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ANALYSIS GEOMETRY STRUCTURE OF FOUR BUILDINGS IN OLYMPIC BEIJING

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This paper analyzes the geometry of the structure forms of unusual architectural objects that were built for the Olympic Games in Beijing. The research of the geometric shapes and constructive-geometric methods used to generate the structure and form of the following four buildings: The National Stadium "Bird's Nest", The National Center for artistic performance (Grand Theatre) "Eggshell", The National Swimming Center "Water Cube" and The Chinese central television tower "Z crisscross".

1. INTRODUCTION

Geometric conceptualization has always been among the essential mental tools required for the invention, modeling, and visualization of spatial building structures. The inspiration for the National Stadium „**Bird's Nest**" was a combination of local Chinese art form - mesh surface cracked glazed vases from Beijing and bird's nest. (Fig.1). For the building of the National Grand Theatre **"Eggshell"** inspiration was big bird egg floating. (Fig.1b).
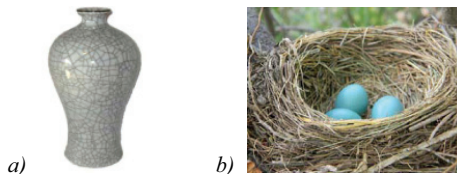

a)   *b)*
Fig. 1: The original inspiration for the National Stadium and National Theatre are Beijing cracle glazed pottery, bird's nest and bird's egg

a)   *b)*
Fig. 2: The original inspiration for the National Swimming Center-Water cube and Chinese Central TV Tower-Z crisscross are water soap bubbles and continuous loop

For the National Swimming Center **"Water Cube"** building, inspiration came from water bubbles (Fig.2a). Inspiration for the Chinese central television tower CCTV **"Z crisscross"** was a continuous loop (Fig. 2b).

2. GEOMETRICAL PRIMITIVES OF THE BUILDINGS
2.1 The National Stadium-*Bird's Nest* and The National Theatre-*Egg shell*

Basic geometrical primitives for obtaining structure of the National Stadium are circle torus, elliptic cone and elliptic cylinder (Fig.3a), and for the National Theatre is triaxial ellipsoid (Fig.3d). <u>Circle torus</u> is doubly curved surface with negative Gaussian curvature. This is undevelopmental surface (Fig.3a). <u>Elliptical cone</u> and <u>elliptical cylinder</u> is a single curved surface with zero Gaussian curvature. This is developmental surface (Fig.3b, 3c). <u>Triaxial ellipsoid</u> is doubly curved surface with positive Gaussian curvature. In his case radii are from same sides of the surface (shell). (Fig.3d)
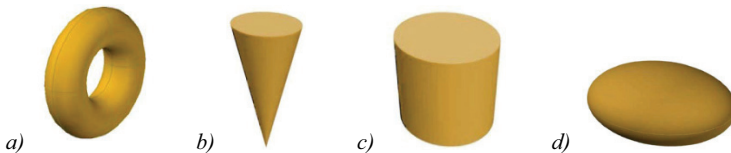

a)   *b)*   *c)*   *d)*

Fig. 3: Basic geometrical primitives for the National Stadium „Bird's Nest"and the Theatre „Egg shell": circle torus, elliptic cone, elliptic cylinder and triaxial ellipsoid

2.2 The National Swim Center-*Water Cube* and The CCTV-*Z crisscross*

Basic geometrical bodies for obtaining structure of the National Swimming Center are tetrakaidecahedron and irregular dodecahedron, and for obtaining the Chinese Central Television Tower is regular quadrilateral pyramid.
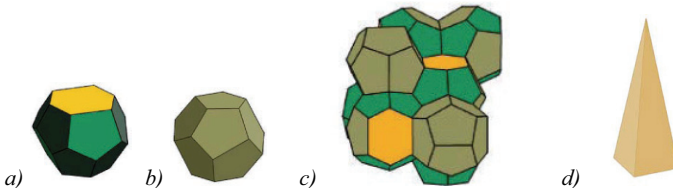

a)   *b)*   *c)*   *d)*

Fig. 4: Basic geometrical bodies for the Swimming Center „Water Cube" are tetrakai- decahedron and irregular pentagonal dodecahedron which combination give the Weaire-Phelan structure and for CCTV is quadrilateral pyramid

<u>Tetrakaidecahedron</u> is convex irregular polyhedron consisting of 12 pentagon sides and 2 equal hexagonal sides, complete polyhedron has 14 sides. (Fig.4a). <u>Dodecahedron</u> is a convex irregular polyhedron of 12 equal pentagon sides together, but irregular (Fig.4b). <u>Regular quadrilateral pyramid</u> is polyhedron which basis of a square and the other four sides are triangles.(Fig. 4).

3. GENESIS AND FINAL GEOMETRY OF THE OBJECTS
3.1. Geometry of The National Stadium "Bird's Nest"

The torus which part of the inner surface is used for the roof of the stadium have radiuses of the main curvature $R_1 = 2 \times R_2$. Parallels of the circular torus is vertical and one of its axis coincides with the main axis of the regular elliptical cone. The regular elliptical cone is set up with basic ellipse which lies in horizontal plane (ground plane). Apex of the elliptic cone is in the negative direction of the z-axis of ground plane. Major radius of the circle of the torus, which passes through the top of the elliptical cone, approximately equal to double height of the elliptical cone. Height of regular elliptical cone is derived from the requirement that all the lines of the elliptical cone are at angle.
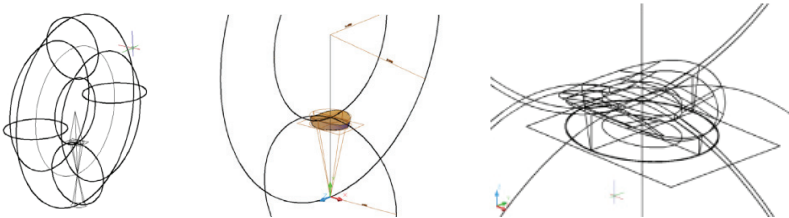

Fig.5 Relative position and size between the circular torus and the elliptical cone

Radius of the meridian of the torus is equal to the height of the elliptical cone (Fig. 5). Mutual intersected regular elliptic cone and a circular torus produced the space curve of the 8.order. The facade is a part of the truncated elliptical cone, and the roof is part of the inner surface of the rotating torus. The final shape of Stadium is obtained as mutual intersection of two concentric rotating torus (with different radii), a regular elliptical cone and two regular coaxial elliptic cylinders with different radius (Fig. 6).
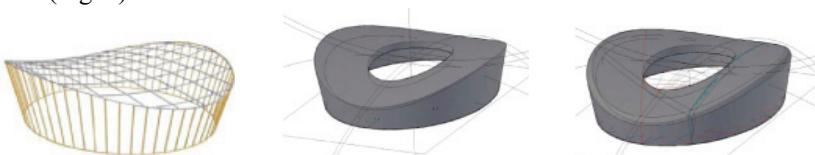

Fig.6 The external shape and final stages of producing forms Stadium"Bird's nest"

The primary structure is constructed as twenty - four places (points) at the same distance on the ellipse are chosen on the ground. From each of these points two lines drawn on the ground that are tangent to the running track, to the primary line (Fig. 7a). The primary structure was obtained by crossing of the vertical plane to the surface - previously designated skin. The basic geometry developed in 3D spatial framework. (Fig. 7b).
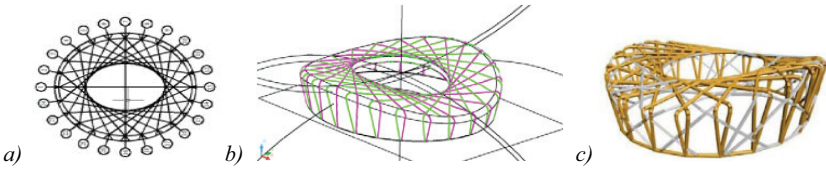
Fig.7 Design primary and secondary structure above the external shape of the surface Stadium-Bird's nest

The geometry of the secondary network connecting the roof to the plan, but then adjusted using the center point of the basic ellipse to create a inclined plane. This plane intersects outer surface and creates a secondary geometry using the current to define the center line of the element. Inclined planes intersect roof by parts of curves 4.order and fasade by the parts of the 2. order curves lines, which are connecting (Fig.7c).

3.2. Geometry of The National Grand Theatre "Egg Shell"

The object of the National Theatre "Egg Shell" is shaped as half of triaxial ellipsoid. The base object is an ellipse-curve intersection between the horizontal plane of the terrain and object-ellipsoid. The dome semi-ellipsoid titanium shell is cut in the middle, glass curtain that gradually spreads from the top of the dome to the ground. Two border lines on the central part of the object are intersecting spatial curve 4. order between the surface of the triaxial ellipsoid and the two regular elliptical cylinders whose generators are normal to the plane of the equator of the ellipsoid. Basic ellipse of two vertical cylinders vary in size. Their parameters are conditioned by the starting and end points of intersected parts of the curve for the construction of the intersected curves were used by only a quarter of two cylinders (Fig. 8a).
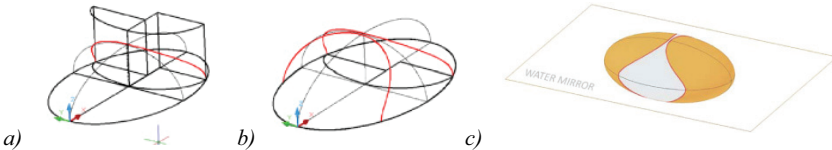

Fig. 8: Obtaining of spatial curve on the surface of the object "Egg Shell"

Intersecting curve on the ellipsoid are symmetrical regarding to the vertical y-z plane passing through the center of the ellipsoid (Fig. 8b). Ellipsoid dome of titanium and glass surrounded by an artificial lake which gives reflection so it looks like that it is not half of ellipsoid but whole (Fig 8c).

3.3. Geometry of The National Swimming Center *"Water Cube"*

The internal steel frame of The National Swimming Center „Water Cube" is based on the unique geometry of water-soap bubbles known as the Weaire-Phelan structure. Weaire-Phelan structure is a complex 3-dimensional structure, which is composed of two types of polyhedra-cells. A polyhedron is an irregular pentagonal dodecahedron and the other is irregular tetrakaidekaedar (Fig. 4c). Irregular tetrakaidekaedar has 12 pentagonal sides and 2 hexagonal sides. This polyhedron with irregular dodecahedron, which has 12 pages pentagonal. Building design that

employs polyhedra derived from so-called Voronoi cells. The design of the „Water Cube" is based on a 3D Voronoi diagram (Fig. 9).
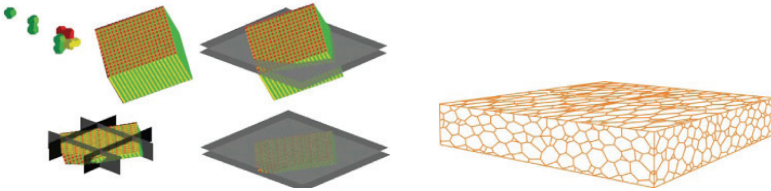

Fig. 9: Rectangular boxed sections Weaire–Phelan structure to get shape of The National Swimming Center "Water Cube"

There are two parts to the Water Cube's structural framework – internal and external. The external structure forms the actual roof, ceiling and walls and comprises a flat web of rectangular boxed sections. These sections are then clad with the inflatable material transparent "teflon" material.

3.4. Geometry of The Chinese Central Television Tower "Z crisscross"

Unlike traditional high-rise buildings, which were built in height, this building is "bent" in the "loop" prismatic forms. CCTV 3D model of the building can be obtained by cutting the regular quadrilateral pyramid, square in shape, with sides 6-degree slant on both axes (Fig. 10a). The CCTV building is formed by the vertical tessellation of a base unit including a diagrid and a frame system to create hybrid form. The façade the main support of critical loads, there are three different types of networks (layers), making such a huge continuous tube (Fig.10a,b,c). The interior structure of reinforced concrete, and the exterior envelope in the form of an irregular recessed diagrid.

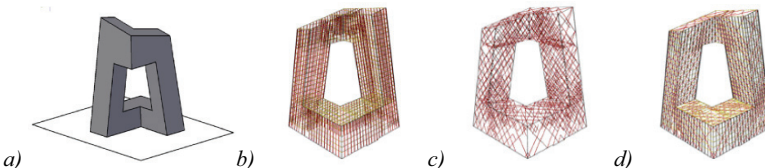a)　　　　　　　　b)　　　　　　　　c)　　　　　　　　d)

Fig. 10: 3D geometrical model of the CCTV Tower by cutting the quadrilateral pyramid and the final facade of three types of network regular grid of columns and edge beams + patterned diagonal bracing = braced tube system.

4. CONCLUSION

To analyze geometry of four complex architectural unconventional buildings we used digital technologies and methods of descriptive geometry. The National Stadium reaches its organic look by using pure geometric forms. It is composed of steel columns and beams, looks like a knotted rope that completely imitates a bird's nest. The National Theatre is simple geometry form as a large egg floating in water with symetrical complex space curve on shell. Loading space with two different irregular polyhedral are cut off with planes producing cuboid form of The National Swimming Center with random network geometry. The CCTV form and its varied

diagrid structure transmit affects of gradation, differentiation and latticing . Irregular network shows on the building facade force paths that pass through the building structure.

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Аннотация.

В статье анализируются геометрия конструктивных форм необычных архитектурных объектов, которые строились для Олимпийских Игр. Исследованы геометрические формы и конструктивно-геометрические методы, которые использовались для создания конструкции и формы следующих четырех сооружений: Национальный стадион "Гнездо Птицы" в Пекине, Национальный Центр для театральных выступлений "Яичная Скорлупа", Национальный плавательный центр "Куб Воды" и китайская башня центрального телевидения.