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SOLUTIONS FOR USING KINETIC SHELLS IN THE BUILDING FACADE IN TERMS OF PERFORMANCE AND ENERGY CONSUMPTION OPTIMIZATION

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ABSTRACT

As an integral part of the building, the building shell is always considered as a level of response to the climate that has the greatest impact on individuals in terms of performance and climate comfort. In the design of the building, unfortunately, little attention is paid to the functional aspects in terms of mobility and geometry, and more emphasis is placed on the aesthetic aspect. This study was conducted to investigate the kinetic facade in terms of performance and environmental comfort. Functional sciences on kinetic facades and architectural theories concerning shells were first reviewed, effective documentation on shell design was then analyzed by functional method, and the results were finally presented. This was a qualitative descriptive-analytical study in which the solutions of using kinetic shells and controlling climatic factors affecting the building through the kinetic design approach were examined.

KEYWORDS: *Energy Consumption Optimization, Shell Climate Design, Functional Methods, Kinetic Facade*

INTRODUCTION

Today, in the vast field of climate science and technology, the use of shells in the building facade affects the functional aspects of the building in addition to the aesthetic aspect. With the beginning of the 21st century, the geometry and parameters affecting the facade have increased the dynamics of building facades.

Due to the growing cost of energy consumption in the construction industry, the rate of energy consumption should be minimized by using modern design strategies. The building shell is one of the main parts of the building that has the largest share in the interior and exterior. Therefore, any changes in the exterior of the building can be affected by the building shell (Okhovat and Bali, 2017). One of the ways to reduce energy consumption in today's world is to use kinetic shells with modern geometric sciences. Architects often use this type of shell because of the increased energy efficiency in addition to the aesthetic aspects.

This study mainly focused on the role of functional methods of kinetic architecture in the design of building shells. In this regard, suggestions were made for re-reading and inferring the shells again, and the sub-topics were not further analyzed in terms of climate. Documentation on shell design was inductively analyzed by the descriptive method according to the assumptions made. It should be noted that the shell in question is the building facade using parametric and geometric sciences, which can be most used in terms of energy efficiency. The main question is what are the functional methods of kinetic facades as a functional and climatic module in the construction industry?

METHODOLOGY

This study was performed by the qualitative method based on case studies and library resources as well as analysis of existing samples of kinetic facades. The shells and their impact on the building in terms of performance and energy efficiency were discussed.

LITERATURE REVIEW

In the literature review, studies close to and similar to the subject matter are examined. In this study, it was tried to mention stereotyped, documented, and parallel studies due to the limited studies in the field. In this regard, the studies are referred to as follows:

To achieve a high-performance canopy shell that also has special visual qualities and arrays, Omidfar (2011) studies parametric tools and methods in the process of designing and simulating forms consisting of complex geometries. By reviewing the history of architecture from the perspective of using arrays, he considers the contemporary era as the era of using performance-oriented arrays, considering its potential, especially in using digital tools for modeling, analyzing, and optimizing the performance of building components.. In this regard, the researcher optimizes the climatic performance of the outer shell (building facade) based on the forms and designs of a sculptor. To limit the study, Omidfar only analyzes the climatic performance of the shell in the southern facade, with certain dimensions and office use. The results indicate that it is possible to achieve suitable alternatives that meet both visual needs and climatic performance for the design of external shells according to today's digital and computer facilities (Omidfar, 2011).

In a study titled "Investigating the Performance of Smart Kinetic Facades in Buildings", Okhovat and Bali argue that among the strategies and solutions proposed for the energy consumption problems of buildings, the facades should play an intermediary role in indoor and outdoor environments. Facades can play multiple and vital roles in energy consumption and determining the quality of the building's interior.

In a study titled "Performance-Oriented Shells for Passive Comfort," Turin et al. examined semi-open urban spaces called urban structures with large-scale roofs. To provide performance evaluation methods in the early stages of the design process, they studied passive solar systems to provide thermal comfort, daylight, and shade and introduced a performance-oriented parametric design approach. The structure of their proposed performance-oriented parametric design approach had two main parts: the first part used parametric geometry to generate design alternatives, and the second part studied the performance and performance evaluation of alternatives. To do this, they used a hybrid tool called ParaGen, which used genetic algorithms and parametric modeling simultaneously. Turin et al. applied their proposed design approach to a case study and, eventually, came up with an interdisciplinary performance-oriented design approach that, in addition to climatic performance, included the structural performance of the ceilings and coatings (Turin, et al, 2011).

THEORETICAL FOUNDATIONS

Building Shell Module and Energy Efficiency

The building shell to respond to natural elements such as sun and shade, as well as interior elements such as indoor heating, can not only provide a more comfortable environment for work or life but can also make the building more energy-efficient. In many studies, repeating modules have been used on building facades and interior shells. These modules are widely used in construction as a basis for making components that can be repeated to make surfaces (Khabazi, 2012: 25).

Changing the Parameters Affecting the Design of Kinetic Facades

From Simplicity to Complexity in the Kinematics of Building Facades

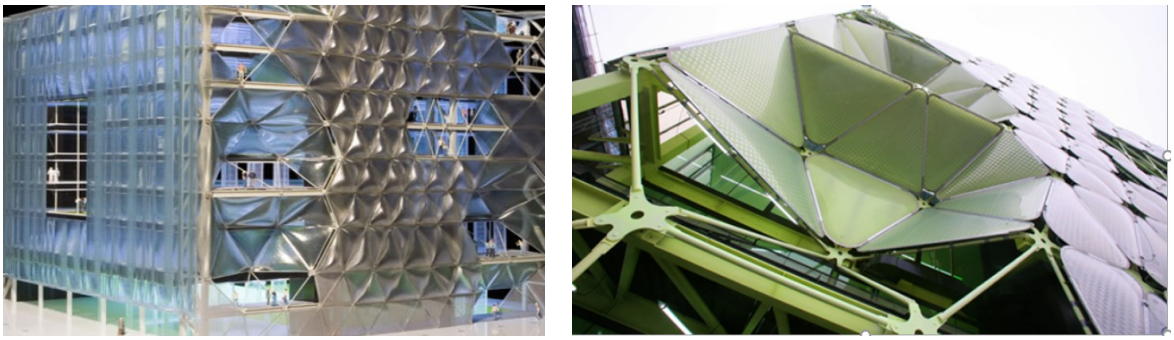
Dynamics means motion in physics, and it is a style in architecture. In this style, buildings have a fourth dimension, which is time, which means that the building facade changes over time. In other words, the kinetic facade is a facade that takes different forms at different times. Changes have taken place around the world since the 1950s. Reductionism has gradually lost its place. In the world of modernity, kinetics is a model for reducing reductionism and paying attention to complexity. It is a type of architecture that involves modifications and changes in form to constantly react to environmental conditions (Sterk, 2003).In reductionism, human understanding of nature was in the form of top-down and whole-part analysis. However, in examining the characteristics of systems, the part-whole analysis is considered today. There has been a paradigm shift in the sciences from reductionism to complexity. Not surprisingly, this new system attracted the attention of architects because the use of new methods of organizing and creating forms by computers and related software were possible using this system (Kotnik, 2001).Thus, the complex kinetic facade acts like a living organism and can act as a bioclimatic and environmental model in reducing energy consumption.

Incremental Sciences in Facade Kinetics

Among these sciences, reproductive sciences can be mentioned. These sciences refer to interdisciplinary and multidisciplinary sciences that analyze the natural world and its complex behaviors from the perspective of reproductive processes and show how the reproduction of unpredictable and unlimited behaviors takes place through the interaction of laws and parameters of natural phenomena. These sciences are prominent in fields such as cognitive science, reproductive linguistics, language processing, systems theory, genetic algorithms, systems of thought, computational sociology, philosophy of science, digital physics, digital philosophy, and many other emerging fields (ibid). Hence, organized notions and concepts have found their way from science to architectural topics over the past decades and are now being explored in design (Riekstins, 2016.p: 22-26). Kinetic facades have had the best performance in terms of increasing attention to ecosystems and climatic stability facade geometry. Smart kinetic facades can regulate internal conditions without user intervention and react to different conditions due to the systems used in them (Okhovat and Bali, 2017).

The Term Module in the Design

The term module generally implies its regularity. The simplest examples of modules are repeating visual units. The main idea is to reuse information either in the repetition of a visual unit to produce a design or in mathematics (Golabchi et al., 2012).As a design initiator, the module plays an important role in initiating the design and is constantly changing in the design path as an idea parameter. Interactive architecture plays an important role in today's buildings. One of the manifestations of this type of architecture is the use of Kinetic facades, which have become popular among engineers and architects in the last decade. Kinetic facades are sensitive to climate change and the needs of residents and are often used as the shell of high-rise buildings. Architects use this type of shell mostly to increase the energy efficiency of the building in addition to the aesthetic aspects. According to the designers of the buildings TIC in Barcelona and Al Bahr in Dubai, the use of kinetic facades has led to energy efficiency and light control.



(Source: https://www.archdaily.com/49150/media-tic-enric-ruiz-geli).

Figure 1: TIC Building in Barcelona

Shell Coatings

In parametric architecture, shells are widely used as covering the spaces outside or the walls inside, and there is a lot of potential for designing and editing these shells in design software. Free-form plates are the main design sources in parametric architecture (Khabazi, 2012: 24).

Climate and Shells

Climate design for sustainable development and conservation of resources in architecture is inevitable today. Therefore, parametric architecture has tried to be integrated in some way with climate design. The issue of climate design has gone beyond the construction profession and has received much public attention. The important point to understand the architectural value of any region is to know how the building adapts to the specific climate of that region. How the sun, breeze, and green space are used in the building and how the architect creates a microclimate are reasons and signs of the designer's skill and mastery. In general, it is not difficult to understand the problem of climate design. Human physical comfort in the building is the result of the balance of thermal energy between humans and the environment. By recognizing the climatic conditions of the region, the designer can select and compare the principles of climate design suitable for that region (Watson, 2013).

Multilayer Systems Affecting the Climate

Multilayer systems have a significant impact on the prevention, absorption, storage, and transfer of heat around shells and have received more attention today than single-layer systems. Completing the workflow of parametric systems, Patrick Schumacher says, "A shift must be made from a single-layer system and design edits applied to it to a multi-layered, coordinated, and continuous design of subsystems."Implementing any design operation on a subsystem must be related to and affect other components of the system (Schumacher, 2009).

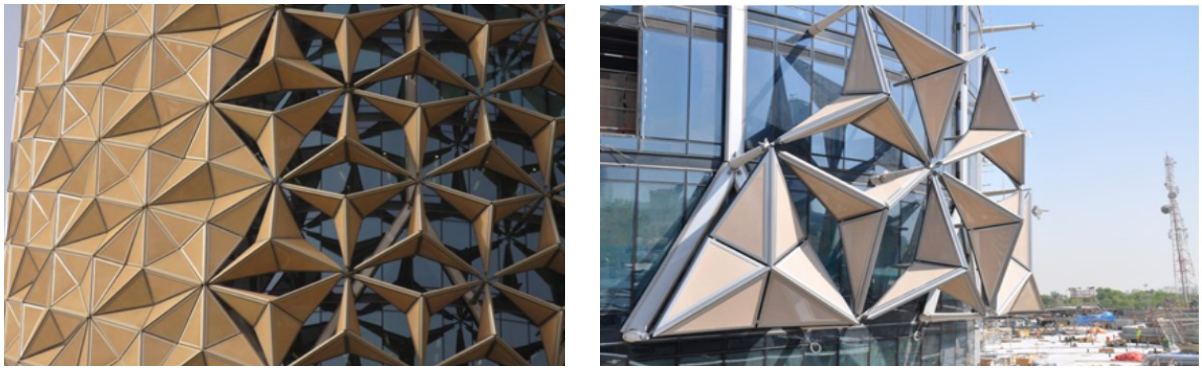


Figure 2: Context Dialectic: The Shell Morphology as a Shell Mobility System: Smooth Versus Corrugated (Schumacher, 2009).

FINDINGS

Parametric Functional Methods in Shells

The outer shells of buildings act as a boundary between inside and outside the building and can be an element that modifies environmental conditions. However, several factors affect their formation, including technical and physical characteristics (Omidfar, 2011 &Turrin, 2011).

Shells and their components can provide environmental sustainability by adapting to changing climatic conditions (Araya, 2011).

Utilizing Dynamic Approaches in the Building Shell

Dynamic approaches try to adapt the condition and structure of the building shells to the changing conditions of the exterior, which means that they are transformed from one state to another to always provide comfort in indoor spaces so that the environmental conditions of indoor spaces are controlled and regulated and uncertain external conditions are responded. The rules of dynamics for formal structure and spatial effects are generally determined by the two main climatic parameters of heat and light, which have a significant effect on energy efficiency (Cohan, 2013).

The Use of Static Systems in Building Shell Design

The use of different types of static systems in building shell design is still an effective factor in reducing energy consumption. It should be noted that dynamic systems are more efficient, but the climatic performance of static systems is also acceptable (Zhao & Others, 2012).

For example, one can point to the facade of the "Kiefer Technic" Showroom in Austria, which has an office and exhibition use. A prominent feature of the design of this building is its facade. Ernst Giselbrecht and his colleagues considered a kinematic shell to design the facade of the building. This shell changes according to the climatic conditions to improve the internal environmental conditions and always creates a favorable environment for users. The parts designed in the facade can be controlled by users (http://www.facade-interior.com).

Figure 3: Kiefer Technic Showroom in Austria (http://www.facade-interior.com).

Taking Advantage of Gradual Changes of Form in Shell Design

Geometric architecture follows the natural sciences in search of adaptation to its surroundings and makes this possible by taking advantage of the gradual changes of form in the design space. This coherent macro pattern arises from the limited internal interactions of system components. In this process, all components operate simultaneously, in parallel, no component acts as the center and conductor of the current, and all components are equal. According to Michael Hansel, in architecture and engineering, this optimization is used for structures to reduce material and energy consumption to deal with gravitational forces and loads on the structure. He calls this path multidisciplinary design optimization (MDO) and states that self-organization can also be used for MDO. Form-finding tools can be used by designers as toolboxes to help them find the form of their desired structures. The architecture will focus on designing systems that will produce the process of self-organization of design elements rather than focus on product and process (meta-process) (Adibzadeh and Karimi, 2014).

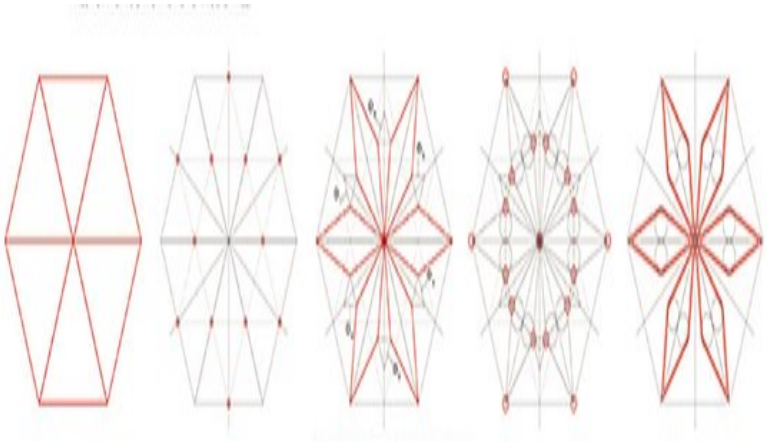
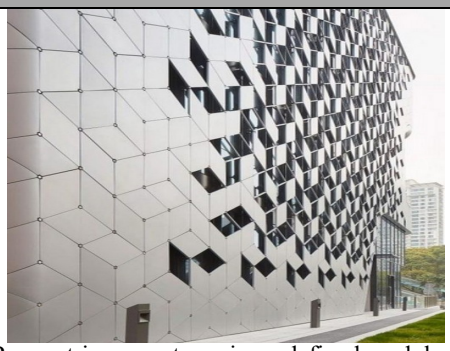
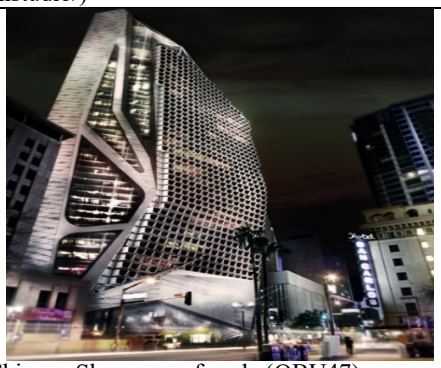
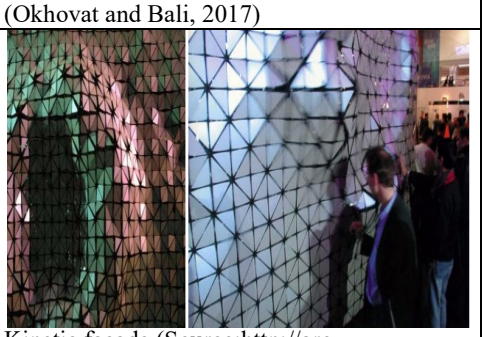


Figure 4. Gradual Changes of Form with Central Management and Authority (Source: Http://Www.Evolo.Us)

Findings of Shells and Their Functional Methods

In kinetic facade architecture, there are several effective solutions in designing shells and their uses, such as shell fluidity, and shell module, which play the most climatic role for the comfort of residents. In the following, they are mentioned on a case-by-case basis.

Table 1: The Type of Shell Coating and Its Application in Buildings (Source: Author)

The Type of Shell Coating	Application in Buildings	Sample Shell
Using the defined module (more surface coverage with a greater angle between the inner triangles of each module and shading)	In this design, the facade is analyzed according to the direction of solar radiation in the desired area, and then, to control the amount of radiation to the interior, the modules are designed so that the angle between the inner triangles of each module is greater in the part of the facade where there is more intense radiation.	 Parametric geometry using a defined module (Source: https://www.arch2o.com/lane-189-unstudio/)
Multilayer shells	Facade elements are multi-layered, open and close according to the amount of light received, and are designed to provide visual clarity, light transmission, and air conditioning.	 Chicago Skyscraper facade (OBU47) (Okhovat and Bali, 2017)
Indirect kinetic facade	Designed by Mark Goltor, which responds indirectly to changes in the environment.	 Kinetic facade (Source:http://arc-hitecture.blogspot.com/2007/10/ex03-case-study.html)

CONCLUSIONS

Shells play an important role in regulating the indoor environment of the building in terms of cooling and heating performance in severe weather conditions. The passage of intense sunlight through these nested pores is accompanied by a gradual and hierarchical reduction of heat. In its path, the light encounters the bends in the facade fractures and sees the shadow next to it. In this path, fractures as thermal buffers affect the internal cooling. The reasons for the decrease in heat of the layers defined in the surfaces are the moving and shifting geometric parameters. Buildings may have very high energy consumption or energy loss due to improper shell geometry and lack of attention to daylight or shading. The shell

acts as a separator between the interior and exterior of the building to provide physical comfort in terms of performance. The shell can provide the physical comfort conditions significantly by providing controlling and sometimes guiding geometric algorithms.

Using the structure of triangulation geometry in functional methods of kinetic architecture can be a shadow of part of the facade of the building or the whole building in the form of a pavilion and provide thermal comfort for people considering the amount and direction of sunlight, and reduce the use of artificial light.

The use of kinetic multi-layered shell systems that can open and close can be very effective in controlling the ambient temperature in hot seasons. Due to the presence of layers and their shell geometry in the facade, these systems can create shadows in deep and fractured spaces, change the direction of the shells in cold seasons, and prevent cold air from entering the building.

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