Revista Romana de Inginerie Civila, Volumul 13 (2022), Numarul 2

Proiectarea unui sistem adaptiv de umbrire solară bazat pe cuboctaedru

Design of adaptive solar shading system based on the Cuboctahedron

Ana-Maria Graur[1].

[1] Technical University of Cluj-Napoca, Faculty of Architecture and Urban Planning.
34-36 Observatorului Street, Cluj-Napoca, Cluj, Romania
E-mail: Anamaria.Graur@arch.utcluj.ro

Abstract. *This paper will develop the design of an interactive, kinetic facade that has the ability to adapt to the intensity of natural light to filter hierarchically, in real time, and prevent visual and thermal discomfort generated by light inside spaces. The purpose of the study is to provide an overview of the main parameters that determine the geometry and design of the system, the kinematic character of the shading system, and also the impact that the kinetic shading system will have on the design of the building facade.*

Keywords: shading envelope, adaptability, kinetic façades, cuboctahedron, hyperbolic paraboloid

DOI: 10.37789/rjce.2022.13.2.6

1. Introduction

Natural light is an essential element of life, it is one of the most significant aesthetic and visual characteristics of architectural spaces, which has a major impact on human physiological and psychological needs. However, it can cause discomfort due to the intensity and overheating of the space.[1] Excessive lighting can cause a number of negative phenomena, among others: photophobia, excessive tearing, pain in the eyeballs, headache. In order to obtain optimal natural lighting, architects and builders must take into account several factors: the orientation of the building in relation to the key points, climate, relief, shape and geometry of the volume, materials used, the vicinity of the building, possible shading of water, the function of the inner spaces and so on.

In the last decades of this century, globally, a series of measures have been taken to stop the waste of natural and financial resources, to limit the harmful effects on the environment, and contemporary architecture is trying to adapt to this requirement by reducing energy consumption. buildings.[2] Changes in the design and image of buildings, with the use of large glazed surfaces outside, allow easy heat transfer, and the comfort of the interior is maintained especially by using mechanical ventilation and air conditioning systems with high energy consumption. These facades have evolved with technology, and today some are made of many different layers and materials that allow the tire to reconfigure itself to cope with various internal or external changes.[3] From a historical point of view, architecture has always used the natural resources available on the site and has responded to the conditions given by the environment, offering in turn an optimal habitat in relation to the climate. Currently, the trend is to use an adaptable, dynamic building covering, and this receptive architecture is becoming the subject of innovative research studies.[4] Adaptive systems or receptive facades are much more suitable and efficient than fixed ones (blinds, sun visors, etc.), because they can be adjusted according to the change of solar radiation, allowing individual construction, optimal shading and maximizing the use of natural light.[5] By using innovative materials, shape memory alloys, the system can always react the same way, fewer parts are needed and the energy used to operate the shading system is greatly reduced. . The incorporation of several functions at the façade level to optimize the response to various external stimuli is a starting point in this study.

Thus, in this research, I will study the design of an interactive, kinetic facade that has the ability to transform through the dynamic action of light during the day to satisfy the visual and thermal comfort of the interior space. The envelope of the building is the interface between inside and outside, therefore, it significantly influences the indoor climate, comfort and energy consumption of the building and at the same time gives individuality to the building.

2. Design strategy of the sun shading device

The purpose of interactive facade systems is to control the thermal heating or cooling loads of the architectural volume, by controlling the transmission of solar energy at the facade level and at the same time allows control over the visual comfort inside the spaces. Starting from these aspects, I tried to find a way to optimize the shape, the process of transformation and reconfiguration of the elements that which form the shading system, depending on the energy flow to meet the comfort values of users. In order to define the shape of the parasol, the following must be taken into account: the shape of the building and the relationship with the activities of its occupants, climate, orientation of the facade in relation to the cardinal points, shading produced by vegetation or that produced by neighboring buildings. Thus, this interactive facade reflects the fluctuations of the environment and changes its shape in relation to these changes.

Interactive shading systems have a significant potential for integration in the design of fades, and most are the second layer of the facade that interacts with environmental stimuli through several types of movements: rolling, sliding, folding, rotating, etc. can be operated by a sensor activated by an external power source. [6]

2.1 Geometric exploration

As a source of inspiration in the creation of the shading system, the generation of modules based on the spatial structure and geometry of regular polyhedra was explored, so that the modules could be interconnected to generate a network. Due to the possibility of linking, in future studies, the digital model to the parameters of natural light, it was decided to use the Rhino 7 program. Thus, the variety of semi-regular polyhedra, the 13 Archimedean solids, provides an infinite source of new architectural forms both through their individual multiplication and the combinations of several. All these volumes have a perfect symmetrical shape, which represents a very good source of inspiration for builders and architects. 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.[7] In order to obtain a greater diversity and dynamics universal laws and principles can be reproduced, such as the asymmetry resulting from the repetition and the combination of some of the volumes. The flat surfaces of the semi-regular polyhedra thus assembled are perfect for overlapping or joining.

From all the semi-regular polyhedra the cuboctahedron was chosen because it offers through the section with a plane passing through the center of the polyhedron and the edges of the cuboctahedron a hexagon that allows the creation of a network of hexagons. Figure 1 shows the cuboctahedron in a sequence of changes in projection planes for a clearer view of the polyhedron.

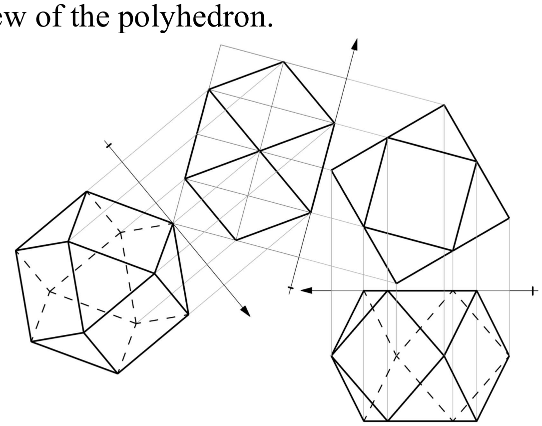

Fig. 1. Geometric representation of the Cuboctahedron

A cuboctahedron is a polyhedron with 8 triangular faces and 6 square faces and he has 12 identical vertices, with 2 triangles and 2 squares meeting at each, and 24 identical edges, each separating a triangle from a square. 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. [8]

However, in order to be able to generate the shading module, three-dimensional continuous minimum surfaces have been aggregated that generate hyperbolic paraboloids between the edges of the three equilateral triangles that form the hexagon and then investigate how these geometries can be modeled to optimize surface displacements. As we know the hyperbolic paraboloid or crooked plane is a smooth surface that is obtained by moving a straight generator in two directions, which are all straight, uncoplanar, movement during which the right generator remains parallel to a given master plane, Figure 2.

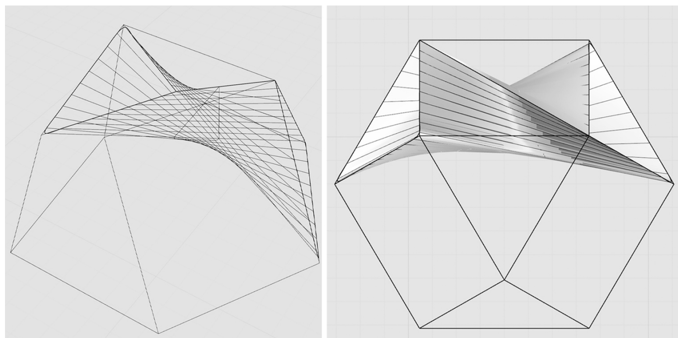

Fig. 2. The use of hyperbolic paraboloid in design of solar shading module

The connection between two hyperbolic paraboloids is made with a small portion of the cylindroid. The cylindricalroid is a directed surface with a directional plane whose generator rests on two directional curves not located in the same plane, remaining parallel to a given plane.[9] In these terms, the design of the light-sensitive sun visor will continue by making different ways of rotating surfaces, exploring the type of hyperbolic paraboloids that generate various curves, Figure 3 and use smart materials as actuators.

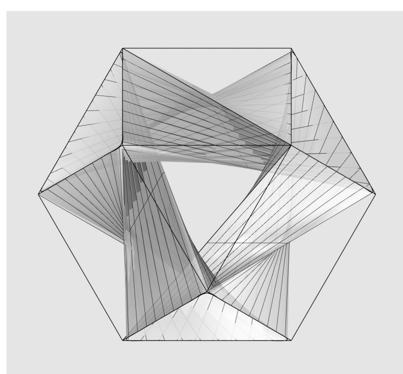

Fig. 3. The view of the solar shading module

2.2 Dynamic characteristics of sun shading device

In this section we will analyze the way in which the movement of the module in the shading system can be achieved, through which the internal lighting and the thermal comfort of the architectural space can be controlled.

Complex drive systems are an unfavorable solution, as the energy required to drive should cost as little as possible. A mechanically operated system is more expensive and requires permanent maintenance to reduce the occurrence of faults. But looking at the architectural context, I noticed that the whole system becomes an integral part of the facade and will influence the overall design of the building, being important to choose drive systems with a design as pleasant as possible. Consequently, the number of actuation points, the required displacements and the actuating forces are important parameters that must be taken into account in the design phase to ensure the sustainability of the systems, so the use of shape memory materials has been considered.

Thermally, SMAs are designed to change shape when the temperature rises to 50-70 ° C (depending on the alloy). As the shading system should be guaranteed throughout the year, the operation of the SMA would be more likely to be activated by a power source. [10] The elasticity of the material results in different types of geometric transformations.

Thus, the deformation process of the solar shading module is performed by rotating to the left or to the right by 28° in relation to the initial position of the equilateral triangle in the level plane with the highest elevation and results in the modification of adjacent surfaces, more precisely, the saddle surfaces of the hyperbolic paraboloids what composes the system, and thus results a modified spatial structure of the cuboctahedron. This three-dimensional structure implicitly provides self-shading, and the planes of the saddle surfaces of hyperbolic paraboloids allow the diffusion and redirection of sunlight.

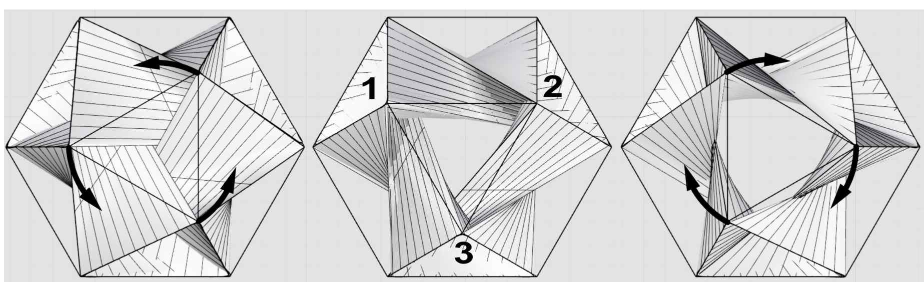

Fig. 4. The phases of solar shading module types

Figure 4 shows how the deformation is generated by pushing points 1, 2 and 3, forcing the surfaces of the hyperbolic paraboloids to change their curvature, to close or to open the free surface between them. The arrows shown in the image indicate the orientation of the actuator. The extension and retraction of the elements, which connect the hexagon and the equilateral triangle located in the level plane, are the movements sought in the generation of this receptive structure.

2.3 Intermediate positions of sun shading device

Reducing the brightness and controlling the thermal energy of natural light in real time are the objectives developed by the design of the proposed shading system. Normally the system uses several phases in the movement process to adapt to the dynamic light of day.

Modifying the radius of rotation of the equilateral triangle by extending and retracting some edges of the cuboctahedron can vary the actuation in this model to generate the opening and closing of the module in the shading system.

To take into account the future development of physical prototypes, digital experimentation has taken into account the spatial structure of the entire system, which also involves anchor points.

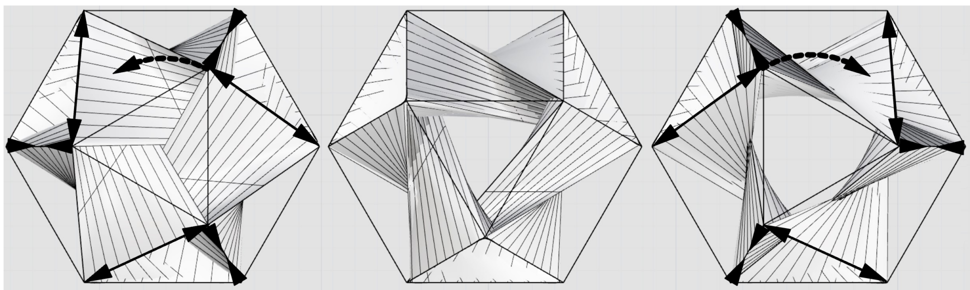

Fig. 5. The phases of solar shading module types

These fixed anchor points are located in the hexagon plane and determine the constraints of the module movement, by twisting the equilateral triangle in the level plane. As shown in Figure 5, the tips and edges operate the entire module for closing or opening, by rotating the equilateral triangle between 0° (initial position, middle figure) and 28° on a two-dimensional surface, providing real-time control of the facade over fluctuations of light intensity and a wide range of intermediate positions. Figure 6 shows spatially some intermediate positions of the shading module.

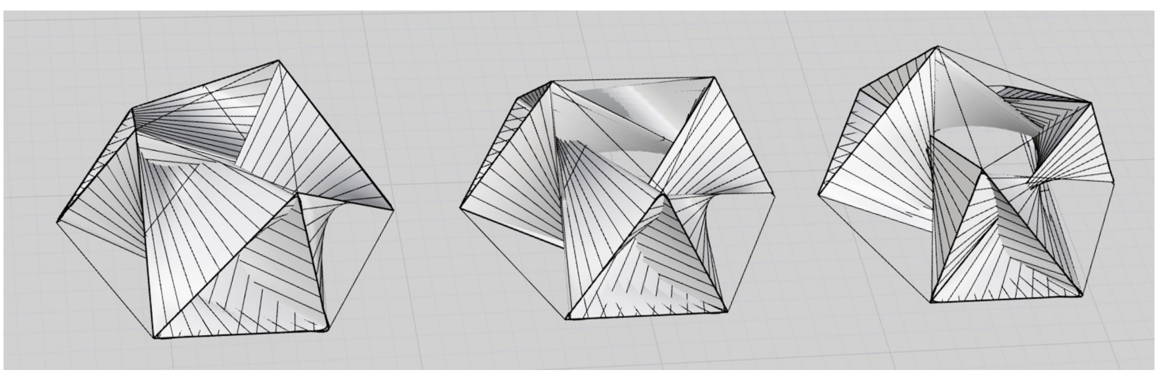

Fig. 6. the perspective view of the solar shading module

3. The impact of the kinetic shading system in the design of the building facade

Over time, architectural thinking has evolved from stability to dynamism and movement, being stimulated by ternological progress, computer-aided design and new building materials. The envelope of the building is the place where the architecture is expressed to the outside, to the public, but also the place that must mediate energy and structural problems, the boundary between interior and exterior conditions, being often considered a two-dimensional surface and less a component of the three-dimensional building, more likely, stratified.

Using the octahedron as the spatial structure and the hyperbolic paraboloid as the connecting surface we have the possibility to generate an adaptable system that can be integrated in the design of the receptive shading elements. Through the proposed design for this shading system, the geometry of the facade is changed due to the kinetic structure, which responds passively to the fluctuations of light intensity. This vibrant movement in the facade of the building changes the image of the architectural volume through the intelligent materials used as actuators of the system, which offers, at the same time, the possibility to act the individual each module. Thus, if the neighboring module responds to the movement of the first one, the fluid effect of a flock of starlings, known as the murmuration of starlings, can occur. The result is gaps with various openings, which in turn generate ingenious dynamic compositions and texture the vertical planes with three-dimensional shapes. The permissive and vibrant envelope, through the attributes of the surface shape, is dynamic and semi-transparent through these variable gaps of the moving modules assembled in this way, Figure 7, with a view of the whole in the direction of the interior space.

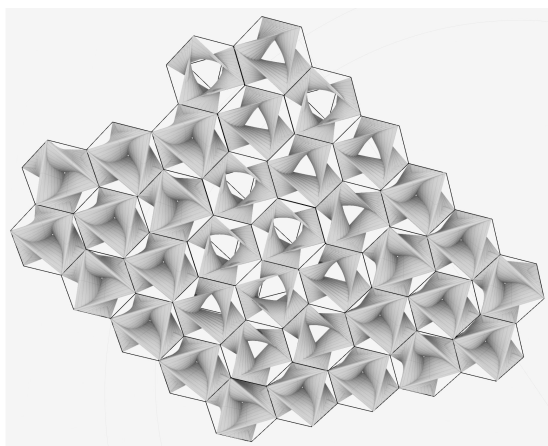

Fig. 7. Solar shading modules assembled - view from the direction of the interior space

The modern facades of buildings, with complex shapes, have geometric and mechanical limits in the realization of shading systems, but an advantage of this system is that it is modular and adapts to a design with flat facades and one with more complex shapes. This shading system makes it very easy to generate a space frame structure, a hexagonal matrix capable of withstanding structural stress. The points where the shading system is operated are integrated in the structure of the module, this semi-cuboctahedron, having a major influence in the general architectural expression of the building, as seen in Figure 8, with a view of the whole from the outside.

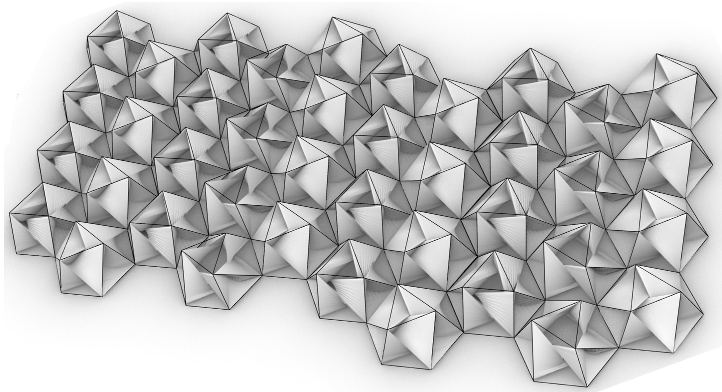

Fig. 8. Solar shading modules assembled - view from the direction of the exterior space

By choosing materials with different light transmitting properties, the interior space will be protected by dynamic elements capable of filtering solar radiation throughout the year and generating a new atmosphere and, of course, meet the requirements of visual comfort due to the design of the facade. By choosing the right materials, this three-dimensional structure can contribute to the diffusion and redirection of the sun's rays. In the future we can consider storing solar energy by using this type of solar shading modules and the right materials for this process.[11]

This study discusses a permissive, spatial, perforated and vibrant envelope through the rhythm given by the modulation of the kinetic shading system, which can contribute positively to the design of a building with flat facades. In Figure 9 you can see a variant of assembling the module as a shadow system, seen from inside and outside.

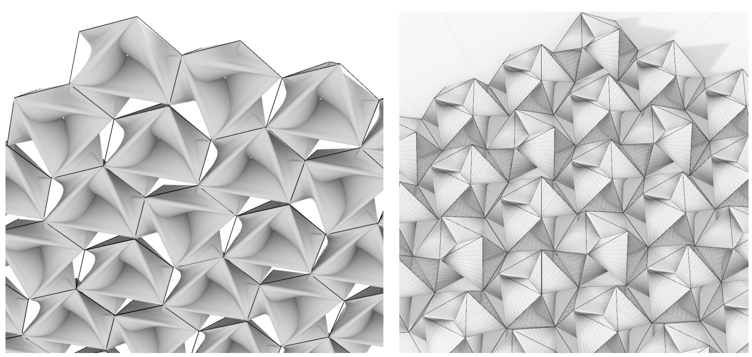

Fig. 9. Solar shading modules assembled

To do architecture means to study, among other things, the way light enters, the way you see the surroundings and this is exactly what we can capitalize on through this envelope. We can generate, so to speak, a film, which focuses your gaze on various interesting exterior perspectives, premeditated in the design phase, and the play of light that enters to animate the interior spaces by moving the whole system, Figure 10.

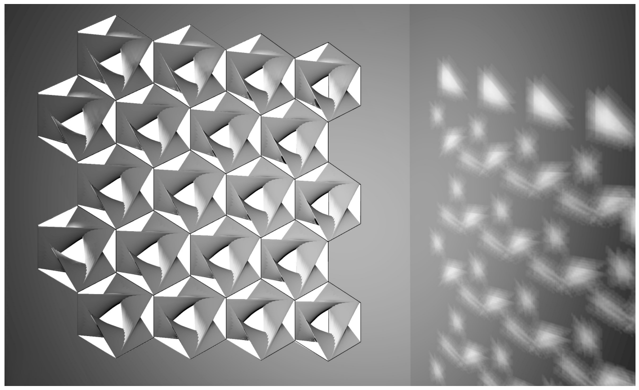

Fig. 10. Solar shading modules assembled

4. Conclusion

The design of a receptive envelope that allows the shading of the building, represents the continuous optimization of the parameters that come from the interior and exterior space, thus improving the thermal and visual values inside the building. As a result, the half-octahedron kinetic modular elements diffuse daylight through three-dimensional configurations of parabolic hyperboloids, providing self-shading of the façade, decreasing the intensity of direct solar radiation and allowing optimal natural light to enter the interior, helping to reduce energy consumption and an increase in the autonomy of natural light. The receptive façade useful for improving the comfort of the interior space is still being developed and represents a new trend in architectural design. Starting from the idea of using shape memory alloys as system actuators to reduce the actuation energy, the research will study how the whole assembly works and how we can improve the shading device included in the layers of a tire.

There are several possibilities for how the research undertaken in this paper could progress in the future, and with the evolution of technologies to adapt the system to a more complex and implicit, improving its performance. For example, the next step would be to apply this logic to a real envelope and study the feasibility and performance of natural light in a prototype experimental research and then study the direct relationship between the occupants of these spaces and the interactive movement of the shading system. This step involves a parametric design approach. The geometry of this facade, surfaces with angles inclined or oriented in a certain direction, offers the opportunity to capitalize on the potential for capturing and using solar energy. This study is intended to serve as a guide for future research in the field of intelligent architecture.

References

[1] Stephen M. Pauley, „Lighting for the human circadian clock: recent research indicates that lighting has become a public health", Medical Hypotheses, Volume 63, Issue 4, ISSN 0306-9877, pp. 588-596, 2004.

[2] Directive 2010/31/EU of the European Parliament and of the Council on 19 May 2010 on the energy performance of buildings [2010] OJ L153/13
[3] Bohnenberger, S., Khoo, C.K., Davis, D., Thomsen, M.R., Karmon, A., Burry, M. „Sensing Material Systems-Novel Design Strategies”. International Journal of Architectural Computing, Volume 10, Issue 3, ISSN 2048-3988, pp. 361-376, 2012.
[4] Khoo, C.K., Burry, J., Burry, M. Soft Responsive „Kinetic System: An Elastic Transformable Architectural Skin for Climatic and Visual Control”. ACADIA 11: Integration through Computation [Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)] [ISBN 978-1-6136-4595-6], pp. 334-341, 2011.
[5] Schnittich, C., Krippner, R., Lang, W. „Building Skins, Detail”, Birkhäuser, Basel, 2012.
[6] Hosseini, S.M., Mohammadi, M., Guerra-Santin, O. „Interactive kinetic façade: Improving visual comfort based on dynamic daylight and occupant's positions by 2D and 3D shape changes”, Building and Environment, Volume 165, ISSN 0360-1323, 2019.
[7] Viana, V. „From Solid to Plane Tessellations, and Back”. Nexus Network Journal Volume 20, pp. 741–768, 2018.
[8] Graur, A.M. „Geometry as assembly in architecture. Semi-regular polyhedra”. Journal of Industrial Design and Engineering Graphics, Vol. 15, Iss. 2, pp. 17-20, 2020.
[9] Iancau, V., Barbat, V., Rusu, I., Zetea, E., Rosa, S., „Geometric representations and technical drawing”, Publisher Didactics and Pedagogics, Romania, pp. 220-223, 1982.
[10] Pesenti, M., Masera, G., Fiorito, F., „Sauchelli, M., Kinetic Solar Skin: A Responsive Folding Technique”, Energy Procedia, Volume 70, pp 661-672, 2015.
[11] Mârza, C., Corsiuc, G., „Considerations on solar energy storage”, Bulletin of the Transilvania University of Braşov • Vol. 10 (59) Special Issue No. 1, pp.390-397, 2017.