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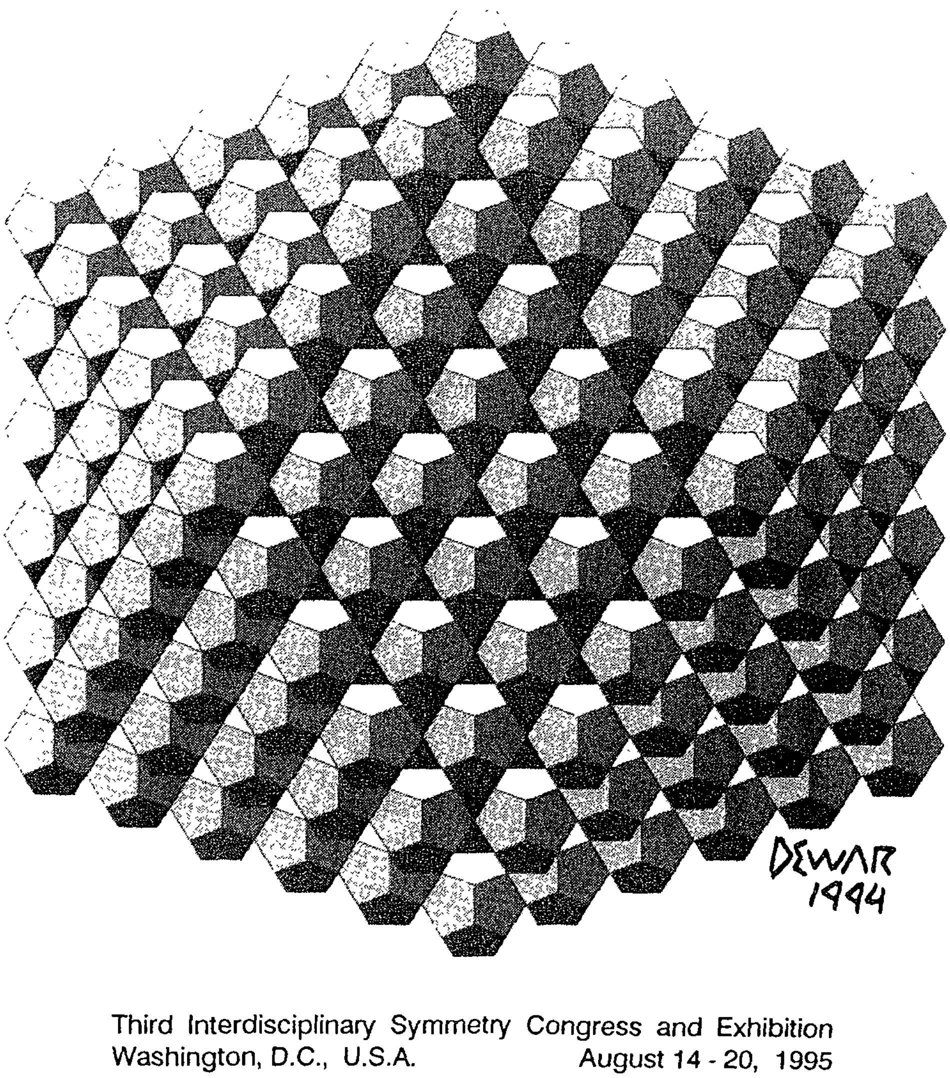

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SYMMETRY AND SELF-ORGANIZATION IN PROTEIN

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When we look at the forms and structures of living matter, with their wonderful diversity, harmony and beauty, we unwillingly ask ourselves: what is the reason? Who is such extraordinary sculptor of living matter?

Although it is well known that the basis of both the structure and performance of biological systems is protein (*Albert et al.* 1989), it is still a question how protein plays its role. What features of protein give rise to symmetry of self-consistent behaviour of molecular ensembles? How do ordered three-dimensional forms appear (*Kolata* 1986, *Gilbert* 1991, *Richards* 1991, *Siman* 1992)?

As far as we know, up to now there have been no direct experiments on the model system "protein - water" which could enable one to observe visually, on micro- or macroscopic scales, the process of structural formation and self-organization of protein. In this regard our experiments, modeling the simple biological system "protein - water" *in vitro*, make it possible to follow the dynamics of symmetry generation in the process of self-organization of protein thus observing correlation between these two phenomena.

It has been found that on condensing a non-differentiated polymeric protein mass up to a particular critical level, the mass starts to break into fragments due to developing defects reminiscent of dislocation loops or cracks. In the process, separate indivisible structural "blocks" similar to cells are generated.

It is possible to hypothesize that at the critical level of condensation the protein molecules do not gain an ideal crystalline, or long-range-ordered structure. The molecules are most likely to be arranged in a structure with a lot of specific defects which are responsible for an increase in free energy of the system. On condensation when the molecules are brought close together, the number of such defects may considerably grow. It is believed in this case that the free energy of the mass under consideration increases with increasing structural density. When the density and free energy increase, the structural molecular vacancies are most probably aggregated into voids, dislocations or dislocation loops. As discussed by many authors (*Frenkel* 1949, *Geguzin* 1976, and others), the regions of defects form an effective source to disturb the equilibrium in such molecular systems. It is in these regions that the effects suddenly undergo a catastrophical transformation from one size scale to another, or from one structural level to another. Such a discontinuous change in the non-equilibrium state may produce a qualitative shift in the boundary near-edge region of the protein mass. This can stimulate a diffusive vibrational process with energy and mass transport, *i.e.* with formation of space-and-time dissipative structures, or generation of self-sustained wave vibrations. According to the theory (*Nicolis, Prigogine* 1993, *Krinsky et al.* 1984, *Vassiliev at al.* 1987, and others), these wave vibrations order the medium.

We believe in our case that it is the above-mentioned self-sustained wave vibrations that order the protein molecular structure, transforming randomly arranged liquid polymeric chains (primary protein structures) into symmetric three-dimensional, functioning molecules of protein. In the process, protein sequentially changes its primary conformation for the secondary, tertiary and quaternary conformations. It has been established that such behaviour of protein is independent of chemical features of its structure and regular for any solvable protein (haemoglobin, albumen, globulin, crystallin, *etc.*). In addition the sense of the defect is perpetually repeated independently of the kind of protein.

One is inclined to think that it is just the defects that transmit, or "translate" symmetry from the molecular level to the macroscopic scale, since the direction of their slip "is closely related to the molecular crystallographic lattice" (*Geguzin* 1976) of protein.

At first, the homogeneous phase rearranges to a discrete phase with different kinds of symmetry (radial, transverse or helical). The symmetry appearing in a protein substratum under condensation can be related only to molecular or supermolecular orientation in the protein molecular system. At the same time the mechanism of "symmetry transfer" via defects can be related to a system of spatial waves as argued by Prati (*Prati* 1994).

Our experiments have shown that in an open system in non-equilibrium conditions the self-organization process in protein exhibits a specific mechanism providing the equilibrium state. This mechanism is not associated with chemical non-equilibrium as commonly believed (*Nicolis, Prigogine* 1990, *Hess* 1980, *Krinsky et al.* 1984, and others). The non-equilibrium state is produced in the boundary structural regions (defects) with no input of energy from the outside for inducing the self-sustained wave vibrations. This is a nonlinear process of protein self-organization.

It is worthwhile to note that the peculiarities of the non-equilibrium mechanism control the character of the self-organization process, because the energy turns out to be confined inside one structural block and can not freely transfer as in the Belousov - Zhabotinski reaction. This governs a specific structural configuration of self-organized protein, which consists of morphologically indivisible units, or blocks similar to cells with one helix and one centre being at rest. Such a configuration may be associated with the peculiarities of the self-sustained wave vibrations in a system with geometrical boundaries. The energy is concentrated inside a small volume of a three-dimensional cylindrical block. For this reason the energy "life-time" is extended and the energy dissipation postponed so that the transition phase elongates, providing the possibility of life.

Thus analyzing the self-organization process in the biological system "protein - water" on dehydration, we have observed special non-linear processes in the non-stable transition phase. Our experiments have shown that the system spontaneously generates an algorithmically repeating complicated structure similar to a turbulent structure in various media, for instance, in the case of the Belousov - Zhabotinski chemical reactions, optical phenomena (*Prati* 1994), and the processes in living organisms. Therefore a helical symmetry develops depending on the peculiarities of the self-sustained wave vibrations in active media. As the helical symmetry inevitably develops in protein, it is thought that protein is an active medium in non-equilibrium conditions, because helical waves represent a fundamental property of active media.

The principal result of this work is as follows: for a protein in the system "protein - water" with no external energy sources appropriate for living systems, we have reliably established a high energetic potential in structural transformations under evaporation of water and condensation. The result has been reproduced in all the experiments. Note that the potential correlates with the protein mass.

Our experiments have shown that nature had brought into existence indeed an exceptionally witty mechanism to gain and concentrate energy seemingly "from nothing". The surprising point is that at the same time the mechanism is sufficient to reproduce biological structural forms. In the system the transmission of information on the form of symmetry therewith occurs. This appears to be possible at standard conditions, for instance, at an ordinary temperature sufficient to evaporate water. Self-organization of protein is closely connected with the developing symmetry, for both the self-organization and symmetry are controlled by physical and chemical properties of biological macropolymeric molecules of protein.

The above presentation is a result of observation of the systems *in vitro* and the related qualitative consideration and characterization. In this connection the most important problem is a quantitative characterization and analysis of the phenomenon revealed experimentally.

BAR SPACE STRUCTURES - RULES OF SHAPING

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Space structures are built of prefabricated elements. This feature causes that arrangement of component parts in the space of a structure can be described by means of simple forms of symmetry which may be distinguish in 2- and 3-dimensional spaces. These structures designed as constructions of roof covers or as a construction of high-rise buildings should fulfil requirements resulting from static. The basic static lows are the lows of nature, therefore it is possible to notice some similarities between the forms found in nature and the results of engineering conception (Otto, 1985).

Bars placed in space in a uniform way and joined together by means of articulated nodes create constructions called bar space structures. Component parts of these constructions are subjected to axial forces only, resulting in the structures being more lightweight than bending constructions (Kolendowicz,1976). The modern shape of construction systems of the bar space structures were developed mainly by M. Mengeringhausen, R. Le Ricolai, S. Du Chateau and Z.S. Makowski.

Space structures are constantly applicable to new and diversified useful purposes. They are often used as constructions of roof covers (Makowski,1993). Recently they are also proposed as structures of high-rise buildings (Rębielak, 1993, 1994).

If bars are located on a surface of single or double curvature then they can create a single-layer construction of roof cover of a span usually not greater than one hundred meters. When bars are joined in articulated nodes it is necessary to apply a triangular grid which is the most rigid form of bar grids. Such a grid, composed of bars of equal length, can be used only in flat or barrel constructions. A spherical structure has to be made of bars of different lengths. A triangular spherical grid of regular form should be made of bars of slight differentiation of their lengths, it should consist of the smallest possible number of bars of various lengths, and it should be composed of a minimum number of different triangular fields enclosed between these bars. This shape of spherical grid makes it easier to use prefabricated elements in such constructions (Rębielak, 1992). The triangular grid is the base of obtaining other forms of spherical bar grids. They are as usual determined on the basis of regular polyhedrons like the icosahedron or the dodecahedron (Fuliński, 1973).

Of all regular polyhedrons the icosahedron possesses the greatest number of the same faces in a form of equilateral triangles. One of the methods which makes possible to obtain regular triangular spherical grid is the method of secondary grid deformation. The concept of the method is to determine a triangular grid on the plane face of the polyhedron in a way which enables obtaining a spherical grid of minimum length differentiation of its segments after the grid projection from the sphere center. This method can be applied with the use of the properties of the central or orthogonal projection. In both the cases differentiation of spherical grid segment lengths is the smallest of all the possible to obtain for triangular spherical grids (Rębielak,1992).

The basic principles of geodesic dome shaping were given in the 50-s by R. B. Fuller. An example of a geodesic hexagonal bar grid is presented in Fig. 1a. A similarly regular pattern of the construction system can be distinguished in the skeleton form of a micro-structure called "radiolaria", the example form of which is shown in Fig. 1b (Tarnai, 1985).

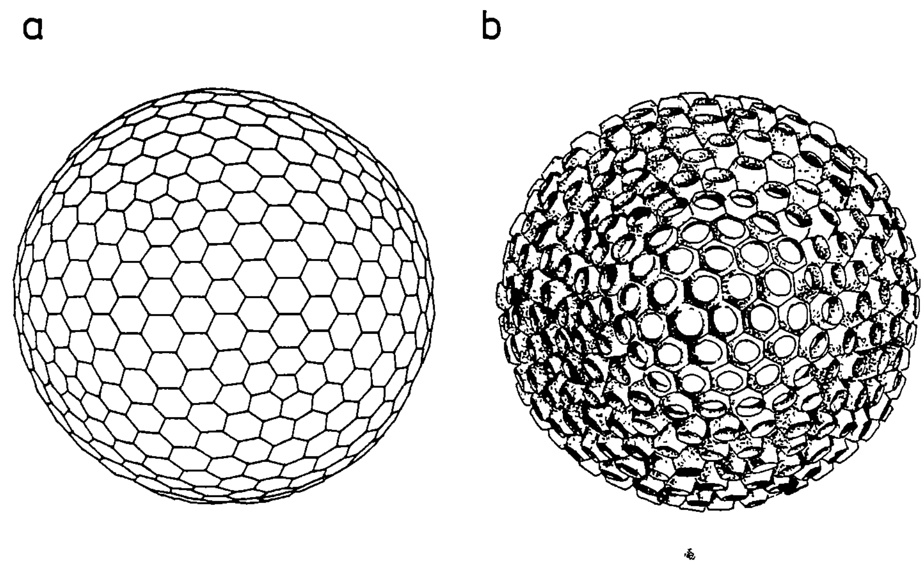

Figure 1

The pattern of this natural shape is very similar to patterns obtained by means of very regular subdivisions of spherical surface (Sanchez Alvarez, 1984).

The double-layer shape of bar structure can be created by connecting together two flat and parallel bar grids, by means of additional bars usually called as cross-braces. In this way it is possible to obtain a space structure of considerable rigidity which may be used as a construction of, for example, a roof cover of great span. In the pattern of bar arrangement in layers of these structures may by observed some similarities to the regularity noticeable in space grids of natural crystal structures. Bar space structures are multiple, statically indeterminate constructions which, among other things, means that forms of symmetry observed in patterns of force system sometimes can be completely different than forms of symmetry perceptible in bar arrangement in their spaces.

In the case of employing such structures in the construction of large span roofs it is advantageous if in areas of action of great stress forces relatively short bars are located (Rębielak, 1992, 1993), (Lalvani, Collins, 1991).

The formula of bar arrangement in multi-layer space structures can be adopted to designing of high-rise building constructions. Figure 2a shows the scheme of a structural system of a very tall building. The basic function of the construction system of a high-rise building is to transfer forces caused mainly by vertical, lateral and thermal loading to the foundation.

The most essential part of this construction (Fig. 2a) is the vertically positioned bar space structure situated on the perimeter of the building. The particular segments of circumferential

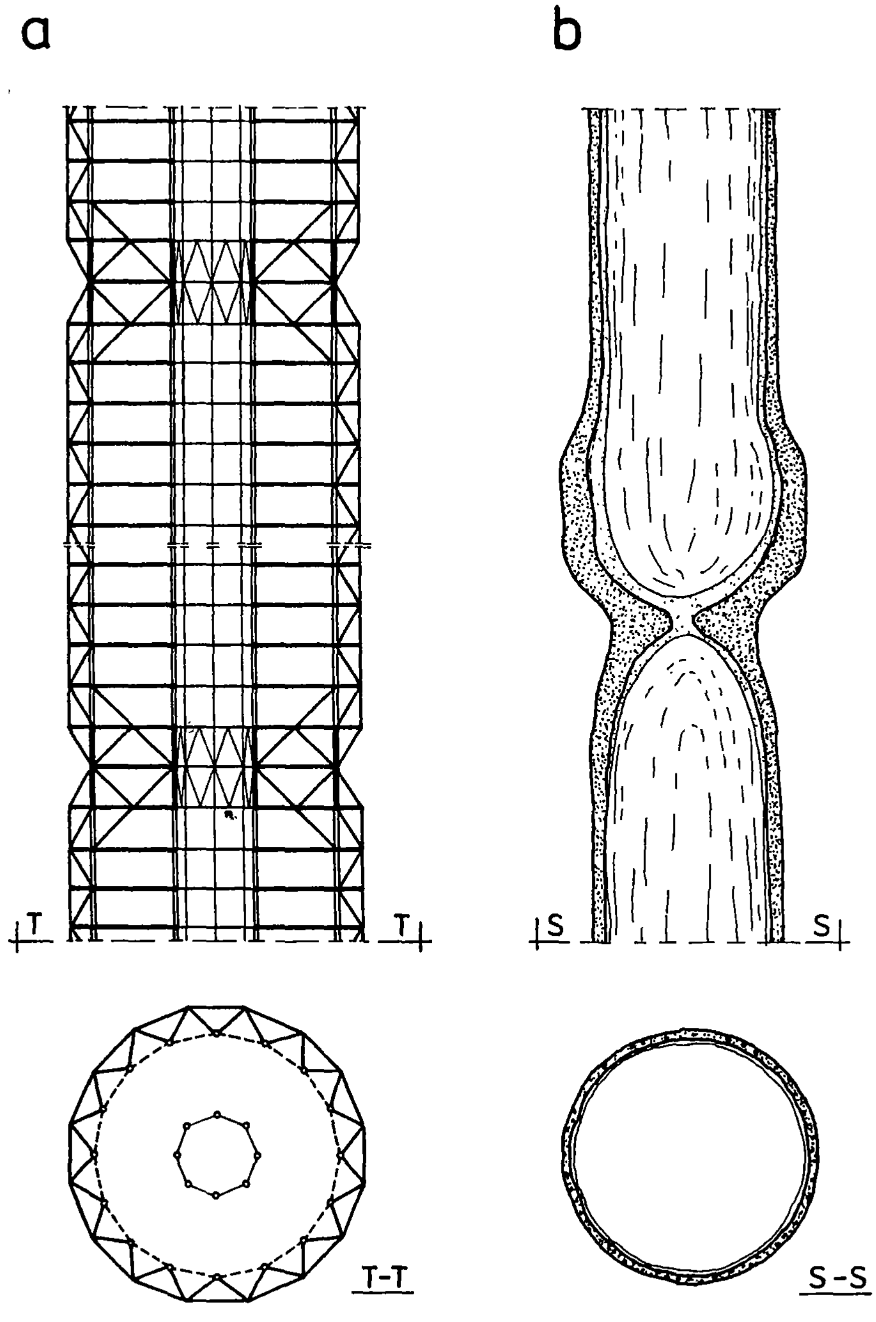

Figure 2.

bar space structure are connected by means of rigid horizontal discs shaped in the form of multi-layer bar space structures. It is proposed to use the spaces of these discs as spaces of the service storeys of high-rise buildings (Rębielak, 1993,1994).

In the scheme of this construction system some features common with biological forms may be seen. Figure 2b presents schemes of a vertical cross-section of a corn stalk.

Space structures can be applied also as constructions of roof covers and horizontal or vertical habitable megastructures. Features of this type of bar construction cause that its application as the structure of various buildings located in earthquake areas can be an economic engineering proposition in the near future.

Conditions of static as well as many other functional factors result in the finding of similar solutions of structures in nature and in engineering constructions. The regularity of these solutions entitles to stating that aspiration to symmetry is the structural necessity of nature formations as well as of results of engineering creativity.

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