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STATE-OF-THE-ART IN CONCEPTUAL DESIGN OF CLASS THETA TENSEGRITY SYSTEMS

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ABSTRACT

The emergence of tensegrity systems opens new fields for conceptual design[1,2,4]. It concerns in this case a selfstress: preliminary forces constitute a system in autonomous equilibrium.
If it is possible to identify states of selfstress in space structures composed of bars and cables, the just tensegrity system constitution, leads to a specified class.
It is currently apparent that among the tensegrity systems also exist cable-bar cells with a discontinuous network of cables[4-6]. It is possible to design a separate set of cables inside the cable-bar elementary cell and to establish a self-stress state of equilibrium. Each of the basic tensegrity systems termed *Class Theta*, or *Class **Θ*** by means of symbol, possesses an external and internal set of tension components. The shape of Greek capital letter ***Θ*** (Theta) reflects two sets of such components (two sets of tendons, cables etc.). This notation corresponds to the *Class **k*** tensegrity structure by Skelton[3]. Thus, it should be understood as follows; both ***k***=1 and ***Θ***=1 means that the proper set of cables is joined at most to one bar in each node. Moreover no bars are in contact each other.
Due to the unique mechanical characteristics; both with and without loads, *Class **Θ*** tensegrity structures can hold various applications in the design of civil architectures, advanced/architected materials, smart devices, biomechanical models and many others.

For example, Fig. 1a shows the simplest *Class **Θ***=1 tensegrity structure, composed of four bars and 10 cables in tension. We can see that the

one set of four cables is located inside the other tetrahedral cable network. Moreover, both cable components are separable and interact with a discontinuous set of compressive members to form a stable cable-bar unit in space. An original approach to solve the self-equilibrium problem independently of material choices and external loads is shown in [6].

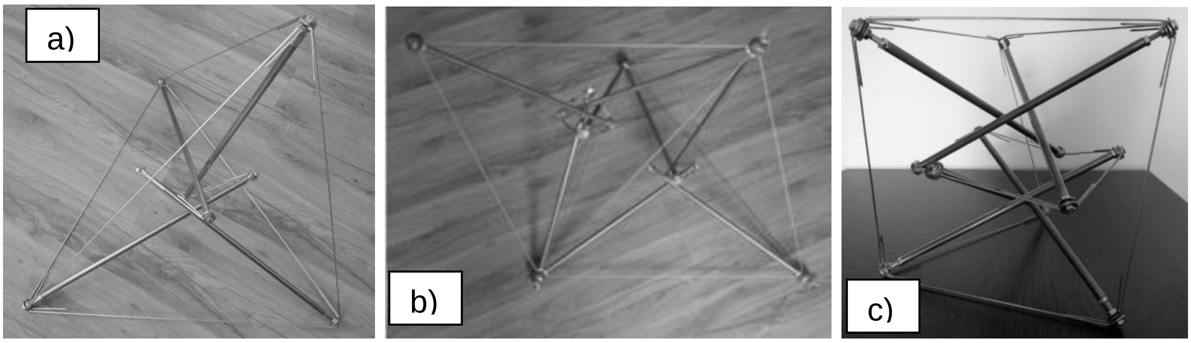

Fig. 1 Examples of the Class $\boldsymbol{\Theta}$=1 tensegrity systems with separable bars, i.e., “pure” tensegrity systems: (a) a tetrahedron; (b) two tetrahedral modules coupled together in ‘face to face’ way; c) a triangular prism.

In this way, we can build another the *Class* $\boldsymbol{\Theta}$ of “pure” tensegrity units[6]. Among examples, there is a triangular prism shown in Fig. 1c.

A mathematical models related to the Class $\boldsymbol{\Theta}$ =1 tensegrity tetrahedron and triangular prism explain, why the tensegrity module is a stable construction, albeit with infinitesimal mobility. In addition, we can modify an external shape of the “pure” tensegrity units by expansion of the internal set of tension and compression components[7,8].

Progress in manufacturing technologies already allows the production of architected materials, also known as metamaterials, with so far unprecedented properties. Most such materials are characterized by a fixed geometry, but in the design of some materials it is possible to incorporate internal mechanisms capable of reconfiguring their spatial architecture, and in this way to enable tunable functionality[6,9-11].

Fig. 2 a) A structure built on the Class $\boldsymbol{\Theta}$=1 triangular tensegrity prism as 3D example of an auxetic metamaterial, that is material with a negative Poisson’s ratio.
b) After loading both prismatic modules by one steel plate with mass 28 [kg], the initial height did not change noticeably. After a two-fold increase in the load (two plates with a total mass of 56 [kg]), the initial height was reduced by 4 [mm].
The mass of one prismatic module made of steel is less than 1.5 [kg].

Among the tetrahedral cable-bar units there are also other tensegrity modules with a discontinuous network of cables, in which ***Θ*** can be more than 1, as shown in the exemplary Figures 3 and 4. Take notice, the module presented in Fig.3 is the simplest tensegrity antiprism which comprises four bars held together in space by cables so as to form a tetrahedral tensegrity cell.

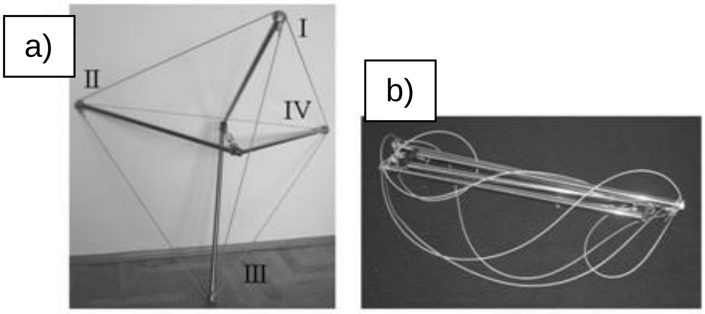

Fig. 3. The model of the class ***Θ***=2 tensegrity tetrahedron: the erected configuration (left), the compact configuration (right).

An experimental setup of the four module cable-bar structure is shown in Fig. 4. The deployable tensegrity girder[12], both rectilinear and curved, made currently from four lightweight cable-bar modules is self-stable, which results in a stiffness that would be difficult to achieve with conventional deployable solutions.

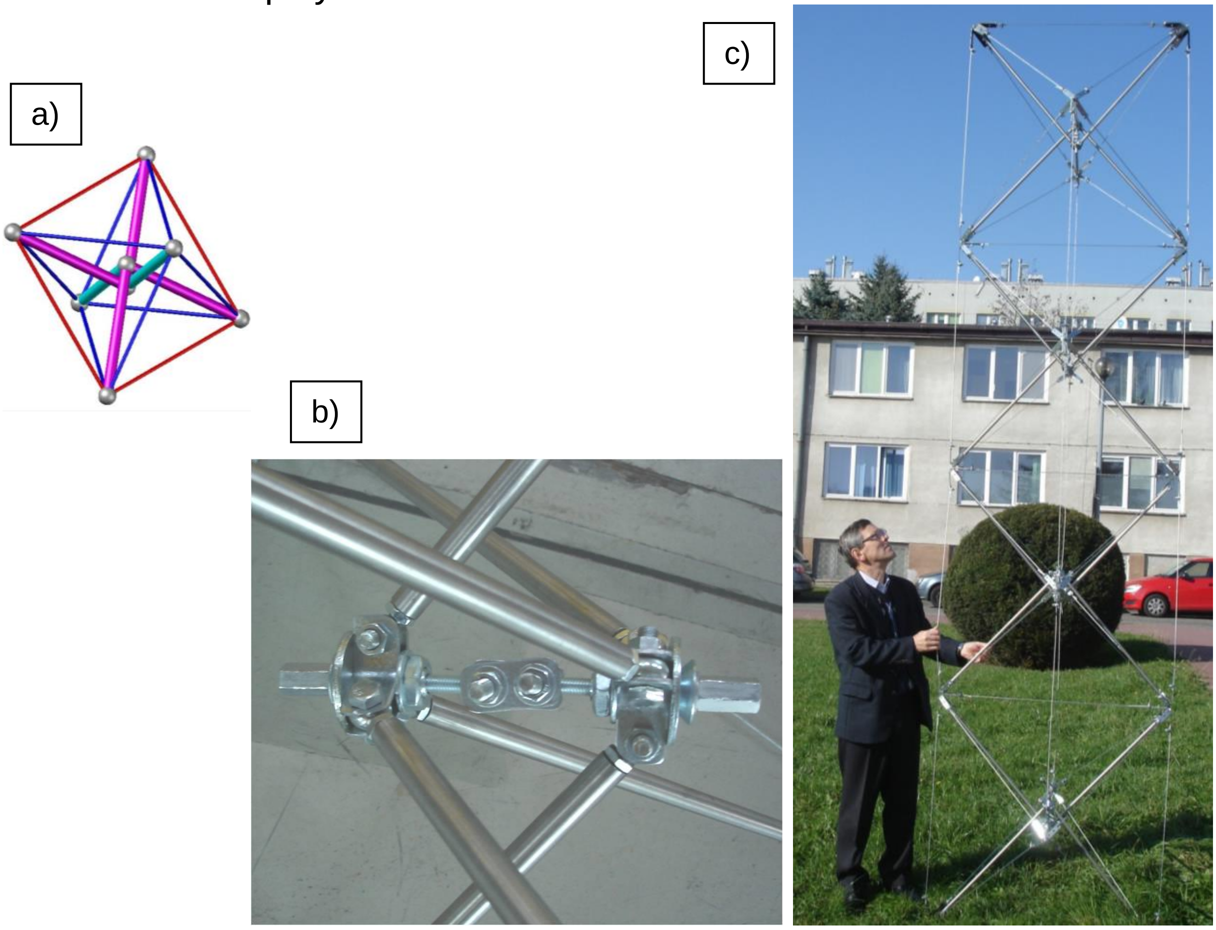

Fig. 4 a) Single octahedral module in a graphical form (a three-dimensional shape with eight equal triangular faces), b) Structural solution of the active cable with nodes located inside each of four tensegrity modules,
c) and d) Class $\boldsymbol{\Theta}$ tensegrity girder as a deployable and modular tensegrity column or beam depending on actual needs.
The single tensegrity module represents Class $\boldsymbol{\Theta}$=3, since each internal node is connected to 3 compressive members.

The shelters, supports and bridges, masts and towers that are lightweight, modular, compact and rapidly deploy in the region of critical phenomena could form the practical target for further investigation, offering immediate replacement of destroyed infrastructure.
Similar to all previous examples, the recently shown model of a folded tensegrity girder can serve as a reference point for future research.

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