MODERN BUILDING STRUCTURES USED FOR MILITARY PURPOSES

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This paper investigates the technical aspects of the spherical spatial structures, focusing on the tensegrity building systems used for military purpose. The spherical spatial structures have been studied and used since antiquity. Pythagoras, Plato and Euclid were conducted extensive research on the concept of such type of structures. Regular pentagon has properties related to the value of the golden section, intuitively used by great architects and engineers since ancient times. In the Middle Ages, Leonardo Da Vinci created spatial objects using proportions based on the golden number, and later R. B. Fuller made the famous geodesic domes. The structures proposed by the authors are based on concepts related to the "golden section", on studies made on the regular pentagon, on the spatial volumes able to be inscribed in spheres and on the tensegrity systems. The proposed structures presents some advantages related to the ease of mounting, to the volume covered, to the resistance to the environmental factors (snow, wind, earthquake, and so on). The paper presents the conclusions of the investigations on the components of the spatial structures and on the outcomes of their use.

Key words: *spherical spatial structure, golden section, geodesic dome, regular pentagon, regular hexagon, tensegrity system.*

1. TYPES OF SPHERICAL SPATIAL STRUCTURES

The spherical structures have been used since ancient times. Nowadays they are parts of the most visited and impressive edifices in the world (Figure 1) [2, 3].

Figure 1. Antique edifices

Introducing the golden section rule in the architecture, the concept of the perfect proportion of the elements that constitute the spatial spherical structures has developed. If a segment is divided so, that the ratio of the whole and the larger side is equal to the ratio of the larger side and the lower side, than the ratio is equal to the golden number, Φ (Figure 2, a) [1, 2, 3].

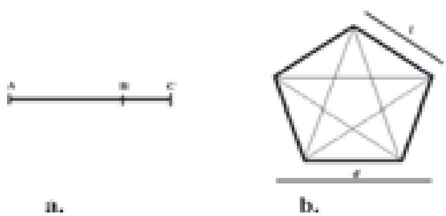

Figure 2 Golden number
a. defining the golden number;
b. finding the golden number into the regular pentagon structure

$$AC/AB = AB/BC = (\rightarrow \Phi^2 - \Phi - 1 = 0 \quad (1)$$

The results of the equation are as follows:

$$\Phi_1 = \frac{1+\sqrt{5}}{2} > 0 \qquad (2)$$

$$\Phi_2 = \frac{1+\sqrt{5}}{2} < 0 \qquad (3)$$

The results show that the negative value is not a solution of the equation, as the Φ golden number is the result of the ratio of two positive numbers [1, 3, 5]. So, the value of $\Phi = \frac{1+\sqrt{5}}{2} \approx 1{,}618...$ having an infinite number of decimals.

The ratio of the diagonal and the edge of a regular pentagon has as result the value of the golden number, Φ (Figure2, b).

By rotating around axes the flat surfaces obtained with the proportion rules of the golden number, Φ, spatial structures can be built on, based on parallelepipeds, prisms or pyramids. Such spatial objects have been first imagined and drawn by LEONARDO DA VINCI (Fig. 3) [3, 5, 6].

Figure 3 Spatial structures imagined by Leonardo da VINCI:
a. "ycocedron planus vacuus" (icosahedron),
b. "duodecedron planus vacuus" (dodecahedron),
c. "vigintisex basium planus vacuus" (semiregular polyhedron),
d. "ycocedron abscisus vacuus" (semiregular polyhedron),
e. "vigintisex basium elevatus vacuus" (stellated dodecahedron),
f. "octocedron elevatus vacuus" (stella octangula)

Domes are spherical structures that cover large openings and they are built in two ways: monolithic ones – using concrete as the base raw material and geodesic ones, a structure made of bars (preferably steel or wood).

The building principle of the geodesic domes has been developed and implemented by R. B. Fuller in "Laminar geodesic domes" (1965). Using isosceles triangles, Fuller found a way to divide the spherical surface into equal flat surfaces, obtaining thus an image of a complete spherical structure made of bars (Figure 4). These spatial structures have two main characteristics: each node is the joint of 6 bar ends; the nodes are connected into triangle shapes.

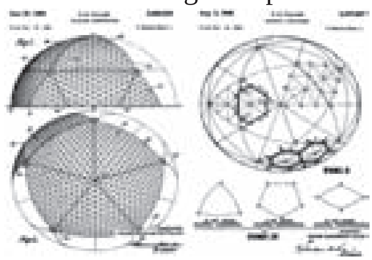

Figure 4. The dome of R. B. Fuller

By using Fuller's principles into architecture, public structures or even single-family homes were built (Figure 5) [7, 8, 9, 10, 11].

Figure 5 Fuller's dome used in public buildings

Defining the spherical spatial structure, the properties of regular polyhedrons as tetrahedron, hexahedron, octahedron, dodecahedron or icosahedron can be used in buildings architecture (Figure 6).

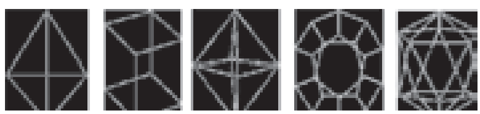

Figure. 6 Regular polyhedron: a . tetrahedron; b. hexahedron; c. octahedron; d. dodecahedron; e. icosahedron

For an optimal use in building architecture, the angle between two adjacent polygons must be as large as possible. The most suitable polyhedron to be used in spherical structures is the dodecahedron, for which the angle between two adjacent polygons is 1150.

In case of rotating the pentagons of the dodecahedron, so that they no longer have a common edge, but a common point, an irregular polyhedron with 60 equal edges is obtained, composed of 12 initial pentagons and 20 equilateral triangles in addition. The polyhedron thus obtained is modified as follows: each pentagon is moved at a distance equal to the length of an edge, so that the 20 equilateral triangles are turning into regular hexagons, each node consisting of 3 edges. Thus, another irregular spherical polyhedron composed of 90 equal edges and 60 identical vertices is obtained (Figure 7) [4, 14].

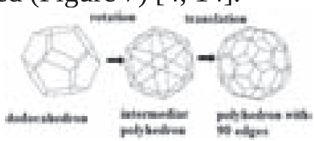

Figure 7 Genesis of the irregular polyhedron with 90 equal bars

When cutting the irregular polyhedron, valuable structures can be obtained for the building architecture (Figure 8) [12, 13].

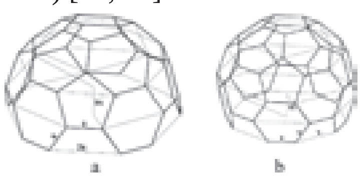

Figure 8 Sectioned parts of the irregular polyhedron

The projection of the spatial structure shown in Fig.8a is obtained by alternating edges with length a and 2a respectively (Figure 9). The radius of the circumscribed circle (the projection circle) has the value of 2,441244516a. The height of this structure is shown in Figure 10 [15, 16, 17].

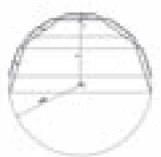

Figure 9 Edges a and 2a inscribed in the projection circle

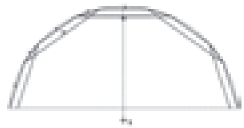

Figure 10 Forming of the transverse module

If a part of the projection that alternates a and 2a edges is mirrored at a distance of 0,850650808a, a module consisting of equal bars is obtained. They form hexagons and half of hexagons. (Figure 11)

Figure 11 The transverse module

Repeating the module, a half cylinder structure is obtained. This structure is composed of hexagons reinforced with anchors with the length 2a, namely the diagonal of the hexagon with edge of length a (Figure 12).

Figure 12 The complete structure

2. TENSEGRITY SYSTEMS

Tensegrity systems are light structures, suitable for knock down and foldable structures. Tensegrity systems are composed of cables and rigid bars and have the following characteristics: the static stability of the structure is the result of pre-tensioning the cables; the rigid elements (bars) are not connected one to the other and they are subjected only to compression strains; there are no rigid joints in the structure, but articulated joints only. (Figure 13) [16,18].

Figure 13 Tensegrity systems

3. SPATIAL SYSTEMS OF THE ARTICULATED JOINTS BARS

The way of calculating the bar strains is presented here below: all bars are considered to be sectioned; the sectioned bars are replaced by their unknown axial internal force in the bar; the equability of each node is expressed by equations, resulting thus 3n equations with (b + r) unknown values,

where: n is the number of nodes;

b – number of bars;

r – number of single bearing bonds.

The equation of the internal stress of the bars results as follows:

$$A \times N = F \qquad (4)$$

where:

A is the equilibrium matrix;

N – vector of the axial internal forces;

F – vector of the forces in the nodes.

If det (A) ≠ 0, than N = inv (A) × F;

The systems of articulated joint bars have the following characteristics:

- b + r = 3n, det (A) ≠ 0 – statically determinate system;
- b + r < 3n, rang (A) = (b + r) – mechanism with m = 3n – (b + r) degrees of freedom;
- b + r > 3n, rang (A) = 3n – statically indeterminate system, s = b + r – 3n – degree of statically indetermination;
- q = rang (A) < min (3n, b + r) –critical system, s = b + r – q; m = 3n – q.

In critical systems there is a number s of vectors with $N_0 \neq 0$, so that $A \times N_0 = 0$ and these can be pre-tensioned and there is a number of m degrees of freedom for each mechanism, so that an infinite number of mechanism could exist.

N_0 is the number of self strains that meet the conditions of equilibrium, without loading the system. If corresponded displacements are applied to the infinite number of mechanisms, than, theoretically, there are an infinite number of strains in the system. For certain loads, the critical system behaves as a statically indeterminate system. For other loads, the system behaves as a mechanism.

The tensegrity systems are critical systems, when are subjected to a set of self strains (s=1) and have one ore more degrees of freedom as a mechanism $(m \geq 1)$. By pre-tensioning the system, it becomes stable and the kinematic freedom of degrees become rigid ones. After removing the disruptive external actions, the resultant of internal stress of the bar restores the system to its initial state. (Figure 14).

Figure 14 Structures that use tensegrity systems

In Figure 15 the use of the tensegrity systems in case of geodesic domes is presented.

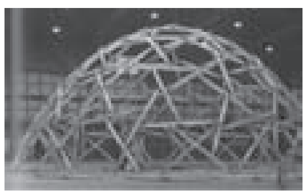

Figure 15 Geodesic tensegrity Dom (1958)

4. CONCLUSION

A possible destination of the spherical structures could be the military buildings, due to the fact that they are light structures and even knock-down ones, able to be placed on any kind of land. If the structure fulfills the conditions imposed by the tensegrity systems, then it can be easily transported as modules, and can be used for military building purpose.

The proposed spherical structures can be fixed or knock-down structures and for the last one the tensegrity structures are recommended.

For fixed structures (sheds for example), sections of the structures with 90 equal bars can be used, but the most appropriate one is the modular structure presented in Fig. 12.

As the strength point of view, the presented structures are possible to be optimized. The structures behave as mechanisms, but using tensegrity systems, they can be optimized so, that the reaction of the structure (and especially of the system) to the action of the external factors to be superior to the current structures used for military building purpose, and not only for them.

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