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REPRESENTATION OF LATTICE STRUCTURES USED IN CONSTRUCTIONS BY PARAMETRIZATION

Abstract: *In the first part of the paper the authors reviewed some methods of representing the covering surfaces used in field of construction and architecture and their evolution according to the technical possibilities available to specialists in various periods of time. With the development of interactive 3D programs, the tools of representation and implicitly of design have experienced a huge leap. These were made using parameterization, ie the development of programs based on algorithms that, by the variation of parameters, automatically allow the modification of results. In this paper, the authors proposed several solutions for polygonal lattice structures, especially triangular, that lay on continuous curved surfaces, using Rhinoceros 7 software.*

Key words: *continuous curved surfaces, lattice structures, parametrization, Rhino 7 software.*

INTRODUCTION

Once the emergence of new construction materials and related technologies allowed, the use of specially shaped roofs such as curved surfaces, ruled surfaces with directrix plane or spatial lattice surfaces, it become a real challenge for both architects and engineers. Their graphic representation followed several stages, depending on the technical tools available to specialists. If initially the covering surfaces expressed by the mathematical and geometrical equations were drawn manually, with the technological evolution and implementation of the current use of the computer, a series of drawing and design programs specific to the construction field and obviously to the industrial field were developed. Those that imposed themselves on the market were the specific drawing programs called Computer Aided Design (CAD), at first with 2D representation, and later 3D representation.

By transcription on the computer, of the equations that contain the relationships between variables / parameters and their basic properties, interactive computer aided design software was created, such as: CATIA, Autodesk 3DSMax, Autodesk Maya, Rhinoceros and Grasshopper 3D, Autodesk Revit etc.

From a graphic point of view, the relationship between the elements that define an object, respectively the interconnection between them can be achieved by adding or subtracting shapes and volumes, by moving them - using for example translation or rotation, according to certain rules, so as to have as objective the final product established together with the design intention. Thus, as computer science evolves, it was possible to pass from drawing, to animation, simulation, rendering functions, currently reaching the complex concept of Building Information Modeling (BIM) used by all categories of specialists who work on a construction, under the coordination of architects, based on parametric design.

Parametric design was conceived and elaborated starting from mathematical thinking based on algorithms and involves the use of equations with several parameters or variables, which define an element, a surface, an assembly, etc. They must comply with certain rules of generation and/or repeatability and, at the same time, to be interconnected with each other within a system. An important advantage is the ability to optimize the design by changing the parameters.

Over time, one can distinguish an interest in the use of these variable parameters that define the shape of the final product, whether it refers to the architecture or to the structure of a building. A pioneer of parametric architecture is Antoni Gaudi, who in the absence of a computer, used chains in patterns hung on the ceiling or strings with small weights attached to them, generating the natural distribution of static loads and reinterpreted them in a fluid architecture that materializes in fact these parameters [1].

The term parametric was first used in architecture in the 1940s by Luigi Moretti. He defines parametric architecture as the study of architectural systems in order to define the relationships between the dependent dimensions of different parameters [2].

Currently, design offices around the world use parametric algorithms in defining architectural forms, such as Zaha Hadid Architects, Arup Associates, Herzog & de Meuron, LAB Architecture Studio, Foster and Partners, Grimshaw Architects and the list can continue. Patrik Schumacher [3] considers that this architectural style can be called parametricism, because the impact of digital solutions on architectural design is a major one.

In this paper, the authors aim to represent some surfaces that can be used as roofs of some constructions, wanting at the same time to highlight the limitations, respectively the leap allowed by the transition from the classical representation to that obtained through the Rhinoceros 3D software, abbreviated Rhino 3D.

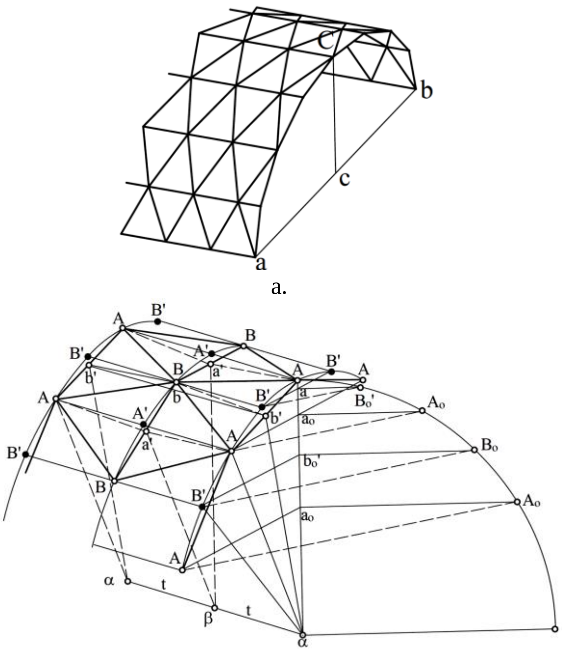
2. STUDY REGARDING THE EPRESENTATION OF COVERING TYPES SURFACES

In contemporary architecture, a design direction of the roofs is the replacement of curved continuous surfaces with spatial lattice surfaces, which means, from a geometric point of view, the approximation of the middle surface with a polyhedral surface [4].

These types of roofs are very suitable for buildings with special destinations, such as exhibition pavilions, showrooms, administrative buildings, greenhouses, etc.

Their design is based on parameterization, and from a technological point of view they are easier to achieve in comparison with curved surfaces, obtaining at the same time special visual effects. Spatial lattice structures are often based on regular and semi-regular plane equipartitions, which, the smaller they are, can be better wrapped over curved or developing surfaces. Equipartitions use those regular polygons that have the vertex angles submultiple of 360º, ie equilateral triangles, squares and hexagons. It is good to know, that between these, only triangles are non-deformable polygons.

Figure 1 shows triangles meshed as a surface of the lattice wrapped on a revolution cylinder. In Figure 1a the triangles have one side along the generatrices and the other sides are the equal strings of symmetrical helix that cut generatrices under an angle of 60 degrees. In Figure 1b the triangular network has some sides along the circular section. To generate this network, the mathematical relationships between the geometric elements explained below must be known [4].



a.

b.

Figure 1 Triangular spatial structure on the cylindrical surface.

Using the following notations:

R - radius of the cylinder;

d - length of the network side;

t - distance between circular sections

the following relation results for regular polygons having side d and rotated with an angle equal to $\angle\frac{A\alpha A}{2}$, so that the triangles ABA and BAB are equilateral:

$$\overline{Bb} = \overline{B'b'} = R - \sqrt{R^2 - \frac{d^2}{4}} \qquad (1)$$

$$\overline{Ab^2} = t^2 + \frac{d^2}{4} \qquad (2).$$

From relation (3) results the equation (4) in t:

$$\overline{AB^2} = \overline{Ab^2} + \overline{Bb^2} \qquad (3)$$

$$t^4 + 2\left(2R^2 - d^2\right)t^2 + d^2\left(d^2 - 3R^2\right)^2 = 0 \qquad (4)$$

From equation (4) results the real acceptable value for t (5), with the condition: $d \le R\sqrt{3}$

$$t = \sqrt{-2R^2 + d^2 + R\sqrt{R^2 - d^2}} \qquad (5)$$

To cover more complex surfaces, classical drawing becomes more difficult because it requires collaboration with mathematicians specialized in analytical and differential geometry, as well as in topology.

In these conditions, the use of specialized software greatly increases the degrees of freedom of designers and allows the generation of some spectacular surfaces.

In this paper Rhino 7 software was used, which is a specialized software for 3D computer graphics applications and computer-aided design. It allows the modeling of free surfaces and uses NURBS - Non Uniform Rational Basis Spline mathematical models, so that it offers a degree of flexibility and precision, obtaining three-dimensional surfaces by manipulating curves [5].

Figure 2 shows the same triangular spatial structure from Figure 1a represented using Rhino 3D software.

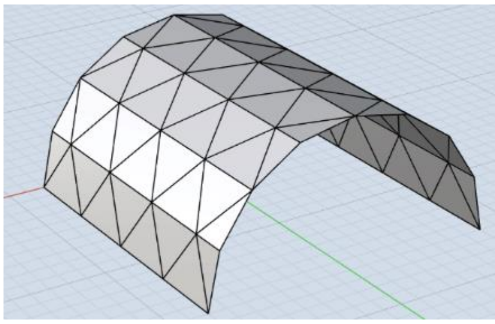
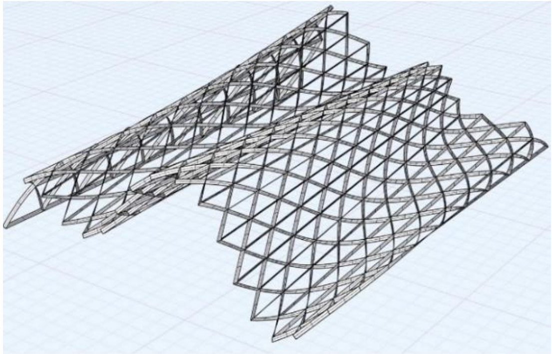


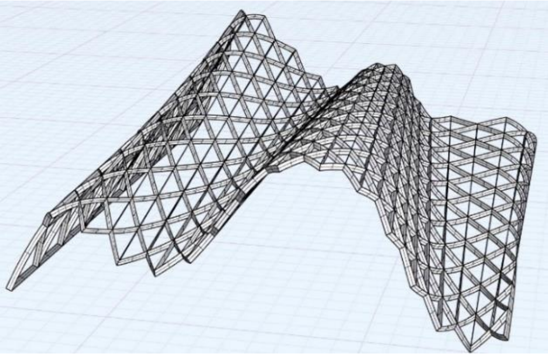
Figure 2 Triangular spatial structure using Rhino 3D.

Further, more complex surfaces were represented. Thus, in Figure 3, a lattice structure that wraps a cylindroid was generated. As a reminder, the cylindroid is defined as a ruled surface with a directrix plane whose generatrices support on two directrices curves which are not located in the same plane, remaining parallel to a given plane [4]. The use of computer programs, in this case Rhino 3D, to generate virtual entities, which will develop the functional and formal design in a complex process, is, as shown above, a new point of view in understanding architectural design. These computer modeling programs offer functions that can be understood as a set of instructions that determine certain properties of the object or design studied and can be manipulated according to certain parameters.

In many situations, polynomial curves, such as the directrices curves of the cylindroid, are used to generate a surface with active elements in an iterative cycle of graphical representation and transforming. One way to achieve this was independently discovered by two French engineers, Pierre Étienne Bézier, who worked for Renault, and Paul de Casteljau, who worked for Citroën. Their idea was to use, instead of the canonical basis of the polynomial functions space, another basis, consisting of the so-called Bernstein polynomials [6].



a.



b.

Figure 3 Spatial structure on the ruled surface - conoid.

In Rhino 3D it is possible to interactively change the shape of curves and surfaces, without passing through a calculus process, but in an intuitive way one can change the vectors that define them or one can change the position of the points defined by these vectors, the so-called control points.

If the materialization of a curved surface is desired, one can observed that the representation by polygons becomes a favorable variant, and depending on the quality of the representation of the surface, the number of polygons can vary from large to small - Figure 4.

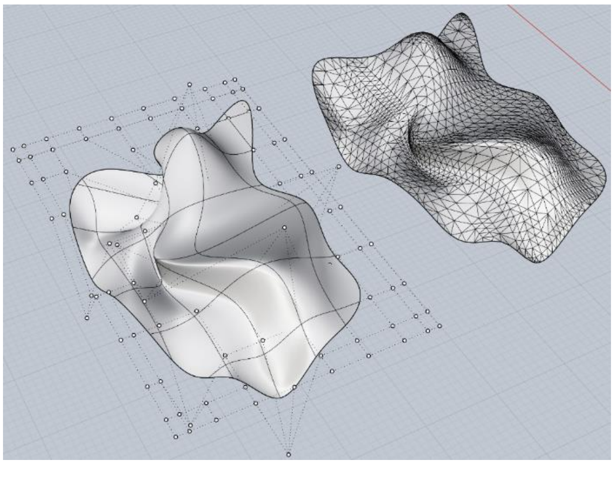
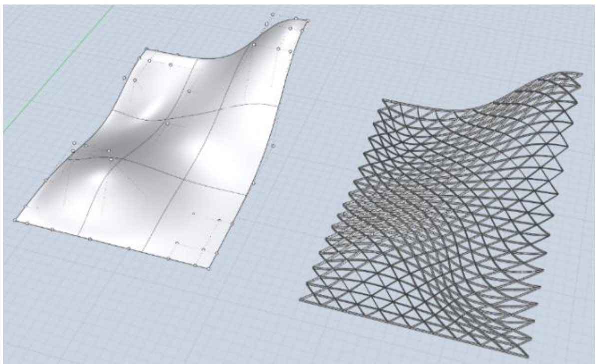
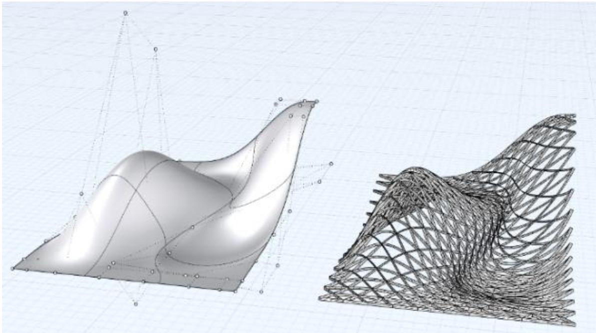


Figure 4 NURBS surface.

Using the same principle of generating a lattice structure for a curved surface, the structures from Figures 5a and 5b were represented.



a.



b.

Figure 5 Spatial structure on b-spline surface.

3. APPLICATION AREAS OF PARAMETRIC DESIGN

Currently, parametric design is used in many fields that use complex relationships between different parameters, an interdisciplinary approach with a multi-processual character.

Urbanism is one of the areas that benefits of the advantages of parametric design, providing the possibility to change any stage of a design and urban planning process, without affecting all decisions previously made. One can use parametric methods that generate an optimization and a repetition of multiple actions that are applied to different sites / locations.

In architecture, by using the parametric modeling is being sought automation and speed, flexibility, and adaptability. The architectural form is closely related to the structure of the building, so the forces acting in the structure are correlated by means of rules, determining a state in which the forces acting are in a stable balance. The shape is no longer a regular one but adapted locally to several criteria that contribute to the differentiation of each element of the structure.

There are some successful examples of the use of parametric design for roofs, among which one mention some spectacular achievements such as the Fiera Milano exhibition pavilion (Figure 6) and the Changi airport in Singapore (Figure 7).

By parametric modeling used in interior and object design, starting from clothing, jewelry, cars, until product design, it allow permanent updating of data to successfully build 3D models whose parameters in terms of shape and size correspond to the requirements of designers.

Medicine is another field that uses parameterization. One of the programs is Statistical Parametric Mapping refers to the construction and assessment of spatially extended statistical processes used to test hypotheses about functional imaging data. These ideas have been instantiated in a free and open source software that is called SPM [7].

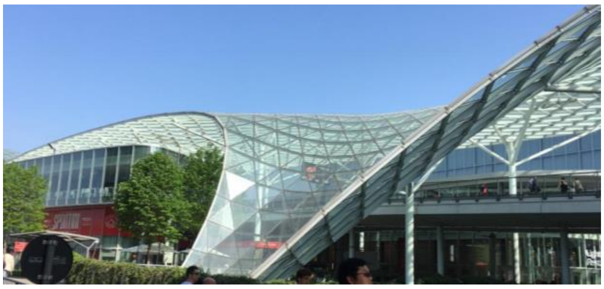


Figure 6 Fiera Milano.

Figure 7 Changi Airport – Singapore [8].

4. CONCLUSIONS AND RESEARCH DIRECTIONS

In this paper, the authors' attention was focused on the graphic representation of spatial lattice surfaces that are supported on curved surfaces, which can be used successfully in the field of constructions, with applications especially for the realization of covering surfaces.

Drawing manually or even with 2D drawing programs it becomes limiting. By developing specialized 3D drawing software, new horizons open for architects and builders.

But, as mentioned above, the current trend in architecture is to use parametric design, which allows mobility and adaptability of solutions according to the requirements and expectations of architects and beneficiaries of works.

Currently, a superior concept of parametric design has been developed, implicitly with the related programs, known as Building Information Modeling (BIM). These software programs contain all the information related to geometry and non-geometry, such as information about constructions [9], so that any modification of an element, is automatically transferred to the whole system and an automatic update of the behavior and form of the system elements takes place. In this context, it is essential to form a database, respectively a library that can be manipulated by the algorithm that underlies the program. In fact, BIM cannot be classified as a simple software, it is a working process that allows access to a series of information about a certain project [10].

Environmental studies can be performed on various projects, buildings, sites that analyze all the changes that may occur over time and can influence in any way the object of study: humidity, solar radiation, wind pressure, heat transfer, acoustics, etc.

A software that is designed with logarithmic steps can quickly manipulate variables and design parameters, can graphically model and display the obtained results. The essential condition is to know the characteristics of the components and the interactions between them.

Studies must be directed in this direction in order to optimize the solutions offered by the programs and to automatically eliminate the inappropriate solutions.

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