Harmony in Space

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In their simplest and most elementary form, the structures used in design science are the three-dimensional version of the planar interlacing (biaxial and triaxial) that has always been used for the construction of gratings, baskets weavings and textures. The reciprocal frames can be considered as a premise to the tensegrity structures, which in turn can be considered as a premise to the geodesic structures. Geodesic structures arise from the correct subdivision of polyhedral shapes. The nascent reciprocal joint as a simple, natural and economic form, can be reworked towards the starred joint where the rods contribute towards a single junction point. The structural stability of natural structures is guaranteed by the presence of the triangle. A triangulated structure, optimized for use, does not require additional materials to ensure its resistance.

1 Introduction

> Space is not a passive vacuum, but has properties that impose powerful constrain on any structure that inhabits it. (A. Loeb)

The knowledge of polyhedra is essential to properly design an architectural work. Children can make a tower putting on various cubes, but a tower can be also made with octahedrons or other space modules; in this case we observe new potentiality of form.

We must educate children from an early age to the concept of space considering not only the plane geometry but also the solid geometry that is the synergetic geometry of polyhedra as space forms. The polyhedra in the space are like the notes for the music, so the polyhedra can be used to create architectural music. Plato wrote that

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to know the nature of the universe we have to concentrate on the unity of all things and dive ourselves in the study of music, astronomy, geometry and the number (the so-called 'quadrivium').

The Platonic and Archimedean solids are not only objects in the three-dimensional space but mainly the modules that create the space texture. Enclosing the space using only four equal regular polygons we will only have four equilateral triangles of the tetrahedron form and not another one.

Music is the exact miniature of the laws operating in the entire universe. There is music both inside and outside the human body. The space delineated by polyhedra and the musical harmony represent the language of beauty. Music and the harmonic space of the polyhedra can open up and strengthen our intuitive faculties.

The five Platonic solids symbolize the four elements (earth, fire, air, water) and the universe. Plato had already suggested that the space had its existence and its very specific rules. The modern scientific research has validated Plato's ancient thesis.

The origin of polyhedral shapes is very ancient. Almost certainly, the Egyptians knew the tetrahedron, the cube and the octahedron. Some dodecahedron shaped objects of Etruscan origin were found near Padova, in Italy.

Considering the five Platonic solids at the microscale, the tetrahedron can be identified in silicates, in methane, in quartz, in diamond, in the water molecule; the octahedron in gold, in aluminium crystals; the cube in the sodium chloride, in pyrite crystals; the icosahedron in the hydrides of boron, the fullerenes (truncated icosahedron) in space; the dodecahedron in pyrite, in dodecahedron, in quasicrystals and in radiolarians.

2 Geodesic Structures Construction

In 2004 I published my book in Italian named "Strutture Geodetiche" including for the first time the tetrahedral ideogram D.S.T. (Design Science Tetrahedron). Then in 2013, I presented its English version at Delft Symmetry Festival within the article 'Design Science Structures'. The tetragram synthetically shows four structural groups having the golden section as a common denominator: (1) platonic and Archimedean solids (2) R. B. Fuller's geodesic structures (3) Kenneth Snelson's tensegrity structures (4) reciprocal frame structures by Leonardo Da Vinci. The polyhedral space modules relating to the design science are the starting point for a correct design tuned with nature. Following the existing micro, medium and macro scale rules, we face the natural method that characterizes the design science.

In their most simple and basic form, the structures used in the design science are the three-dimensional version of the planar weaving (biaxial and triaxial), always used for the manufacture of baskets and weavings. Reciprocal frames can be considered as an introduction to tensegrity structures, which in turn can be considered as an introduction to geodesic structures. Geodesic structures derive from the proper division of polyhedral shapes. In this way, we obtain a reciprocal frame joint in a

natural and economic form, it can be modified into the 'stellated' joint where all the rods join to a single point.

Sacred geometry is the universal language contemplated in the macrocosm reflected in the microcosm that is the language of harmony, of beauty, of faith, of proportion, of the universal order and rhythm. The person living within a spherical space thinks to be the centre of things and feels the presence of the geometric rigor linked to the beauty and the perfection of the golden ratio structures. Observing a geodesic structure and its shadow from the inside, you get a spatial perception comparable to the magical suggestions of mandalas and sacred geometry.

The 'takraw ball' is used in Malaysia and Thailand for a game called Sepak Takraw.

In Southeast Asia, there is still an intense debate about its origin. It probably originated in China and is related to the decorative spheres used in the Temari's art in ancient China and Japan. It is possible to recognize the basic elements of design science in the Takraw Ball: polyhedra (icosidodecahedron and truncated icosahedron), the great and small circles of the geodesic sphere, the triaxial weaving of reciprocal frames, the non-resonant quality of tensegrity. It is not easy to find the data for its construction, because this art is handed on orally by the basket maker masters. The original version is made of bamboo or rattan while the current version is made of plastic. The most common versions are two: the first one is referred to geodesic geometry of an icosidodecahedron (Icosa alt 2v) with 6 great circles. The second one is much more complex because there are 12 small circles added to the 6 big ones, to get a geodesic sphere Icosa Alt. 4V, so we have 18 circles in all. All circles are interwoven in semi-reciprocal way.

In the various workshops I held in different Italian and foreign universities and schools, I always felt the participant's ludic and creative involvement. Above all, children aged 8 years and older were excited. They worked with big belief, responsibility and a lot of fun, anxious to see the result. Kids always want to be involved and not excluded. They often invent new forms, showing intuition, creativity and a great desire to learn while having fun.

The workshops were done on polyhedra, geodesic domes, tensegrity structures, the bridge, the arch and Leonardo's ring. We often used cardboard, cardboard tubes, rolled paper rods, bamboos, jute canes and 'arundo donax' reeds. The rods were connected by Leonardo's reciprocal frame joint. The workshop targets were:

- to be aware of the shapes that make up the space geometry;
- to learn the design science concept in harmony with the natural world;
- to consider math, geometry, science and architecture both scientifically rigorous tools and instruments for a ludic activity;
- to get the shape optimization concept, and the dimensional stability of the structures;
- to stimulate creativity and intuition;
- to promote socialization.

3 Workshops

In my workshops I regularly use the poster 'CARTA DEI POLIEDRI' I first designed in 1983. Later it was published in 'Dome Magazine', 1999 and 'Bioarchitettura', 2000. It is a poster containing: the five Platonic solids, the 13 Archimedean solids and the 13 duals of Archimedean, all divided in families. For example, looking at the family of the icosahedron we immediately see that the pentakis dodecahedron is a triangulated dodecahedron, corresponding to a geodesic 2v. The 'Carta dei Poliedri' is a very useful tool to quickly locate a polyhedron and its immediate family.

Bamboo is a sustainable material par excellence, being rugged, inexpensive, easily available and highly resilient. Bamboo plants are the living example of resilience: during a hurricane, they can bend but do not break. For centuries, Japanese used the bamboo, which is very similar to a tensegrity structure. In fact, its internal cells are able to withstand both the traction and the compression forces. In nature, the tensile and the compressive forces always interact each other. Our body, made of rigid bones and flexible ligaments, is an example of tensegrity structure. Recently Stephen Levin, Donald Ingber, Graham Scarr, Tom Flemons and others innovated the biology science with biotensegrity, proposing a new paradigm that revises and expands the understanding of the kinematics, biomechanics and functional anatomy.

4 Conclusions

In my workshops, I always propose structures belonging to the design science. Design science is considered as a bridge between art and science: geometry becomes an intermediary between harmony and unity of the natural world. The geometry is a creation of nature not a human invention. Men can learn from nature itself. According to Fuller, all the natural forms tend toward the curved shape. Nature refers to the value of the golden section, not to the phi- Greek or the Cartesian axes.

In the transition from the micro to the macro scale, the form starts with a point and ends with a sphere (new point), passing through endless space modules. Kandinsky's methods in his art have a scientific verification in aggregation theories about compact balls (close packing) and in the structural chemistry.

All natural forms are the result of interactions between the physical forces of the external environment and the fundamental laws that govern them. The natural structures reach stability by means of triangulation. A structure built with triangles, does not need additional materials to be reinforced. It is very important to build and manipulate scale models because they contain all the necessary information to build the object in its actual size. By manipulating a model, everything becomes clearer, we can guess the results and the touch of the model parts is stored forever.