Biomimetic Adaptive Facades

Preeti Panjwani [1], Khushboo Sahu[2]

[1] *Student, Amity School of Architecture & Planning, Amity University Chhattisgarh*
[2] *Professor, Amity School of Architecture & Planning, Amity University Chhattisgarh*

***

Abstract - *Industrialized and developing nations are embracing the low-carbon city and society development plan, which aids in the prevention and adaptation to climate change. Buildings continue to be a major concern because they account for 30% of the world's power consumption and for 23% of its main energy use. Space heating and cooling accounts for 60% of all energy used in buildings.*

The primary factor in regulating energy consumption in buildings and preserving internal comfort is the building envelope. A building envelope has traditionally been thought of either a thermal barrier to stop heat escape or as shade to regulate solar gain. The conventional solutions for building envelopes lack the ability to adapt to contextual issues and needs.

Advancements in Architecture have led to developments of façade that give solution to this problem is biomimicry, which involves using nature-inspired design principles to create sustainable technologies. Building envelopes that respond to changes in the external environment, such as temperature and sunlight, to maintain a comfortable indoor environment while reducing energy consumption are known as Biomimetic Adaptive Facades. These facades are inspired by the natural adaptive mechanisms found in many organisms that allow them to respond to changing environmental conditions to survive and thrive. These are designed to regulate temperature, humidity, and light within buildings while minimizing energy consumption with the help of advanced control and automation systems to optimize their performance. These systems may include sensors, actuators, and algorithms that respond to changes in the environment and adjust the facade's properties accordingly.

Key Words: **Biomimicry, Adaptive Facades, Energy Consumption, Building Skins.**

1.INTRODUCTION-

Buildings are responsible for a significant portion of global energy consumption and greenhouse gas emissions. As such, finding ways to make buildings more energy-efficient is critical for mitigating the effects of climate change. One promising solution to this problem is biomimicry, which involves using nature-inspired design principles to create sustainable technologies. One example of this is the development of biomimetic adaptive facades for buildings. Biomimetic adaptive facades are building envelopes that respond to changes in the external environment, such as temperature and sunlight, to maintain a comfortable indoor environment while reducing energy consumption. These facades are inspired by the natural adaptive mechanisms found in many organisms, which can respond to changing environmental conditions to survive and thrive.

Biomimetic adaptive facades offer several advantages over traditional building envelopes-

- They can significantly reduce energy consumption by minimizing the need for heating and cooling systems.
- They can improve indoor air quality by allowing for natural ventilation.
- They can enhance occupant comfort by regulating temperature and reducing glare.
- It can increase the lifespan of a building by protecting it from weather damage.

Some challenges to be addressed in the development of biomimetic adaptive facades are-

- High cost of these technologies, which can make them prohibitively expensive for many building projects.
- The complexity of these systems can make them difficult to maintain and repair.
- Integrating these systems into existing buildings may require significant modifications to the building structure.

1.1 Aim & Objectives-

The aim of the study is to study biomimetic adaptive envelopes that can adapt to changing environmental conditions and reduce energy consumption.

The objectives of the study are-

- To understand and study facades that are inspired by the natural adaptive mechanisms found in living organisms that can regulate temperature, minimize glare, and enhance indoor air quality.
- The study is focused on studying control systems that can be used to create these facades.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 06 | Jun 2023 www.irjet.net p-ISSN: 2395-0072

1.2 Research Methodology-

The research methodology involves the study of Biomimicry as a concept and Adaptive Facades. It includes a comparative analysis of the case studies of applications in the building context.

2. BIOMIMICRY IN ARCHITECTURE-

2.1 What is Biomimicry-

Otto Schmitt, an American inventor, first used the term "biomimetics" to describe the process of transferring biological principles to technology in the 1960s. To provide sustainable solutions, biomimicry is described as imitating the functional foundation of biological shapes, processes, and systems. Biomimicry is the study of, and imitation of, biological structures, functions, and ecosystems that have been modified by evolution and subjected to environmental testing.

The benefits of using biological examples are that they have undergone more than 3.8 billion years of testing and research through evolution, which makes them a solid foundation for developing innovative approaches to sustainable development.

Designers can migrate to their new role as sustainability practitioners with the help of the growing notion of biomimicry. The use of Biomimicry prompts fresh inquiries that can be used to examine both the course of design and its conclusion. For instance, biological designs are often zero-waste, durable, flexible, and adaptive. When biology has a significant impact on design thinking, it moves from an anthropocentric perspective and considers product life cycles and earth system restrictions.

2.2 Biomimicry Application Levels-

When solving design issues, biomimicry must be used at three levels. The three levels are: organism, behavior, and ecosystem. The organism level demonstrates the imitation of a specific organism or a portion of the entire organism. The second level of behavior is the mimicking that every creature exhibits. Level three, which is regarded as the toughest level since it focuses on a technically complex subject, replicates the complete ecosystem.

a) Organism Level-

On the organism level, the architecture looks to the organism itself and applies its form, shape, or structure to a building. This level of biomimicry focuses on emulating the physical forms and shapes found in nature to inspire architectural design. Architects may draw inspiration from the shapes of leaves, shells, animal bodies, or other natural structures to inform the design of building facades, roofs, interiors, and other architectural elements.

One of the best examples for organism level in Biomimicry is "The Gherkin," officially known as 30 St Mary Axe, located in London, United Kingdom. The Venus Flower Basket Sponge, a particular kind of glass sponge, served as the basis for the structure of The Gherkin, which was created by architect Norman Foster and finished in 2003.The silica spicule mesh that makes up its body's structural integrity could bend at its intersections to absorb stress. Seawater is filtered for nutrients through the sponge's hollow "basket" made of the silica skeleton. [4]

Fig -1: Venus Flower Basket
Source: Britanica.com

b) Behavior Level-

- This level of biomimicry involves emulating the functional strategies and mechanisms found in nature to inform architectural design. Architects may study how nature optimizes energy, manages water, regulates temperature, or achieves structural stability, and apply those strategies to building design.
- Using natural ventilation strategies inspired by termite mounds to design more energy-efficient buildings or incorporating rainwater harvesting systems inspired by plant root systems to manage water runoff and reduce water consumption.
- One such case example is Council House 2. One of the key biomimicry principles applied in CH2 is the concept of thermal regulation inspired by termite mounds. Termites build mounds that maintain a relatively constant temperature inside, despite the extreme temperature fluctuations outside. CH2's design mimics this behavior by using a combination of natural ventilation, thermal mass, and shading devices to regulate its internal temperature. The building is designed with a double-

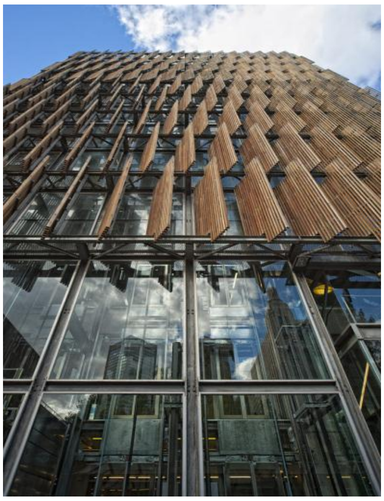

Fig -2: CH2 Facade Inspired by Termite Mounds
Source: Arch Daily

skin facade, with the outer layer providing shading and the inner layer allowing natural light and views. The facade is operable, allowing for natural ventilation to regulate the building's internal temperature reducing energy consumption by 50%, gas consumption by 87% & main water supply by 72%. [5]

c) **Ecosystem Level-**

- This level of biomimicry involves emulating the complex systems and ecosystems found in nature to inform architectural design. Architects may study how ecosystems function, how different organisms interact, and how natural systems achieve balance and resilience, and apply those principles to building design.
- For example, designing buildings that integrate with their surrounding ecosystems, mimic the circular economy and waste reduction of ecosystems, or create symbiotic relationships with local flora and fauna.
- An advantage of designing at this level of biomimicry is that it can be used in conjunction with other levels of biomimicry (organism and behavior).
- The unique tidal approach used by Living Machine Systems to purify water is based on the concepts of wetland ecology. Utilizing biomimicry, this technology turns black water into non-potable water that can be recycled for agriculture. A small number of wetland cells filled with specific gravel that promotes the growth of micro-ecosystems were introduced into the system. These cells are incorporated into the ground-floor green platforms, underground gardens, and greenhouses. Like how tidal cycles occur naturally in wetlands, the water circulates through the system, flooding and draining the cells to produce numerous tidal cycles per day. [3]

2.3 Biomimicry & Energy Consumption-

The International Energy Agency estimates that approximately 50% of all energy is consumed by buildings. This reality emphasizes the need of proposing techniques that lower building energy consumption yet continuing to contribute to the ultimate sustainability goal. Nature appears to employ low-energy techniques, suggesting that a variety of biological species could be examined as an origin of creative solutions for reducing power consumption. For improving energy-efficient design in the same way, biomimicry has been acknowledged as a pioneering design methodology. To address the issue of high energy consumption, contemporary technology developments and nature is identified a source of problem-solving will work together to provide architectural solutions. [6]

With the help of these solutions, a building's energy efficiency may change as well as the indoor environment's quality, which would significantly increase occupant contentment. The most important component for a building's energy efficiency is its building envelope. Building envelopes can be made more energy-efficient by using biomimetic techniques.

Termite mounds are a well-known natural example of energy efficiency because their air conditioners move warm and cool air between the mound and the surrounding area. Based on the termites' process, Mick Pearce constructed Eastgate Centre in 1990. Compared to a building of same size and climate, it uses 90% less energy. Utilizing convective airflow from cool to warm, they utilize the stack effect. [1]

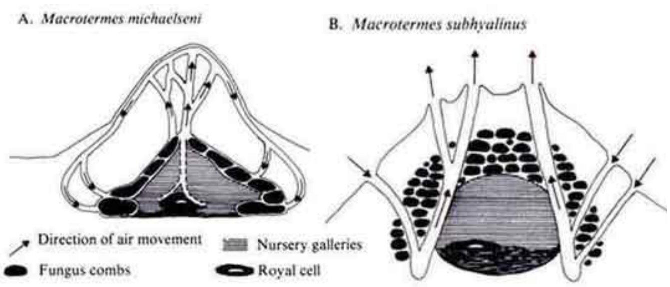

Fig -3: Termite Mounds- Eastgate Center
Source- Inhabitat.com

3. ADAPTIVE FACADES-

Adaptive facades, also known as responsive facades or dynamic facades, are building envelopes that can adjust their performance in response to changing environmental conditions. These facades are designed to optimize energy use, enhance occupant comfort, and improve building performance by adapting to external factors such as sunlight, temperature, wind, and humidity. Adaptive facades can be integrated with various technologies, such as sensors, actuators, and control systems, to enable real-time adjustments and optimize building performance.

Adaptive facades can take different forms and can include various features, such as movable shading devices, adjustable insulation, variable transparency, and ventilation openings that can open or close based on environmental conditions. These features allow the facade to respond dynamically to changing conditions, reducing the need for mechanical heating, cooling, and lighting systems, and thereby reducing energy consumption and improving sustainability.

Adaptive facades are increasingly being used in contemporary architecture as a sustainable design approach, as they can optimize building performance, improve occupant comfort, and reduce environmental impact. They can be found in various building types, including commercial buildings, residential buildings, educational institutions, and public buildings, and can be applied to both new construction and retrofit projects. Adaptive facades represent a promising approach to creating high-performance buildings that are responsive to the environment and promote sustainable design practices.

3.1 Biomimetic Adaptive Building-

Biomimetic adaptive facades in architecture have gained increasing attention as a sustainable and innovative approach to building design. These facades are inspired by the adaptive strategies found in nature and can adjust their performance in response to changing environmental conditions, optimizing energy efficiency, and enhancing occupant comfort.

Some of the strategies used to achieve this are-

•Self-shading:

Biomimetic adaptive facades can be designed to self-shade, like the way trees and plants adapt to changing sunlight by adjusting their leaves or branches. This can be achieved using movable shading devices, such as louvers, fins, or blinds, that automatically adjust their position based on the angle and intensity of sunlight. This helps to reduce solar heat gain during hot periods and allows more natural light to enter during colder periods, optimizing energy consumption and enhancing occupant comfort.

For example, some biomimetic adaptive facades may incorporate leaf-like shapes, textures, or patterns in their shading devices, mimicking the natural adaptation of leaves to changing sunlight conditions. By emulating nature's self-shading strategies, biomimetic adaptive facades can optimize building performance, enhance occupant comfort, and promote sustainability.

•Thermoregulation:

Just like how animals and plants thermoregulate, biomimetic adaptive facades can use materials with thermal properties that allow them to adapt to changing temperatures. For example, phase-change materials (PCMs) can store and release heat as they change from solid to liquid and vice versa, helping to regulate indoor temperature. PCMs can be incorporated into the facade's construction materials or used as a separate layer to provide thermal insulation, reducing the need for mechanical heating or cooling.

•Ventilation and airflow:

Biomimetic adaptive facades can be designed to facilitate natural ventilation and airflow, like how termite mounds or beehives are designed to optimize airflow for temperature regulation. This can be achieved using strategically placed openings, vents, or porous materials that allow for passive ventilation and promote natural convection currents. This can help reduce reliance on mechanical ventilation systems and improve indoor air quality.

•Biomimetic materials:

The use of biomimetic materials, which are inspired by natural systems, is another strategy in adaptive facades. For example, materials that mimic the hydrophobic properties of lotus leaves can be used to create self-cleaning facades that repel dirt and pollutants, reducing the need for frequent cleaning and maintenance. Similarly, materials that mimic the microstructure of bird feathers can be used to create lightweight and strong facades that are also highly efficient in terms of insulation and thermal performance.

•Sensor-based controls:

Biomimetic adaptive facades can incorporate sensor-based controls that monitor environmental conditions, such as temperature, humidity, solar radiation, and wind speed, and adjust the facade's performance accordingly.

These sensors can provide real-time data that triggers the movement of shading devices, adjustment of ventilation openings, or activation of other adaptive features, optimizing the facade's performance in response to changing environmental conditions. The collected sensor data is then processed by a control system, which uses algorithms to analyze and interpret the data. Based on the analyzed data, the control system can trigger appropriate responses in the adaptive facade to optimize its performance. [8]

4. CASE STUDIES & INFERENCES-

Table -1: Comparison Table

Parameters	NBF Osaki Building	City Council House	Inferences
Location	Japan	Australia	-
Project Type	Office	Office	-
No. of Floors	11	10	-
Concept	Uchimizu and Bio skin System	Synergy – a building comprised of many overlapping systems, each being more than the sum of its parts.	-
Biomimicry Level	Behavior	Behavior	All the three types of biomimetic levels can be

			implemented, and each type of level benefits the building envelope.
Inspiration	Japanese concept of water spraying mechanism	Epidermis.	Taking Inspiration from nature that can make buildings energy efficient.
Design Features (façade)	1. Unglazed porous pipes, which are easily permeable and can double as balcony handrails thanks to inspiration from sudare [traditional bamboo screens], were employed. 2.Rainwater that had accumulated underground was drawn up using electricity generated by direct sunlight, which subsequently evaporated in the pipes that lacked glazing. 3. The building and the entire vicinity are cooled by the heat of vaporization.	1. West Façade is composed of timber vertical slats with a glazed wall. These slats pivot vertically opening& closing in response to the time of a day and angle of sun. 2. North & Southern façade consists of air ducts that symbolizes bronchi.	-
Design Features (any other)	Partial Greening was used to lower Heat Island Effect.	Thermal mass is used to absorb heat and minimize heat gain through window arrangement, and photovoltaic and thermal solar panels are used to generate power and heat.	-
Energy Saving Systems	-	Use of Shower Towers- AC water is run down on these 15 m long towers which is piped into basement where it is cooled through phase change apparatus and distributed when needed.	Use of energy systems combined with inspiration from nature lowers the buildings energy consumption.
Material	Specialized Ceramic Louvers	Timber Vertical Slats	Using local materials innovative methods can be created.
Façade Control Type	Sensor Based	Sensor Based	-

[7] [2]

5. REVIW & DISCUSSIONS-

Biomimetic adaptive facades are designed to mimic natural systems and biological methods to create a building envelope that can dynamically adjust to changing environmental circumstances, enhancing energy efficiency and occupant comfort. Here are some of architectural design strategies which can be used currently for designing biomimetic adaptive facades-

•Form and Shape-

a) Biomimetic adaptive facades are frequently inspired by natural forms and geometries, such as tree branching patterns or seashell spiral designs.

b) The facade's design can be optimized to catch and utilize natural light and ventilation, as well as to offer shading and insulation as needed.

•Material-

a) The materials utilized in the construction of biomimetic adaptable facades are frequently influenced by natural systems, such as lotus leaves' self-cleaning features or photosynthetic organisms' energy-harvesting capacities.

b) Thermal and acoustic qualities, as well as durability and ease of maintenance, can all be considered when selecting materials.

• Systems & Mechanisms-

a) Solar shading devices that modify their position based on the position of the sun are examples of biomimetic adaptive facades.

b) These systems and mechanisms, which may include sensors, actuators, and control systems, can be powered passively or actively.

• Integration with BMS-

a) Biomimetic adaptive facades may include a variety of systems and methods that allow for dynamic reactions to changing environmental conditions, such as solar shading devices that vary their location based on the position of the sun.

b) These systems and mechanisms may be powered by passive or active means, and may include sensors, actuators, and control systems.

Most biomimetic buildings that have already been constructed have failed to fully retain the properties or qualities of the mimicked organism or biosystem. This is due to the inability to completely access biological potentials, limitations in describing biophysical knowledge, and difficulties in abstracting and altering biological mechanisms. The evolution of biomimicry in engineering and technology is limited to specific scales for transferring biological techniques from nature to design. These limits have limited the scope of the inquiry, restricting the use of biomimicry in creating more sustainable designs. Furthermore, following strategies can be used included in the building design to make the buildings more functional-

•AI & Machine learning-

a) Artificial intelligence (AI) and machine learning algorithms may be used in future biomimetic adaptive facades, allowing the facade to learn and adapt to human behavior and environmental circumstances over time.

b) These algorithms may use data from sensors and other sources to optimize the facade's performance while also giving the building's energy use and environmental effect more control.

•Active Response Mechanisms-

a) Future biomimetic adaptive facades may include active reaction mechanisms, such as robotic components that modify the position and configuration of the façade in real-time, in addition to passive response mechanisms such as shading devices and natural ventilation.

b) These active response mechanisms may enable greater precision and control over the performance of the facade, which can be designed to incorporate energy storage and distribution systems that allow the building to generate and store its own energy while also sharing excess energy with the grid or neighboring buildings.

c)Batteries, fuel cells, and other technologies that provide increased energy independence and resilience may be included in these systems.

•VR & AR-

a) Virtual and augmented reality technology could be used to mimic the performance of biomimetic adaptive facades in real time, allowing designers and building owners to test and optimize the performance of the facade before it is erected.

b) These technologies could also be employed to give residents a more immersive and interactive experience with the facade, increasing their engagement and connection to the structure and its surroundings.

•Self-Regulating thermal mass-

a) Future biomimetic adaptive facades may be created with self-regulating thermal mass that may collect and release heat based on the external temperature and the building's interior heating and cooling needs.

b) Materials such as phase-change materials and thermal mass walls, which may store heat and gently release it over time, provide natural temperature regulation and reduce the building's reliance on heating and cooling systems, may be used in the facade.

•Dynamic Coloration-

a) Future biomimetic adaptive facades may include dynamic coloring, which can alter color and transparency in reaction to light and heat fluctuations.

b) Electrochromic glass and thermochromic coatings, for example, can vary their color and opacity based on the external environment, giving natural shade, and decreasing the need for artificial lighting and cooling.

•Multi Scale Ventilation-

a) Future biomimetic adaptive facades may include multi-scale ventilation systems that may control air flow at various scales, from individual rooms to entire structures.

b) Shape-memory alloys and adaptive louvres, which can modify their shape and position to optimize air flow and lessen the building's dependency on mechanical ventilation systems, may be used in the facade.

6. CONCLUSION-

Human problems can be resolved by incorporating the ecological and energy-efficient components found in nature into design. By drawing inspiration from nature, an innovative approach for developing energy-efficient building envelopes can be developed. By studying and modelling natural processes, the biomimicry technique can help humans consume less energy.

The research revealed numerous features of biomimetic design and adaptable building skins that address numerous shortcomings in architectural design. Most architectural systems, which employ automatic control ideas and intelligent materials, are only capable of adapting to human wants and weather circumstances. The study discovered that biomimicry presents a wide range of opportunities for flexible sustainable architecture designs. However, there are several challenges that biomimetic investigations must overcome, especially when converting natural ideas into technical systems. Most imitation techniques don't consider the entire system, only specific components. The current study has also shown that applying biomimicry ideas to architecture is still in its infancy, as seen by the many levels and scales of ideas, particularly those systems that deal with function and process.

To properly approach and realize functional systems, the ideal relationship between external elements (environment and process) and internal factors (form and behavior of organisms) should be formed. Designing adaptive systems is difficult, because it should resemble how natural systems function under many settings and circumstances.

Instead of thriving specifically on standard analysis, it is important to comprehend adaptive systems at several levels (organism, behavior, and ecosystem). Due to a lack of distinct ecosystem-based systematic designs and a dearth of relevant design methodologies, the current study discovered that prior literature primarily focused on materials and ideas—rather than implementation. Additionally, there are restrictions on how to search for and choose solutions from nature, which leads to scalability issues and conflicts between integrated pieces in design concepts. Most study aims to comprehend.

Most of the study aims to comprehend the informational, procedural, and structural components of biomimetics. However, categorizing biomimicry concepts still presents significant difficulties because of the unavoidable overlap of many categories and the difficulty of explaining biological systems.

REFERENCES

[1] Annon. (2005). Natural innovation: the growing discipline of Biomimetics. *Strategic Direction*.

[2] *Archdaily CH2 Melbourne City Council House 2.* (n.d.). Retrieved from archdaily.com: https://www.archdaily.com/395131/ch2-melbourne-city-council-house-2-designinc

[3] Benyus, J. M. (2007). *Biomimicry: (Innovation Inspired by Nature).* Harper Collins.

[4] Ehsaan. (2010, March 24). *Lord Foster's Natural Inspiration: The Gherkin Tower.* Retrieved from web.archive.org/biomimeti-architecture.com: http://www.biomimetic-architecture.com/2010/lord-fosters-natural-inspiration-the-gherkin-tower/

[5] Pearce, M. (n.d.). *mickpearce.com.* Retrieved April 2023, from https://mickpearce.com/CH2.html#:~:text=CH2%E2%80%99s%20public%20face%20is%20the%20tall%20facade%20overlooking,of%20day%20and%20the%20angle%20of%20the%20sun.

[6] Roy, H. &. (2007). Technological innovation, energy efficient design and the rebound effect.

[7] Sekkei, N. (n.d.). *BIOSKIN: A Facade System for cooling city heat islands.* Retrieved from www.nikken.co.jp: https://www.nikken.co.jp/en/expertise/mep_engineering/bioskin_a_facade_system_for_cooling_city_heat_islands.html

[8] Tabadkani, A. (2020). *Natural innovation: the growing discipline of adaptive facades : A Review.* Science Direct.