the elevation being taken in a direction normal to the X-plane (and thus normal to one of the three orthogonal sets of elements making up the lattice);

FIG. 16 is a similar side elevation of a variation of the lattice shown in FIG. 15 in which one tier of elements has been expanded along the X_1 dimension and another perpendicular tier of elements has been contracted along the X_2 dimension.

Structures embodying the invention can be constructed to almost any scale and from any of a variety of materials depending upon the intended use and application. Metal, plastic, plywood, paper, glass, and concrete are among the many suitable materials. The method of joining adjacent elements may likewise be varied in accordance with the strength required and other design requirements such as cost and appearance. In the figures, the individual elements are shown as thin, solid, generally planar members. Although these embodiments illustrate the basic concept of the invention in a simple form, it should be understood that the actual elements used to practice the invention need not have any of these characteristics. They must be "generally planar" only in the sense that the points at which any given element is joined to adjacent elements lie in a plane such as that of the thin flat elements shown in the figures. Between the points of joining, however, the surface and perimeter of any given element can be varied at will. Any given element can be pierced with one or more apertures and indeed can be constructed as a mere hollow frame rather than as a solid plane. The term "generally planar" as used in the claims is intended to embrace this broader meaning. In all the figures except FIG. 10, FIG. 11, FIG. 12, and FIG. 16, the elements of all three orthogonal sets are shown as identical squares. This choice of shape produces lattices of maximum symmetry and serves well to show the basic principles of the structure, but it is not intended to be limiting. The points of joining of any given element to adjacent elements lie at the corners of a rectangle but the perimeter of the given element need not be a straight line between those corners (for example see FIG. 10 and FIG. 12).

A single cell is shown in perspective in FIG. 1. Eighteen square elements are joined corner-to-corner to produce this basic structure. Six of the eighteen elements are oriented parallel to each of three mutually orthogonal reference planes which may be designated X, Y, and Z as shown, for example, in FIG. 14. The cell shown in FIG. 1 is a tetraxi-decahedron having fourteen faces and thirty-six identical edges. The cell is symmetrical about seven axes, four axes through the centers of opposite pairs of hexagonal apertures, and three axes through the centers of opposite pairs of square elements.

In an extensive multi-cell lattice with the cell of FIG. 1 entirely in the interior of the lattice there would be fourteen additional cells each sharing one face with the single cell shown in FIG. 1. Six of these fourteen adjacent cells would share "square faces" (elements) with the cell shown, and the remaining eight adjacent cells would share "hexagonal faces" (apertures) with the cell shown. At the interior of a multi-cell lattice each of the square elements forms part of the periphery of six separate cells, each element edge is shared by three cells, and each element forms a square face of two cells. This high degree of element-sharing results in great economy of construction particularly for large lattices where the ratio of the number of interior cells to exterior cells becomes high. In the limit as the number of cells becomes great the ratio of elements to cells approaches three. This may be seen by reflecting that any given cell has only six square faces and that each square element provides one square face for each of two adjacent cells.

The structure of the cell shown in FIG. 1 is more fully illustrated in FIGS. 2 through 6. As can best be seen from FIG. 2, the cell may be built up from two identical "end caps" **22** and **26** linked to each other by an intermediate center "ring" **24**. Each of the two end caps is composed of five elements; the ring is composed of eight. The eighteen elements are coded as follows to show their orientation with respect to three predesignated mutually orthogonal reference planes:

Element parallel to reference plane	Shading
X	None
Y	Dashed
Z	Lined

The "top" end cap **22** shown in perspective in FIG. 2 is shown in top view in FIG. 3 and in side elevation in FIG. 4. The central Z-plane element is joined at its corners to two Y-plane elements (seen side-on in FIG. 4) and to two X-plane elements (seen edge-on in FIG. 4). End cap **26** is identical to end cap **22**.

The central ring **24** shown in perspective in FIG. 2 is shown in top view in FIG. 5 and in side elevation in FIG. 6. Each of the four Z-plane elements of the ring are joined to one X-plane element of the ring and one Y-plane element of the ring. Each of the X-plane elements of the ring are in turn joined to one of the Y-plane elements of each of the two end caps. Each of the Y-plane elements of the ring are in turn joined to one of the X-plane elements of each of the two end caps.

It is not in general true that the plane of a given element must lie along the diagonal of an adjacent element to which the given element is joined. This is true only for the special case in which the adjacent element is square; it is not the case if the adjacent element is rectangular with unequal sides. In that event the plane of the given element bisects the corner angle of the rectangular adjacent element. (If the sides of the adjacent element are reshaped between points of joining, as for example in FIG. 10 or FIG. 12, the points at which additional elements adjacent to the adjacent element are joined to the adjacent element nevertheless form a rectangle in the plane of the adjacent element and the plane of the given element bisects the corner angle of that rectangle.)

The structure shown in FIG. 1 through FIG. 6 is entirely symmetrical in that when it is iterated throughout a volume of space as shown in FIG. 15, any given interior X-plane element is joined to two adjacent Y-plane elements and to two adjacent Z-plane elements, any interior Y-plane element is joined to two adjacent X-plane elements and to two adjacent Z-plane elements, and any given interior Z-plane element is joined to two adjacent X-plane elements and to two adjacent Y-plane elements. That is, the particular "end cap and ring" method of assembly shown in FIG. 2 is relevant only as an explanatory aid; any given element at the interior of a multi-cell lattice belongs to various end caps and various rings, and any given interior element is joined to its four adjacent elements in an entirely identical manner. (It is proper in defining this identity of structure to neglect the arbitrary designations "X-plane," "Y-plane," and "Z-plane." This is true because of the overall spacial symmetry of the structure which can, of course, be freely rotated so that the X-plane takes the place of the Y-plane or Z-plane etc.). Any given cell of a lattice (such as that shown in FIG. 15) can be considered to be composed of six interior elements and twelve peripheral elements (as shown in FIG. 1) each of the six interior elements being joined to four adjacent peripheral elements. In FIG. 1, the six interior elements form the six square faces of the cell, and each of the twelve peripheral elements is joined to two of the interior elements. The interior elements need not, of course, be squares, but may be of any shape which permits the contact points with adjacent peripheral elements to lie upon the vertices of a rectangle.

A simple and convenient method of rigidly joining adjacent elements is provided by the use of interlocking notches lying along the bisectors of the element corner angles as shown in FIG. 7 and FIG. 8. The notched joints may be locked in place by adhesives, mechanical fasteners, or friction alone depending upon the structural strength required and other design criteria. The notches may be of any suitable depth and it is evident that an increase in the depth of the notches results in a reduction in the effective size of the resulting cells. Other means of joining adjacent elements without the use of interlocking notches will be readily apparent to those skilled in the mechanical arts. Because even the most complex multicell lattices require only a single type of joint (every joint is essentially a corner-to-corner linkage of two perpendicular planes), the structures of the invention are well adapted to the use of standardized and inexpensive fastening means.

FIG. 9 shows a "top view" taken normal to the Z-plane of the basic cell shown in perspective in FIG. 1. FIGURE 11 shows the same cell viewed normal to one of the hexagonal apertures. A lattice formed of many such cells is shown in FIG. 15 viewed normal to the X-plane. An interesting feature of such a lattice is the presence of four sets of parallel hexagonal "tunnels" which penetrate the entire structure and which are readily usable for access to interior portions of the lattice, air shafts and like purposes. The lattice, of course, need not be complete, but, consistent with structural strength requirements, any number of elements can be omitted from any point of the structure, as shown for example at **34**. One tier of elements have been shown at **36** as hollow frames rather than as solid rectangles.

As may be best seen in FIG. 1 and FIG. 15, each interior element of the lattice is joined to four adjacent elements and each peripheral element at the edge of the lattice is joined to less than four adjacent elements. The structure of the lattice is determined primarily by the relative location of the four contact points of each interior element. A rectangle is defined by the imaginary reference lines joining the four points at which each such interior element is joined to the four adjacent elements. As previously pointed out, the actual physical structure of a given element may vary with respect to both perimeter and surface configuration between the points of joining. For example, the basic structure of the cell shown in FIG. 10 is identical to that of the cell shown in FIG. 9. The Z-plane squares (as indicated by reference line **28**) have been curved outwardly between the points of joining to form circles, but the basic cell structure remains unchanged. Similar modifications could of course be made to the inter-joint configuration of the X and Y-plane elements of the cell shown in FIG. 10. Elements at the periphery of a lattice may of course be reshaped in any desired manner outside of the joints with adjacent elements (see FIG. 15 at **38**) thus providing variety in the peripheral contour of the lattice.

FIG. 11 shows a more fundamental way in which the structure of the cell can be modified. The X-plane squares of the cell shown in FIG. 1 have been doubled in length along dimension X_1 (see FIG. 14) thereby producing rectangular rather than square elements. As can be seen from FIG. 11, this has the effect of "stretching" the cell along the X_1 dimension. The angular relationships of the joinings have not been changed in any way. In FIG. 12 the cell of FIG. 11 has been further modified to produce elliptical elements in the X-plane. The principle illustrated by FIG. 11 can obviously be extended to stretch or shrink a given cell by any desired constant on any of six non-parallel dimensions (two mutually perpendicular dimensions for each of the three orthogonal element sets). This feature of the invention offers great practical advantages. Often, for example, it proves desirable to exaggerate one or both dimensions of those elements of a lattice that are oriented parallel to the earth's surface, thereby providing more usable "floor area" in a lattice. Nor is there any requirement that all elements of a given lattice parallel to a given reference plane be stretched or shrunk by the same amount. It is sufficient that all elements in a given "tier" of the lattice be of the same width. This is illustrated in FIG. 16 which shows a variation of the basic lattice of FIG. 15 in which one tier of cells generally designated **30** has been stretched on the X_1 axis and another perpendicular tier of cells generally designated **32** has been shrunk on the X_2 axis. Interesting and attractive lattice structures can be formed by modulating the size of successive tiers of cells in waves, that is, by making each successive tier slightly wider than the preceding tier for a given number of tiers and then making each tier slightly smaller than the preceding tier for a number of additional tiers and repeating the cycle throughout the structure.

Color patterns of great variety and beauty are possible by making adjacent elements or tiers of alternate colors, by making elements of the three orthogonal sets of different colors, or by varying the hue, shade, or intensity of successive tiers by increments. The design possibilities provided by the described embodiments of the present invention are far more varied than those available from conventional Cartesian structures. If conventional Cartesian corners (such as those of an ordinary rectangular room) are desired for certain cells of a lattice they can be readily obtained by merely extending the planes of appropriate elements to a desired line of intersection. (The normal Cartesian planes of conventional architecture are always present in the lattice together with the additional planes defined by the hexagonal apertures.)

A variety of uses are possible. The simple square-element lattice shown in FIG. 15 has been used (without the modifications illustrated at **34**, **36** and **38**) as a three-dimensional chess board and as a window display rack for small high-value items. Larger units may be used for children's jungle gyms, for storage chambers, for human dwelling units, and for a variety of other structural or architectural applications.

These uses by no means exhaust the possible applications of the invention. Other embodiments will occur to those skilled in the art.

What is claimed is:

1. A modular structure comprising a lattice of adjacent cells; each said cell having six generally planar interior elements and twelve generally planar peripheral elements;

said six interior elements disposed in three element pairs, the two elements of each said pair being parallel, the elements of differing pairs being mutually perpendicular;

each of said interior elements having at its periphery four element contact points so arranged that lines drawn between adjacent contact points define a rectangle;

each of said interior elements joined at each of its element contact points to one of said peripheral elements;

the plane of each of said peripheral elements lying perpendicular to the plane of the interior element to which it is joined and bisecting the adjacent interior angle of the contact-point rectangle of the interior element to which it is joined;

peripheral elements of some of said cells forming interior elements of other adjacent cells.

2. The modular structure of claim **1** wherein the contact-point rectangles of all mutually parallel interior elements are of the same length and of the same width.

3. The modular structure of claim **2** wherein the contact-point rectangles of all interior elements are of the same length and of the same width.

4. The modular structure of claim **3** wherein the contact-point rectangles of all interior elements are squares.

5. The modular structure of claim **1** wherein the contact-point rectangles of all interior elements are squares.

6. The modular structure of claim **1** wherein all interior elements have circular perimeters.

7. The modular structure of claim 1 wherein at least one of said elements defines at least one aperture.

8. The modular structure of claim 1 wherein the peripheries of adjacent elements are notched to permit interlocking.

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U.S. Cl. X.R.

13—1.5; 46—30; 52—80, 237, 663; 211—135