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GEOMETRY AS ASSEMBLY IN ARCHITECTURE. SEMI-REGULAR POLYHEDRA

Abstract: *When the principle of modular assembly of semi-regulated polyhedra is applied in architectural design, we obtain functional and structural autonomous architectural structures, based on a common matrix system. This system is subdivided into modules that allow independent changes or adjustments and offers great adaptability to the environment. The development of computer technology and 3D printing enables tessellation of more spectacular geometric modules. The studied surface is much easier to control both in terms of shape and structure. Therefore, research on the applications of modular assembly in the design of architectural geometry it is a great necessity for architectural studies. This paper aims to present several buildings that use the three-dimensional assembly of semi-regular polyhedra, explore the feasibility and significance of application of modular assembly in architectural geometry design and can be considered the beginning of a much more detailed ongoing research.*

Key words: *modular assembly, tessellations, semi-regular polyhedra, architectural design.*

1. INTRODUCTION

Nature is an infinite source of inspiration and offers countless solutions in solving various requirements of architectural design. Over time, many designers have been fascinated by how different geometric solids can be packed to fill space or generate various symmetrical assemblies in space. This challenge descend from the study of the structure of materials in chemistry, where the spontaneous organization of individual building blocks into ordered structures is ubiquitous in nature, for examples simple and complex crystals in atomic systems, liquid and plastic crystals in molecular materials, and superlattices of nanoparticles and colloids [1].

By the concept of modular assembly we mean a system for sizing the construction using a basic module, and by multiplying them we can create a variety of new geometric shapes. When we use standardized components to generate a much larger structure than the components used, we obtain an object or a modular building. The modular architecture, developing a lot in terms of time efficiency, through standard elements already designed, but also materials, through automation and modulation, repetitive dimensions, has shown that it can create stable, functional and versatile constructions.

In this paper I want to present some buildings that use semi-regular polyhedra as geometry. These polyhedral volumes allow modularity and repetitiveness, and this process can be extended to give rise to more complex shapes.

2. SEMI-REGULAR POLYHEDRONS

The semi-regular polyhedra are convex polyhedra, having different regular polyhedra faces (the same type of polygons, being equal) and equal polyhedral angles without being regular. The semi-regular polyhedra are also called the Archimedean polyhedra, they all have equal edges, can be inscribed in a sphere but cannot be circumscribed to a sphere of the same center. After Archimedes there are 13 semi-regular polyhedra. These can be obtained from regular pleats on which the necessary geometric operations are performed (edge division, truncation or cutting of the vertices). They are: truncated tetrahedron, cuboctahedron (rhombitetratetrahedron), truncated cube, truncated octahedron (truncated tetratetrahedron), rhombicuboctahedron (small rhombicuboctahedron), truncated cuboctahedron (great rhombicuboctahedron), snub cube (snub cuboctahedron), icosidodecahedron, truncated dodecahedron, truncated icosahedron, rhombicosidodecahedron (small rhombicosidodecahedron), truncated icosidodecahedron (great rhombicosidodecahedron), snub dodecahedron (snub icosidodecahedron).

The variety of semi-regular polyhedra provides an infinite source of new architectural forms both through their individual multiplication and the combinations of several. Polyhedra that can be joined together to fill the space exactly with no gaps, so that every face of each polyhedron belongs to another polyhedron, may be thought of as cells in a space-filling honeycomb [2]. There are 28 convex examples in Euclidean 3-space, also called the Archimedean honeycombs. All these volumes have a perfect symmetrical shape, which represents a very good source of inspiration for builders and architects.

2.1 The graphical/descriptive representation of the semi-regular polyhedrons. The Truncated Octahedron, the Truncated Tetrahedron and the Cuboctahedron

The truncation process can be applied to semi-regular polyhedra. The truncated octahedron, like I said before, is an Archimedean solid, the twelfth of the thirteen polyhedra. It has fourteen faces - eight regular hexagonal and six square, thirty-six edges, and twenty-four vertices. Its construction is realized by inscribing the faces in a cube. In order to multiply and obtain a tiling system with the help of the truncated octahedron, it will be considered a unit / module as shown in Figure 1a. The space is tiled with identically shaped tiles that fill the entire space, with no gaps or overlaps, Figure 2.

The truncated tetrahedron has 4 regular hexagonal faces, 4 equilateral triangle faces, 12 vertices and 18 edges (of two types) as shown in Figure 1b.

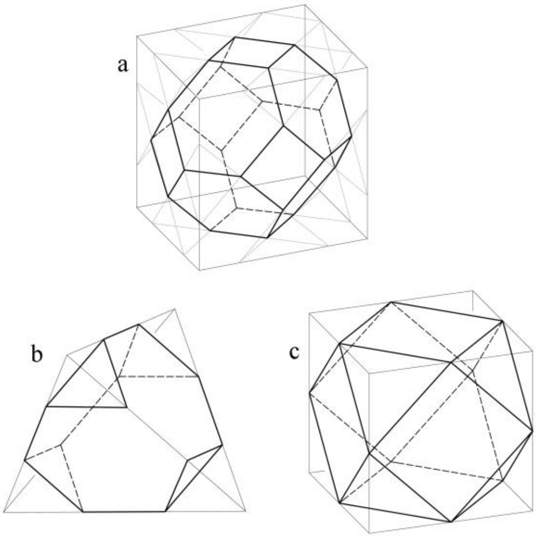

Figure 1 a. Truncated Octahedron, **b**. Truncated Tetrahedron, **c**. Cuboctahedron.

It can be constructed by truncating all 4 vertices of a regular tetrahedron at one third of the original edge length.

The cuboctahedron is a polyhedron with 8 triangular faces and 6 square faces. A cuboctahedron has 12 identical vertices, with 2 triangles and 2 squares meeting at each, and 24 identical edges, each separating a triangle from a square in Figure 1c. For any pair of vertices, there is a symmetry of the polyhedron that transforms one vertex to another. It is the only radially equilateral convex polyhedron. This polyhedron is obtained by successively cutting off each of the vertices of the octahedron or cube.

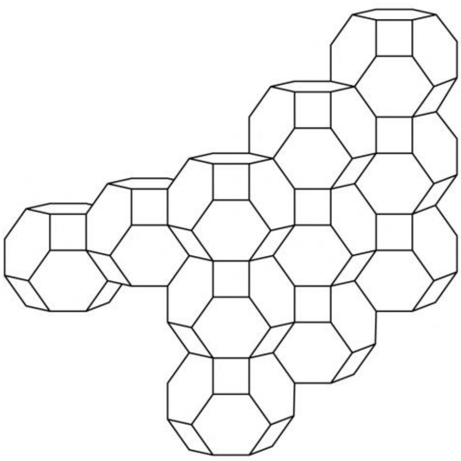

Figure 2 Assembling several Truncated Octahedron.

We can assemble a single semi-regular polyhedron to fill the perfect space, the example is the truncated octahedron in Figure 2.

Assembling these semi-regular polyhedra presented above we obtain one of the optimal variants to fill the perfect space and this is represented in Figure 3.

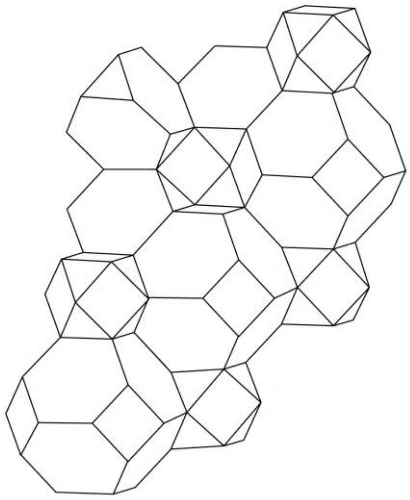

Figure 3 Assembling several Truncated Octahedron, Truncated Tetrahedron and Cuboctahedron.

3. ACHIEVEMENTS IN THE FIELD OF ARCHITECTURE

In order to obtain a greater diversity and dynamics in architectural design, universal laws and principles can be reproduced, such as the asymmetry resulting from the repetition and the combination of some of the volumes studied. As in nature, we usually find cellular repetition and multiplication to give the shape of each life.

3.1 Assembling a single type of semi-regulated polyhedron. The Truncated Octahedron

Same could be said, in geometry, a honeycomb is a space filling or close packing of polyhedral or higher-dimensional cells, so that there are no gaps [3].

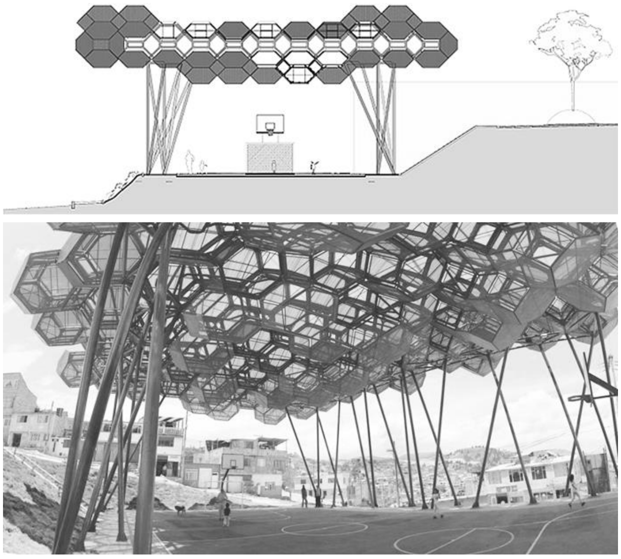

Figure 4 Hope Forest located in Bogotà, Colombia, 2011 [4].

A very good example of this is Hope Forest located in Bogotà, Colombia, Figure 4, designed by Giancarlo Mazzanti, the new center is a formation of interconnected linear shapes that create a canopy supported by columns, resembling a group of lush trees. The team suggests that the structure is a symbol of "nature, union and hope" for the area, and believes that the new center can be a catalyst for positive change [16]. The modular construction is a collection of green prefabricated of semi-regular polyhedrons of 12 surfaces, namely the truncated octahedron the truncated octahedron, that make up a larger lattice within the top canopy. Each one of them which are wrapped with a steel mesh that offers a light and porous mode of shading.

3.2 Assembling several types of semi-regular polyhedra

Architecture that adapts to the natural environment rarely has order and symmetry, has a dynamism adapted to the site and will develop as a complex, asymmetrical volume. This will allow the planimetry more freedom than when using symmetry. Each architectural volume will be able to develop freely, presenting different images depending on the facade we are looking at. The building is much better adapted to the place where it is located and will be able to more easily meet the requirement of the architectural program.

To exemplify this combination of semi-polyhedral volumes, we have chosen Museum Of Architecture built by architect Toyo Ito, on the island of Omishima, Japan, in 2011.

Three types of semi-regular polyhedron modules, which can be freely assembled and closely packed, were used to create this building: truncated octahedron, truncated tetrahedron, cuboctahedron. Each unit has two kinds of wall slant angles [14]. These geometric volumes are grouped due to the common features that allow a perfect assembly as can be seen in the Figure. 5.

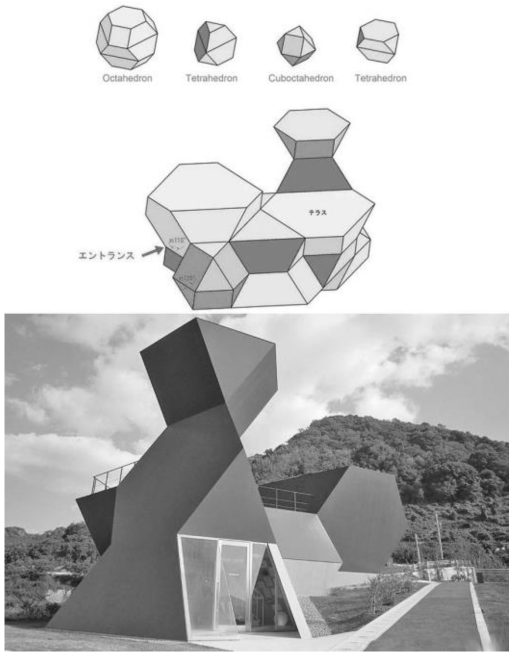

Figure 5 Museum Of Architecture, Omishima, Japan, 2011 [5].

Like crystals, quasi-crystals contain an ordered structure, but do not have the attribute of translational symmetry, they can be repeated in certain rules in different positions and directions. We can say that it is a three-dimensional honeycomb composed of polyhedral cells and having all the tips the same. This museum has a free, relaxed composition, determined by the functional needs and the configuration of the land.

Another method of generating an architecture in a more complex form is to use the truncated tetrahedron in a chaotic ensemble with free spaces between volumes. In this way we can obtain spaces both inside the tetrahedra and outside them, by joining several truncated tetrahedra, Figure 6.

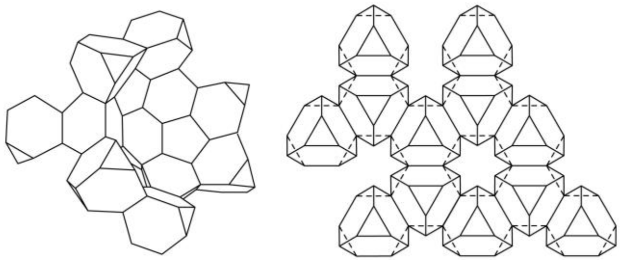

Figure 6 Assembling several truncated tetrahedron.

We can use this design on office or apartment buildings, which can be developed both horizontally and vertically, in multi-storey buildings. The Truncated Tetrahedron can be used to create a complex spatial surface or envelope resulting from the joint shown in Figure 6. We thus obtain a vibrant image in which the facades or roofing systems designed by the architect capture from any point of view.

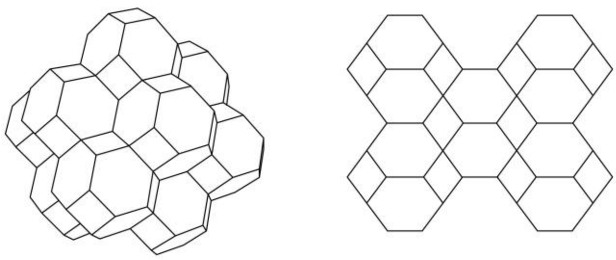

Figure 7 Assembling truncated Octahedron.

The Truncated Octahedron, Figure 7, and the Cuboctahedron, Figure 8, allow a much more orderly and symmetrical assembly, the structure of the building can be developed in height.

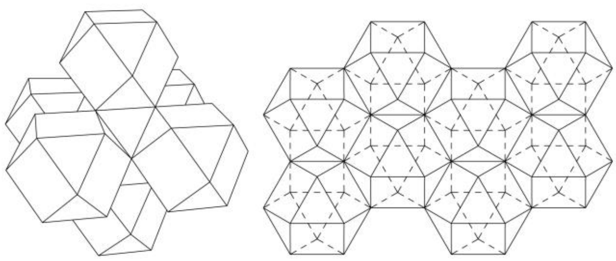

Figure 8 Assembling several Cuboctahedron.

Such an agglomeration of modular spaces uses proximity to relate the spaces to each other. There are cellular spaces, repetitive with the same use. The flat surfaces of the semi-regular polyhedra thus assembled are perfect for overlapping or joining.

4. RESEARCH DIRECTIONS

The goal is to generate polyhedral geometric bodies that can be used as modules in architectural design, as well as to make connections between various bodies through joints, which will determine a harmonious whole that works with both the required function and the environment. The model assumes the existence of a base volume that is repeated, that multiplies and articulates to generate continuity.

Contemporary design seeks to move away from the approach - the whole and then the detail - where geometry dominates the architectural form. Thus, in order to be able to build the new forms, it is necessary to decompose the whole into parts. This subdivision is integrated into the design process, being part of the concept. The design process approaches the detail and after the assembly, and the geometry of this assembly is generated by the articulation of the components, but this time they do not have to be identical.

A very useful example in this regard is Olympics National Aquatics Centre structure in Beijing. The shape of the building is inspired by the natural formation of soap bubbles. Arup designers and structural engineers realized that a structure based on this unique geometry would be very repetitive and buildable, while looking organic and random [6].

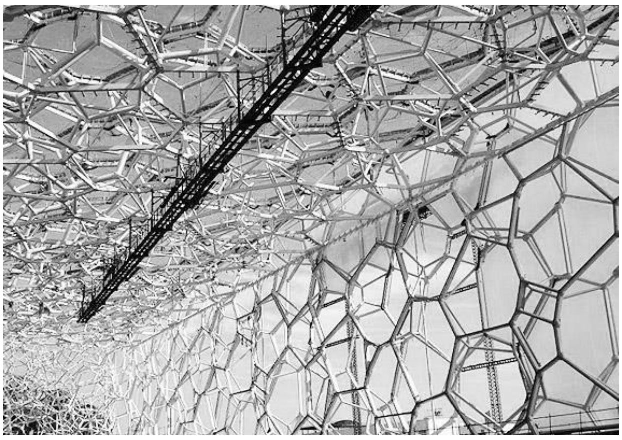

Figure 9 Olympics National Aquatics Centre structure, Beijing, China 2008 [6].

We are not talking about free surfaces, but articulated structures, where differentiation serves as a way of articulation. It is a gradual transformation of a module that, by articulating with the other modules, transforms to adapt to new characteristics of the assembly. The relationship between the modules reflects both a global logic and the local character. The different modules are characterized by variability, weaving and assembly that will generate a unitary whole.

5. CONCLUSIONS

I started this study with semi-regular polyhedra that generate complex shapes by assembling them and the possibilities they offer us. The result demonstrates the ease with which the image of a building can be enhanced by a multitude of structural and formal solutions, which can be easily adopted by architects and designers for further advancement and use. Through a spatial assembly of semi-regulated polyhedra we can obtain a structure with an efficient load distribution, and the damage of a single component will not lead to the collapse of the whole structure. Besides, this assembly of polyhedra has a strong adaptability to be connected into various irregular shapes.

Today, these assemblies are also the basis of digital graphics, they are used by 3D programs and contribute to the development of digital design.

Due to the compact and relatively homogeneous combinations depending on the requirement of the architectural design, the modular assembly has the remarkable advantage of generating the building envelope or even the structure of the building itself. In this way, the resulting assemblies provide variants that can be further explored to develop the production and construction of new complex shapes.

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