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Riedberger et al.

[11] **3,710,528**

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[54] **BUILDING STRUCTURES**

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[52] **U.S. Cl.**......................................**52/236,** 52/237

[51] **Int. Cl.** **E04h 1/00**

[58] **Field of Search**......529/79, 80, 81, 236; 52/235, 52/237

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[57] **ABSTRACT**

A truss structure with an open-work skeleton of beam construction comprising octahedral units and tetrahedral units some of which have their apices in a first horizontal plane and the remainder have their apices in a second plane, the edges of each tetrahedral unit being the common edges of adjoining octahedral units. Beams are disposed along the edges of these octahedral and tetrahedral units. Rectangular panel members lying in the vertical planes defined by the tetrahedral unit edges are attached to those beams. Hexagonal panel members are disposed in the first and second planes. The rectangular and hexagonal panel members define cells in the form of hexagonal prisms.

5 Claims, 14 Drawing Figures

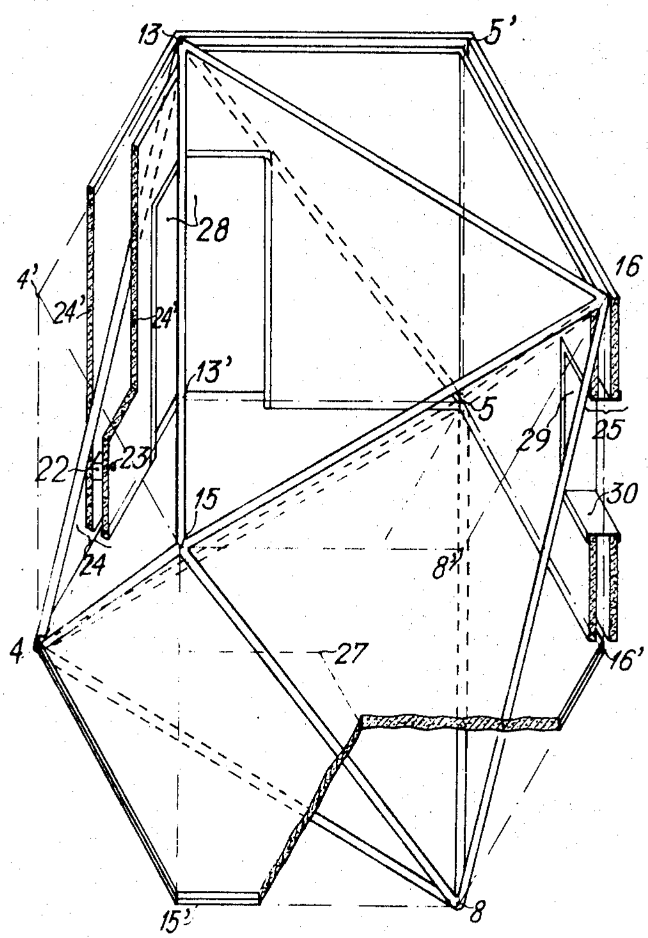

Fig.1

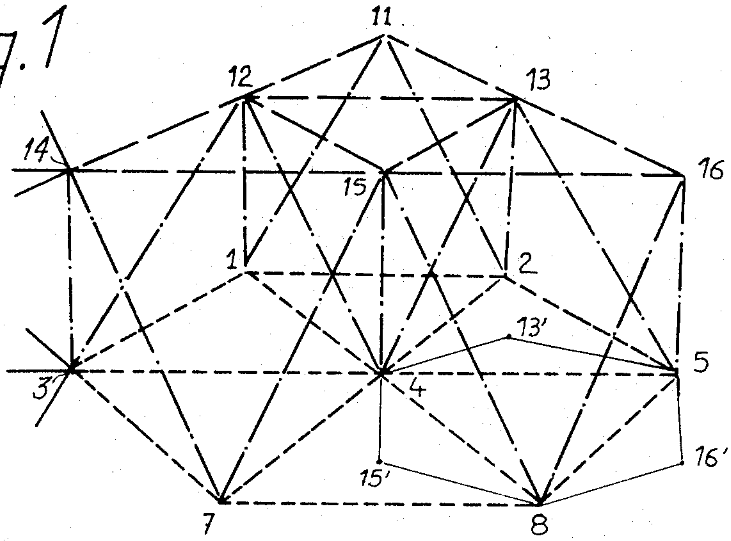

Fig. 2

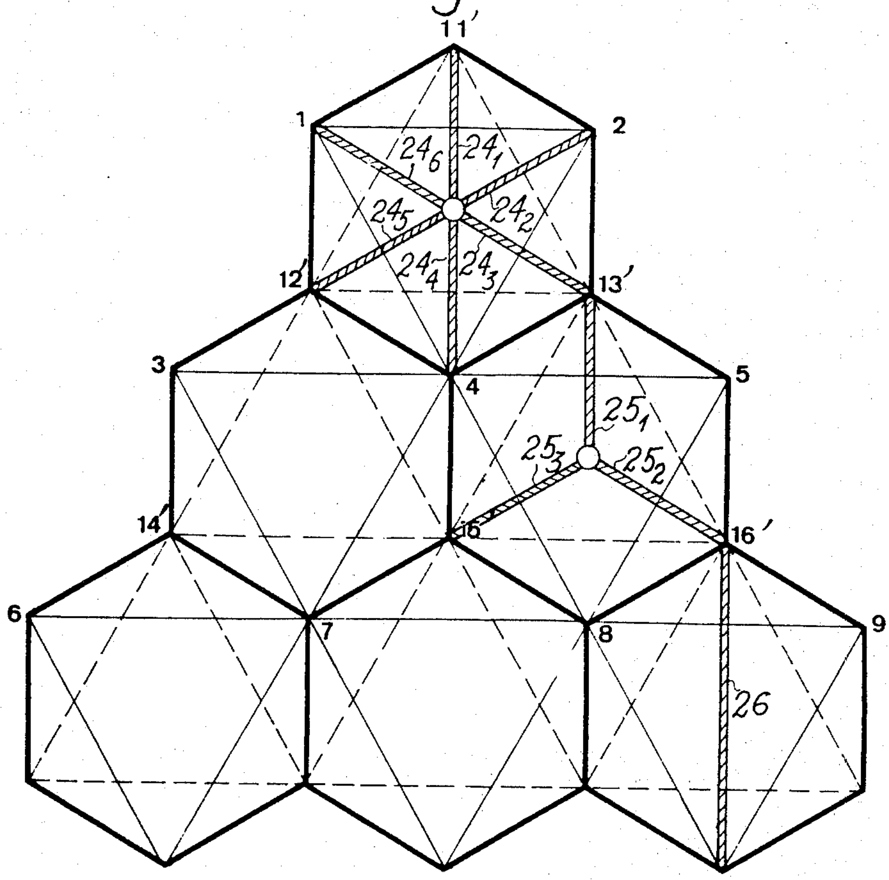

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Fig. 3

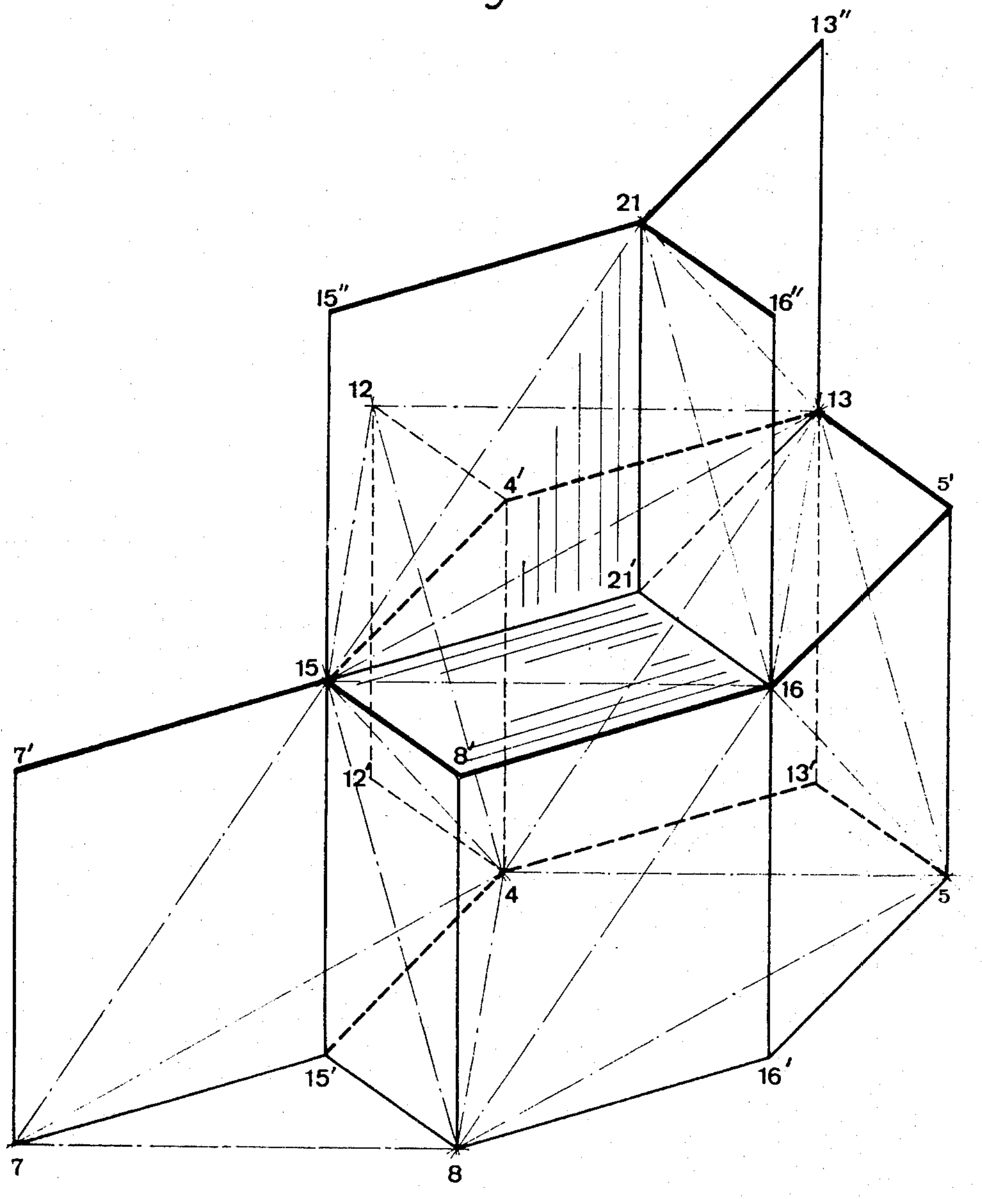

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Fig. 4

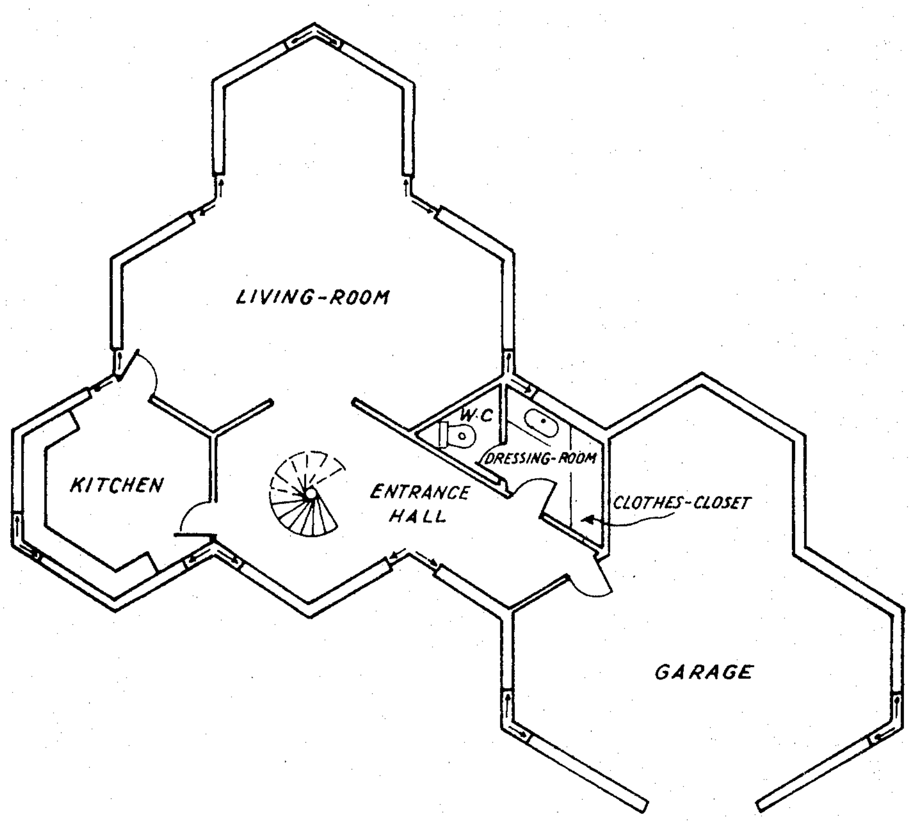

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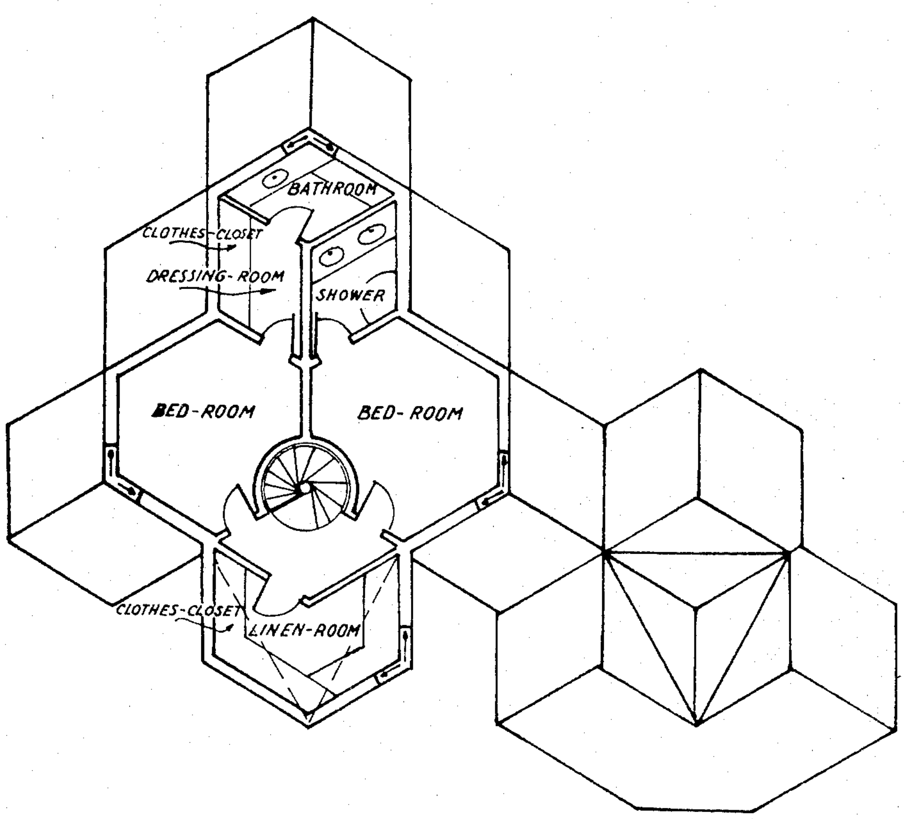
Fig. 5



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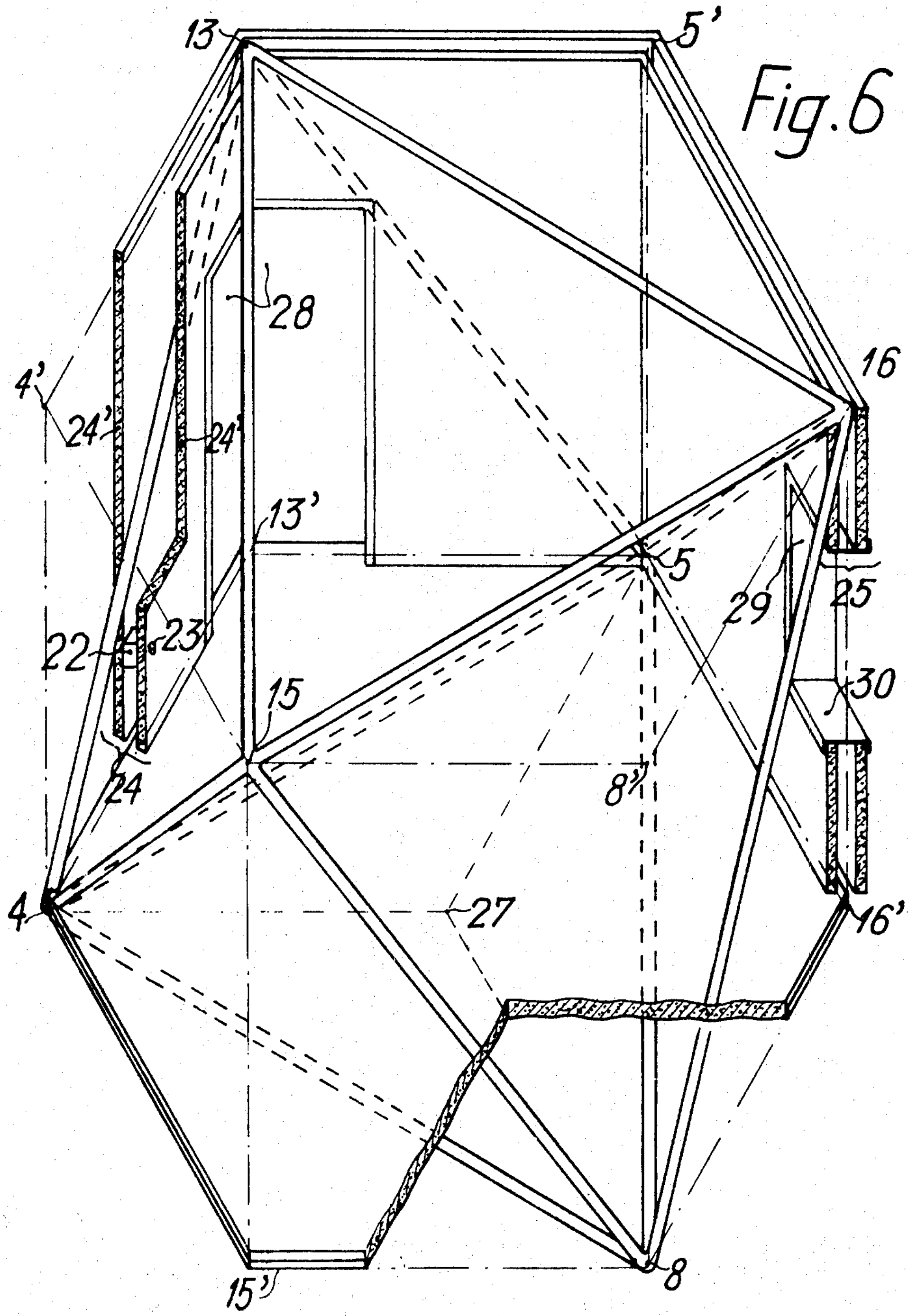

Fig. 6

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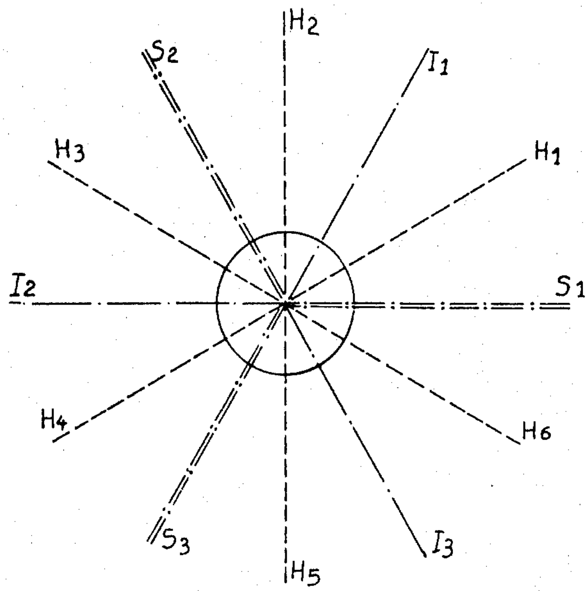

Fig.7

Fig.12

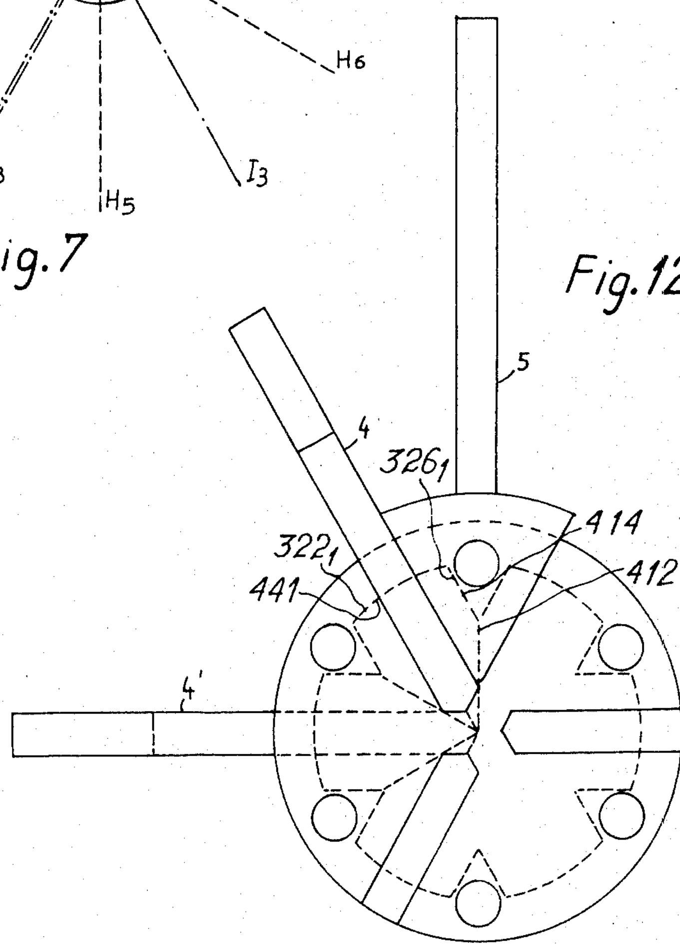

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Fig. 8

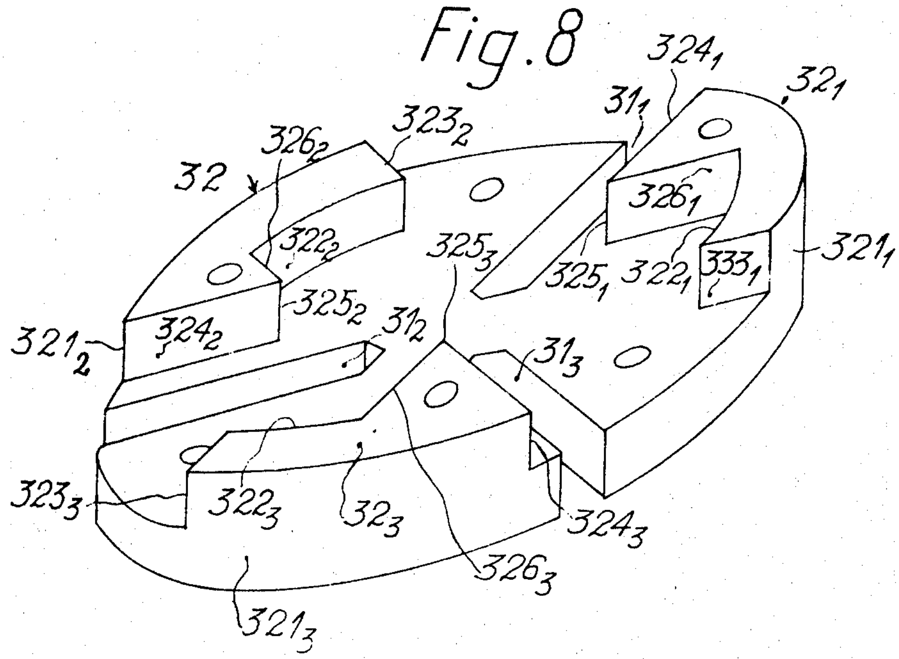

Fig. 9

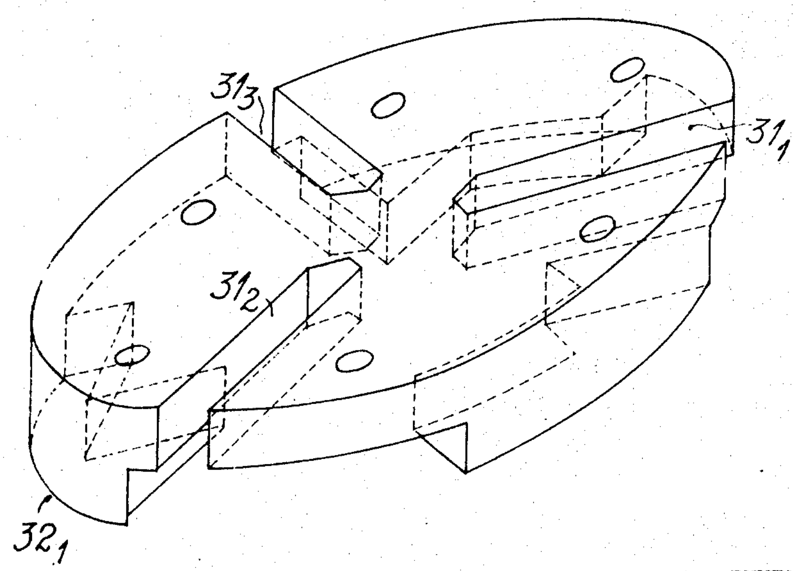

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Fig. 10

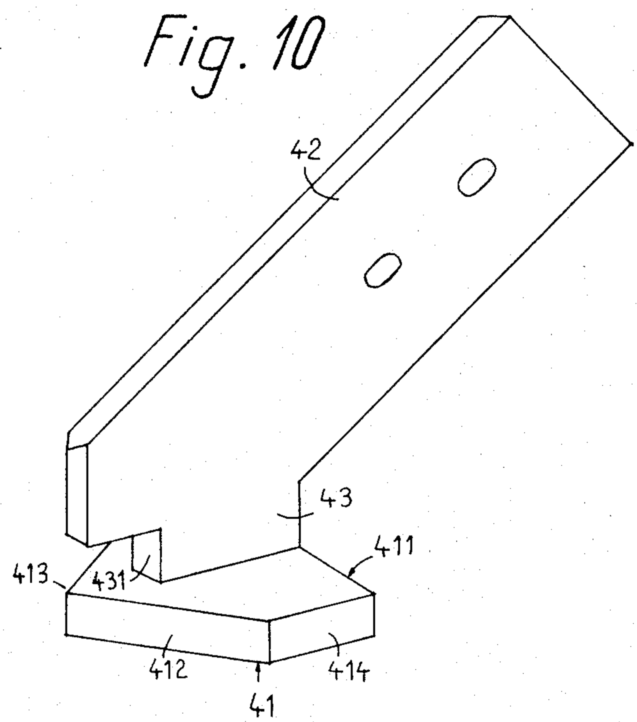

Fig. 11

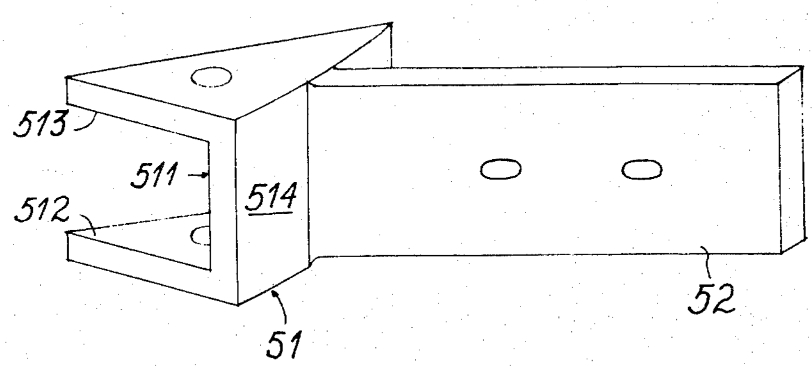

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Fig. 13

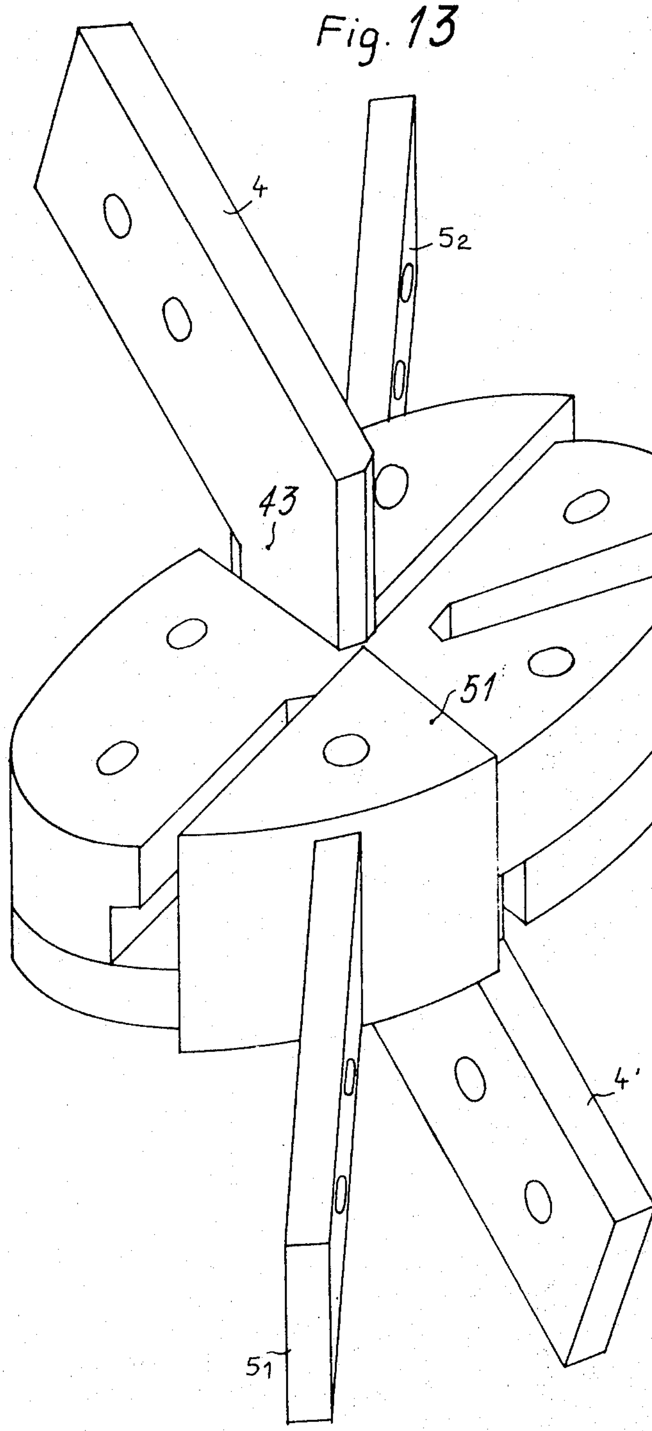

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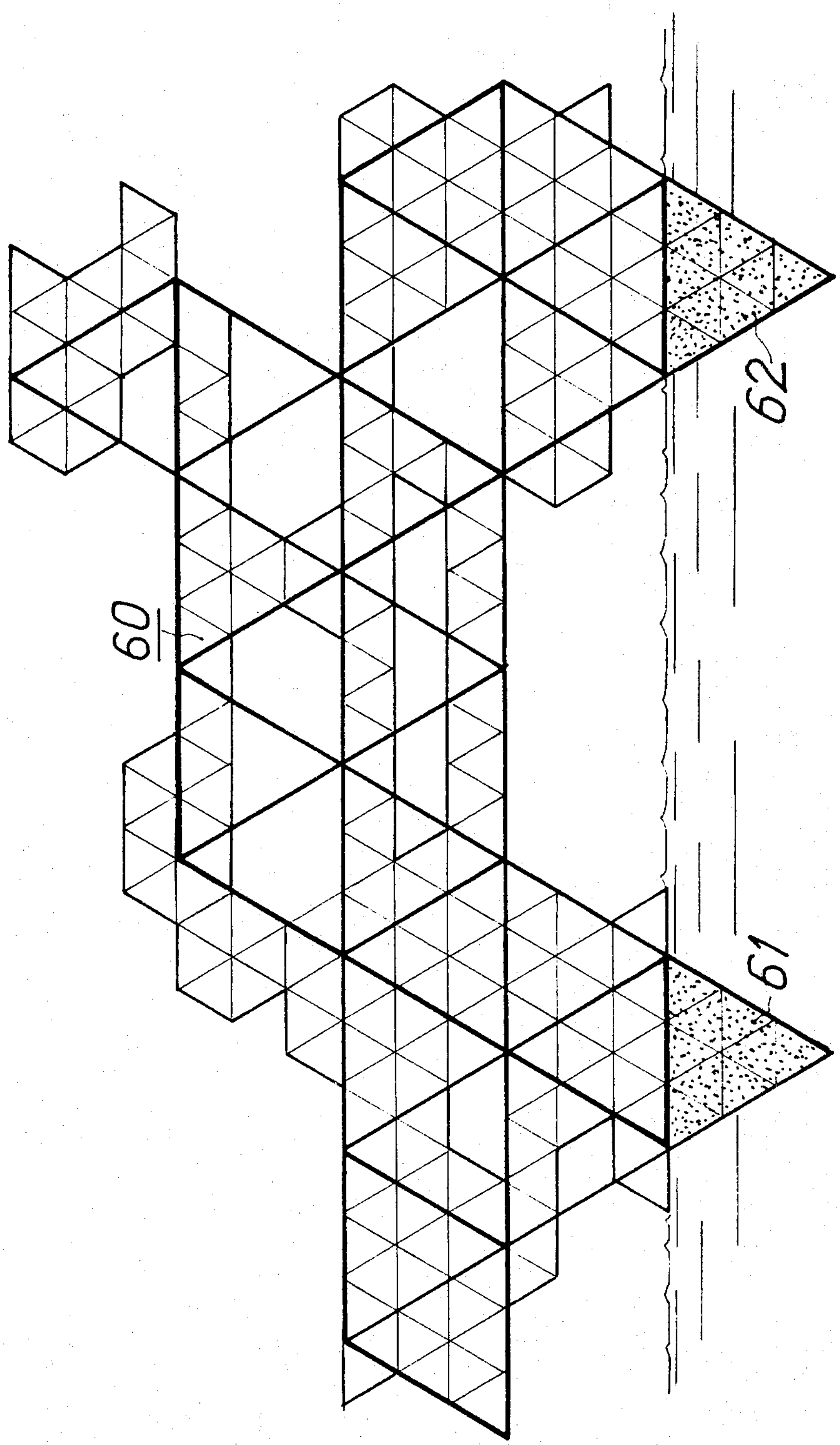
Fig. 14



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BUILDING STRUCTURES

The present invention concerns a structure with an open-work skeleton of beam construction, suitable for the construction of buildings. The invention also comprises a junction device used for assembling such structures.

It has previously been proposed, for example in U.S. Pat. No. 2,709,975, issued on 7th June, 1955, to construct a roof truss from a plurality of triangular pyramidal units or tetrahedral units, each comprising a base made up of three base members connected together at their extremities to form base corners and three web members connected to the base corners and converging to form an apex. The bases of the tetrahedral units form one truss face while the apices thereof define a second truss face. In the plane of the apices, each apex is connected by truss members to the apices of all of the adjacent tetrahedrons. More specifically, the truss structure comprises a plurality of regular tetrahedrons so connected together that each internal unit, that is, each unit of the truss other than an edge unit, is connected at its base corners to six surrounding units and at its apex to the apices of the same six units surrounding it.

Until now, such tetrahedral structures have been used for the construction of roofs or floors for supporting substantially uniformly distributed loads. They have not been used for providing buildings for human habitation since, although the planes of the bases and of the apices are horizontal, the planes defined by the lateral faces of a regular tetrahedron with a horizontal base are inclined at an angle of 19°24′ with respect to the vertical, and rooms with inclined walls are not well suited for human inhabitants.

Further more, when such a structure includes tetrahedrons with an upwardly directed apex, it includes octahedrons and tetrahedrons with apices at the bottom. If one storey of the truss comprises $n(n+1)/2$ tetrahedral units with an apex at the top, it also comprises $(n-1)(n-2)/2$ tetrahedral units with an apex at the bottom and $n(n-1)/2$ octahedral units. Tetrahedral units with an apex at the bottom are rather difficult to make suitable for good human living conditions.

In accordance with the invention, a structure with an open-work skeleton of beam construction comprises octahedral units each with parallel first and second faces defining respective first and second planes in the structure, adjoining octahedral units having only one common edge which is inclined with respect to the first and second planes, and tetrahedral units, some of which have their apices in the first plane while the remainder have their apices in the second plane, the edges of each tetrahedral unit being common edges of adjoining octahedral units, rectangular first panel members attached to those beams along the tetrahedral unit edges and hexagonal second panel members in the first and second planes, the first and second panel members defining enclosed cells in the form of hexagonal prisms each with an axis extending perpendicularly between the centers of its hexagonal second panel members.

At least one cell may be provided with rectangular panel members parallel to the cell axis and extending to alternate edges of the cell parallel to the axis, so that the cell is divided into lozenge-shaped sub-cells.

Some of the cells may be provided with rectangular panel members parallel to the cell axis and extending to every edge of the cell parallel to the axis, so that the cell is divided into triangular sub-cells.

Thus, using the invention, it is possible to provide a building with an open-work skeleton of metal beam construction made up of tetrahedral and octrahedral units or trusses, the arrangement being such that cells are provided within the structure which are suitable for human habitation.

The invention will now be described in more detail, by way of examples only, with reference to the accompanying partly diagrammatic drawings in which :

FIG. **1** is a perspective view of an open-work schematic skeleton of metal beam construction in accordance with the invention;

FIG. **2** is a plan view of a structure such as that of FIG. **1** with some additional octrahedral units ;

FIG. **3** is a perspective view showing how a building divided into cells or rooms by vertical wall elements can be obtained from the structure of FIG. **1**, showing the variation in cell division between stages of the structure ;

FIGS. **4** and **5** are respectively plans of the ground floor and first floor of a human dwelling using a form of open-work skeleton;

FIG. **6** shows how wall and floor members of the dwelling are applied to the units of the open-work skeleton ;

FIG. **7** is a diagrammatic plan view of a junction device used for building up the structure of the dwelling ;

FIGS. **8** and **9** are perspective views of first and second disc members of a junction device ;

FIGS. **10** and **11** are perspective views of, respectively, an oblique beam-end-receiving stub and a radial beam-end-receiving stub of the junction device ;

FIG. **12** is a plan view of an assembled junction device ;

FIG. **13** is a perspective view of another assembled junction device ; and

FIG. **14** is a side elevation of a structure adapted to float in, for example, a river.

Referring to FIG. **1**, the first of three octahedral units of a single storey building structure is made up of a first rectangular pyramid with summit **11** in a plane defining the ceiling of the storey and a rectangular base **1–2–13–12**, and a second rectangular pyramid with summit **4** in a second plane defining the floor level, this second pyramid having the same rectangular base **1–2–13–12**. This first octahedral unit may be designated **11 (1–2–13–12)4**. With the same notation, the second and third octahedral units are respectively **7(3–4–15–14)12** and **8(4–5–16–15)13**.

The bases **1–2–13–12**, **3–4–15–14**, and **4–5–16–15** are not vertical but lie in planes inclined to the vertical at an angle of 19°24′. Each octahedral unit has a triangular face in the ground floor plane and a triangular face in the ceiling plane ; these faces are **1–2–4**, **3–4–7** and **4–5–8** in the floor plane and **11–12–13**, **12–14–15** and **13–15–16** in the ceiling plane.

The structure of FIG. **1** also includes tetrahedral units with horizontal bases. Some, such as **12 (1–3–4)**, **15 (4–7–8)**, **13 (2–4–5)** have their apices upwardly directed while others, such as **4 (12–13–15)**, have their apices directed downwardly. In the notation just used to describe these tetrahedral units, the number outside the brackets is that of the tetrahedron summit and those inside the brackets are the points defining the tetrahedron base.

If the structure is extended horizontally between the floor and ceiling levels, as shown at apices **3** and **14**, it will be seen that each octrahedral unit is surrounded by six tetrahedral units, three with upwardly directed and three with downwardly directed apices. Two adjoining octrahedral units have a common edge, for example the first unit **11(1–2–13–12)4** and the second **7(3–4–15–14)12** have a common edge **(4–12)**. Likewise, the second octahedral unit **7(3–4–15–14)12** and the third **8(4–5–16–15)13** have a common edge **(4–15)**. The first octahedral unit **11(1–2–13–12)4** and the third **8(4–5–16–15)13** have a common edge **(4–13)**. The common edges of the octrahedral units coincide with the edges of the tetrahedral units. For example, the tetrahedral unit **4(12–13–15)** has edges **(4–12)** common to the first and second octrahedral units, **(4–13)** common to the first and second octrahedral units, and **(4–15)** common to the second and third octrahedral units.

It will be appreciated that further stages or floors may be added to the single floor structure of FIG. **1**.

The structure shown in FIG. **1** enables a habitable building to be constructed by using the following elements ; a junction device for assembling the beams of the open-work skeleton, to be described later; beams of identical form whose section and dimension are chosen in accordance with the strains imposed on the structure by floor loading, by wind and possibly by seismic disturbances; panel members of uniform rectangular design placed in vertical planes in which lie the three oblique edges of each tetrahedral unit; and floor panels for arranging horizontally, having one of a small number of forms all derived from a basic hexagonal module form.

A mathematical relationship exists between the distance between successive parallel level planes of a structure, in the case of a building the successive floors, and the horizontal dimension of the vertical rectangular panels making up the walls.

If A is the length of a side of the regular octrahedron, basic to the structure, the distance between levels or floors is $A\sqrt{2/3} \cong 0.82A$ and the horizontal dimension of each vertically disposed panel is $A/\sqrt{3} \cong 0.58A$.

Each node of the structure, that is each point where two or more beams intersect, can be projected onto the horizontal plane at the base of the structure, the ground floor level in the case of a building. For example, nodes **15, 13** and **16** have projections **15′, 13′** and **16′**. This projection results in regular hexagons, such as **4, 13′, 5, 16′, 8, 15′** at the ground floor level. At each level in the structure, that is on each floor of the building, these hexagons make up a "paving" without gaps and without overlapping. Such hexagons are found on all levels within the structure.

FIG. **2** shows in heavy line the hexagons produced by such projection in a more extensive structure, corresponding to vertical panels defining the walls of habitable cells or rooms of the structure.

The structure may be divided up between each pair of levels into prismatic cells of hexagonal form by means of rectangular and vertical wall panel members of uniform design.

As each of these hexagonal cells has no beam inside it, it can be divided into six triangular sub-cells by further panel members such as $\mathbf{24}_1$ to $\mathbf{24}_6$. Alternatively, each hexagonal cell may be divided into lozenge-shaped sub-cells by rectangular panel members $\mathbf{25}_1$ to $\mathbf{25}_3$. Using a single rectangular panel **26**, each hexagonal cell may be divided into two cells with semi-hexagonal bases. Alternatively, each hexagonal cell may be divided into a combination of triangular, lozenge-shaped and semi-hexagonal subcells.

FIG. **3** shows a portion of the structure of FIG. **1** in which a basic hexagonal cell **(4–13′–5–16′–8–15′–4)** has been formed between the ground floor plane and the first floor plane. Between the first and second floor planes, dividing walls of three hexagonal cells follow the vertical planes passing through lines **(21′–15)**, **(21′–16, (21′–13)**.

The floor of the hexagonal cell **(4–15′–8–16′–5–13′–4)** is supported by beams **(4–5)**, **(5–8)**, **(8–4)**.

FIGS. **4** and **5** are plans of the ground floor and first floor of a human dwelling using the structure just described. These show that the hexagonal motif can be used to provide a functional division of each floor. Where this calls for the omission of particular oblique connecting beams, the remaining beam sections of the structure are such as to assure, in co-operation with the horizontal beams, the necessary strength for the structure.

FIG. **6** is a perspective view of a unit of the structure with certain of the floor and wall panels in place. The octahedral unit **8 (15–4–5–16)13** has its face **(4–5–8)** in the plane of the floor and its face **(13–15–16)** in the plane of the ceiling.

The hexagonal floor **(4–15′–8–16′–5–13′–4)** is supported by beams **(4–5)**, **(4–8)**, **(8–5)**. The floor is divided into three lozenge-shaped portions **(4–13′–5–27)**, **(4–15′–8–27)** and **(8–16′–5–27)** whose diagonals lie along the horizontal beams **(4–5)**, **(4–8)** and **(8–5)**. These lozenge-shaped floor sections are attached to these horizontal beams, for example by collars, and to the lower sections of the wall panels. They are joined at a common point **27**. The hexagonal ceiling **(13–4′15–8′–16–5′–13)** is supported on horizontal beams **(13–15)**, **(15–16)** and **(16–13)**.

To provide a hexagonal room, vertical wall panel members are disposed in the vertical planes defined respectively by the oblique beams **(13–4)**, **(4–15)**, **(15–8)**, **(8–16)**, **(16–5)**, **(5–13)**. Shown in the diagram are wall panel **24** in the plane of beam **(13–4)** and panel **25** in the plane of beam **(16–5)**. Each wall panel is double-walled, panel **24** comprising parallel and laminated wall elements **24′** and **24″**, for example of plaster strengthened with metal foil. One is disposed on each side of the beam **(13–4)**. They are held together and in place by any appropriate means, for example wedge members **22** fixed by screws **23**.

A folding door **28** has two panels which, when the door is closed, lie at 120° to one another, one panel lying in each of two adjacent walls of the hexagonal room. A window **29** has two panes, likewise at 120° to one another. The window frames are generally U-shaped metal channels which also help to maintain the spacing of the wall elements.

The structures just described are made up by connecting together the beam ends at each node using a junction device which will now be described.

The junction device is so designed that all the beams attached to it have their axes converging at a common point, in aligned pairs and are supported on the device and simultaneously restrained in the direction of the longitudinal and traverse loads. A perfect geometry is thus obtained for the open-work skeleton, with precise distribution of the loads on it.

Referring to FIG. **7**, the device must cater for a maximum of six horizontal beams $H_1 - H_6$, shown in dotted line, and six oblique beams, three $S_1 - S_3$ being upwardly directed and shown by double chain-dotted lines, whilst three $I_1 - I_3$ are downwardly directed and shown in single chain-dotted line.

The junction device comprises co-operating first and second disc members, shown in FIGS. **8** and **9**, in which are fitted a set of beam end receiving stubs, of two sorts shown in FIGS. **10** and **11**. The stub of FIG. **10** is for an oblique beam and that of FIG. **11** for a horizontal beam. In the structure, the disc members are horizontal.

Referring to FIG. **8** and **9**, the first and second disc members have substantially the same thickness and one is the mirror image of the other. They have co-operating projections and recesses by means of which they may be engaged together without play. Each disc member has three equi-angularly spaced radial slots 31_1, 31_2 and 31_3 whose walls are parallel to an axis passing perpendicularly through the disc center. The width of each of these slots is substantially equal to the width of a root portion of the oblique stub shown in FIG. **10**.

Each disc member also has three flat and equi-angularly spaced peripheral projections 32_1, 32_2 and 32_3. Each consists of a 60° part-cylindrical segment having an external part-cylindrical face, 321_1, 321_2 and 321_3 respectively, coinciding with the disc periphery. Each has an internal part-cylindrical face, 322_1, 322_2 and 322_3 respectively, and two plane faces parallel to the axis passing perpendicularly through the disc center and respectively parallel to the walls of the adjacent slots; a smaller of the plane faces, 323_1, 323_2 and 323_3 respectively, is at one end of the corresponding annular projection, while a larger, 324_1, 324_2 and 324_3 is at the opposite end. A further plane face parallel to the axis passing perpendicularly through the disc center, 326_1, 326_2 and 326_3 respectively, intersects each of the faces 324_1 to 324_3 to define an inwardly directed dihedron, 325_1, 325_2, 325_3 respectively. These intersecting faces thus form a triangular shoulder on the respective internal cylindrical face, and the three greater plane faces, 324_1–324_3 are slightly shifted in the same sense with respect to the three radial slots.

Referring to FIG. **10**, the oblique beam and receiving stubs each have a generally triangular flat heel piece **41** whose thickness is the same as that of the projections on each disc member. An outwardly facing surface **411** of the heel piece **41** is part-cylindrical and engages the inner cylindrical face of the respective disc member projection when the stub is engaged between the disc members, as will be further described shortly.

Two plane faces **412** and **413** of the heel piece **41** intersect at 60°. The heel piece **41** has two parallel side faces, both parallel to the plane of the stub proper **42** and one of which is shown at **414**. The stub proper **42** is attached to the heel piece **41** by a pedestal **43** whose height is substantially equal to the thickness of the disc member projections and which defines a notch **431**.

Referring to FIG. **11**, the horizontal beam-end-receiving stubs each have a bifurcate end providing a segment-shaped heel piece **51**. This defines parallel tines **512** and **513** whose separation is substantially equal to the total thickness of the two disc members when engaged together. The root of the heel piece **51** is a part-cylindrical wall with internal part-cylindrical surface **511** and external part-cylindrical surface **514** from which project the stub proper **52**. The stub proper **52** extends along a radius of the part-cylindrical surface **514**. The stubs **42** and **52** each consist of a flat plate, suitably with holes for receiving bolts attaching the beams of the structure to the junction device.

Referring to FIGS. **12** and **13**, when the disc members have been assembled together, for example by bolts, with the heel portions of the oblique stubs such as **4** and **4'** trapped between them, these stubs are precisely located and immobilized. Each horizontal stub such as **5** is then assembled to the engaged disc members by engaging these between the tines so that the outer cylindrical surface of the engaged discs comes to bear against the inner part-cylindrical surface **511** of each heel piece **51**. The stubs are then attached to the discs for example by means of bolts.

The two disc members engage within one another thanks to their co-operating projections and recesses to define between them a quasi-cylindrical hollow space with triangular projections spaced at 60° from one another and directed radially towards the disc centers. The oblique stubs, whatever their number, have their heel pieces locked between the disc members because of the contact between the cylindrical faces **411** and 322_1 and between plane faces **326** of the inwardly facing projections on the disc members and the plane faces **414** of the heel pieces of the stubs. The division of the hollow space inside the assembled discs by the six triangular projections permits the maximum number of six oblique stubs to be lodged in the device, three upwardly directed ones corresponding to the three equiangularly slots of the upper disc member, and three downwardly directed stubs corresponding to the equiangularly spaced slots of the lower disc member. When the two disc members are assembled together the two sets of slots are shifted with respect to one another through an angle of 60°.

The horizontal stubs, whatever their number, have their triangular heel pieces grasping the assembled disc members and forming with them both plane surface and part-cylindrical surface contacts. Six holes spaced at 60° from one another are formed in the two disc members so that they may be attached together by bolts, for example, and also for locking the maximum number of horizontal stubs. It is seen in FIG. **12** that these six holes have their centers on the radial axes of the triangular projections in the internal space of the assembled disc members, so enabling the necessary geometric distribution of the horizontal and oblique beams to be respected.

FIG. **13** is a perspective view of an assembled junction device, the bolts having been omitted, showing how the two disc members are engaged within one another and the arrangement of the horizontal and oblique stubs. It will be appreciated that all the stubs are formed with the necessary holes for fixing the beam ends linking pairs of nodes.

So far the structure has been described with reference to a building on land. It may also be used to build floating structures, such as water-borne buildings.

FIG. **14** shows an open-work skeleton structure **60** such as those just described but rather more complex. Certain of its lower cells, for example those indicated at **61** and **62**, serve as floats. For example, they may be closed off in water-tight fashion, or filled with a bouyant material such as an expanded plastics material or cork.

It will be appreciated that numerous modifications may be made to the structure just described within the scope of the invention. The panel members making up the walls can be made in any appropriate material, for example in plaster reinforced with a metal skin. When the panel members are double-walled, the space between the walls may house pipework, cables and the like, as well as serving for thermal and acoustic insulation.

What we claim is:

1. Building structure with stories and rooms made up by beams joined by junction devices and forming between two consecutive stories of the building a plurality of octahedral units some of which adjoin each other; each of said octahedral units being provided with parallel first and second faces in the floors of said consecutive stories; adjoining octahedral units having only one common inclined edge, said building having rooms which are set up by prisms between said consecutive stories; and said prisms being provided with vertical axis the lateral walls of which are vertical rectangular panels; each of said prisms including a beam directed upon a diagonal of said panel; said junction device comprising first and second disc members with co-operating projections and recesses for engaging the beams; and said prisms having a hexagonal shape and forming said rooms while the floors and the ceilings of said rooms are made up by horizontal regular hexagons.

2. Building structure as claimed in claim **1**, in which said hexagons forming floors and ceilings of said rooms each have three beams forming an equilateral triangle and connecting the apices of said hexagons in pairs.

3. Building structure as claimed in claim **1**, wherein the beam which is directed upon the diagonal of said rectangular panels is a common bar to two adjacent octahedral units.

4. Building structure as claimed in claim 1, wherein said rooms formed by hexagonal prisms are divided in two rooms having trapezoidal floors and ceilings by a rectangular wall going through a diagonal of said regular horizontal hexagons and including a beam going through one of its diagonals.

5. Building structure as claimed in claim **1** wherein said co-operating first and second disc members of said junction device have substantially the same thickness and one is the mirror image of the order, said co-operating projections and recesses engaging together without play; each disc member having three equi-angularly spaced radial slots with walls parallel to an axis passing perpendicularly through the disc center, and three flat and equi-angularly spaced peripheral projections each consisting of a 60° part-cylindrical segment having an external part-cylindrical face coinciding with the discperiphery, an internal part-cylindrical face, two plane faces parallel to said axis and respectively parallel to the walls of the adjacent slots, a further plane face parallel to said axis and intersecting one of said plane faces at 60° to form a triangular shoulder on said internal cylindrical face, the three plane faces being slightly shifted in the same sense with respect to the respective radial slots, not more than six oblique beam-end-receiving stubs held between the engaged disc members and each having a generally triangular flat heel piece whose thickness is substantially the same as that of the projecting portions on each disc, with a part-cylindrical face engaging the inner cylindrical face of the respective disc member projection and two faces intersecting at 60° directed towards the disc centers, the stub extending obliquely away from its heel piece and a portion thereof adjacent the heel piece having a cut-out notch whose dimension perpendicular to the heel piece is substantially equal to the thickness of the projecting disc portions and a set of at most six radial beam-end-receiving stubs each with a bifurcate end defining respective flat, parallel and segment-shaped tines whose separation is substantially equal to the overall thickness of the two disc members when assembled together, the radial stubs being attached to the assembled discs by engaging the discs between the tines.

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