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DESIGN AND APPLICATIONS OF PRESTRESSED TENSEGRITY STRUCTURES

J. Burša, Y. D. Bansod[*]

Abstract: *The tensegrity framework consists of both compression members (struts) and tensile members (cables) in a specific topology stabilized by induced prestress. Tensegrity plays a vital role in technological advancement of mankind in many fields ranging from architecture to biology. In this paper we have reviewed topological classification of elementary cells of tensegrity structures including rhombic, circuit and Z type configurations. Further, different types of tensegrities created on the basis of these configurations are studied and analyzed, for instance Tensegrity prism, Diamond tensegrity, and Zig-zag tensegrity. Then we focus on special features, classification and construction of high frequency tensegrity spheres. They have a wide range of applications in the construction of tough large scale domes or in the field of cellular mechanics. The design approach of double layer high frequency tensegrities is outlined with help of a six frequency octahedral tensegrity network where inner and outer layers of tendons are inter-connected by struts and tendons. The construction of complicated single and double bonding spherical tensegrity systems using a repetetive pattern of locked kiss tensegrity is reviewed. Form-finding procedure to design a new tensegrity structure or improve the existing one by achieving the desired topology and level of prestress is discussed at the end. Types of tensegrities, their configurations and topologies studied in this paper can be helpful for their recognition and, consequently, bring their broader application in different technical fields.*

Keywords: Tensegrity, Struts, Cables, Prestress, Configuration.

1. Introduction

Fuller (1961) coined the term “tensegrity” by combining two words “Tensional + Integrity”; it means that integrity of a structure consisting of tension and compression components relies on the tension members. A brief definition of tensegrity structures could be ‘A tensegrity system is established when a set of discontinuous compressive components interacts with a set of continuous tensile components to define a stable volume in space’. They don’t need any support to keep their shape and are self-equilibrated pre-stressed structures (Fuller, 1975). Theory of tensegrity structures is well known in statuary, architecture or civil engineering while in other engineering branches the potential of these structures is not yet fully explored. This paper summarizes the up to date knowledge on tensegrity structures and presents some of their applications in various technical fields, especially in computational modelling.

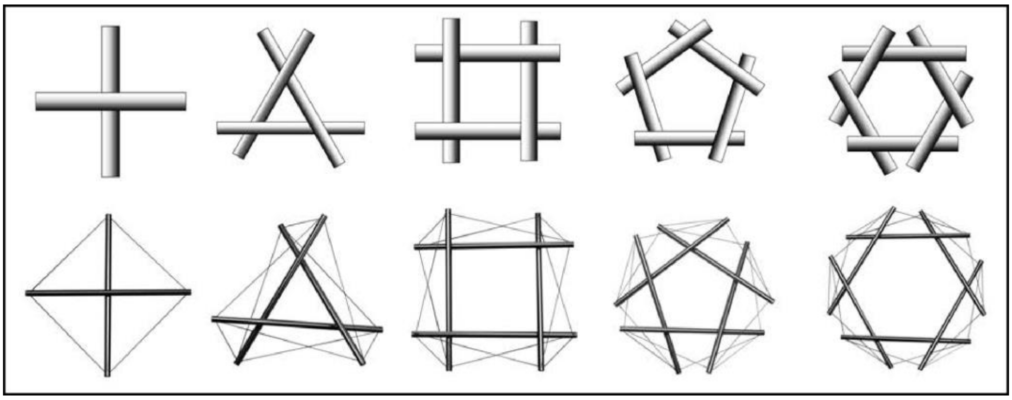

Fig. 1: Primary weave cells and equivalent basic 2D tensegrity modules (from Snelson (2012)).

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[*] Prof. Jiri Bursa, PhD.; Yogesh Deepak Bansod M.Sc.: Institute of Solid Bodies, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology, Technicka 2, 616 69, Brno; CZ, bursa@fme.vutbr.cz

2. Simplest and Diamond Tensegrities

Tensegrities differ from more usual strut-frames (lattice works, truss frames) by existence of cables bearing tension only. Therefore they can be designed as equivalents of statically indeterminate strut frames; prestress induced by pretension in cables ensures shape and integrity of the structure under load. The simplest 2D tensegrities are presented in Fig. 1. Fig. 2 presents creation of simple 3D tensegrities, while Fig. 3 shows how they can be enlarged into more complex multilayer structures.

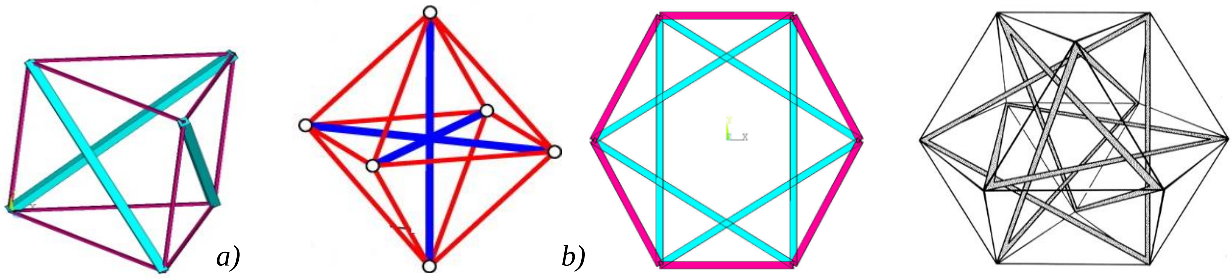


Fig. 2: a) Rhombic configuration; b) 2D and 3D tensegrity with circuit compression members.

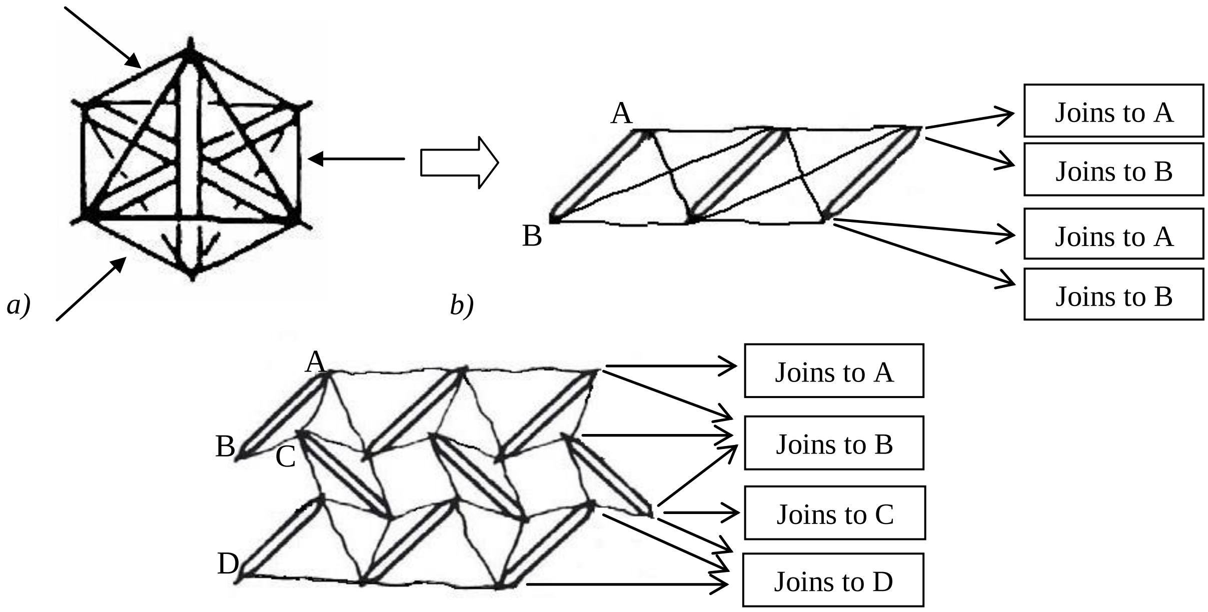


Fig. 3: Creation of more complex tensegrity structures from the octahedron.

3. High Frequency Spheres

Another principle of how to create more complex sphere-like tensegrities is based on principal (Platonic) polyhedrons (see Fig. 4). Triangular faces of these polyhedrons can be subdivided into smaller triangles (see Fig. 5) to create high frequency spheres with their shape closer to a sphere and with shorter elements more resistive to buckling.

Fig. 4: Principal (Platonic) polyhedrons.

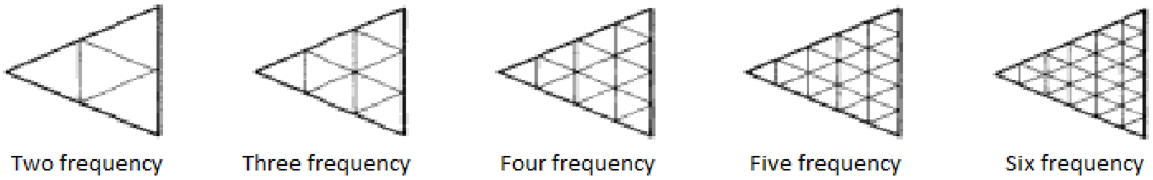


Fig. 5: Subdivisions of a triangular face applied in creation of high frequency spheres.

For higher frequencies the individual triangles can be created of basic triangular tensegrity units created on the basis of octahedron tensegrity. This unit consists of three struts with some of the vertexes shifted centrally from the strut end (see Fig. 6). A sphere-like tensegrity structure can then be created by repeating these basic units over the surface of a chosen geometrical body (see Fig. 7).

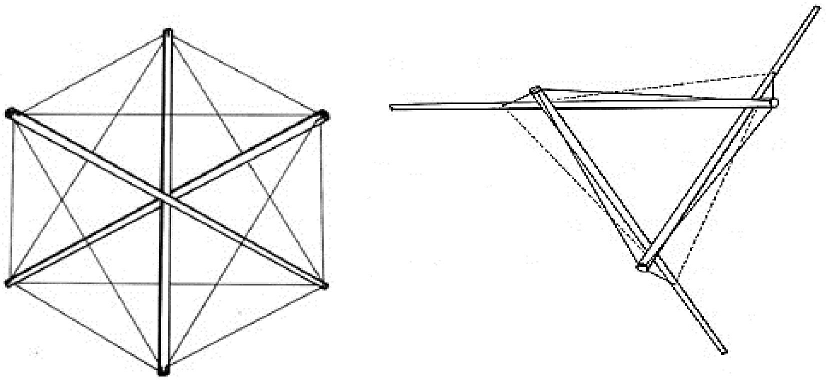


Fig. 6: Creation of a basic tensegrity unit from an octahedron by flattening it and removing some cables.

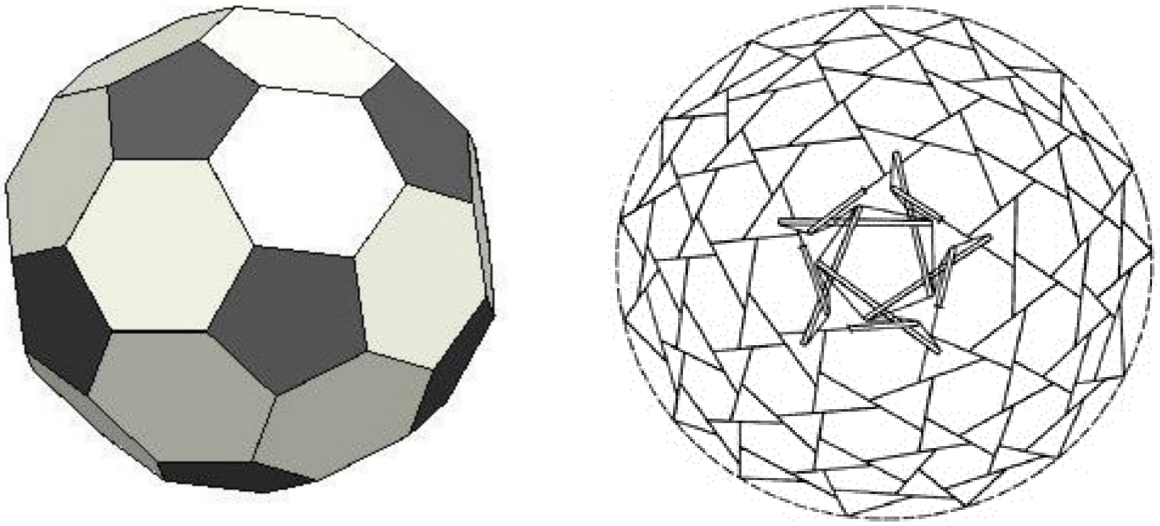


Fig. 7: Creation of a complex sphere-like structure from basic tensegrity units.

4. Examples Based on Form-Finding Technique

As shown above, the shape of the structure may vary rather substantially with respect to dimensions of the elements, positioning of vertexes, pretension of cables etc. The procedure of achieving a certain configuration of the structure is called form-finding. It is a method of how to design and generate a stable geometrical configuration of a tensegrity structure (when using mathematical modelling) inspired by specific geometrical forms under given conditions of pre-stress, such that it will remain stable and maintain its shape under a certain range of external loads and impacts.

Examples of complex tensegrity structures are presented, applied in the field of modelling of mechanical properties of living cells (Fig. 8). In many animal cells, the most important mechanical component of the cell is cytoskeleton, a typical discrete structure created by submembrane actin stress fibres, intermediate filaments surrounding the nucleus and attached to membrane receptors, and microtubules oriented in radial directions and connecting centrosome (an organel very close to nucleus) with membrane receptors. Realistic modelling of these structures during mechanical tests of cells is decisive for understanding the influence of mechanical stimuli on biochemical responses of the cell.

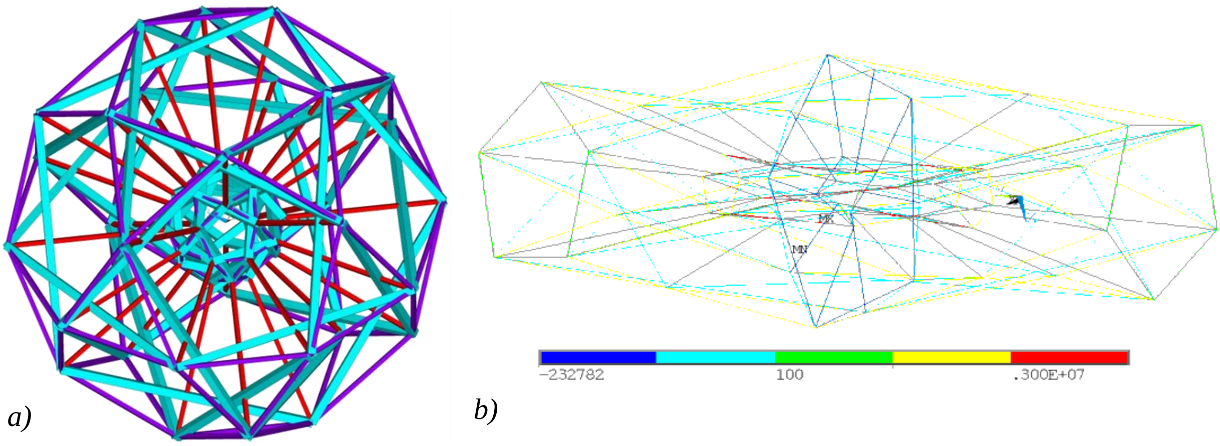
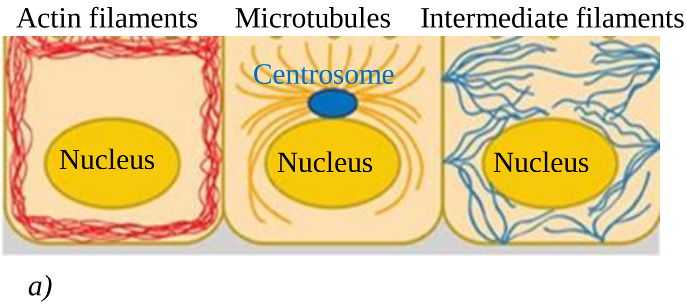


Fig. 8: a) Tensegrity based computational model of intracellular structure with 210 members; b) The same tensegrity model in simulated tension test of a cell (from Bursa et al. (2012)).



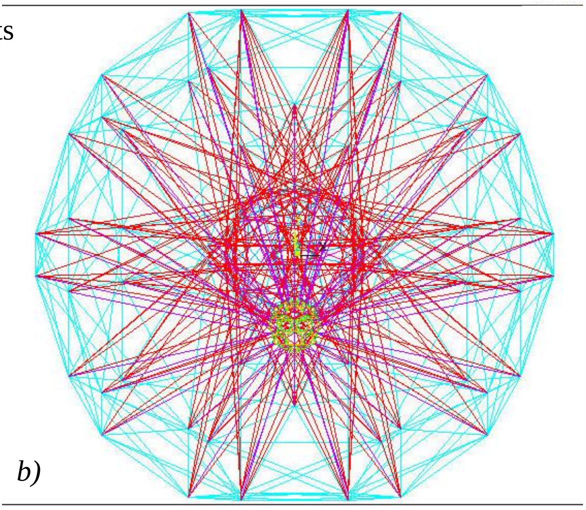


Fig. 9: a) Basic mechanical components of animal cell; b) A new tensegrity based computational model of intracellular structure with 862 members, created using the form-finding technique.

Acknowledgement

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References

Fuller, R. B. (1961) Tensegrity, Portfolio and Art News Annual, 144 (4), pp. 112-127.

Fuller, R. B. (1975) Synergetics: Explorations in the geometry of thinking, in collaboration with E. J. Applewhite, Macmillan Publishing Co. Inc., New York.

Snelson, K. (2012) The art of tensegrity, International Journal of Space Structures, 27, pp. 71-80.

Bursa, J., Lebis, R., Holata, J. (2012) Tensegrity finite element models of mechanical tests of individual cells, Technology and Health Care, 20 (2), pp. 135-150.