Tensegrity systems in nature and their impacts on the creativity of lightweight metal structures that can be applied in Egypt

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Abstract

The search for integrated design solutions has been the designer's dream throughout the different stages of history. Designers have tried to observe natural phenomena and study biological structure behaviour when exploring creation within nature. This can happen through trying to follow an integrated approach for an objects' behaviour in biological nature systems. Donald E. Ingber, a scientist, confirmed this by his interpretation of the power that affects cell behaviour. This interpretation was proved through physical models called "the Principle of Tensegrity". It is an interpreting principle for connectivity within a cell that represents the preferred structural system in biological nature. "Tensegrity" ensures the structural stability arrangement for its components in order to reduce energy economically and get a lower mass to its minimum limit by local continuous tension and compression. The aim of this research is to monitor "Tensegrity" systems in biological nature with a methodology for use and formulation in new innovative design solutions. This research highlighted the way of thinking about the principle of "Tensegrity" in nature and its adaptation in creating lightweight metal structural systems. Such systems have many functions, characterized by lightweight and precise structural elements and components. Moreover, a methodology design has been proposed on how to benefit from Tensegrity systems in biological nature in the design of lightweight metal structures with creative application in Egypt.

Keywords: Tensegrity, lightweight structure, design in nature.

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1 Introduction to tensegrity

The word “Tensegrity” is a concatenation of tensile integrity. It was coined by Buckminster Fuller to describe structures popularized by the sculptor Kenneth Snelson in 1948 [1]. It was not known until 1947, when he delivered a lecture on “Energetic-Synergetic Geometry” at Black Mountain College. Nowadays, it is accepted as a starting point for Tensegrity structures. A young artist, called “Kenneth Snelson”, built different models of the structures proposed by Fuller in his lecture. In the early 1960s the term “Tensegrity”, a contraction for tensile integrity, was coined by Fuller [2].

“Tensegrity” is, therefore, a brief expression for tensial integrity. It had been more widely adopted when an American architecture (Fuller) and one of his assistants (K. Snelson) defined “Tensegrity factor”. These factors are “Islands of compression in a sea of tension” [3].

Thus, this means, as Fuller said in the Geometry of Thinking, that “Tensegrity” is the balance produced from two forces (press and tense) with a win-win relationship, in which tense continues and press attends. Press and tense are equivalent. Fuller proved that Tensegrity is a part from synergy, coexistence between the opposite parts of natural laws such as pull-push, press-tense, aversion-attraction, etc. Therefore, it means the integration of nature [1].

A Tensegrity structure is a self-supporting structure that consists of a set of disjointed rigid elements (struts) whose endpoints are connected by a set of continuous tensile elements (strings), and which maintains its shape due to the self-stress equilibrium imposed by compression of struts and tension of strings [4].

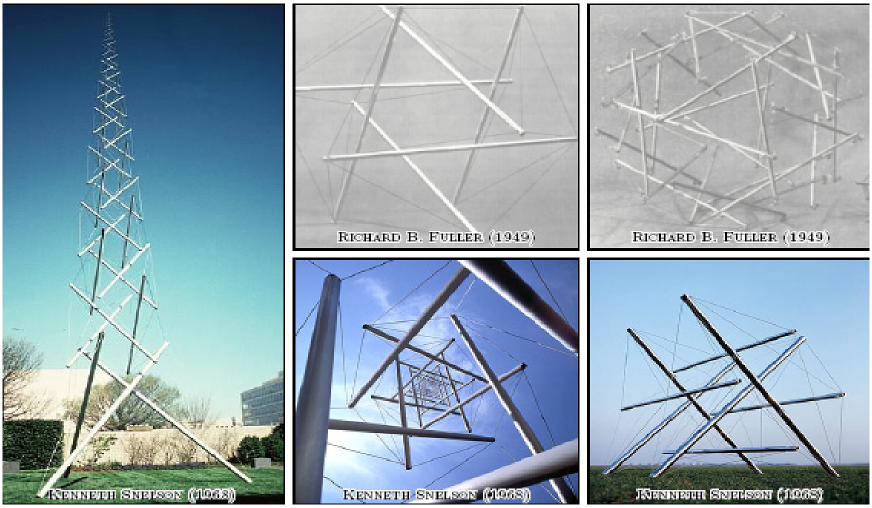

Figure 1: K. Snelson’s Tensegrity structure.

Fuller was the first who proposed the Tensegrity structures. They have been developed in recent years due to their innovative forms, lightweight and deploy ability. They belong to a class of free-stand, pre-stress, pin-joint, cable–strut system where contacts are allowed among the struts [5].

2 Tensegrity in nature

In the history of mankind, nature and its phenomena were the main motives for creative thinking development. It affects the secrets of nature. Thinking and regarding were the tools to transact with nature, in order to solve its mystery and clear its secrets. Man was much closer to them since he is conscious as to what made humans want to find out about its laws, and still do.

Hence, nature is an information sourcebook of behaviour, function, colour and shape that can inspire visual design and invention.

Tensegrity represents the preferred structural system in biological nature, which ensures the structure stability through arranging its components to reduce economically energy and getting smaller mass to the minimum limit through the local continuous tension and compression. This is presented as follows:

2.1 Cellular tensegrity

In Harvard University, "Donald E. Ingber" clarified that the concept of Tensegrity tells us the thread inside the cells. He opposed the thoughts of "Heidemann" and proved that Tensegrity (as a pre-stress structure) is the only structural base representing a number of cellular phenomena. Ingber has presented experimental conclusions supporting the method of tensegritial models [6].

In addition, he stated that when the cell is extracted its nucleus is extracted as well (parallel wise). This could be proved only through "tensegritial model". Ingber proved that nucleus configures the cells that always resist pressure as maintenance for the integrated model called "Life" [3].

Ingber, in his experiment "Modelling", simulated the structural living-cell system through nucleated tensegrity models. The "cell" is constructed from aluminium struts and thick elastic cord; the "nucleus" is a geodesic sphere composed of wooden sticks and thin white elastic thread; the cell and nucleus are

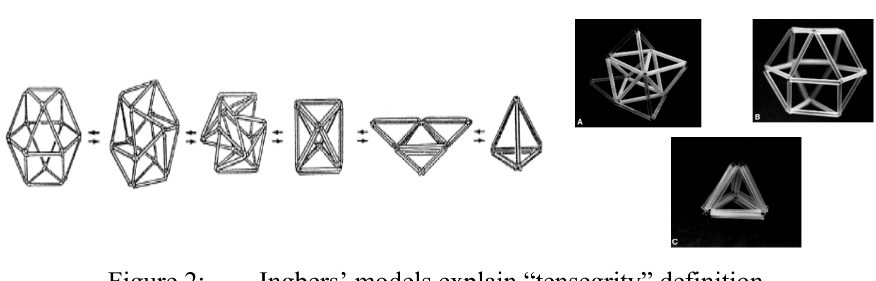

Figure 2: Ingbers' models explain "tensegrity" definition.

inter-connected by thin black elastic thread, which cannot be seen due to the black background. (figure 2). From the experiment, he proved that tensegritial structures behave the same as living-cells [7].

2.2 Spider fibre tensegrity

In nature, spider fibre is one of these classes of structure, with a continuous network of tension members and a discontinuous network of compression members. It is called class-1 Tensegrity structure. The important lessons learned from Tensegrity structure of the spider fibre are:

1. Structural members never reverse their role. The compressive members never take tension and, of course, tension members never take compression.
2. Compressive members do not touch each other, as there are no joints in the structure.
3. Tensile strength is largely determined by the local topology of tension and compressive members [8].

2.3 Tensegrity in body

From class-1 Tensegrity definition, there are rigid bodies that do not touch each other. Such bodies can have specific shapes for particular reasons (e.g. class-2 Tensegrities in biological systems that compose the arm in (figure 4). If there are no shape constraints on the rigid body design, it is common to use the simplest one for the compressive members, namely rods [9].

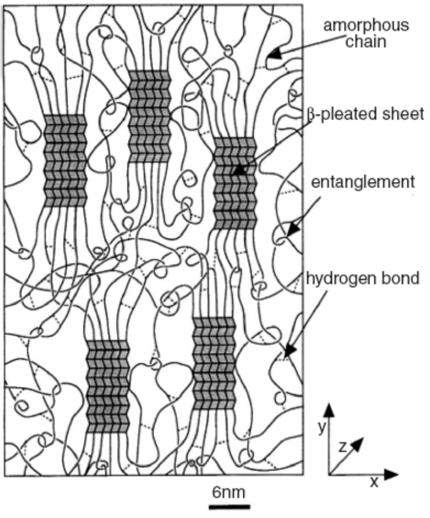

Figure 3: Spider fibre tensegrity.

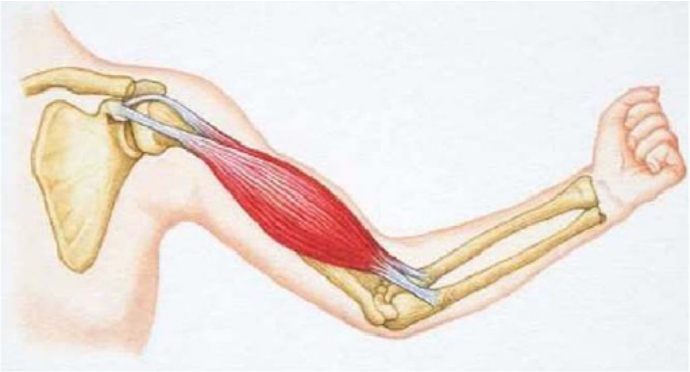

Figure 4: Tensegrity in body.

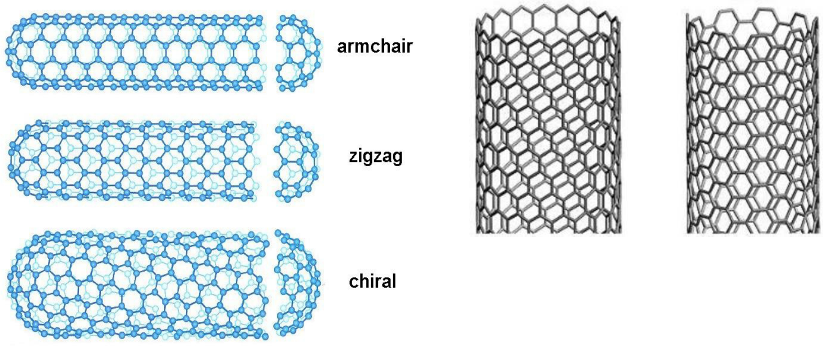

Figure 5: Buckytubes.

2.4 Buckytubes

Carbon nanotube is another example from nature with important lessons for our research. It is the often called the Fullerene (or Buckytube), which is a derivative of the Buckyball. Imagine the 1-atom thick sheet of a graphene with hexagonal holes due to the arrangements of material at the atomic level in (figure 3). Try now to imagine that the flat sheet is closed into a tube by choosing an axis to form it. A certain set of rules must define the closure that takes the sheet inside this tube. Besides, electrical and mechanical properties of the resulting tube depend on closure rules (axis of wrap, relative to the local hexagonal topology) [8].

3 The methodology for lightweight tensegrity structure design from nature

3.1 Advantage of lightweight tensegrity structures

The current tendency for using more slender structures with greater strength makes Tensegrity structures an interesting solution for structural design of large spans. The satisfactory responses for certain applications, assembly speed, transportation convenience and modulation are some important advantages of Tensegrity structures. Nowadays, architects and engineers are seeking new geometrical types of structures that provide efficient structural response, economic and safe, such as Lightweight Tensegrity structures [10].

Lightweight Tensegrity structures represent a class of space structures composed of two sets of members: soft and hard. On the one hand, soft members cannot carry other significant loads except for tensile ones. This is presented in the example of an elastic tendon, which cannot be compressed for all practical purposes but can carry significant tension. Because of this property, we shall refer to these members as tensile members. On the other hand, hard members are characterized by the fact that they can carry any type of load. It is clear in a bar that can carry significant and comparable tension, compression forces, bending moments, etc. [11].

It is evident that these structures are capable of large displacement and can easily change their shapes. Furthermore, they could be built, with or without, very few complicated bars through joints. They offer excellent opportunities for physically integrated structure and controller design, since the elastic components can carry both the sensing and actuating functions. These structures are very promising deployable structures due to packaging efficiency and ease of deployment, unlike systems with telescopic struts and complicated joints .Their deployment can be accomplished by controlling the tendons, without involving complicated telescopic struts [11].

3.2 A design methodology from nature

The method of designing from nature is the way that a designer should use to represent his thoughts and design visions. This could happen through some steps:

1- Identify the assumed design.
2- Note the needs of the design (through them we can know the base and the secondary needs for designing a structure).
3- Find Organisms / Ecosystems.
4- Simulate the main model in order to find out a shape.
5- Put a tensegritial design for the expected shape.
6- Get a final design.
7- Expect an evaluation for the final design to show how far the design fulfils the required needs.

Figure 6 presents the above steps.

4 An applied study on the main entrance of the Pharaonic Village (Giza – Egypt)

4.1 A design from nature: Lotus flower

The Lotus flower was chosen as it belonged to nature in the Pharaonic time. It is one of the famous factors in the Ancient Egyptian art. In Pharaonic memorials, such flower was used as it could be a significant mark for this art.

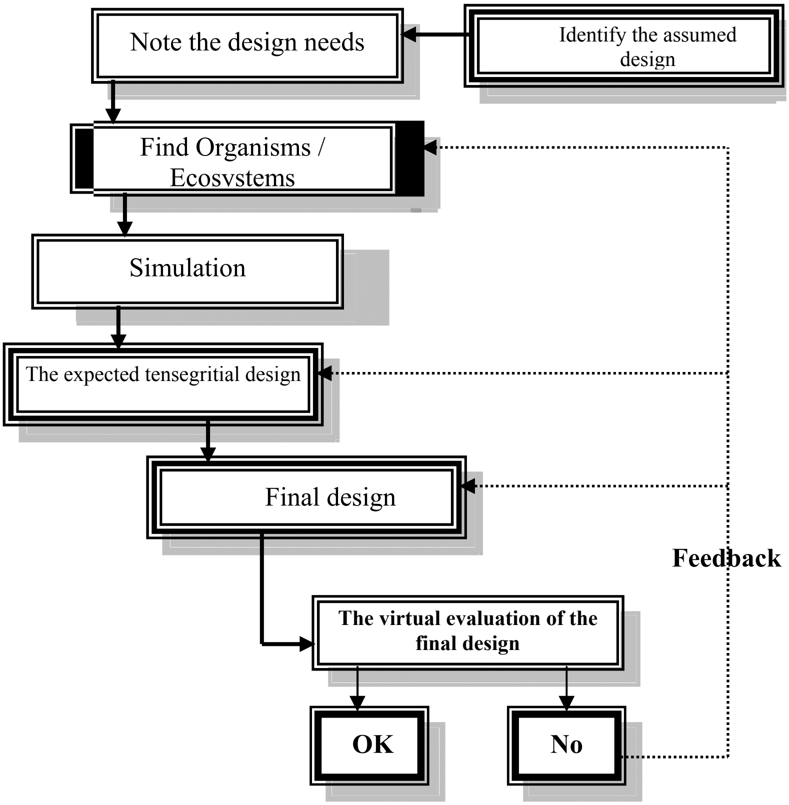

Figure 6: Design methodology from nature.


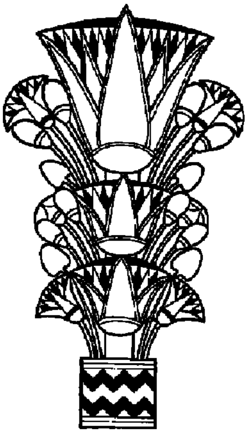

Figure 7: Lotus in nature and Pharaonic Lotus flower.

The Lotus flower had its big part of religious thoughts. It was the master flower and was found on the mummy of “King Tutankhamen” in 1922.

Moreover, it was a symbol for river Nile (whom its goddess was Habi). For the pharaohs, the Lotus flower simulated the Nile. It leaves are lakes coming from the Nile, its shank simulates the path of the Nile and the flower itself is the Nile-Delta.

4.2 Redesign for the entrance

This village is in (Giza – Egypt) and is known as an important touristic site. It was chosen for study in this research.

Step One: The design went through a group of steps. It started with a tensegritial model. This model consists of a tensegritial repeated unit. It contains steel pipe struts and metal cables (figure 9).

Step Two: A tensegritial model was made through simulating and using the general shape of Lotus flower. It consists of tensegritial repeated units representing the general shape of the Pharaonic Village main entrance (figure 10).

Step Three: again, the shape was used by constructing a circus in front of the Pharaonic Village main entrance. It consists of inclined tensegritial structures that simulate Lotus leaf flexible lines (figure 11).

Figure 8: Pharaonic village.

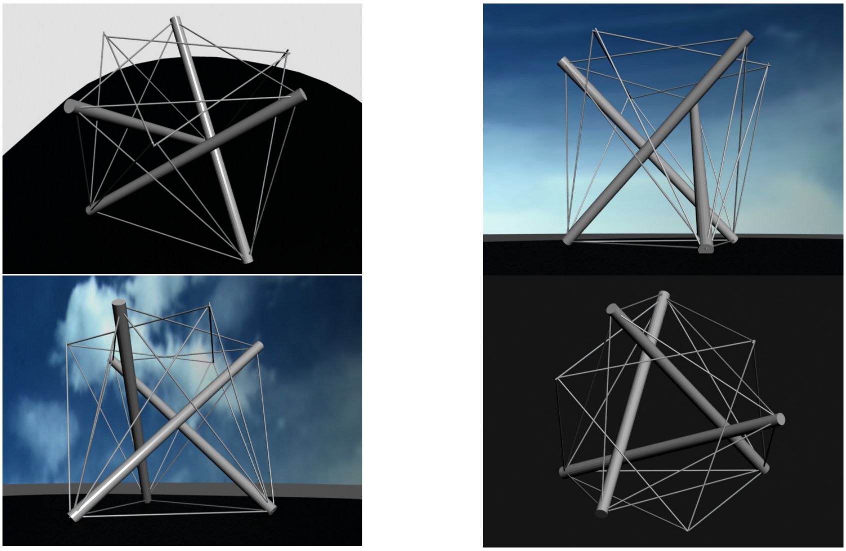

Figure 9: Main tensegritial unit.

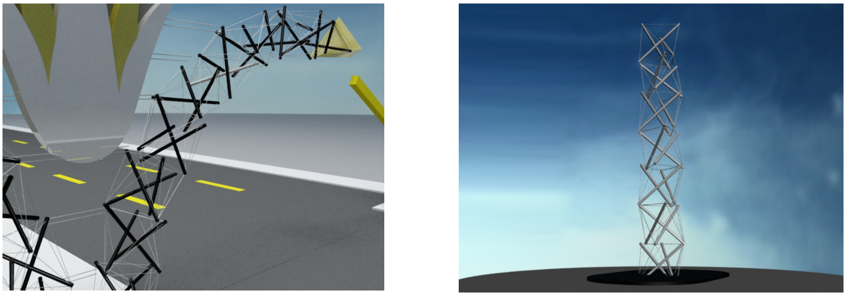

Figure 10: Main tensegritial repeated unit.

5 Results

1. The application of Tensegrity is shown in the usage of pre-stress cables that have shown large abilities with press and push. Tensegritial concept is shown only with one structural condition, where every nodal point has one vertical support linked to many cables. According to Fullers' definition, Tensegrity names the structural relation of the tensegritial structure. It refers to the concept in any structural finitely close. Thus, there is a continuous tension in the whole system and alternated local pressure.

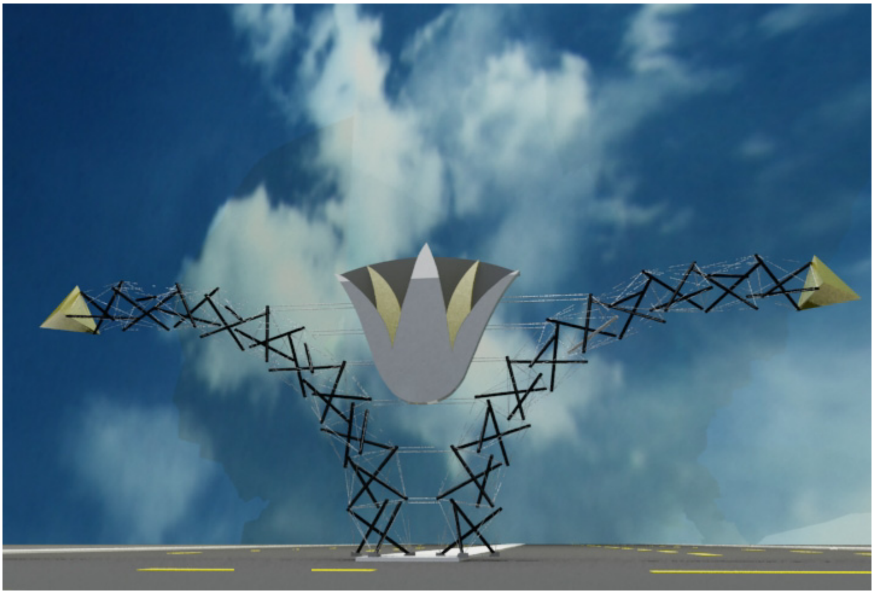

Figure 11: Simulation and using Lotus flower for the main gate.

Figure 12: Lotus flower shaped front circus.

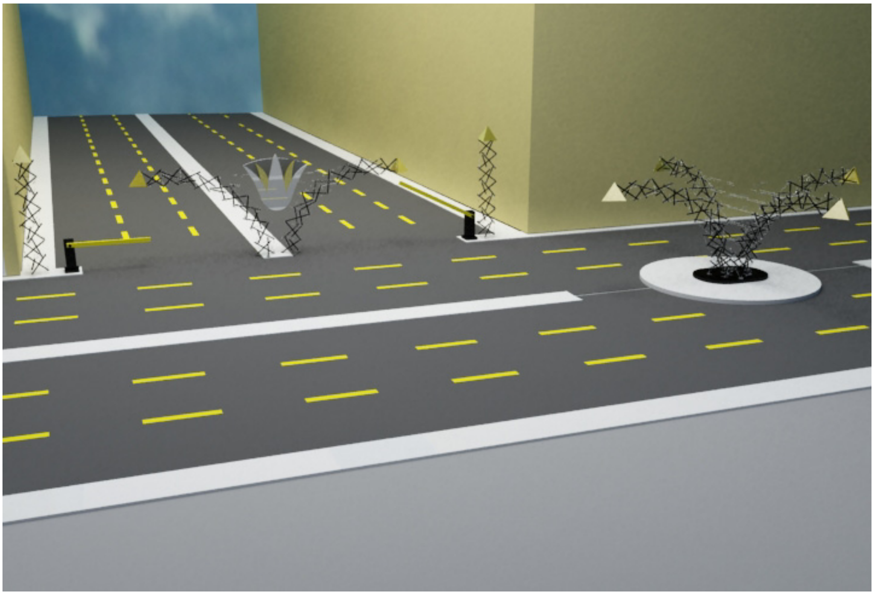

Figure 13: Simulation and using Lotus flower for the main gate and circus.

2. Tensegrity is more than a biological model such as Cellular Tensegrity, spider fibre Tensegrity, Tensegrity in body and Buckytubes.
3. The research has concluded to highlight the thought on the principle of Tensegrity in nature and its adaptation in creating lightweight metal structural systems. They are used for various functions characterized by lightweight, and precision of the structural elements and components.
4. The research found out a proposed design methodology about how to benefit from Tensegrity systems in the biological nature. This design for light metal structures is applicable with such methodology to create designs for lightweight metal structures in Egypt (e.g. structure of the entrance for the Pharaonic village that is designed with the spirit of the "Lotus flower").

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