Structural Systems Generated for Various Architectonic Purposes

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Premise

During process of the design of the structural system of a building there have to be taken into account numerous and complex aspects. In all the cases the safety and the reliability of the system constructed by the possible small energy consumption in connection with the reasonable financial expenses are the main, principal requirements. The contemporary computer techniques together with an appropriate software make the design processes very fast and efficient. All these sophisticated tools are based on elementary rules of mathematics and theory of structures. Application of these rules are visible in shapes of the nature's creatures, patterns of which are always valuable inspirations for architects and engineers.

The paper presents some selected examples of the structural systems invented earlier or recently by the author. These systems are aimed to be the main bearing structures for various types of roof covers and for tall buildings.

1. Structural systems for roof covers

One of the most structurally efficient systems of roof covers are the geodesic domes, see Fig. 1a, initially invented by Walter Bauersfeld, then developed and popularized by Richard Buckminster Fuller [1]. Some patterns of them have their counterparts in forms of the sea creatures called *radiolaria*, see Fig. 1b.

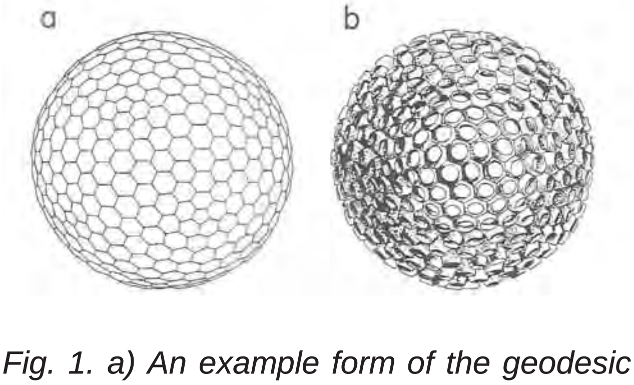

Fig. 1. a) An example form of the geodesic hexagonal grid with several pentagonal meshes, b) scheme of skeleton of one of the radiolarian species

Geodesic domes are mostly design and constructed as a specific types of the spatial trusses, due to which - and among numerous other reasons - they are very effective structural systems for these types of roofs. Covers of large spans have to be built by application of the double- or multi-layer spatial systems.

1.1 Group of the VA(TH) tension-strut systems

Space frames built of struts have been considered in the middle of XX century as the very modern and economic solution for construction of large span roofs [2]. Rapid changes of economic conditions in the building industry have caused a significant evolution in ways of the design of structural system towards application in them the possible big number of the tension members [3, 4]. The hanging roof systems and the inflated membranes are the most lightweight structural solutions but because of architectonic reasons they not always can be applied in the roof structures. Tension-strut system are nowadays consider as the most convenient technical solutions for numerous forms and types of the roof covers [5]. A specific group of the VA(TH) tension-strut systems was invented by the author, see Fig. 2 and Fig. 3 [6].

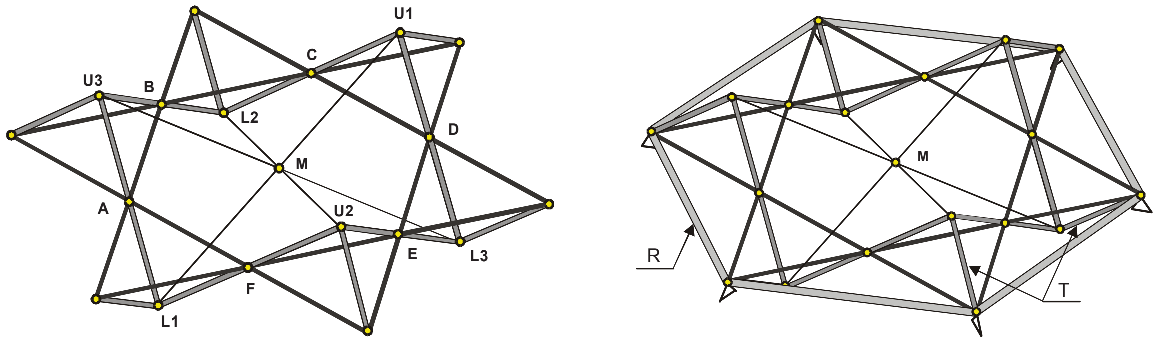

Fig. 2. Schemes of a simple structural configuration of components in the inner space of the VA(TH)No2 tension-strut structure

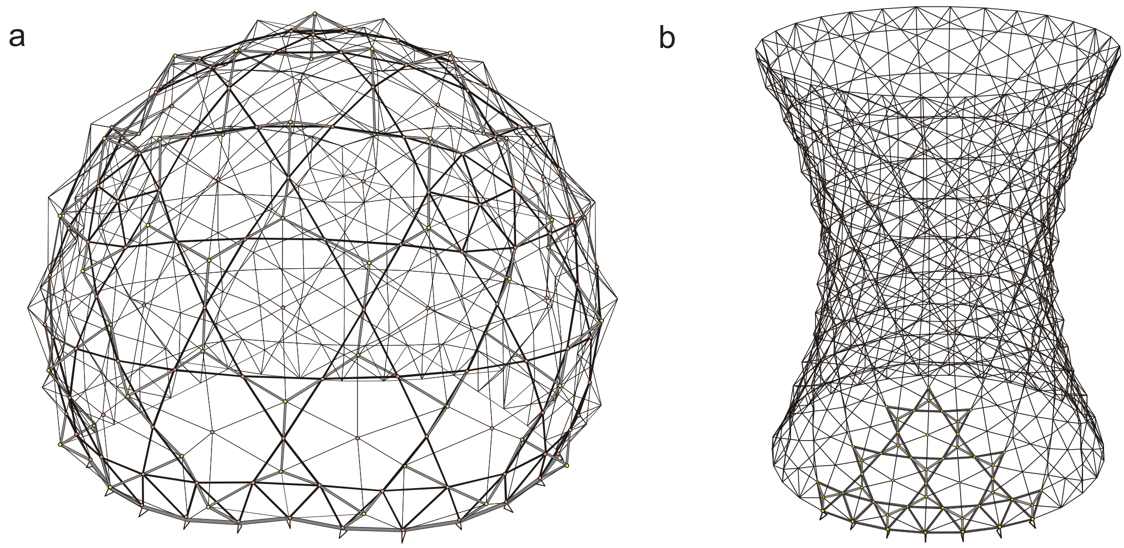

Fig. 3. a) The geodesic form of the VA(TH)No2 structure created over the fifteen faces of the icosahedron b) hyperbolical form of the VA(TH)No2 structure

The point of the structural concept of this group of the support systems is that the single layer grid of the compression bars is supplemented by means of oppositely directed tetrahedron bar modules, arranged respectively onto inverse sides of the grid. The top vertices of these modules are suitably connected by means of tension members used for the pre-tensioning of the system and the whole structure is fastened in the perimeter ring. The unusual feature of these types of structural systems is that the single layer grid, supplemented by bars and tension members, creates a three-layer space structure. In this manner is built an unique type of spatial system, having nodes located at three levels, which obtains characteristics of the double-layer tension-strut structure. The VA(TH) group of the tension-strut systems can be applied in designing of various types and forms of spatial structures. For instance, they can be the main support structures of flat covers, roofs designed as barrel vaults or geodesic domes, see Fig. 3a, or roof structures having the forms of a paraboloid hyperboloid. This group of structural systems can take shape of hiperboloid of one sheet, see Fig. 3b, and moreover these systems can built each type of form of the roof surface and they can be spaced over optional shape of the basis projection of the cover.

The VA(TH)No2 tension-strut structure was proposed by the author to be a support structure of the central building of the Geo Centre designed by himself for the Wrocław University of Technology, see Fig. 4.

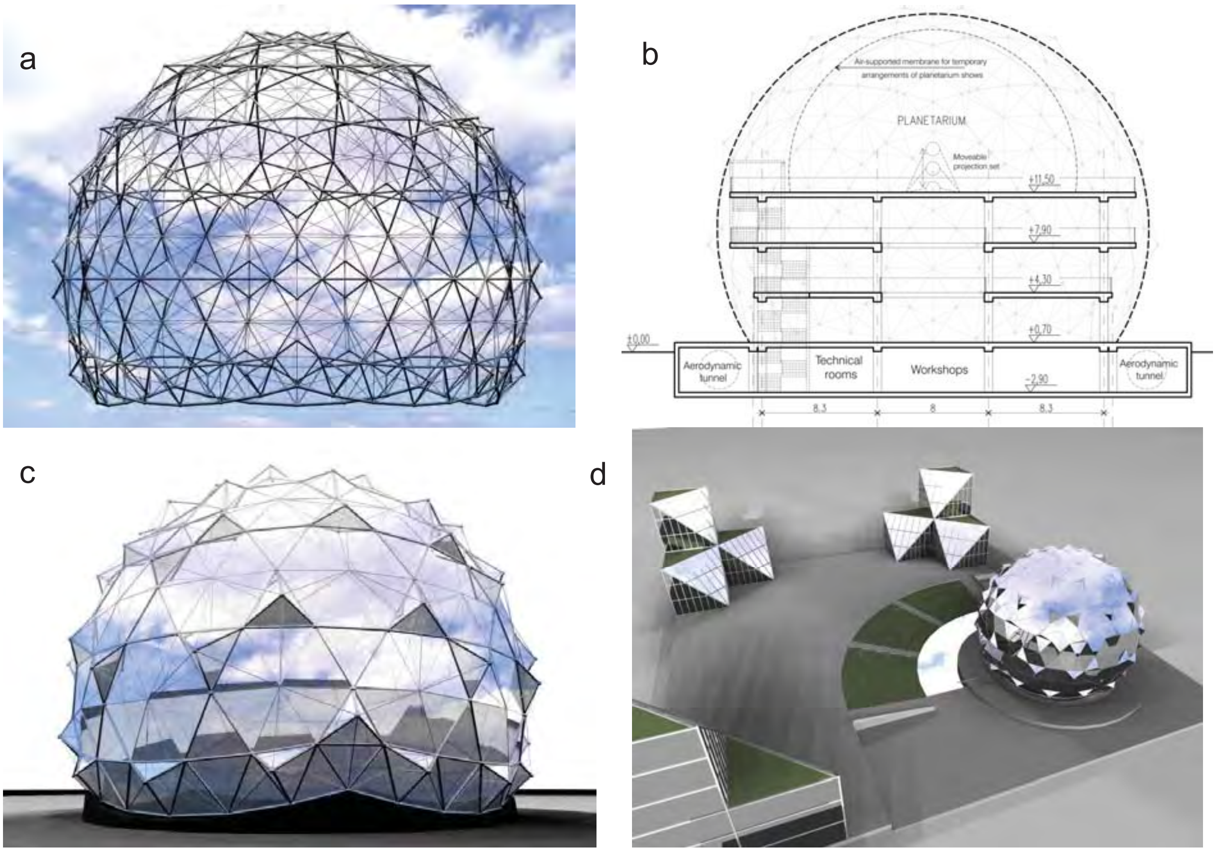

Fig. 4. a) View of the VA(TH)No2 tension-strut structure, b) vertical cross-section of the main pavilion of the Geo Centre, c) view of the structure with the glass panels cladding, d) bird view of the whole Geo Centre

The Geo Centre was proposed as the integration forum for the students, academic staff and visitors of the new part of the University. Diameter of the central geodesic structure equals only about 32 meters because its geometrical dimensions are limited by the urban regulations assumed for this part of the Wrocław city. The tension-strut structure geodesic dome was aimed to be a subject for the long term testing of behave of such a system under numerous types of loads and for testing of various types of cladding systems. In the top area of the dome is located a multi-purpose hall, which can be sometimes arranged as the Planetarium, below are placed research laboratories and in the basement were designed technical workshops together with the wind tunnel.

1.2 Special forms of the lenticular girders

Basic rules of theory of structures, as it was previously mentioned, can be very helpful as an inspiration for the processes of shaping of very effective structural systems. An example of such applications can be the trajectories of the main stresses in the free-ends beam, see Fig 5a, which patterns were inspiration for defining a new type of the lenticular girder, see Fig. 5b [7, 8].

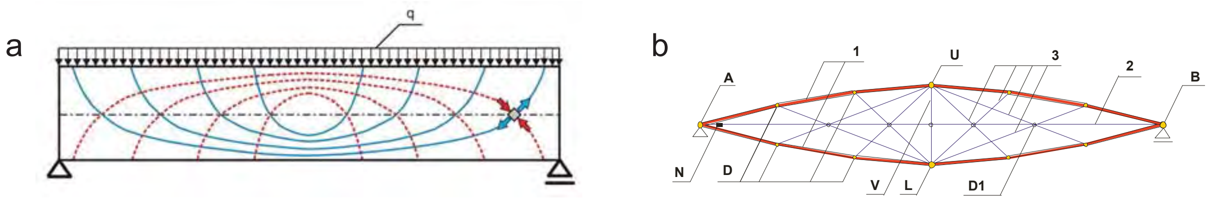

Fig. 5. a) Patterns of trajectories of the main stresses in a simple beam, b) scheme of the basic form of new type of the lenticular girder

The point of this structural system is to use the possible big number of tension members and the possible small number of compression members in a lightweight form of a girder, which can be able to transmit load forces applied at any direction to its structural nodes. Because it consists of tension and compression members the system requires a suitable pre-stressing. The planar structural configuration presented Fig. 5b has some spatial counterparts, exemplary forms of which are presented in Fig. 6. These spatial shapes of the lenticular girder can be applied for designing of numerous and various forms of the roof structures, see Fig. 7.

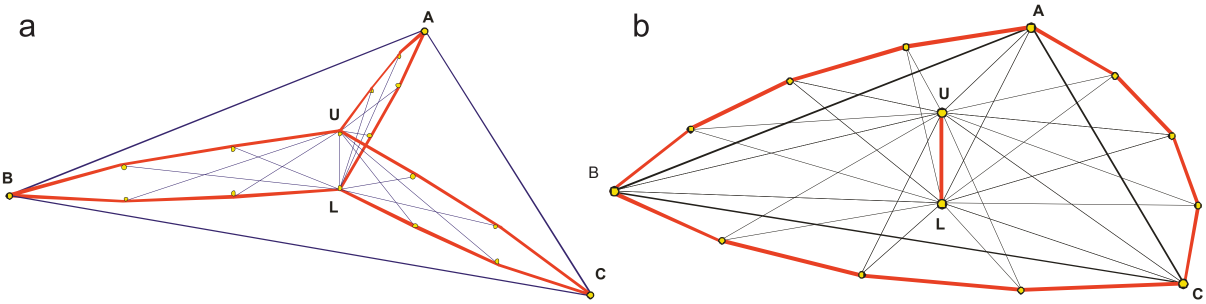

Fig. 6. a) Spatial form of new type of lenticular girder called system MT, b) another form of this girder called system D

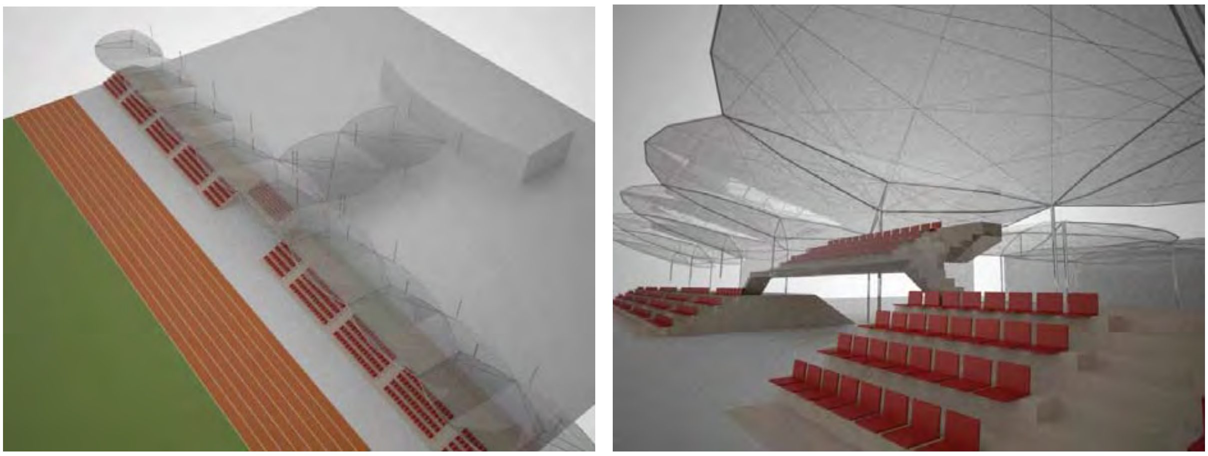

Fig. 7. General views of the stands cover designed for a small stadium in Złotów

The spatial of system MT of the newly proposed type of lenticular girder has been applied in the conceptual design of the lightweight and semitransparent roof cover spaced over stands of a sport stadium in Złotów, in north of Poland.

2. Structural systems proposed for tall buildings

The task of design and construction of the tall buildings is always a challenge to architects and engineers. The complexity and difficultness of this problem increases significantly when the tall building has to be located on subsoil of small load capacity or in the seismic areas. The horizontal load is the dominant type of loads obligatory taken into account during design of the safe structural system of a high-rise building, which at the same time has to have two contradictory features. It has be very stiff but on the other hand it should be to some degree flexible [9]. The below presented examples of such systems have been invented by the author by inspirations of shapes of the biologic structures as well as the inspiration of the trajectories of the main stresses in the free-ends beam, see Fig. 5a, and form of the Michell beam [10].

2.1 Systems of circumferential space structures

Inspiration for working out of this group of systems were conclusions coming from comprehensive analyses of the thermal strains of structures of the tall objects and analysis of the vertical cross section of a corn stalk.

Structures of the very tall objects are subjected not only to the vertical and horizontal loads. By increasing of the height the impact of the thermal load may also play a significant role. Differences of temperature between vertical columns located inside space of the building and columns arranged along perimeter of the tall building can be sometimes quite big, what causes their various lengths. In the structural systems called *tube* or *tube in tube* the problem is relatively easy solved by suitable connection of the floor girders, above the 20th storey, to the perimeter columns. In the last decades the double-layer space frames are proposed to be the main parts of the bearing systems of the high-rise buildings, see Fig. 8 [11].

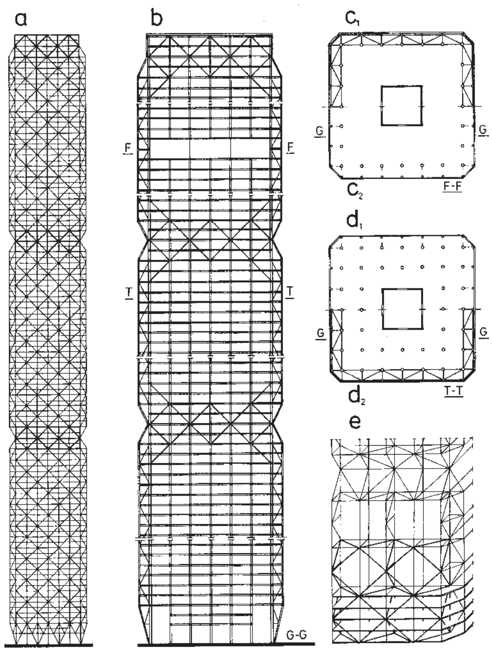

Fig. 8. General schemes of a structural system of a tall building shaped as a special form of the circumferential bearing space frame

This structural system is created by means of three segments vertically positioned each on other. A single segment contains 36 typical storeys, what implies that the whole building should have 108 storeys but in fact the real number is slightly smaller. Double-layer space frame vertically arranged along perimeter is the main bearing system of this building. The two adjacent segments are connected together by means of horizontal disks designed in form of the multi-layer space frame. External layers of the vertically positioned circumferential structures are devoid of members on levels of central layers of these disks. Due to this structural configuration strains of a single segment should have a significantly reduced impact on level of strains acting in members of the adjacent vertical segments.

2.2 Combined structural system of the tall building

The proposed structural systems of the combined foundation and the combined structural system of the tall building make possible to design and to construct a very stable and relatively inexpensively foundation structure, which can obtain an extremely large horizontal surface and can be placed not deeply beneath the terrain level. It can be a very solid support structure for the tall building placed on very weak subsoil and at the same time located in seismic area [12]. The author has invented these systems by inspiration of shapes of creatures existing in the nature, like for instance the very effective root system of a tree, see Fig. 9a, and again the patterns of stress trajectories in the free-ends beam. The combined structural system of the tall building, scheme of vertical cross-section of which is shown in Fig. 9b, can be characterized at the same time by the previously mentioned two contradictory features. It is very stiff but on the other hand it can be to some degree flexible. This system can also be applied for the design of the mega-structures, see Fig. 10a.

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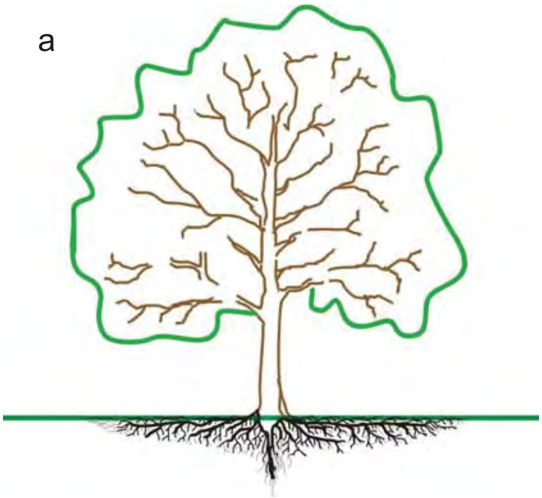

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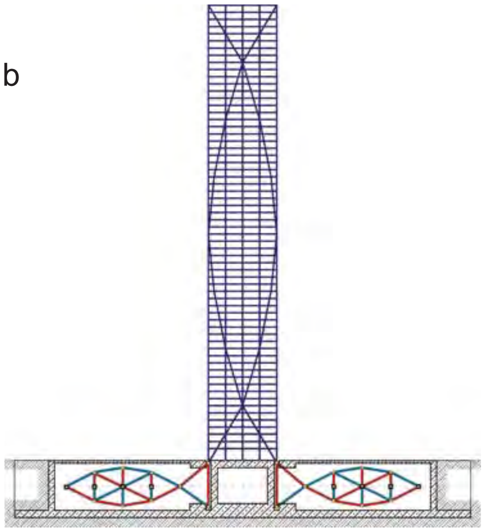

Fig. 9. a) Simplified scheme of the root system and structure of a tree, b) scheme of the main vertical cross-section of the combined structural system of a tall building

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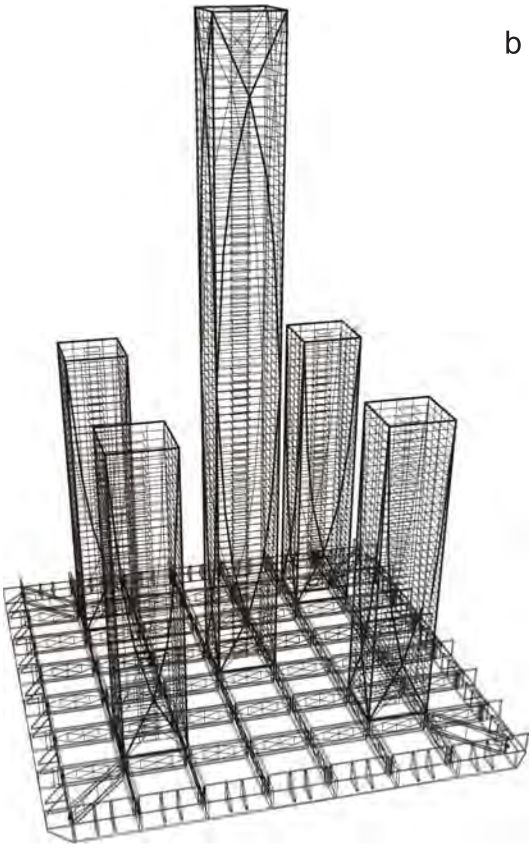

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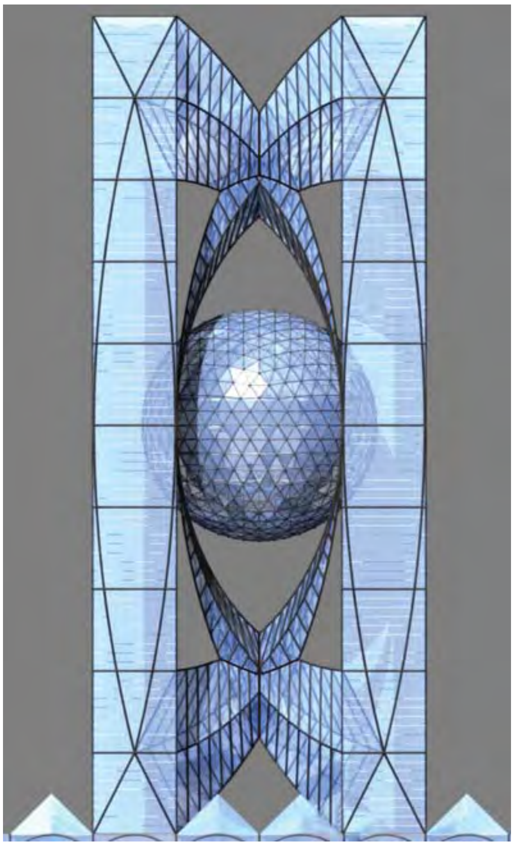

Fig. 10. a) Example of form of a mega-structure based on system of the combined foundation, b) typical elevation of the complex GeoDome Sky Towers

The surface of the combined foundation is theoretically unlimited. The combined structural system was applied by the author in the conceptual project of the building complex called the GeoDome Sky Towers located in the south part of the city of Wrocław, in the south-west region of Poland, see Fig. 10b. It is composed of four towers, each of them contains 80 storeys of the typical height equals 4,50 meter. The horizontal base of this complex is shaped in form of the combined foundation, which is of the height equal to 18,00 meters and it is placed directly on the subsoil level. The total height of this complex equals slightly more than 380 meters. The system of combined foundation can be applied not only for the new buildings but also for the existing objects and it can be used for straighten the previously inclined houses. One can to state that the combined structural system proposed for the whole building has a big develop potential.

Closing remarks

Structural systems, shaped in an appropriate way, are very helpful in processes of generating of the interesting and individual architectonic forms of buildings designed by means of them. Stable, efficient and economic shapes of the building structures can be generated by suitable application - during crucial stages of their design - of basic rules of the theory of structures as well as the inspirations of structural forms existing in the nature.

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