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DEPLOYABLE ROBOTIC WOVEN WIRE STRUCTURES AND JOINTS FOR SPACE APPLICATIONS

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ABSTRACT :

Deployable robotic structures are basically expandable and contractable structures that may be transported or launched to space in a compact form. These structures may then be intelligently deployed by suitable actuators. The deployment may also be done by means of either air–bag or spring–loaded type mechanisms. The actuators may be pneumatic, hydraulic, ball–screw type or electromagnetic. The means to trigger actuation may be on–board EPROMS, programmable logic controllers (PLC's) that trigger actuation based on some input caused by the placement of the structure in the space environment. The actuation may also be performed remotely by suitable remote triggering devices. In this presentation several deployable woven wire structures are examined. These woven wire structures possess a unique form of joint, the woven wire joint, which is capable of moving and changing its position and orientation with respect to the structure itself. Due to the highly dynamic and articulate nature of these joints the 3–D structures built using them are uniquely and highly expandable, deployable and dynamic. They naturally give rise to a new generation of deployable three–dimensional spatial structures.

INTRODUCTION:

Woven wire structures are comprised of intersecting multi–wire elements which are preferably capped and possess sliding positionable retainers. The unique feature of these structures is a joint called the woven wire joint (Patent Pending) which is capable of shifting its position with respect to the structure itself in a three–dimensional manner. Traditionally a lower pair prismatic joint is the only classical joint capable of shifting its position with respect to its structure in a linear fashion. The classical joints fall into two categories of

1– Lower–pair joints (LPJ)
(surface–to–surface contact)

which comprise, revolute joints, (Fig. 1a) prismatic joints, (Fig. 1b) sliding joints (Fig. 1c), and ball–and –socket or spherical joints (Fig. 1d).

2– Upper–pair joints (UPJ)
(point–to–point or line–to–line contact)

which comprise a variety of contact joints as shown in Figures (2a,2b,2c,2d).
In the context of the above two categories the woven–wire joints fall in a separate category which may be appropriately called internal or intermeshing–pair joints, or IPJ's as shown in Figure 3. Thus, here is introduced a new category of joints, namely

3– Internal or Intermeshing–Pair Joint (IPJ)
(a collection of line–to–line contacts)

These woven wire joints are comprised of intersecting multi–wire elements as shown in Figures 3 and 4. Similar to other classical joints, there exist a variety of topological configurations for these woven wire

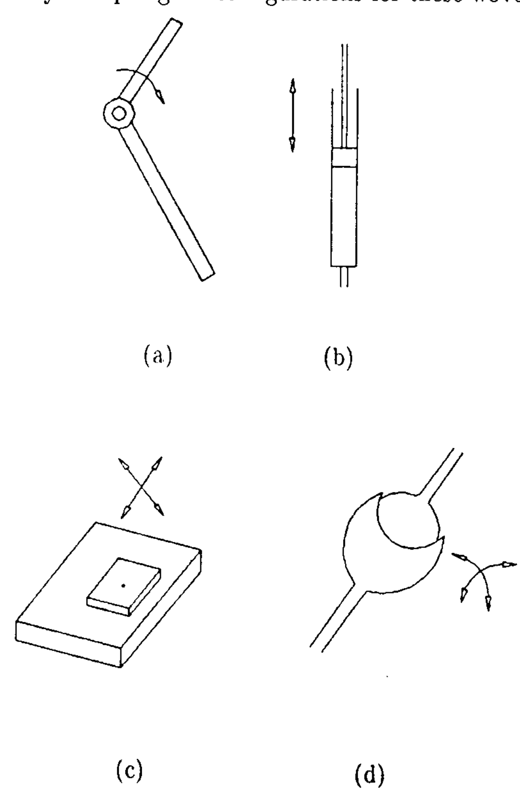


Fig. 1– Lower–Pair Joints

joints which will be discussed in this article. However, before elaborating on various ramifications of woven–wire structures it will be appropriate to briefly discuss the general nature of spatial structures in the context of Peter Pearce's minimum inventory/maximum diversity principle as well as Wiliam P. Thurston's generalization of three–dimensional manifolds.

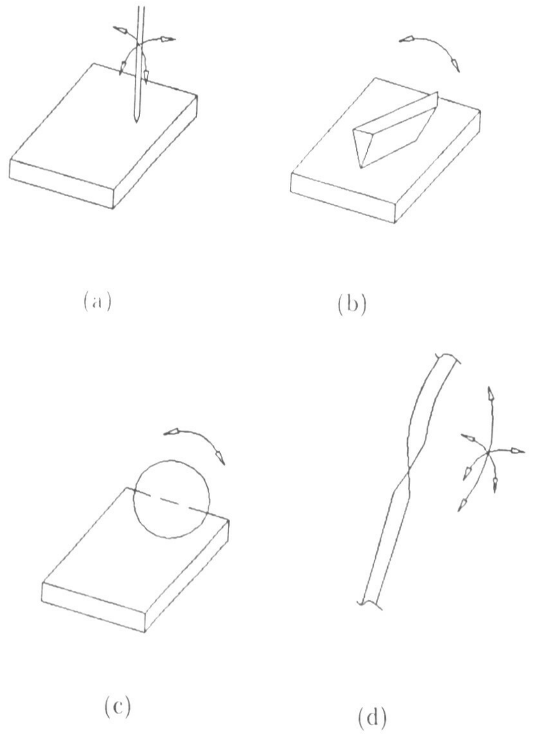


Fig. 2– Upper–Pair Joints

Geometry and geometrical configurations are the fundamental disciplines based on which the entire universe is constructed. The mathematical topology of three–dimensional manifolds reveals that most of the manifolds can be analyzed by means of geometry. The construction process is the motion of primitive entities. The most primitive entity is a point whose translation constructs a line. The translation and rotation of a line in multitude, is capable of generating all possible geometrical entities in the entire universe.

The study of three–dimensional manifolds is, thus, a generalization of two–dimensional manifolds which, itself, is a generalization of one–dimensional manifolds.

Due to the complex structure of some three–dimensional forms no complete classification of three–manifolds has, thus far, been achieved. Based on work by William P. Thurston at Princeton University it is possible to generate all possible three–manifolds by means of a specific pattern. This implies that all twistings and windings of three–manifolds can be described in geometric terms. Peter Pearce's book "Structure in Nature is a Strategy for Design", MIT Press 1980, has presented a systematic and to some extent comprehensive study of 3–D spatial systems. Clearly, Circles can give rise to cubes and polyhedra.

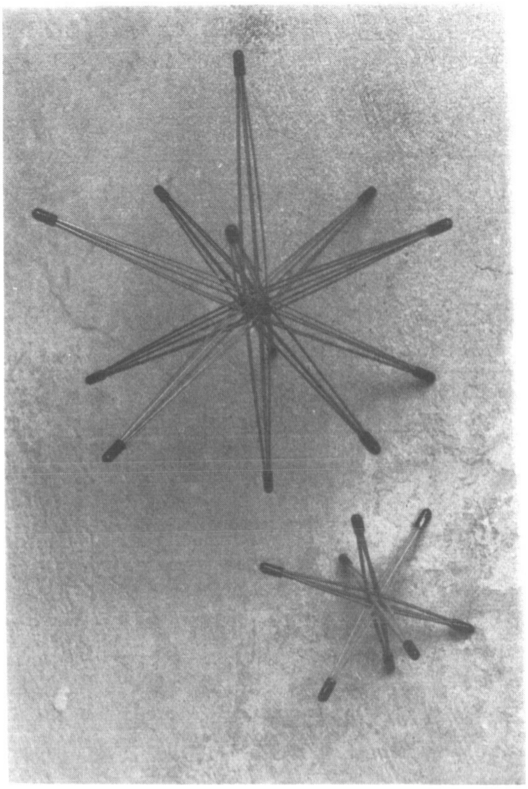


Fig.3– Two different configurations of woven wire joints

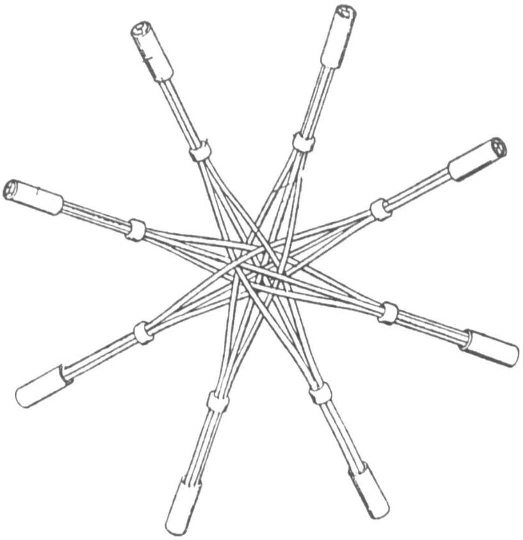


Fig. 4– The three wire, six element (36) weave

Polyhedra can, in turn, generate all possible geometrical entities. As originally suggested by Herbert Seifert and C. Weber in 1933, the three–manifolds can be understood from a polyhedron by abstractly glueing certain faces together. By abstractively glueing the opposite Pentagons of a dodecahedral the Seifert–Weber dodecahedral space can be constructed.

Figures 5 and 6 illustrates some fundamental relationships between motions of a point in three–dimensional space and the evolution of Platonic solids, i.e., tetrahedron, cube octahedron, and dodecahedron.

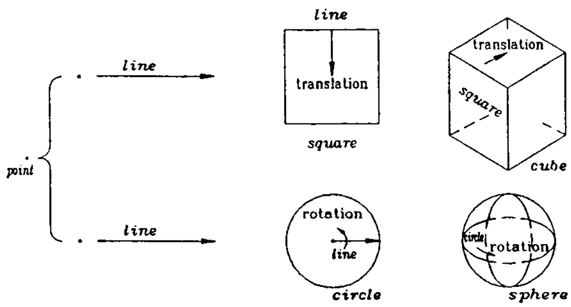


Fig. 5– Evolution of Primitive Solids

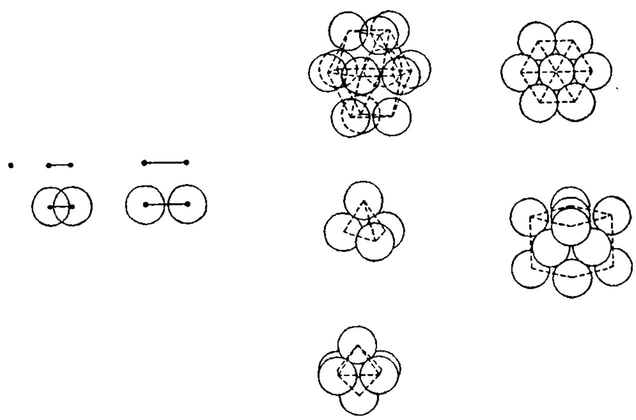


Fig. 6– Evolution of Platonic Solids From Spheres

A useful metaphor to study the complex nature of three–manifolds is the use of mechanical systems of linkages. A mechanical linkage is represented mathematically by a set of line segments in the plane with pivot points at line intersections. Mathematically, it is assumed that the lines and pivot points can pass freely through one another. Woven–wire joints and structures approximate such an idealization with a great degree of accuracy. Up until now, constructing a physical model whose bars and joints replicate the idealized linkage has not been possible. For any mathematical version of a linkage system there exists a physical linkage that produces the same motion. However, the actual physical linkage may be quite different, geometrically, from the ideal linkage. The "configuration space" of a linkage system is the set of all of its possible positions in the three–dimentsional space.

In order to understand the configuration space of linkages one should consider the possible configurations of the double–linkage mechanism regardless of position of its free end (Fig. 7).

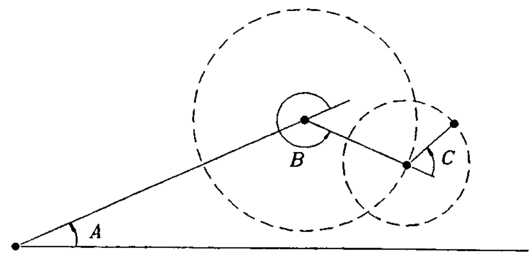


Fig. 7– Double and Triple Linkage Configuration Space

Every configuration of the double–link system can be described by two angles A and B. If a third linkage is considered, a third angle C is needed to completely specify the associated configuration space. Every possible position of the triple crank is represented by a unique point in a cube whose apposite pairs of faces are abstractly glued together.

The work space of a triple–double cranks joined by one end pin (Fig. 8a) is an 8–dimensional space in which every point corresponds to 8 different configuration of the system (Fig. 8b). In this space the boundaries are four–dimensional spaces (Fig. 8c) and the vertices are two–dimensional surfaces (Fig. 8d).

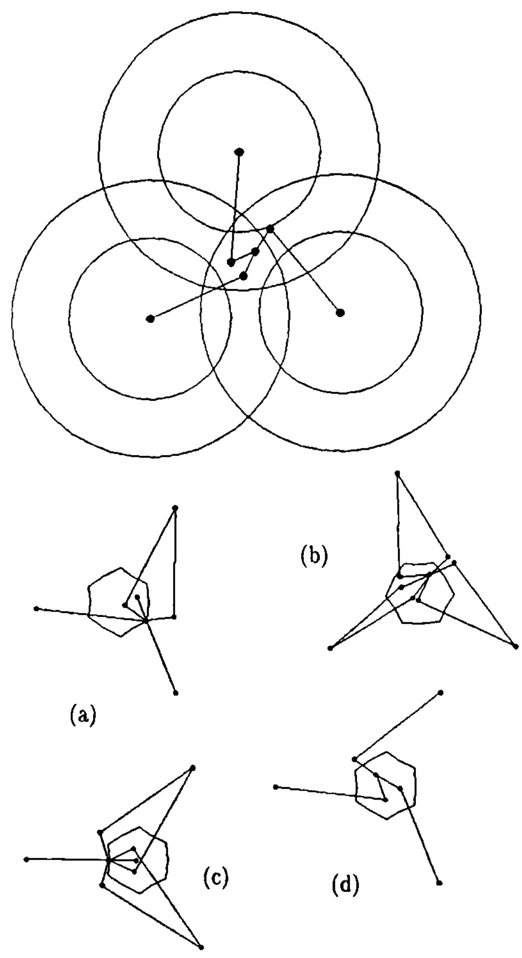


Fig. 8– The Work Space of a System of Three Double–Cranks

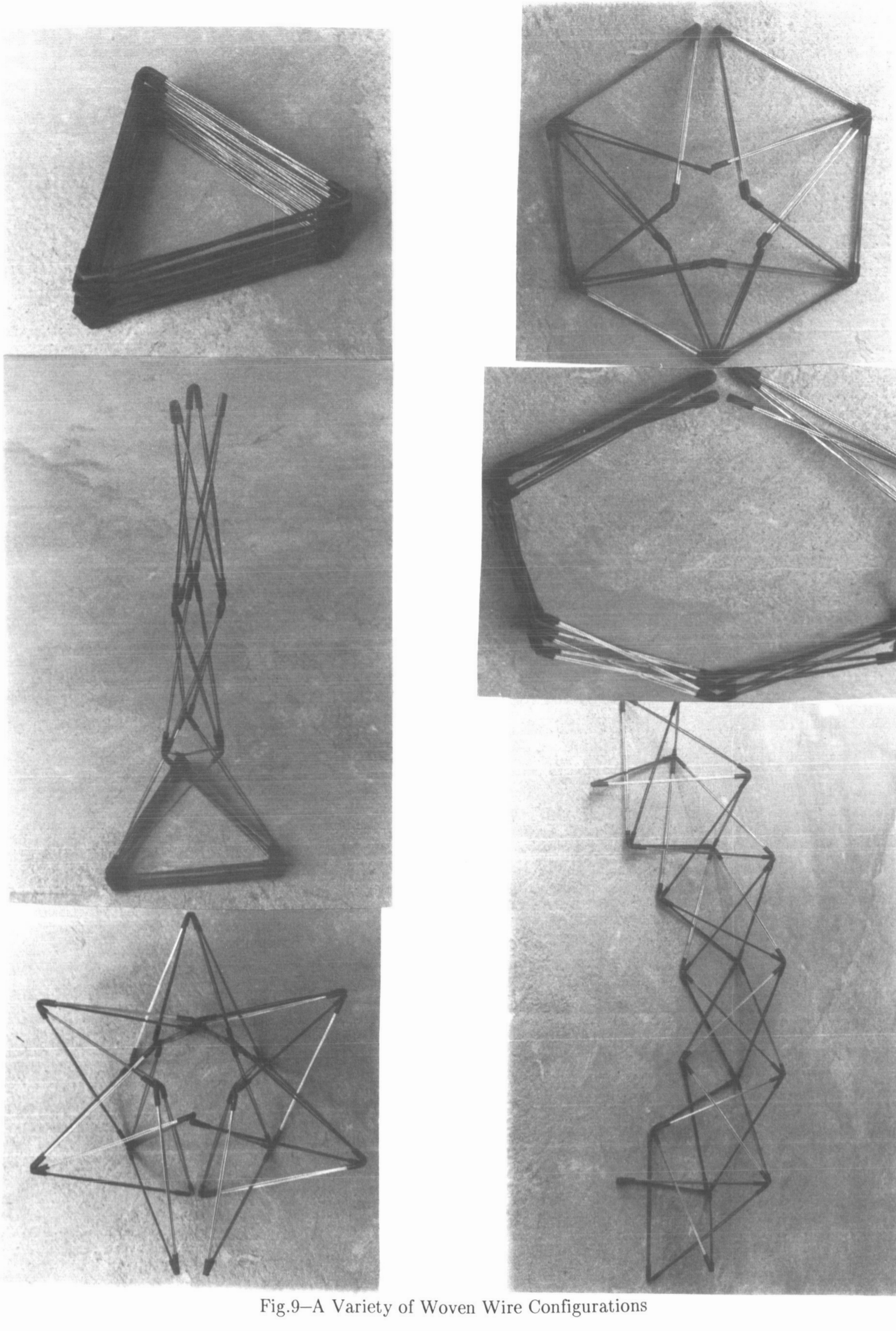


Fig.9–A Variety of Woven Wire Configurations

The woven–wire structures, in the context of linkages, define highly complex higher dimensional work spaces. The woven–wire structures and joint can also be considered in the context of Peter Pearce's systems of diversity; minimum inventory/maximum diversity systems. Endless variety of three–demensional structures can be constructed by a set of one, two, or three woven–wire joints (Fig. 9a,b,c,d,e,f). A fundamental property of minimum inventory/maximum diversity systems is the principle of conservation of resources. This principle sometimes manifests itself as the principle of minimum potential energy for greater stability. For example the closest packing of entitities is a structural arrangement of inherent geometric stability creating three–dimensional arrangements of polyhedral cells in living and non–living systems. If, for instance, the centers of closest packed equal spheres are joined, a three–dimensional arrangement of equilateral triangles is created. It is well known that triangulated frame–works exhibit inherent geometric stability because they are stress–compensated. Woven–wire structures are also inherently triangulated and polyhedral in nature.

Figure 10 shows a collapsible woven–wire structure that can be accordioned by a user, either horizontally or vertically. The wire bundles are movable in concert about their woven–wire (weave) joint.

A woven wire apparatus may be comprised of at least one bundle, which bundle comprises a plurality of multi–wire elements. Each multi–wire element has a first end and second end, and each multi–wire element further comprises a plurality of stiff but slightly flexible wires of substantially similar length. Each multi–wire element comprises a structure for positioning the multi–wire elements in a mutually intersecting relationship to one another. The apparatus preferably has a structure for joining the first end and a structure for joining the second end of the multi–wire elements whereby the elements are retained in intersecting relationship to one another. The wire retaining structure fixes the elements in position. The end joining structures are removably positioned on the ends of the multi–wire elements and comprise generally tubular caps, flat bases, suction bases, balls, padded bases, or the like. The end joining structure of the apparatus preferably comprises rigid connectors, movable connectors, or a mechanical hinge structure, but may further comprise color coding.

A woven–wire structure further comprises wire retaining structures which are generally cylindrical and slidably and romovably positionable on multi–wire elements. The wire retaining structure preferably comprises color coding and a ring, tube, strap, clip, or the like, fixable about the joint.

These structures comprise mutually intersecting multi–wire elements which further comprise a like plurality of wires. The multi–wire elements may comprise wires of substantially similar length or substantially different length. The bundles in a woven–wire structure further comprise support members.

The multi–wire bundle of a woven–wire structure is collapsible and comprises an odd number of wires, preferably at least three wires. Multi–wire elements may be chosen with the same length to provide a generally symmetric apparatus.

The woven–wire structures are useful for holding an object within the joint. They may further comprise two or more bundles positionable in an adjoining relationship being stackable or positionable side by side or stackable. The bundles preferably comprise stabilizing means. Bundles of the preferred embodiment comprise stabilizing structures. They are useful as a support structure or a cover, when the bundles are positionable in a substantially concave shape. The bundles are also positionable in a spherical shape.

A woven–wire apparatus with at least one bundle, comprising the additional structures for joining the first end and second ends of the multi–wire elements, whereby the elements are thereby retained in said intersecting relationship to one another, further comprising dynamic means also provides alternating motion of the multi–wire elements. The bundle is fixed in position after motion is provided, by dynamic means. A woven–wire joint creates a spherical and structurally sound joint using intersecting wire bundles. Such joints are usable in a wide variety of structures. The movability and generality of such joints makes them far superior to traditional lower or upper pair joints.

The accompanying drawings and photographs (Figures 11 through 20) illustrate several embodiments of the woven–wire structures and, together with the description, serve to explain the potential and the beauty of woven–wire structures and joints for space applications.

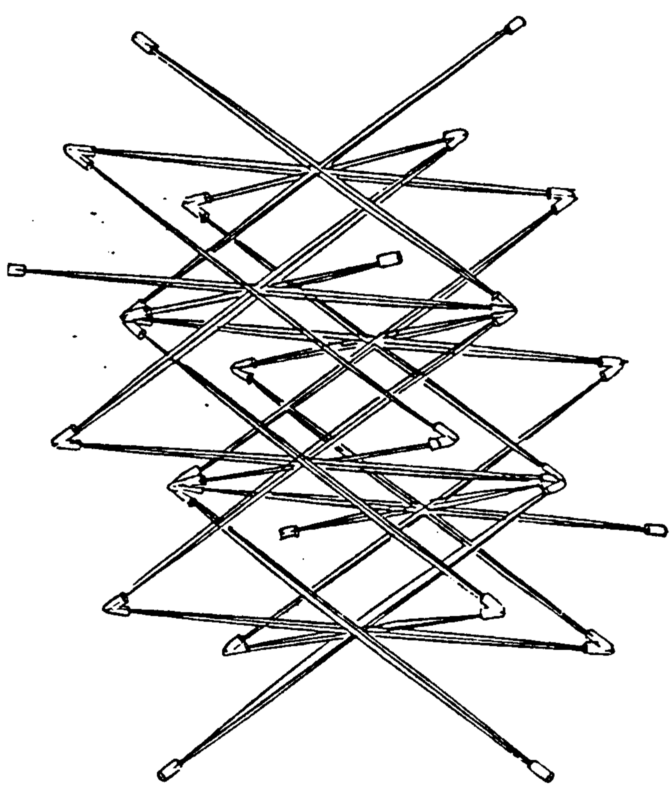
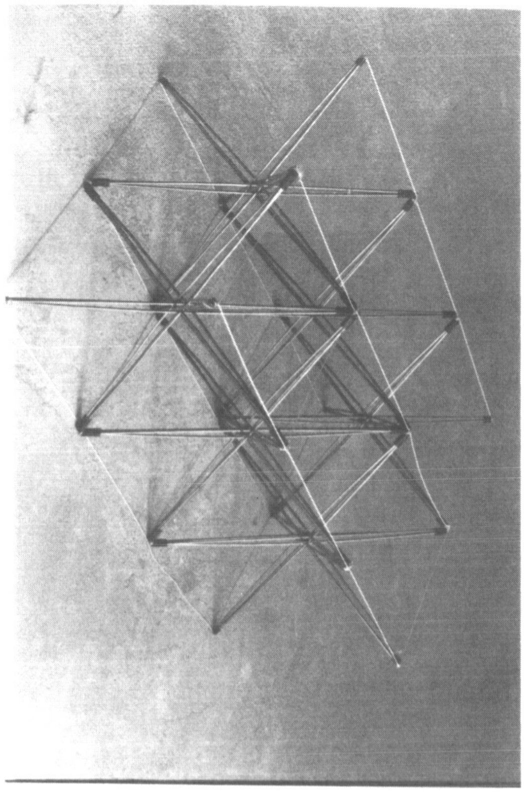


Fig. 10– A collapsible Woven Wire Structure



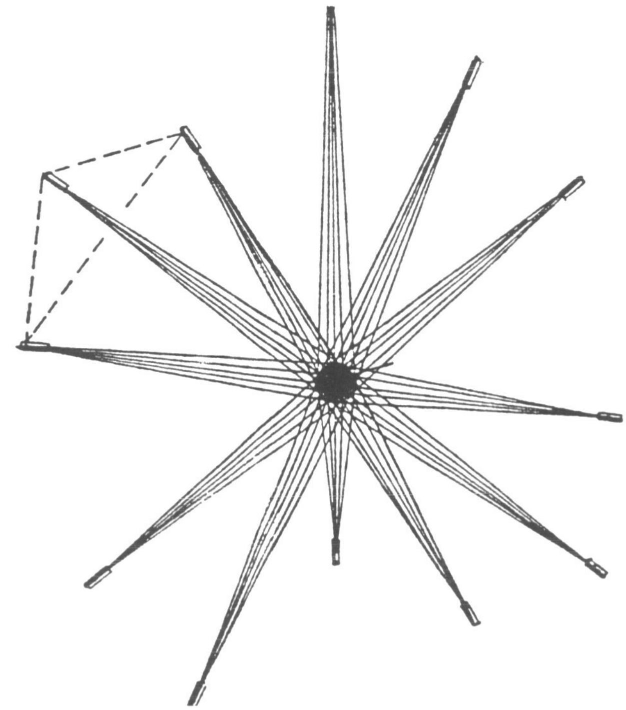


Fig. 12– A woven wire joint holding a sphere.

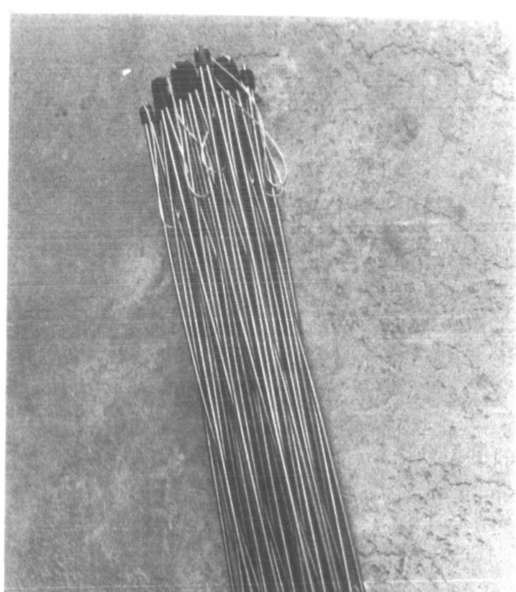


Fig. 11– A collapsible woven wire net of 6 individual modules.

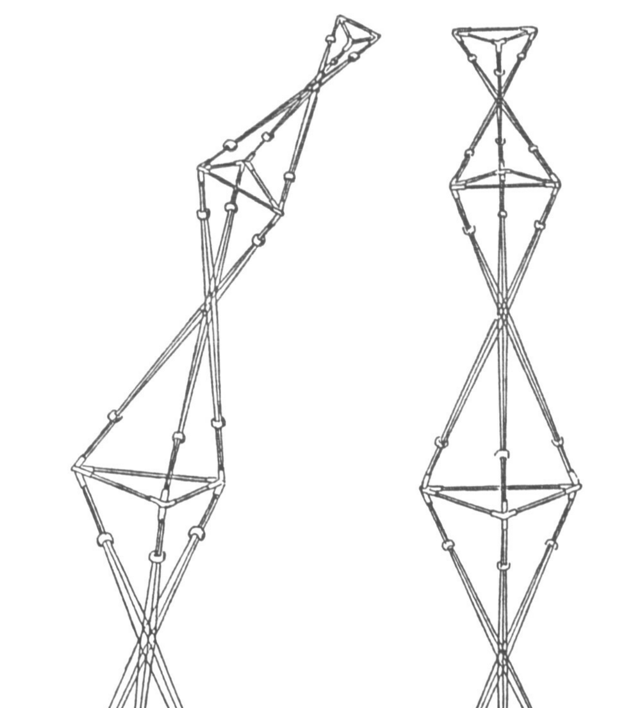


Fig. 13– The tower–type structure made from woven wire joints

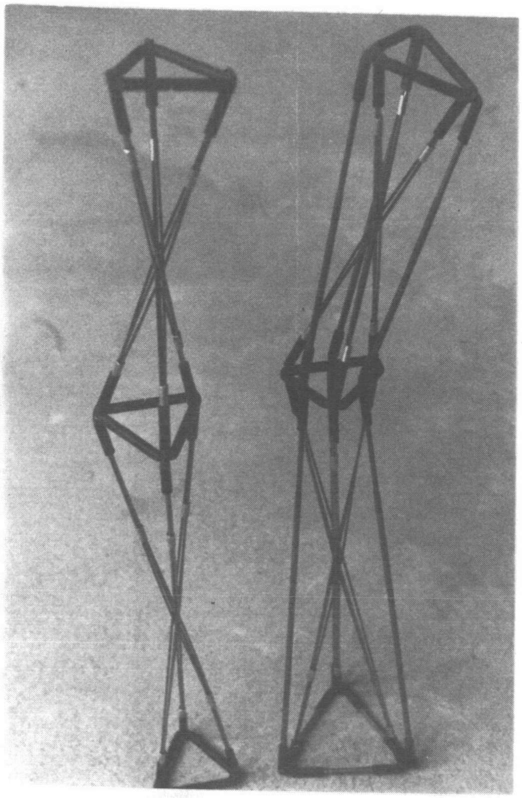
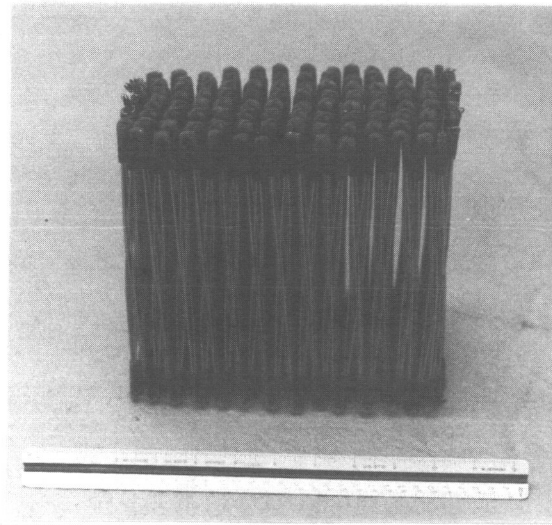
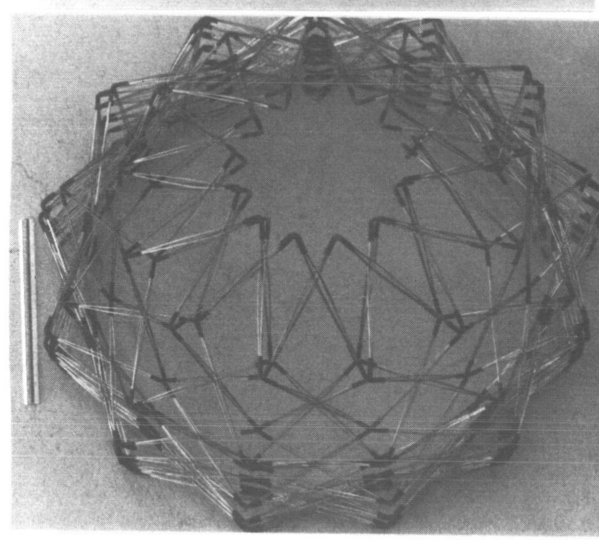
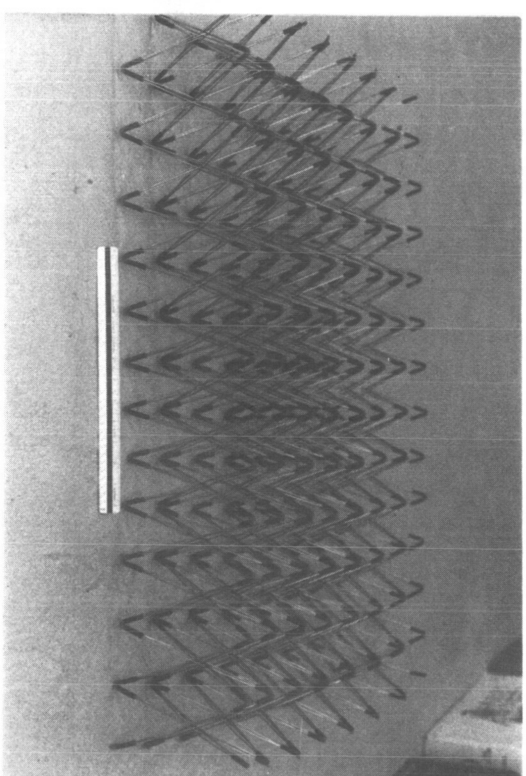


Fig. 14– Constructed tower–like woven wire structures







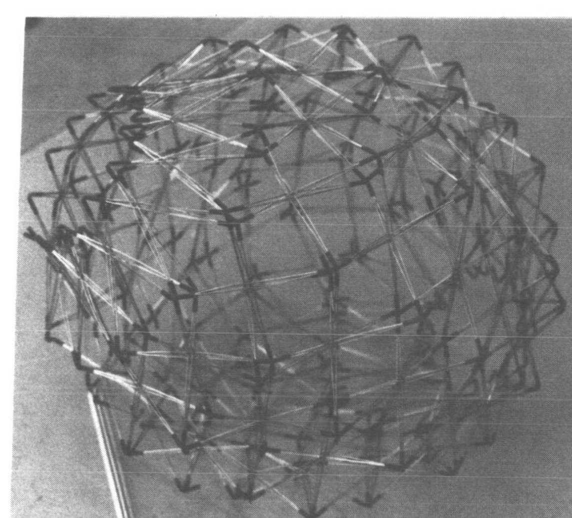


Fig. 15– Various configurations of woven wire dome structures

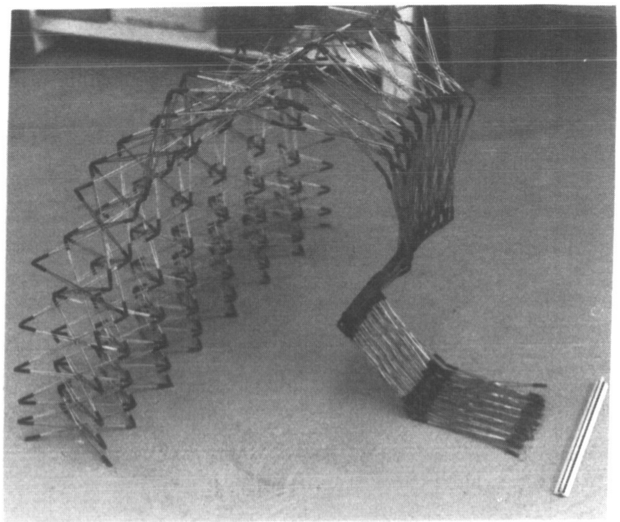


Fig. 16– Woven wire net strucutres

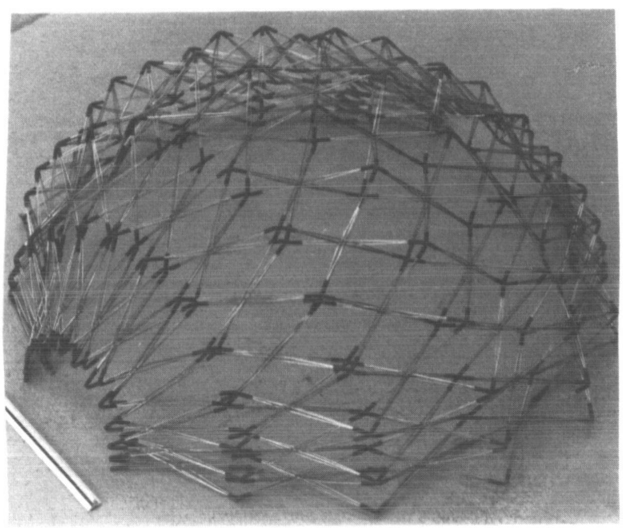


Fig.17– Various woven wire dome structures

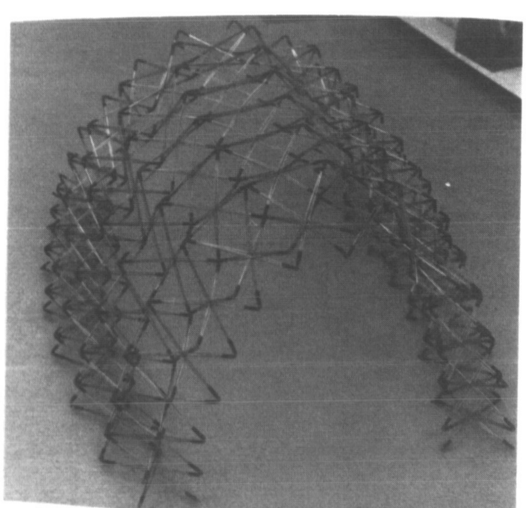


Fig. 18– Various woven wire deployable structures

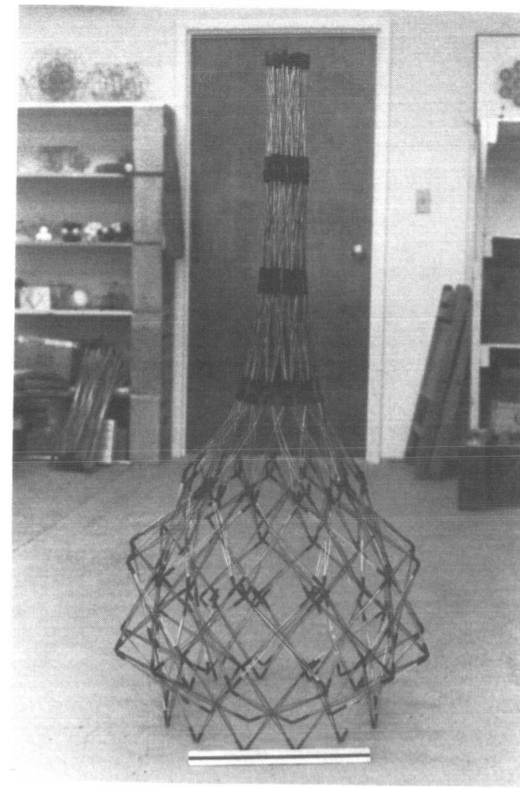


Fig. 19– Various deployable bottle–like structures

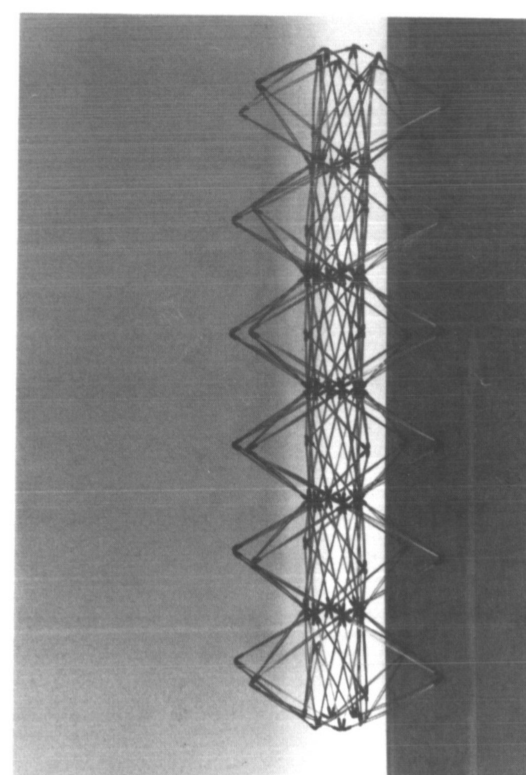


Fig. 20– Various deployable woven wire tunnel–like structures