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Controversial Origins of Tensegrity

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Abstract
Tensegrity is a developing and relatively new system (barely more than 50 years old) which creates amazing, lightweight and adaptable figures, giving the impression of a cluster of struts floating in the air. The intention of this paper is to explain the origins of tensegrity, original patents included, and shed light on some polemic aspects about the authorship, enquiring personally to its discoverer, the sculptor Kenneth Snelson. Finally, the history and progress of this kind of structure will be revised, tracing a line of the time and pointing out the most relevant authors, specialists and publications, which could serve as a guide for further investigators.

Keywords: Tensegrity, structures, origins, history, tension, floating compression, Kenneth Snelson, Buckminster Fuller, David Emmerich, patents.

1. Introduction
Tensegrity is a developing and relatively new system (barely more than 50 years old) which creates amazing, lightweight and adaptable figures, giving the impression of a cluster of struts floating in the air. As it is explained in Gómez Jáuregui [1], it is not a commonly known type of structure, so knowledge of its mechanism and physical principles is not very widespread among architects and engineers. However, one of the most curious and peculiar aspects of tensegrity is its origin; controversy and polemic will always be present when arguing about its discovery.

The intention of this paper is to explain the origins of tensegrity, original patents included, and shed light on some polemic aspects about the authorship, enquiring personally to its discoverer, the sculptor Kenneth Snelson.

Finally, the history and progress of this kind of structure will be revised, tracing a line of the time and pointing out the most relevant authors, specialists and publications, which could serve as a guide for further investigators.

2. The origins.

Three men have been considered the inventors of tensegrity: Richard Buckminster Fuller [2], David Georges Emmerich [3] and Kenneth D. Snelson [4]. (As a precaution, these names have been mentioned in chronological order of their granted patents: Fuller-13 Nov 1962; Emmerich-28 Sep 1964; Snelson-16 Feb 1965).

Although all of the three have claimed to be the first inventor, R. Motro [5] mentions that Emmerich [6] reported that the first proto-tensegrity system, called "Gleichgewichtkonstruktion", was created by a certain Karl Ioganson (some authors call him Johansen) in 1920 (figure 1.a). As Emmerich explains:

"Cette curieuse structure, assemblée de trois barres et de sept tirants, était manipulable à l'aide d'un huitième tirant detendu, l'ensemble étant déformable. Cette configuration labile est très proche de la protoforme autotendante à trois barres et neuf tirants de notre invention."

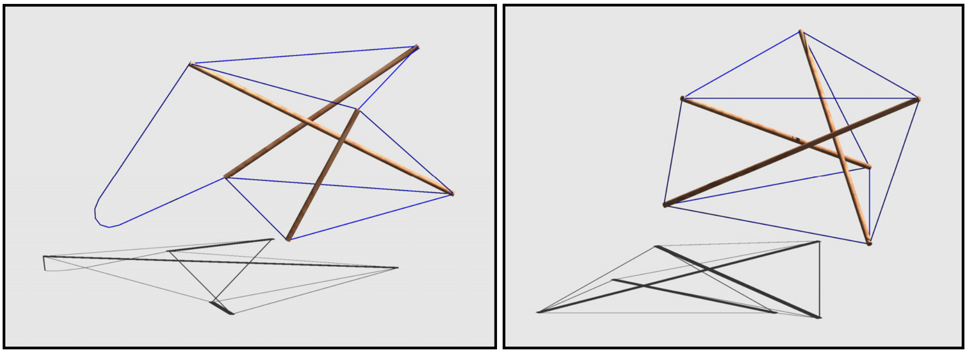
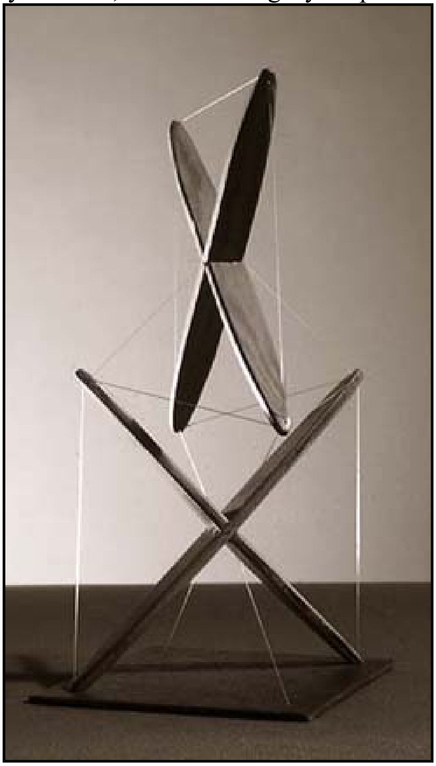


Figure 1: Comparison between the "Gleichgewichtkonstruktion" or “Structure-Sculpture” by Karl Ioganson, first proto-tensegrity system (1.a), and the Simplex by Snelson, simplest tensegrity system (1.b).

This means it was a structure consisting of three bars, seven cords and an eighth cable without tension serving to change the configuration of the system, but maintaining its equilibrium. He adds that this configuration was very similar to the proto-system invented by him, the "Elementary Equilibrium", with three struts and nine cables (figure 1.b). All the same, the absence of pre-stress, which is one of the characteristics of tensegrity systems, does not allow Ioganson's “sculpture-structure” to be considered the first of this kind of structures.

The most controversial point has been the personal dispute, lasting more than thirty years, between R. B. Fuller (Massachusetts, 1895-1983) and K. D. Snelson (Oregon, 1927). As the latter explains in a letter to R. Motro, during the summer of 1948, Fuller was a new professor in the Black Mountain College (North Carolina, USA), in addition to being a charismatic and a nonconforming architect, engineer, mathematician, cosmologist, poet and inventor (registering 25 patents during his life). Snelson was an art student who attended his lectures on geometric models, and after that summer, influenced by what he had learnt from Fuller and other professors, he started to study some three-dimensional models, creating different sculptures (figure 2).

Figure 2: "X-column" by Snelson, his first tensegrity art piece. Illustration donated by the



artist.

As the artist explains, he achieved a new kind of sculpture, which can be considered the first tensegrity structure ever designed. When he showed it to Fuller, asking for his opinion, the professor realized that it was the answer to a question that he had been looking for, for so many years. In Fuller's [7] words:

"For twenty-one years, before meeting Kenneth Snelson, I had been ransacking the Tensegrity concepts. (...) Despite my discovery, naming and development of both the multi-dimensional vectorial geometry and the three dimensional Tensegrity, I had been unable to integrate them, thus to discover multi-dimensional four, five and six axes symmetrical Tensegrity."

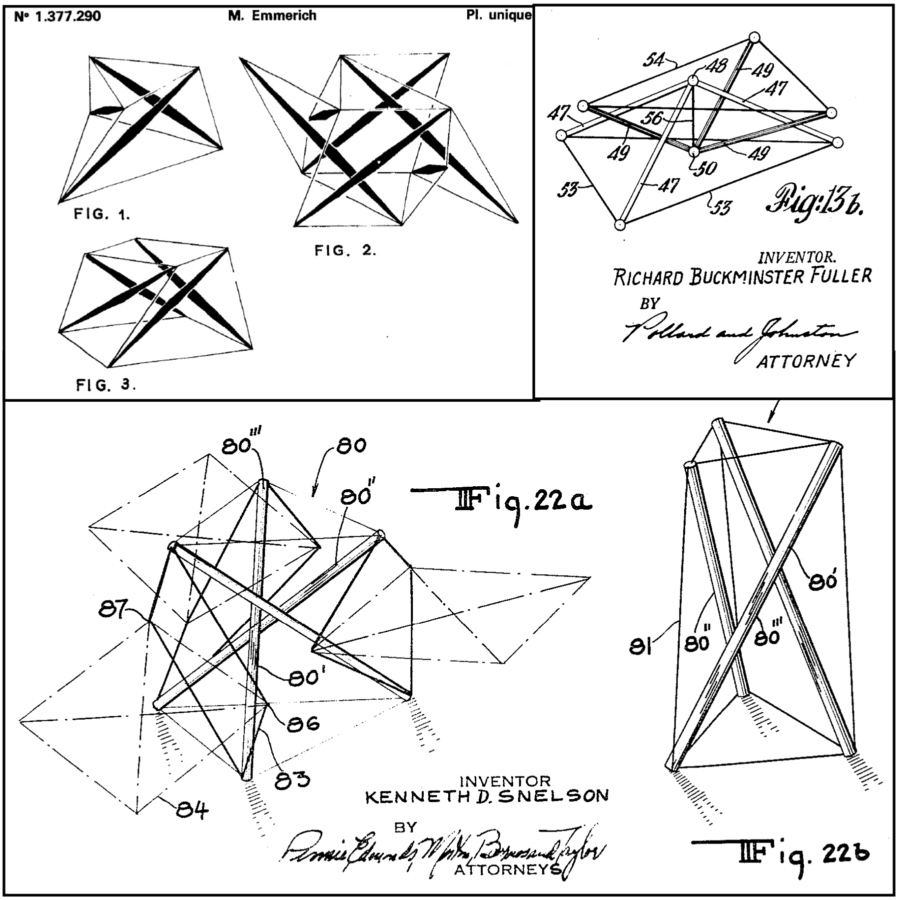


Figure 3: Comparison of three details of the three patents: Fuller-13 Nov 1962; Emmerich-28 Sep 1964; Snelson-16 Feb 1965

In contrast to other authors, and serving as an illustration of how important it was considered, he always wrote “Tensegrity” starting with a capital T.

At the same time, but independently, David Georges Emmerich (Debrecen-Hungary, 1925-1996), probably inspired by Ioganson's structure, started to study different kinds of structures as tensile prisms and more complex tensegrity systems, which he called "structures tendues et autotendants", tensile and self-stressed structures (figure 3). As a result, he defined and patented his "reseaux autotendants", which were exactly the same kind of structures that were being studied by Fuller and Snelson.

3. The controversy

Even though at the beginning Fuller mentioned Snelson as the author of the discovery, after some time he started to consider it as “my Tensegrity”. Actually, he coined this term in 1955 as a contraction of “Tensional-Integrity”, so by calling these structures with the denomination he chose, he let people think that it was his invention. “Creating this strange name was his strategy for appropriating the idea as his own”, quotes Snelson in various publications (Coplans [8] and Schneider [9]).

Obviously, his art student was certainly confused; at the end of 1949 Fuller wrote to Snelson saying that his name would be noted in history, but some years later he changed his mind, asking his student to remain anonymous for some time. This situation pushed Snelson to insist on acknowledgement during an exposition of Fuller’s work in 1959, at the Museum of Modern Art (MOMA) in New York. Therefore his contribution to tensegrity was credit and recognized publicly.

A couple of years later, Fuller [7] referred to Snelson again:

“(...) an extraordinary intuitive assist at an important moment in my exploration of the thus discovered discontinuous-compression, continuous-tension structures was given me by a colleague, Kenneth Snelson, and must be officially mentioned in my formal recital of my "Tensegrity" discovering thoughts.”

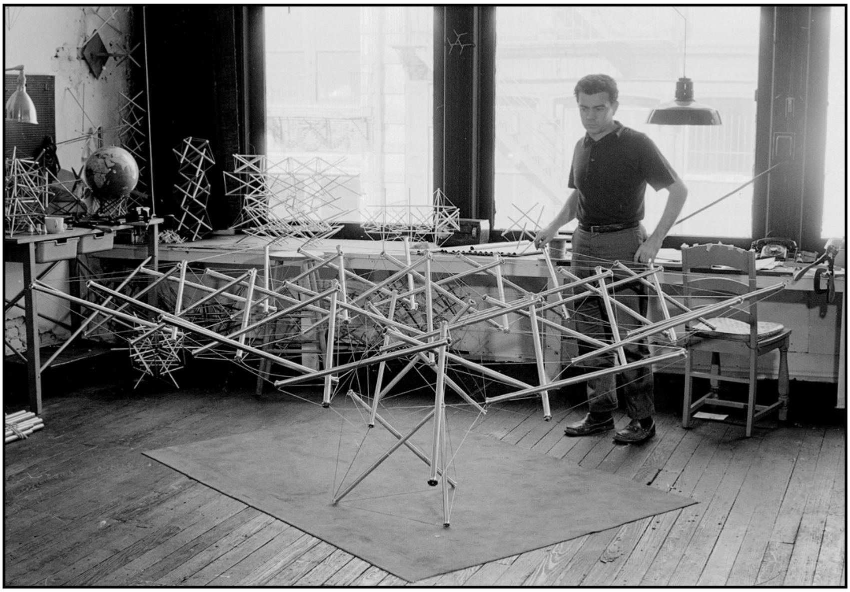


Figure 4: Kenneth Snelson working in his studio in 1961. Illustration donated by the artist.

However, he always thought that if he had not catalyzed Snelson's discovery, Tensegrity would have never been invented as a new structure. In fact, he never mentioned Snelson in one of his most important and renowned books about tensegrity, "Synergetics" (Fuller [10]) and failed to do so again in his correspondence with Burkhardt [11].

The accuracy in reporting (expression suggested by Snelson instead of *battle of egos)* by both men continued furthermore, when in 1980 Fuller wrote a 28-page letter to Snelson, in answer to a Snelson's one-page letter. According to Vesna [12], in those letters they tried to clarify the authorship of the discovery, and not the inventor, because Fuller affirmed that inventors can't invent the eternal principles-cosmic laws of the universe. Paradoxically, he had patented those universal laws in 1962.

Who invented tensegrity? It is evident that the answer is not evident. In the author's opinion, the synergy (a word so often used by Fuller) created by both the student and professor, resulted in the origin of tensegrity. As quoted by Stephen Kurtz's [13]:

"If Fuller acknowledges his debt to Snelson for the invention of the tensegrity principle, Snelson likewise acknowledges his own debt to Fuller's visionary work".

Although acknowledgement is very important for the two of them, especially for Snelson (the only one still alive), perhaps it would be better to pay more attention to the possibilities of these structures than to the past controversy.

4. The evolution.

After the brief moment of acknowledgment in the MOMA, Snelson was once again keen to continue working with tensegrity as an essential part of his sculptures, which he has been creating until the present day. Even though he commenced studying the fundamental concepts of tensegrity, gathered and summarised in his web page [14], he focused his work on the sculptural and aesthetic aspect. He avoided very deep physical and mathematical approaches, due to his artistic background and his opinion in relation to the difficult application of tensegrity systems. This process provided him the facility to develop very different configurations, asymmetrical and non conventional, applying his intuitive knowledge and achieving impressive sculptures that are spread all over the world. Moreover, the construction of tensegrity systems requires a fine and delicate technique that he has been improving over the years. The actual process whereby Snelson erects his works is a science and an art in itself; actually, as it is stated by Fox [15], he is the only person capable of engineering his constructions.

On the other hand, Fuller and Emmerich took a different approach, studying the different possible typologies of tensegrity, mainly spherical and one-dimensional systems: masts. They did it using models and empiric experiments as their main tools, and in contrast to Snelson, they looked for possible applications to architecture and engineering.

Just after viewing Snelson's sculpture, the inventor from Massachusetts studied some simple compositions, and produced a family of four Tensegrity masts characterised by vertical side-faces of three, four, five and six each, respectively (Fuller [7]). He also discovered the "six-islanded-strut icosahedron Tensegrity" (expanded octahedron). Subsequently, this work was developed by other people, creating such Tensegrity systems as the “vector equilibrium” (cubo-octahedron), the “thirty-islanded Tensegrity sphere” (icosahedron), the “six-islanded Tensegrity tetrahedron” (truncated tetrahedron) and the “three-islanded octa-Tensegrity” (all quotation marks are Fuller’s denominations). Consequently, a hierarchy of premier Tensegrity structures was created and the comprehensive laws of universal tensegrity structuring were completed.

Thus, Bucky (as Buckminster Fuller was also known), kept on looking for new designs, applications and methods of construction. He made several attempts to design geodesic tensegrity domes (figure 5) (although they lacked of stability due to the absence of triangulation), and patented some of his works connected to this subject (Fuller [16] and [17]). However, the final application of Tensegrity was not as successful as he thought it would be; he was never able to produce the Tensegrity dome which could cover a whole city, as he intended; and, in addition, he was forced to build the Montreal bubble at Expo ’67 as a geodesic dome but without using Tensegrity principles due to time and budget reasons.

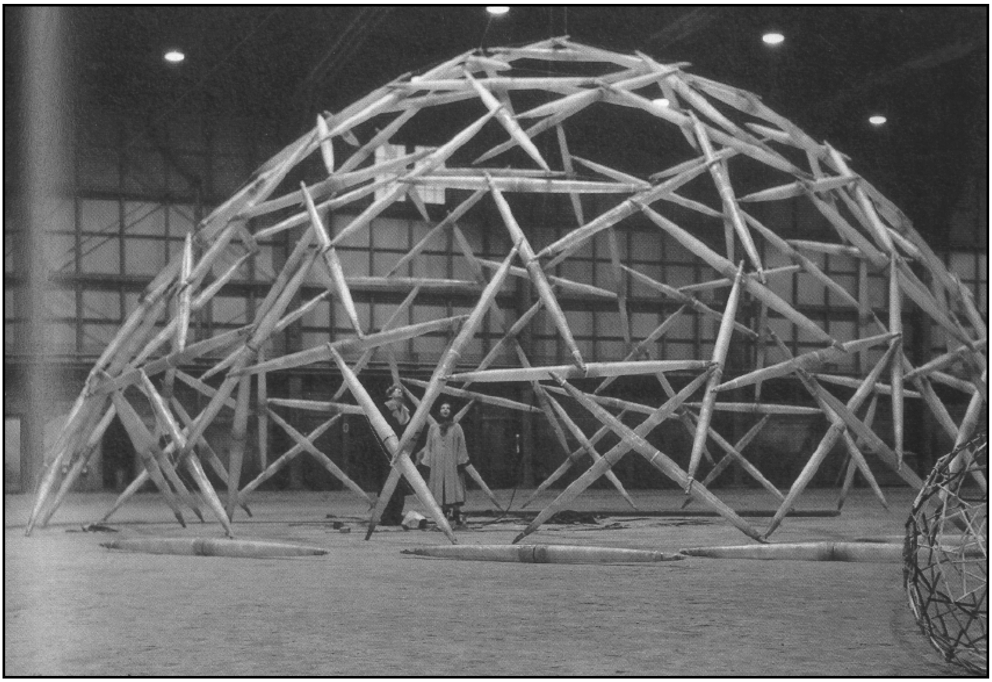


Figure 5: “Geodesic Tensegrity Dome” by Fuller in 1953. Illustration taken from Gengnagel.

Henceforth, some people who were influenced by Fuller’s work, started to explore this new structural system, looking for any application to architecture and engineering. For instance, J. Stanley Black [18] wrote an unpublished study which tried to recall the main concepts known at that time and to figure out some possible systems and configurations. Although it was a good attempt, the basis of tensegrity were not very clear at that moment, and his final design was not a reflection of a true tensegrity system, but something more similar to Levy and Geiger's works (Geiger [19], Goosen et al. [20] and Setzer [21]). After some first attempts of tent-shaped structures by Frei Otto during the 60s, tensile structures became more popular in the 1970s, e.g. the Olympic Stadium of Munich by Fritz Leonhardt, Frei Otto and Jörg Schlaich in 1972.

René Motro, probably one of the most important specialists in tensegrity at present, started to publish his studies on the subject in 1973: "Topologie des structures discrètes. Incidence sur leur comportement mécanique. Autotendant icosaédrique". It was an internal note for the Laboratory of Civil Engineering of the University of Montpelier (France) about the mechanical behaviour of this kind of structure. From this time forth, this laboratory and engineer became a reference in terms of tensegrity research.

Some years later, in 1976, Anthony Pugh [22] and Hugh Kenner [23], both from the University of California (Berkeley), continued this work with different lines of attack. On the one hand, Pugh wrote the "Introduction to Tensegrity", which is interesting for the variety of models that it outlines and his strict classification and typology. On the other hand, Kenner developed the useful "Geodesic Math and How to Use It", which shows how to calculate "to any degree of accuracy" the pertinent details of geodesic and tensegrity regular structure's geometry (lengths and angles of the framing system), and explores their potentials. Even though the latter work is more explicit in geometric and mathematic subjects, it also lacks the treatment of behaviour of tensegrity under load. Nevertheless, both of the authors realized that, apart from some of Fuller's writings, little reliable information had been published on the subject. It is important to note that there is conflicting information in both books: Kenner affirms that Snelson's work was "unknown to Tony" (pg. xi), while Anthony Pugh refers to Snelson in several paragraphs of his book (pgs. ix, 3,…).

During the 1980s, some authors made an effort to develop the field opened by their predecessors. Robert Burkhardt started an in-depth investigation and maintained a correspondence with Fuller [23] in order to obtain more details about the geometry and mathematics of tensegrity. The final result, 20 years later, is a very complete, useful and continuously revised Practical Guide to Tensegrity Design (Burkhardt [11]). Other important investigators have been Ariel Hanaor [25], who defined the main bi-dimensional assemblies of elementary self-equilibrated cells and Nestorovic [26] with his proposal of a metallic integrally tensioned cupola.

Recently, several works have been adding to the body of knowledge. Since it is not always possible to read all the publications that are appearing in relation to a specific field, only the most relevant will be pointed out in the next paragraphs.

Connelly and Back ([27] and [28]) have aimed to find a proper three-dimensional generalization for tensegrities. Using the mathematical tools of group theory and representation theory and the capabilities of computers, they have drawn up a complete catalogue of tensegrities with detailed prescribed types of stability and symmetry, including some that have never been seen before.

Other authors (S. Pellegrino, A.G. Tibert, A.M. Watt, W.O. Williams, D. Williamson, R.E. Skelton, Y. Kono, Passera, M. Pedretti, etc.) have also studied the physics, mathematics (from geometrical, topological and algebraical points of view) and mechanics of tensegrity structures. However, apart from the authors mentioned above, and Motro and his group in Montpellier, there have not been many works seeking to apply this new knowledge to any field in particular. The most recent works will be referred to again in other papers.

Acknowledgement

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