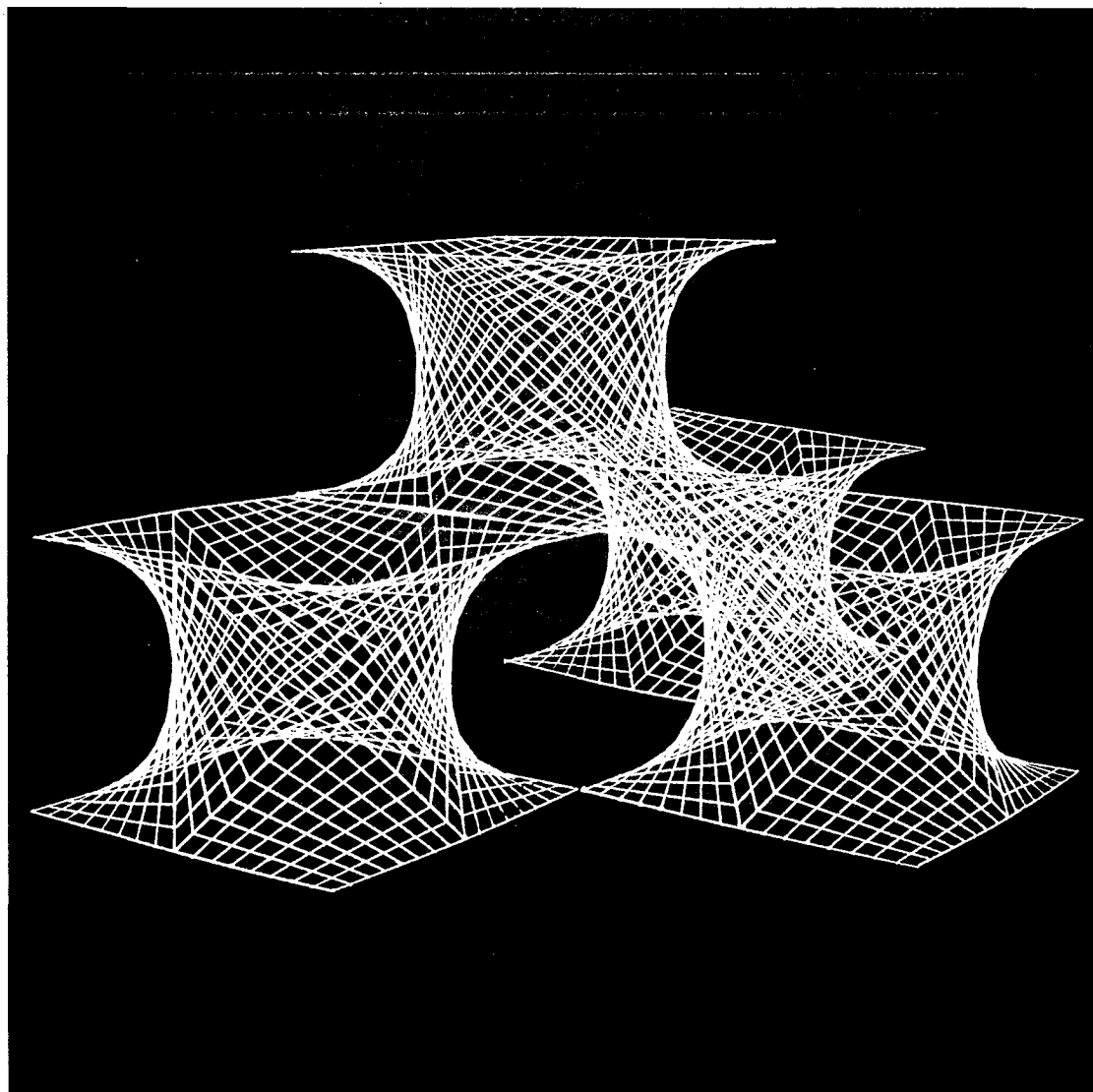


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SOME ASPECTS OF SPACE STRUCTURES SHAPING

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Fields of interest: the morphology of space structures together with their applications as roof constructions of large spans and as structures for high-rise buildings.

Publications: Regular spherical grids obtained with the method of deformation of a secondary network, in: *Symmetry of Structure*, eds. : G Darvas, D. Nagy, August 13-19, 1989, Budapest, Hungary, pp. 467-470., The application examples of the method of the secondary grid deformation, *Symmetry: Culture and Science*, 3 (1992), 3, 293-303, Symmetry in spherical grid shaping. Pattern examples of some geodesic domes, in: *Symmetry of Patterns*, Second Interdisciplinary Symmetry Symposium and Exhibition, Hiroshima, Japan, August 17-24, 1992, *Symmetry: Culture and Science*, 3 (1992), 1, 62-63., Elementy symetrii w kształtowaniu struktur przestrzennych, (Elements of symmetry in space structures shaping - in Polish), in: *Symetrie w przyrodzie, sztuce i naukach humanistycznych*, ed. A. Nobis, Wrocław: Leopoldinum, Studium Generale Universitatis Wratislaviensis, IV (1994), 119-133.; Bar space structures - Rules of shaping, in: *Symmetry: Natural and Artificial, Proceedings of the Third Interdisciplinary Symmetry Symposium and Exhibition*, Washington, USA, August 14-20, 1995, *Symmetry: Culture and Science*, 6 (1995), 3, 442-445.

The subject of the paper refers to the basic principles of the process of space structures shaping. In architecture and civil engineering the notion of *space structure* usually concerns the structures composed of straight bars which are appropriately connected together in articulated nodes.

At present the meaning of this notion is larger than it was in the past. It can be used to describe different kinds of engineering works and it may refer to many various types of structures being the nature creations. In both cases the tendency to apply the same simple rules in order to obtain the efficient, lightweight and strong structure is noticeable. The same basic principles, which are taken into consideration during the creation processes in both cases, have to give in the result the solutions of similar features. Some nature creations are seemingly of very complex shape, for instance the inner structure of bones, but after the comprehensive analysis it becomes clear that they are of very economic shape.

Many types of space structures, designed by an engineer, may consist of optional bars having various lengths and sizes of their cross sections. In that case it can be expected

that the obtained structure will be of irregular shape and in its pattern it will be almost impossible to find any regularity. These forms of structures are not considered as good solutions also because of architectonic reasons. The accidental usage of any type of bar will give in the result a space structure, which will have small practice usability or which can not be considered as a building structure. The aim of the engineer's activity is to apply rules of exact sciences in order to obtain desirable product by means of minimum usage of energy, material and the human manual labour. The economic reasons force designers to use simple forms of structures having legible regularities, sometimes called also as the symmetry.

The endeavor to apply structural solutions of visible symmetry may be noticed in many important buildings of great dimensions designed in the historic periods, at present and proposed for the future. The high-rise buildings and roof covers of great span are very spectacular members of that group of architectonic objects.

INITIAL REMARKS

The notion *space structure* refers today usually to the modern type of construction which is characterized by the high degree of the inner ordered state. Then it seems that space structures are sometimes very distant to the nature creations in patterns of which one could very often observe the considerable quantity of accidental connections between their component parts. There could be given many examples of very close similarity between shapes of engineering creativity and forms founded in the nature (Rębielak, 1995).

The arrangement of basic component parts in the inner space of some creations of the nature appears very often like a kind of chaotic connections but after the careful analyses it is taken as a clear and economic solution in this particular case. On the other hand some very regular engineering structures may be considered as having very irregular patterns which depends on many factors, and among others, on the point of their observation. In both cases the component parts are displaced in the planned way in the whole structure which causes the obtained construction system to have an economic form and its pattern can be of many good esthetic features.

TYPICAL FORMS OF SPACE STRUCTURES

The very often used definition of modern type of space structures is as follows: it is a construction composed of straight bars arranged in a uniform way in its space. These bars are connected together in theoretically articulated nodes. The meaning of this definition is presently much larger than it was in the past.

Shell structures belong to the surface space structures. They are usually made of reinforce concrete that is why they are expensive and they were mainly designed and built in the 50s and 60s of the 20th century. Because of economic reasons structures having mainly the tensile members are nowadays very often preferred in the practice.

Space structures are initially applied in civil engineering and in architecture in the second half of the 20th century. They are lightweight and at the same time they are suitable great rigidity, they are flexible in the process of their shaping and they could obtain interesting architectonic views (Makowski, 1992). The spectacular achievements in the development of space structures were done by M. Mengerhausen, M. Nowicki, R. Le Ricolai, R.B. Fuller, Z.S. Makowski, F. Otto, S. Du Chateau, W. Zalewski and M. Kawaguchi.

EXAMPLES OF STRUCTURAL SHAPES

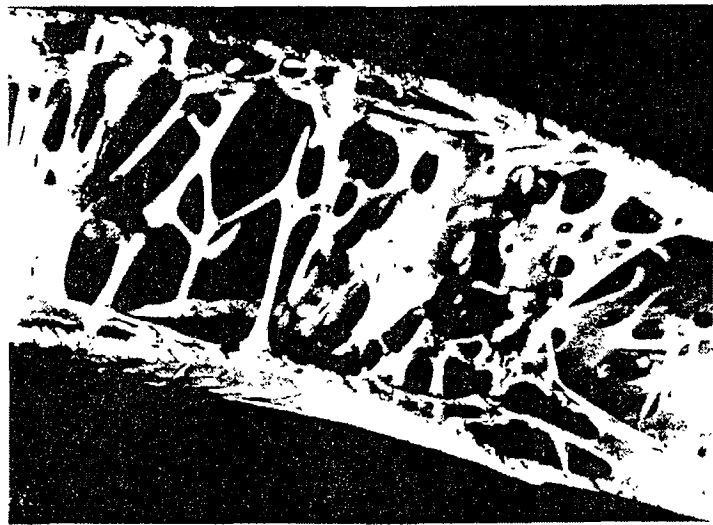


Figure 1

The short review of structural forms may be started from e.g., the nature creation in shape of the inner construction of bones. The main part of the human skull has the shell form which it is made possible to use the minimum amount of material in order to build very efficient type of construction which is able to take sometimes great loading applied from various directions. By the further investigation one could notice that in the cross section this structure has more complex and sophisticated shape. It consists of two surfaces of shell constructions and these two external shells are connected by means of seemingly chaotic system of little pieces of the osseous tissue. Some similar regularities can be particularly good observed in the example of the cross section of the humerus of the eagle (Otto, 1985), see Figure 1.

This sophisticated shape of natural support structure has to be lightweight and it can be able to take sometimes really great load. The structural form is the result of many experiences made in a very long way of evolution of the species. The human works made by engineers can obtain patterns similar to the presented above. Figure 2 presents results of the computer aided topological optimization of a simple beam-truss (Reichhart, 1997). They can be considered as a certain kind of the outcomes of the conceptual design of structures. Space structures obtained in this way are efficient construction solutions and they have interesting forms of individual esthetic features.

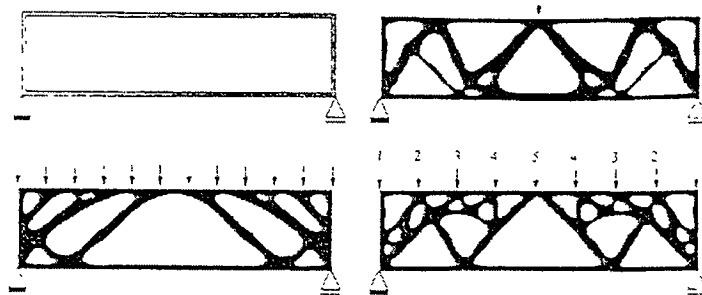


Figure 2

Very effective forms of structures, applied in architecture and in civil engineering, were obtained by means of special procedures of the model testing of chosen materials having the initial simple shapes. For example the forming process which uses the moistened threads with "limited excess length" may be applied in designing of many types of support structures. In this case one should notice the compromise between the rules of the so-called direction path system and the minimal path system (Kołodziejczyk, 1997). Certain types of structural systems obtained in this way have patterns very similar to patterns of systems of tree branches.

SOME PROPOSALS OF FORMS OF SPACE STRUCTURES

This chapter presents examples of systems of space structures. These examples are representative for many groups of structural systems proposed by the author for large span roofs and for high-rise buildings (Rebielak: 1992, 1993, 1996, 1997, 1998).

Various types of space structures are used as construction systems in designing of many forms of large span roofs. The economic clear span of a flat shape of a space structure is estimated as about $20h$, where h means their construction depth defined as the distance between external layers of bars. The interdependence causes that structure designed as a construction of very large span cover has to be made of bars of considerable great lengths. The load carrying capacity of the whole structure is in great part determined by the load carrying capacity of a few members subjected to acting the greatest compress forces. Their load capacity depends, in an inversely proportional way, on the square of their reduced buckling lengths. Therefore in areas of acting of these forces should be applied the shortest bars of a space structure.

Figure 3 shows the bar arrangement in the space of one of the structures designed specially for large span roofs (Rebielak: 1996, 1997). This kind of structure is called B3{T – T}A. It was shaped by means of reduced parts of “big” tetrahedral modules separated by means of additional octahedral bar sets.

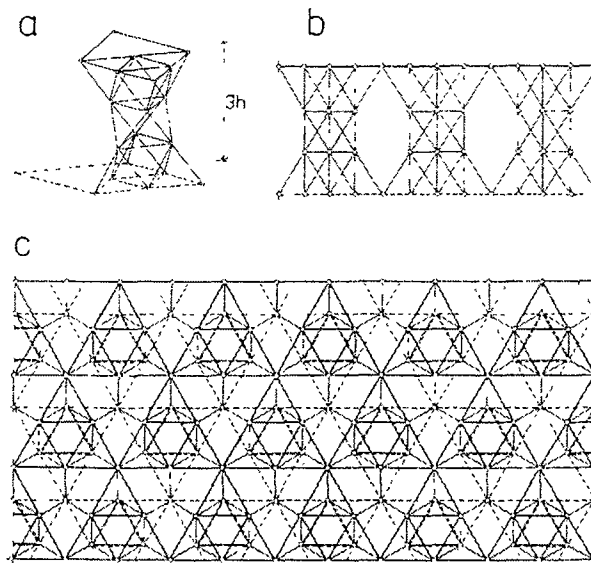


Figure 3

This space structure has considerably great construction depth and it is composed of relatively short bars of the same length. It is of somewhat complex form and that is why one could notice some similarities between its sample and the pattern of the nature creation shown in Figure 1. Because of great number of bars and nodes falling on the unit of the covered surface it can be expected that this form of space structure will have only the potential possibility to use in the real design of large span roofs.

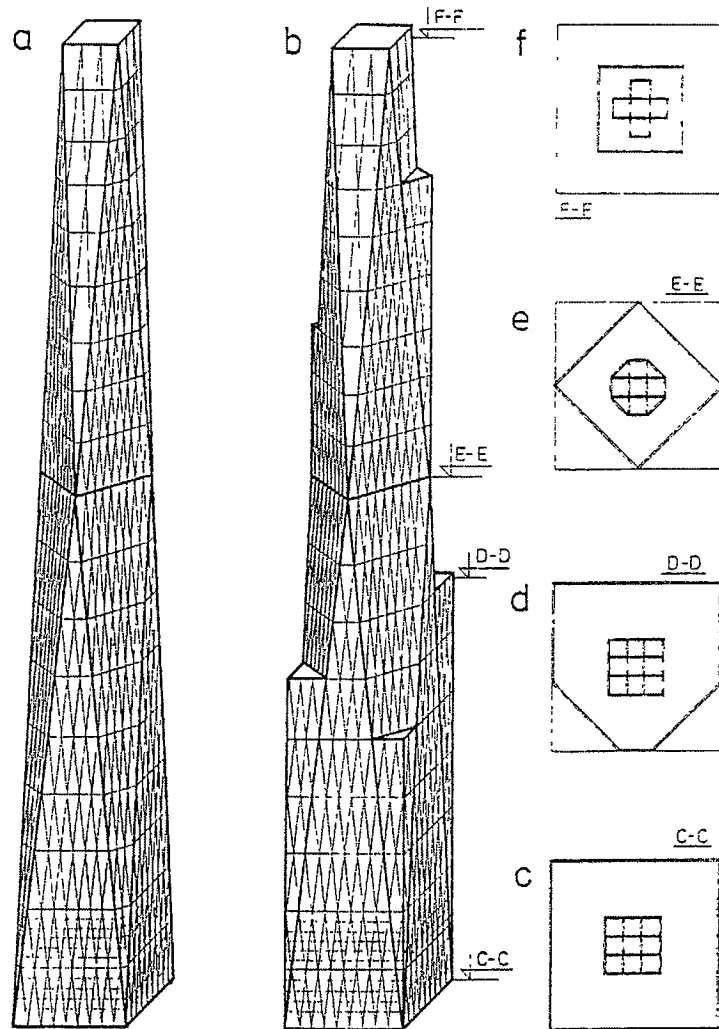


Figure 4

The basic rules of space structures shaping are also used in designing of structural system for high-rise buildings. The highest buildings are presently of the height equals about 450 meters. They are usually built in steel or reinforced concrete structural systems called as follows: exterior frame tube, tube in tube or bundled tube. The construction system should ensure a suitable stiffness of the tall building under acting of forces caused by many types of loading. Among a few systems there should be chosen that one which does not require considerable enlarging of dimensions of component parts above those which are necessary to carry the vertical load.

Figure 4 presents schemes of one of the structural systems proposed for designing of high-rise buildings (Rębielak, 1998). The structural system is proposed to call framed polyhedron. The basic component parts of such a building have forms of elongated halves of cubooctahedrons which are vertically located each on other, see Figure 4a.

The upper component part is suitably smaller than the lower one. The main support system consists of skew columns and horizontal beams creating the triangular grid onto each face of the chosen forms of big polyhedrons. The degree of subdivision of appropriate faces may be different.

A more complex form of a tall building is presented in Figure 4b. It was formed by means of arrangement of additional parts, in form of suitable tetrahedrons, in chosen corners of each component part. It can be expected that this shape of structural system could be a very efficient solution for designing of support structures for the highest buildings. Owing application of the proposed system these buildings could obtain individual and interesting architectonic forms.

CLOSING REMARKS

Certain accidental connections between component parts inside spaces of some nature creations can be considered as a kind of disorder but by the further investigation they become as intended way of their economic building. In the engineering design accidental joints between component parts are not accepted. It is the basic formula which requires the order in every planned economic activity of human beings.

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