Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 12 December-2025, Page No.- 8126-8133

DOI: 10.47191/etj/v10i12.12, I.F. – 8.482

Biomimicry as A Tool for Form Creativity of Building Envelope to Enhance Thermal Performance

Amal Ebrahim Ahmed Hassanin[1], Alaa Mohammed El-aishy[2], Marwa Atef Abd-Elhady[3],

[1] Teaching assistant, Faculty of Engineering, Mansoura University, Mansoura, Egypt

[2,3] Associate Professor of Architecture, Architectural Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

ABSTRACT: It has become necessary to achieve thermal comfort for users in buildings, which enhances human ability to work, create, or rest and enjoy. Since the building envelope serves as the link between the inside and outside of the building, forming the building envelope creatively improves and enhances thermal performance of buildings, thus achieving thermal comfort for users.
Nature is the primary teacher and source of creativity for humans. Therefore, Biomimicry was chosen as a tool for creative formation, and the descriptive analytical approach was used by analyzing an example where nature was simulated in the formation of the external envelope of the building. By studying the impact of this on the building's thermal performance, the research concluded the importance of forming the external envelope of the building and its direct effect on the building's thermal performance, highlighting the effectiveness of the biomimicry approach as a tool for creative forming.

KEYWORDS: Biomimicry, Outer skin, Building envelope, Thermal performance, Form creativity.

INTRODUCTION

Scientific and technological advancements have increased the need for achieving comfort within buildings and for finding solutions to environmental and thermal issues, as well as ensuring harmony between the building's interior and exterior. Since the building envelope is the medium through which external climatic conditions are transferred to the interior, its design must be creative to fulfill the building's functions, meet the users' needs, and ensure thermal comfort while preserving the environment.

Allah Almighty has created this universe with unparalleled precision and creativity, which provides a rich source of inspiration for human contemplation. This realization helps us understand that nature is the first teacher and the ultimate source of creativity, as it is the creation of God. Can the methodology of biomimicry—learning from how organisms adapt to their surrounding environment—serve as an effective tool to achieve creative formation of the building envelope?

The research follows two main approaches to achieve its objectives:

A. Theoretical Approach:

- Studying the creative design of building envelopes and its impact on thermal performance.
- Using nature simulation as a tool for creative design.

B. Analytical Approach:

- Analyzing a case study that adopts Biomimicry in designing the building envelope.
- Examining the methods used by architects to improve thermal performance in building envelopes.

I. Study of Form creativity in the Building Envelope

This refers to a cognitive process undertaken by individuals with unique traits to create forms characterized by organizational relationships between mass and space, along with their inherent attributes, features, and secondary elements, leading to a distinctive and innovative product.

Architectural creativity has three essential components, as shown in Figure 1 (جودة, 2021)

Figure 1: physical form creativity, Artistic form creativity, and Intellectual form creativity

A. Study of the Determinants of Form Creativity in the Building Envelope

Architectural formation is influenced by several determinants, as follows:

- **Function**: The function determines the geometric, material, and visual properties of the formation, making it suitable for a specific human activity.
- **Construction Technology and Building Materials**: Modern construction technology has contributed to the creation of new forms and designs that were previously difficult to achieve, as shown in Figure 2.

- **Environmental Context**: Creative formation is influenced by the surrounding environment, including topography and climatic conditions, as well as cultural traditions and building regulations.
- **Spirit of the Age**: Architectural forms reflect the nature of society, its economic level, and the prevailing architectural trends of a specific time period, as shown in Figure 3

Figure 3 The Union Square project of the Architecture Factory in Melbourne represents the prevailing architectural trend (Marwan, 2019).

Figure 2 The Sea Towers building is equipped with shutters that move with sensors according to the movement of the sun. (المنشاوى and نبيه, 2016)

b. Study of Sources of Artistic Creativity in Building Envelope

- Artistic creativity derives from three main sources as illustrated in Figure 4: nature, past human experiences, and heritage, including both folk and formal traditions. However, the architect's creativity in designing the building's facade lies in their ability to imitate and adapt these forms to suit their intended purpose.(رأفت, يناير 1997)

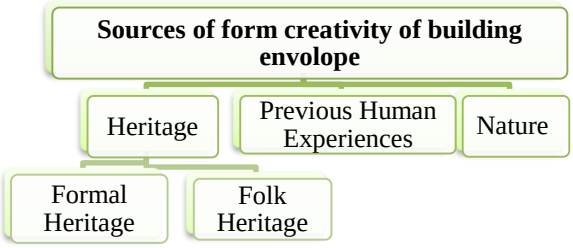


Figure 4: Sources of artistic creativity in architecture. (Prepared by the researcher)

c. Study of the Visual Characteristics of Architectural Design Elements

Architecture is a creative process that involves physical forms, which are perceived through the sense of sight. Therefore, architectural design elements have several visual characteristics, including form, colour, texture, transparency, and porosity. These are the elements or tools that architects use to create a design.

- **Form:** It is the most important characteristic of design, as a large portion of any design can be perceived through its form, as shown in Figure 5.
- **Color:** The use of colors helps emphasize different design elements and has an impact on mood and behavior.
- **Texture:** Through texture, a building can convey an appropriate expression of its location, character, construction method, or function.
- **Transparency and Porosity:** These elements control the passage of light, air, and heat into and out of a space, as shown in Figure 6, and they are key to linking the building to its external environment (تميم, 2017)

Figure 6: The building of the Italian global wing Elsherbiny et al., 2024

Figure 5: The Dancing House in the Czech Republic is distinguished by its unique shape (Vojcak)

II.

III.

Study of Thermal Performance Improvement in Building Envelope

- This refers to how the design of a building's Envelope, including its form and elements (such as roofs, walls, and openings), responds to changing climatic conditions with the aim of achieving thermal comfort for the occupants.

Table 1 (Abed, 2012) illustrates the factors affecting thermal comfort as follow

TABLE I FACTORS AFFECTING THERMAL COMFORT

FACTORS	IMPACT ON THE FEELING OF THERMAL COMFORT	THERMAL COMFORT LIMITS
Air temperature	If the air temperature is high, it affects the skin and prevents the body from releasing excess heat, activating the sweat glands. Conversely, if the temperature is low, the blood vessels in the skin constrict, leading to a sensation of cold.	From 22-28°C.
Relative humidity	A drop in humidity below the optimal level causes skin dryness, and in cold weather, it increases the sensation of cold. On the other hand, high humidity causes discomfort while breathing.	From 30-70%.
Solar radiation	Regardless of air temperature, a person feels heat when exposed to direct sunlight. In winter, exposure to sunlight provides an immediate feeling of comfort.	2°C higher than the air temperature.
Air movement	Air movement affects the rate of heat exchange through convection. When a person sweats to maintain body temperature, vapor rises from the body, and the surrounding air becomes saturated with moisture, causing its temperature to rise. If the air is stagnant, evaporation stops, and the effect of heat increases.	Summer: 25.0 m/s, Winter: 15.0 m/s.

IV. Methods of Controlling Building Thermal Performance through Exterior Envelope Elements

The exterior envelope directly affects the building's thermal performance as it represents the medium through which external climatic conditions are transferred into the building via the envelope elements, as shown in Figure 7. This can be managed through the following:

1. **Solar Radiation through the Roof:** The thermal transfer through the roof can be controlled by adjusting the construction material, thickness, and shape of the roof.
2. **Conduction from Air to Walls:** The rate of thermal transfer through the walls varies depending on the wall material, thickness, and shape.
3. **Direct and Reflected Solar Radiation, as well as Heat Leakage through Openings:** To control the rate of thermal transfer through openings, changes can be made to the design, shape, position, orientation, and treatments of the openings.(عباس et al., 2019)

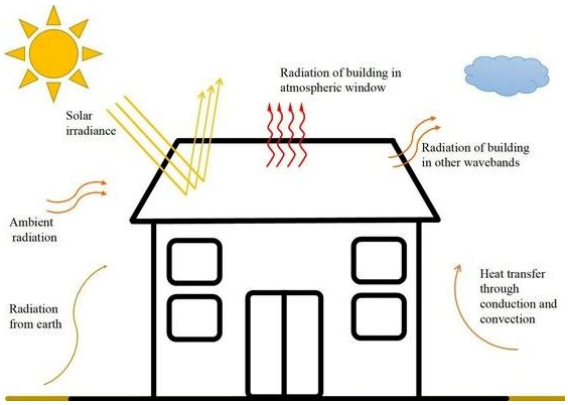


Figure 7: Heat transfer in the building through the exterior shell

V.

VI. Study of Biomimicry as a Tool for Improving Thermal Performance in Building Envelope

Biomimicry involves learning from nature and then replicating its models, processes, and ecological systems. Pedersen Zari has classified levels of Biomimicry into three levels, as illustrated in Figure 8:

1. **Organism Level:** This level refers to mimicking a specific living organism, which can be either a part of that organism or the entire organism.
2. **Behavior Level:** This level involves simulating a particular type of behavior or action performed by the organism to survive.
3. **Ecosystem Level:** This level simulates a specific ecosystem, including its living organisms and the processes they perform to sustain themselves. (جودة, 2021)

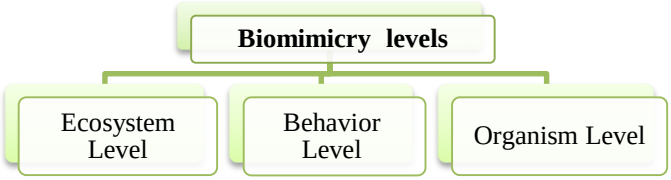


Figure 8: Levels of Nature Simulation.

a. Study of Biomimicry Approaches in Building Envelope

Biomimicry relies primarily on biological knowledge. The architect's role is to derive principles and strategies used by living organisms to adapt to their environment and apply these principles and strategies as inspiration for creativity in the design of building envelope. There are two approaches to Biomimicry design:

1. **Direct Approach:** This method involves identifying the problems faced in designing the building's envelope and

then comparing them to similar problems in nature to select the best solutions inspired by nature, leading to innovative design for the building's envelope. VII.

For example, the Parkview Square building in Singapore, as shown in Figure 9, mimics the shape of durian fruit spines, as illustrated in Figure 10, to design sunshades for its exterior. This design addresses the problem of high temperatures and intense solar radiation.

Figure 9: The Park Theatre in Singapore. (Eisawy, 2023)

Figure 10: Durian plant (vtrading, 2019)

2. **Indirect Approach:** This method involves examining nature and understanding the various solutions used by living organisms. By identifying a specific property, behavior, or function of an organism, this approach applies these insights to the design of building exteriors or uses them in various designs across different fields.

For example, the lotus flower, shown in Figure 11, has self-cleaning properties. This characteristic was used to develop a paint (Sto's Lotusan paint), as shown in Figure 12, which can be applied to building facades to provide self-cleaning capabilities. (El Ahmar, 2011)

Figure 12: Coating (Sto's Lotusan paint) inspired by the lotus flower (El Ahmar, 2011).

Figure 11: The lotus flower has the ability for self-cleaning (El Ahmar, 2011).

b. Study of the Principles for Creative Design Inspired by Nature

Nature can be considered a design method through learning from it as a pattern and system. It can be utilized through several principles as follows:

- **Solution Approaches Grow from the Place:** Each location has its own climate and materials.
- **Making Nature Visible:** Learning from nature by borrowing natural forms and making them evident.
- **Designing with Nature:** Utilizing natural resources such as energy, water, land, and minerals.
- **Incorporating Ecological Considerations in Design:** Applying sustainability principles, conserving energy, recycling materials, and considering user comfort.

Since living organisms follow designs and forms suited to them, designers should choose the best design that harmonizes with nature. (جودة, 2021)

Analysis of Projects Adopting Biomimicry in Creative Design for Building Envelope

The analytical study aims to illustrate an example of a building that adopted the Biomimicry approach in designing its exterior envelope. It examines the methods the architect mimicked from nature to enhance the thermal performance of the building's envelope. The selected project for this purpose is the S.C.A.L.S. building (a global project).

1. **Identifying Analysis Principles for Case Studies**

Figure 13 illustrates the principles through which the examples will be analyzed as follows:

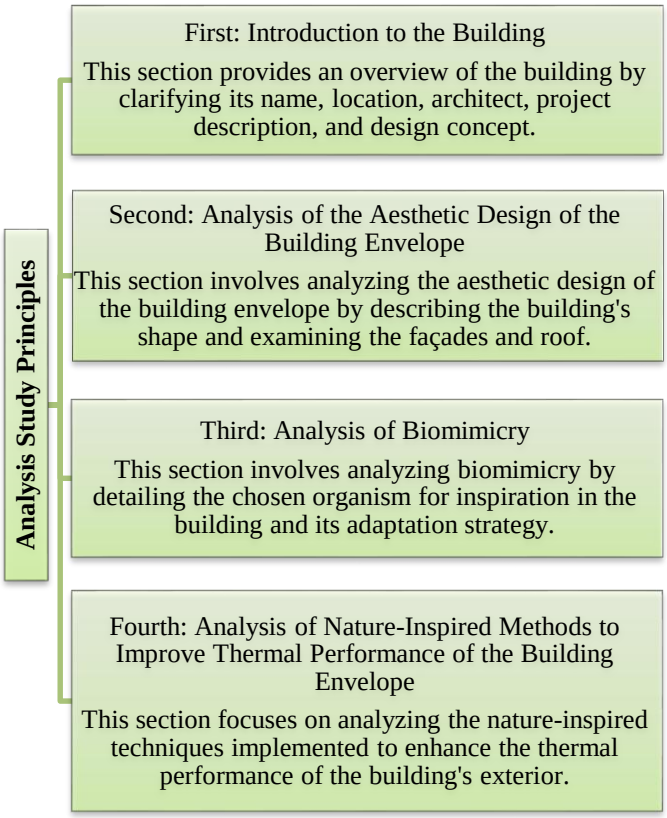


Figure 13: Axes of the analytical study

2. **Analysis of the S.C.A.L.E.S Building**

a. **Introduction to the S.C.A.L.E.S Building (International Project) as shown in Table 2 (Mazzoleni, 2010, غنيمى إبراهيم et al., 2020)**

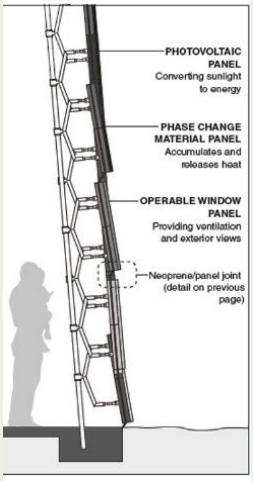
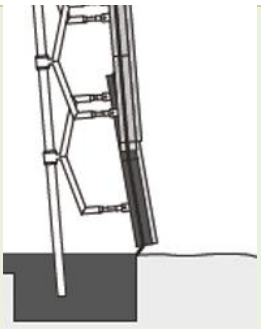
TABLE II Analysis of the S.C.A.L.E.S Building

An introductory overview of the building S.C.A.L.E.S.		
Site	Palm Springs, California, Western United States.	 Figure 16: S.C.A.L.E.S. Building.
Usage	Residential Studio	
Architect	Ilaria Mazolini and her students (Yuan and Juan San Pedro)	

Project Description	A residential studio directly anchored to the ground, much like a lizard, as shown in Figure 14.
Design Concept	**Idea:** Achieving thermal comfort in extremely hot days and freezing nights. **Inspiration:** The concept is inspired by the behavioral strategy of lizard skin and its ability to regulate temperature and avoid sunlight.
Climate Region	Desert region, characterized by hot, dry summers and intense solar radiation

b. Analysis of the Creative Design of the Building Envelope as shown in Table 3 (Nessim, 2016)

Table III Analysis of the Creative Design of the Building Envelope

Analysis of the Creative Design of the Building Envelope		
Building Shape	The building takes the form of a cube with walls and a roof angled according to the movement of the sun, as shown in Figure 15.	 Figure 17: Building Shape
Exterior Envelope Structure	The envelope consists of a reinforced steel grid to which panels are attached. These panels vary depending on their orientation and exposure to sunlight, and between them is a flexible neoprene foam membrane that allows the panels to move and rotate.	 Figure 18: The exterior envelope structure
Walls	**Shape:** The wall is made of panels of specific shapes. **Color:** Panels have light colors on the east and west sides and dark colors on the south side. **Texture:** The envelope comprises three types of panels: photovoltaic panels, movable glass panels for ventilation, and solid panels. **Transparency and Porosity:** Solid panels with glass panels for ventilation, as shown in Figure 16.	 Figure 19: Vertical section in the building envelope showing the color, texture, transparency, and porosity of the panels that make up the building envelope.
Roofs	**Shape:** Made of panels of specific shapes. **Color:** Panels have dark colors on the roof. **Texture:** Includes photovoltaic panels and hollow insulating panels filled with PCM material. **Transparency and Porosity:** Solid panels, as shown in Figure 19.	 Figure 20: The panels making up the roof of the S.C.A.L.E.S building.
External Openings	**Shape:** Panels of specific shapes. **Color:** Transparent. **Texture:** Glass panels. **Transparency and Porosity:** Transparent panels, as shown in Figure 20.	 Figure 21: A vertical section in the building envelope showing the color, texture, transparency, and porosity of the external

		openings in the building.

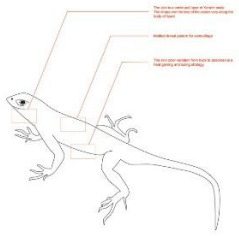
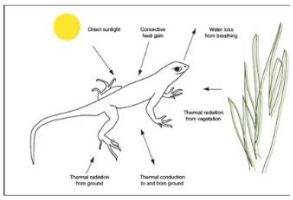
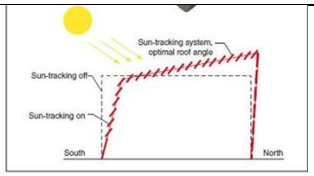
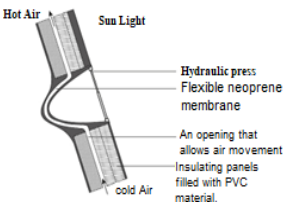
c. Biomimicry analysis as shown in Table 4 (Khalaf et al., 2018)

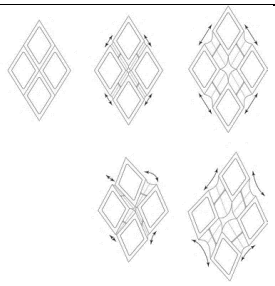
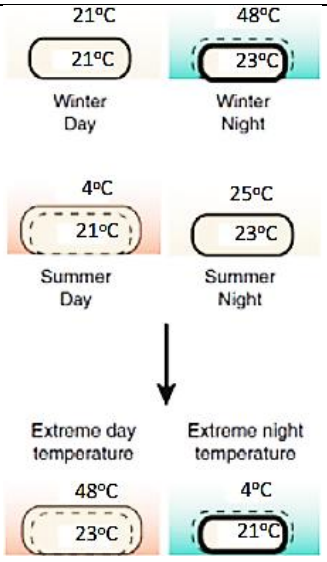
Table IV Biomimicry analysis

Aspect	Details		image
Simulation Method	Direct method in design.		
Level of Simulation	Organism and behavior level.		
Selected Organism	Organism	The **Uta** genus lizards	 Figure 22: The **Uta** genus lizards
	environment.	They live in arid desert regions.	
	description	They use their environment to regulate their body temperature. Their skin consists of two layers covered with scales, which protect the body from intense heat and prevent dehydration.	

d. Analysis of Nature-Inspired Methods for Improving Thermal Performance in Building Exteriors as shown in Table 5 (Mazzoleni, 2010, Khalaf et al., 2018)

Table V Analysis of Nature-Inspired Methods for Improving Thermal Performance in Building Exteriors

1. The lizard's ability to change its skin color has been simulated, as shown in Figure 20. Typically, the lizard has a dark color on its back to absorb sunlight and a lighter color on its belly to reflect heat from the ground.	 Figure 23: The lizard adapts by changing its skin color. (Khalaf et al., 2018)
In the design, panels have light colors on the east and west sides and dark colors on the south and roof sides to absorb ample heat and light.	 Figure 24: Variation in panel colors on different facades of the project. Researcher's coordination: (Mazzoleni, 2010)
2. The lizard adjusts its body position according to the need: it becomes vertical to the sun's rays to absorb heat, or parallel to the sun to avoid excessive heating, as shown in Figure 24.	 Figure 25: The lizard's strategy of adjusting body position as needed to regulate its temperature. (Khalaf et al., 2018.
In the building design, panels are equipped with a hydraulic system allowing them to rotate and follow the sun's rays, powered by electricity collected by photovoltaic cells, as shown in Figure 25.	 Figure 26: Vertical section showing the rotation of panels according to the sun's angle. Researcher's coordination: (Nessim, 2016)
The lizard spends the hottest hours of the day in the shade to prevent overheating, as shown in Figure 26.	 Figure 27: The lizard's strategy of hiding in the shade to avoid heat gain. (Khalaf et al., 2018)
This strategy is simulated by having insulating panels on the envelope that regulate indoor temperature, filled with Phase Change Material (PCM) and separated by an air passage that absorbs or cools heat depending on the time, as shown in Figure 27.	 Figure 28: Section showing the panels and the foam membrane between them. Researcher's coordination: (Nessim, 2016)

The lizard curls its toes upward to reduce the heat by minimizing the body's contact area with the ground, as shown in Figure 28.	 Figure 29: The lizard curls its toes upward to avoid increasing heat. (Khalaf et al., 2018)
This strategy is simulated by installing panels on devices with sensors allowing small movement and expansion, as shown in Figure 29	 Figure 30: Movement and expansion of panels according to temperature differences. Researcher's coordination: (Mazzoleni, 2010)
As a result of the movement and expansion of the panels, during winter nights when the temperature outside the building is 4°C, the building's volume increases and the temperature inside the building rises by 17°C, reaching 21°C inside. In contrast, during summer days when the temperature outside the building is 48°C, the building's volume contracts and the temperature inside the building decreases by 25°C, reaching 32°C inside.	 Figure 31: Temperature and volume changes due to panel movement and expansion. (Ghneimi Ibrahim et al., 2020)

RESULTS

Theoretical Study Results

- The creative design of the building envelope consists of several components, determinants, sources, and visual characteristics that architects must consider when shaping the building's exterior.
- The building envelope acts as the medium through which external climatic conditions transfer into the building. It can be controlled through various elements of the envelope as shown in Table 6.

Table VI various elements control the building envelop

Element	Heat Transfer Methods	Control of Heat Transfer through Envelope Elements
Roofs	Solar radiation	Control the construction material, thickness, and shape of the roof.
Walls	Conduction	Control the construction material, thickness, and shape of the wall.
Openings	Direct and reflected solar radiation, and heat leakage	Modify the design, shape, location, orientation, and treatment of the openings.

- biomimicry is not merely imitation, but rather understanding the organism's design principles, life lessons, and how it secures its needs and enhances its external habitat.
- Collaboration between biologists, engineers, and especially architects is essential to study living organisms, learn from them, and apply their adaptive strategies to building designs.

Analytical Study Results

- In the S.C.A.L.E.S. building, due to the movement and expansion of the panels, the following effects were observed:
  - **a)** During winter nights, the temperature inside increased by 17°C. When the outside temperature was 4°C, the building's size expanded, leading to a rise in internal temperature to 21°C.
  - **b)** During summer days, the temperature inside decreased by 25°C. When the outside temperature was 48°C, the building's size contracted, reducing the internal temperature to 23°C.

CONCLUSIONS

With rapid technological advancement, achieving thermal comfort for building occupants has become an essential responsibility for architects, along with preserving the environment and reducing pollution. Based on this, the study recommends the following:

- The establishment of laws and regulations governing the design of the building envelope aimed at improving thermal performance.
- Raising awareness among architects about the importance of creatively designing the building envelope to ensure it performs its functional role, rather than being seen merely as a final aesthetic layer.
- Increasing scientific conferences and training sessions focused on raising awareness among architects about biomimicry and the latest discoveries in how living organisms adapt to their environments and exploring ways to mimic these adaptations in architectural design.

- Future studies should focus on applying the biomimicry approach to other building elements, such as lighting and acoustics, and assessing its impact.
- Exploring the possibility of imitating the same living organism across buildings with different uses and monitoring the resulting thermal performance.

REFERENCES

1. ATTAR, S. & AL-EISAWY, M. 2023. method to improve thermal performance. Fayoum University Journal of Engineering, 6, 95-113.
2. EL AHMAR, S. A. S. 2011. Biomimicry as a tool for sustainable architectural design. Unpublished Master of Science Thesis, Alexandria University, Alexandria.
3. KHALAF, S., ABDELMOHSEN, M. & SHAMSELDIN, A. 2018. Simulating the natural environment to achieve thermal comfort in the desert environment.
4. MARWAN. 2019. The architectural structure between chaos and construction [Online]. अन्धेसमाग. Available: https://egyresmag.com/%D8%A7%D9%84%D8%AA%D8%B4%D9%83%D9%8A%D9%84-%D8%A7%D9%84%D9%85%D8%B9%D9%85%D8%A7%D8%B1%D9%8A-%D8%A8%D9%8A%D9%86-%D8%A7%D9%84%D9%81%D9% [Accessed].
5. MAZZOLENI, I. 2010. Biomimetic Envelopes. Academic research.
6. NESSIM, M. 2016. Biomimetic architecture as a new approach for energy efficient buildings. Cairo University, Cairo.
7. VTRADING. 2019. Vietnam Durian [Online]. Available: https://vtrading.vn/vietnam-durian/ [Accessed]
8. ا .المنشاوى, ا .n. & Prophet, 2016 .ا. Effect of construction technology on the structure of the building and its surface in the study of thermal comfort and applied effect of the project. Journal of Al-Azhar University Engineering Sector, 11, 343-359.
9. Tamim. 2017. sustainable architecture and architectural styles. University of Sudan for Science and Technology.
10. quality, 2021 .ا. How to improve the performance of a biological system by simulating nature. Doctor's letter, College of Engineering, University of Al-Mansoura
11. Shaykh A. Yanair 1997. Al-Bada'i Fandai Fil Mara'ata, Matabar Ahram..
12. ع .عباس, السني, ع .A. & Hasan, S. 2019. The impact of climate design on the thermal comfort of users. University of Sudan for Science and Technology. 13. Ghanimy Ibrahim, ج., عبد القادر الحناوى, م., الكردى, ع., عحمد & سبح, ع .m. 2020. The environment of life and its impact on the external environment. Environmental Science Journal, 49, 1-29..