Biomimicry for Developing Energy Efficient Facades

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***Abstract* - Mankind has often drawn inspiration from nature to solve problems since nature has complex mechanisms that have been perfected over thousands of years. Natural processes, on the other hand, embody sustainability values, but there are many lessons to learn from nature to solve design challenges and build a more sustainable future. A biomimetic design methodology retains this promise. Bio-design is another design approach that includes incorporating natural elements into the design. The building façade is a challenging research area because it sits at the intersection of living spaces and the natural environment, posing numerous challenges, especially in terms of energy-air-water transitions between indoors and outdoors. Natural processes may be used to strengthen the implementation of key energy-efficient principles in architecture, such as energy requirements, shape and function, and development considerations. Through the perspectives of biomimetics and bio-design, this study examines cutting-edge design concepts, materials, and designs in building façades. The design principles are explained first, followed by the materials and a few examples. Biomimicry and bio-design are in line with the philosophy of energy efficiency; but, to achieve energy-efficient façade solutions, biomimetic concepts must be at the center of the design.**

***Index Terms* - biomimetics, biomimicry in architecture, building skin, energy-efficient, façade development.**

I.INTRODUCTION

Concerns about energy's long-term viability are understandable, given that it provides 'basic services' for human life, such as heat for warmth, cooking, and manufacturing. In the twenty-first century, an overwhelming amount of primary energy is lost due to inefficient building design all over the world. In addition to the equipment that converts energy, services are needed. As a result, there has been a rapid rise in public understanding of energy conservation and reliability, necessitating the development and implementation of a variety of design methods and solutions to address energy problems.

Biomimicry is one of these approaches, which is described as "the applied science that stimulates approaches for solving human problems by studying natural designs, structures, and processes". While biomimicry is a relatively recent concept, its implications have been part of architecture for millennia, especially in terms of shape generation and structural system replication.

The relationship between nature, technology, and architecture is a long-standing conflict with numerous historical twists and turns; however, paradigm shifts have occurred at an unprecedented rate in recent decades. Material sciences are one of the recent development areas, such as modern ways of producing old materials and nanoscale innovation. Biomimicry processes are usually problem-based, ranging from design to biology, or solution-based, ranging from biology to design.

Bio-design is a newer concept that involves mimicking biological processes as well as incorporating biological organisms into design or construction processes. Redesigning building techniques and material sciences using biological materials are two recent fields of progress. Though there are few built examples, biomimicry is still evolving and employs both a problem- and a solution-based approach at the same time. Benyus' concept of architecture as the creation of environments conducive to human life is shifting during this time of paradigm shifts.

A. Aim- Influence of biomimicry for energy-efficient façade development.

B. Objectives-

- To understand biomimicry and its methods of integration in façade development or building skin design.
- To study the different levels of biomimicry and their influence on developing façade.

- To research the effect of biomimicry on emerging technologies with its material and construction methods.
- To analyse if biomimicry can inspire building façade to be energy –efficient through analysis of functional examples.

C. Scope-

- To investigate the degree to which biomimicry can influence architecture in terms of façade development.
- Applications of the techniques developed using biomimicry for façade development.
- Analysing different aspects related to façade like a thermal envelope, use of HVAC, source of light and electrical consumption concerning biomimetic design.
- Development of form, material, construction method, process along with its function for biomimicry.

D. LIMITATIONS-

- The study will focus only on the behaviour level of biomimicry for façade development.
- The study will restrict to Marine West Coast Climate (cfb) of Koppen climate classification.
- The study will focus on static and dynamic façades.

E. METHODOLOGY-

To achieve the research objectives, an inductive research approach was used. Making observations is the initial step in the inductive approach; from these observations, a pattern will form, leading to an end theory. The inductive approach does not need a theory at the start of the analysis; it will develop as the study progresses. As a result, no hypotheses must be checked as they form through learning: "patterns, resemblances, and regularities in experience (premises) are found to reach conclusions (or generate theory)". First, a study of the literature on Biomimicry and energy-efficient buildings is done. The analysis of current literature shows methods and biomimicry in the construction of skin. Second, an observational analysis for international case studies will be discussed and evaluated in terms of biomimicry's use and effect on building energy consumption.

II. HISTORICAL BACKGROUND OF BIOMIMICRY

Biomimicry has a long history, going back to 500 B.C. when Greek philosophers used natural beings as models for creating a harmonious balance and proportion between the aspects of a design that corresponds to the classical ideal of beauty. Later, in 1482, Leonardo Da Vinci was inspired by birds to create a flying machine, which is considered the first example of Biomimicry. It aided in the construction of the Wright brother’s first aeroplane prototype in 1948. The term bionics was first coined by Jack E. Steele in 1958, and he described it as “the analysis of natural systems or their analogues”. The term Biomimicry, on the contrary, was coined in 1982. Janine Benyus, a scientist and author, popularized the word in her book “Biomimicry: Creativity Inspired by Nature13” in 1997. Bryony Schwan and Janine Benyus co-founded the Biomimicry Institute in 2005, and Chris Allen accompanied Beynus and Schwan in 2007 to help launch “AskNature,” the world’s first digital library that includes a list of natural solutions, where designers can browse through this set of natural systems that are categorized based on their architecture and engineering.

III. BIOMIMICRY DEFINITIONS

Many researchers have sought to describe Biomimicry. For example, biomimicry according to Benyus is “a new discipline that explores natures best ideas and then mimics their designs and processes to solve human problems”. Although Pederson Zari pointed out that one of the problems facing architects is the lack of a consistent concept from the many choices open to them in their projects. As a result, it's critical to assess the best strategy for completely implementing the best Biomimicry process and taking the benefits. Biomimicry, on the contrary, is known as “the study of overlapping biological and architectural fields that demonstrate innovative potential for architectural problems,” according to Guber.

A. Biomimicry in Architecture-

In terms of architecture, biomimicry is the imitation of biological structures, processes, and systems found in nature to construct architectural solutions that can be used for long-term solutions.

Biomimicry in architecture can take many forms, such as the use of biomorphic forms, which is the design of a building type that mimics a natural form. An example of this is council house 2 (Figure 1), also known as CH2, by Architect Mick Pearce, in Melbourne Australia where the building's façade took inspiration from a tree's bark. There are other, more purposeful ways to draw inspiration from nature. For example, the structure of Institute du Monte Arabe in Paris (Figure 2), uses mashrabiyas on the south façade of the structure to show the connection between Arab and France. Furthermore, biomimicry is used in structures that are inspired by nature. An example is this is the use of airflow and movement inside a structure such as The Gherkin in London (Figure 3) by Architect Norman Foster. The inspiration for the structure was drawn from the Venus' flower basket sponge, a type of glass sponge. These are only a few of the many examples of biomimicry that exist; many of these designs use biomimicry as a part of a larger feature or system, rather than as a complete design solution.

Figure-1 Council House 2, Melbourne

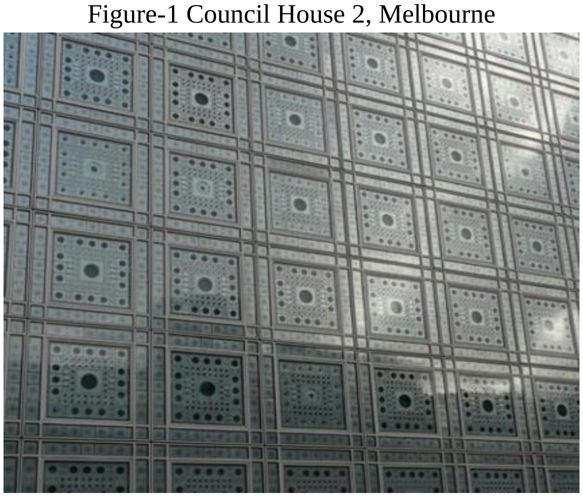


Figure-2 Institute du Monte Arabe, Paris

Figure-3 The Gherkin, London

B. Approaches Towards Biomimicry-

In an interview, Janine Benyus explains how biomimicry is about what we can learn from nature rather than what we can extract from it. Biomimicry is a growing field of research in architecture because it offers new and inspiring ideas while also allowing for energy conservation in the built environment. Two approaches to biomimicry are established as a result of this: biology to design and design to biology.

The Problem-Based Approach:

This approach is driven by biology and requires a sequence of steps that are either non-linear or dynamic. In the loops, this provides feedback as well as refinement. The designers use this method to look for solutions by first identifying the problem. This encourages the biologists to search for an organism that has solved a problem close to the one at hand. The problem-based approach aims to identify goals and limitations. Design to biology begins with the human design challenges, describes the practical problem, and then explores how the problem has been solved by species or ecosystems.

The Solution-Based Approach:

The biology influence design, bottom-up approach, and solution-based biological inspired design are all terms used to describe this process. When a biological process proposes a new way to address a human design problem, it is called biology to design. This method is used when the design process is based on biologists' and scientists' scientific experience rather than human design issues. For example, the scientific study of lotus flowers that emerged clean from swamp water resulted in many new designs.

C. Levels of Biomimicry-

When addressing a design issue, there are three key levels of biomimicry that can be used. These include form, process, and ecosystem. A solution can be found in nature by studying the organism or ecosystem, form, and process. It's crucial to find out which part of biology is being mimicked for this application. This is known as level.

The three levels identified of biomimicry are- organism, behaviour and ecosystem. When a specific flora or fauna mimics the entire organism or a specific function, this is referred to as organism level mimicry. The transition of an aspect of how an organism interacts with its environment, or broader context, is referred to as the behaviour level. The core principles that allow an ecosystem to work effectively are emulated or recreated at the ecosystem level.

IV. BUILDING SKIN AS AN ENERGY MANAGEMENT TOOL

Many researchers have defines the term building skin. For example, According to Rankouhi, it is the "boundary through which the building's interaction with the environment occurs". It responds to light, air, moisture, sound, and heat by forming layers and filters. "The ability to maintain optimal internal conditions that respond to the functions they bear is the most common feature." The building envelope, according to Hoeven, is the boundary between the interior of a building and the exterior and is identified as the building shell, fabric, or enclosure. Kieran, on the other hand, described the building skin as the location where the majority of energy and material exchange takes place. It is the perception of a structure's identity. It's how a building's name is perceived. The facade and roof cover the building's skin. External walls, floors, roofs, ceilings, windows, and doors are all included.

V. BIOMIMICRY AND BUILDING SKIN

It is appropriate to explore the parallels between building skin and biomimicry to draw analogies. This involves assessing the main similarities and driving forces that influence both nature and the architectural design process. The skeleton (structure) of a building is protected by a thin membrane that controls the organs (mechanical, plumbing, and electrical) and determines the interior spaces. The building skin resembles natural skin in that it is made up of layers and filters that respond to light, air, sound, moisture and heat in the same manner that natural skin does. Natural skin is known for its ability to maintain internal conditions while remaining responsive to its purpose. The building skin, like natural skin, acts as a buffer between the regulated and unregulated environments. It is the arrangement of the outcomes of both internal and external forces. They both function as filters in the process of allowing what is permitted to enter and exit.

VI. DESIGN PARAMETERS FOR ENERGY EFFICIENT BIOMIMETIC FAÇADE

Thermal, optical, airflow and electrical mechanisms are used by architects to enhance the efficiency of façades. High-performance sustainable façades are exterior enclosures that use the least amount of energy necessary to maintain a secure interior atmosphere that promotes the health and productivity of the building occupants. Biomimetics and bio-design have long assisted in the construction of façades in this context; however, not all designs that consider nature are energy efficient. The criteria for energy-efficient living models, such as how organisms heat, cool, give shade and regulate light, should be taken into account when designing a biomimetic façade. An organic skin will be driven by natural phenomena such as wind, sun, rain, drought, snow, and so on in a sustainable design crisis. It may also perform other critical functions such as breathing, carbon capture, and water balance; these functions are normally performed by multiple layers. The fundamental concepts of bio-inspired façade architecture are adaptability, multi-ability, and evolvability. As a result, a more energy-efficient façade could incorporate energy requirements, functional considerations, and structural efficiency.

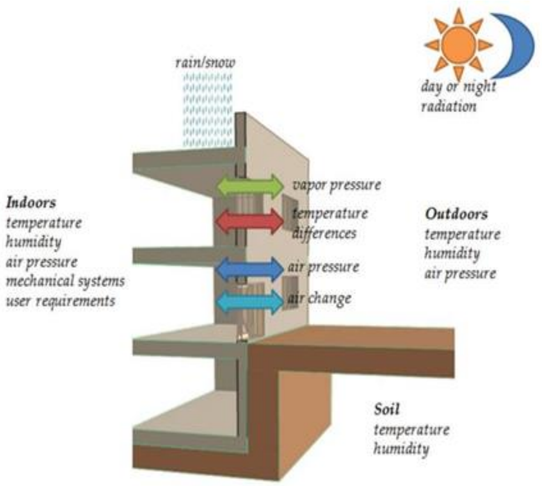


Figure 4 - Design principles of traditional façade

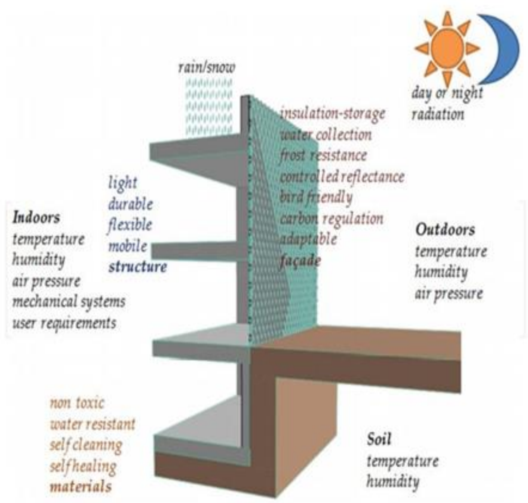


Figure 5- Design principles of energy efficient façade

A. Energy Requirements-

The energy required to control indoor environmental conditions is the most common design metric for energy-efficient building. The majority of the energy used in a building is for heating and cooling, which is directly related to the façade design since the façade is the primary conduit for heat and light exchange between indoors and outdoors. Solar radiation, ambient temperature, sky temperature, wind speed, and relative humidity are all time-dependent weather data that must be controlled. These technologies can be categorized as thermal comfort, visual comfort, and renewable energy production from a sustainability perspective.

Solar radiation, wind, and climate are all factors that influence heat and energy transfer. Due to both the properties of the materials and the heat balance on the element's surface, the use of a façade for thermal comfort varies depending on the properties and thickness of the material layers, as well as the heat balance on the element's surface (i.e., thermal absorption, emissivity, density, specific heat, and thermal conductivity). Usually, architectural technologies such as solar orientation, insulation, and shading are used to control these. There are also a few less popular dynamic technologies including thermal mass, dynamic insulation, radiative cooling, phase change, energy storage, natural ventilation, and energy generation.

The amount of required light and the lack of glare determine visual comfort. Internal light transmission and indoor lighting conditions are affected by levels of light transmission, visibility, translucency, colour, and reflection. Facades can be used to produce renewable energy. Photosynthesis is the main source of energy on Earth, and it is the predecessor to fossil fuels. Photovoltaic technology today mimics plant photosynthesis to produce artificial photosynthesis. Some façades may be used to cultivate or function in conjunction with species like algae that can grow and be harvested for oil, making them more suitable as a source of biodiesel, bioethanol, bio-hydrogen, or biomass. However, these do not have to be living organisms; instead, they may be structures that imitate living organisms.

B. Form and Structural Efficiency-

The most popular form of biomimicry in architecture is the imitation of natural surface morphology. Bones, leaves, shells and flowers are only a few examples of objects that take their shapes from nature. Often the comparison is purely morphologic, such as the famous Sydney Opera House's analogy of an orange shell, but other times the appearance serves a functional reason. For example, DP Architects used durian fruit served as a model and their spikes served as inspiration for sun shading on the roof of Esplanade Theatres in Singapore, and it also has a secondary sun shading lattice; so it captures the sun, uses less energy, and reduces artificial lighting.

Since most architectural discourses emphasize the impact of biological data on architectural paradigms, the majority of studies are based on shape generation. Complex geometries can now be described in parametric terms using computational methods by a collection of growth rules. Although the use of evolutionary algorithms in parametric design is a highly debated research subject, another feature of digital technology in architecture is the ability to fabricate these complex geometries entirely digitally using CNC or 3D printing. This would allow for better material quality and fabrication ease while also remaining biomimetic. However, a low carbon footprint can only be achieved with a well-designed structure that is stable and long-lasting, and that allows optimal use of its environment.

The use of biological processes as inspiration and the application of natural principles allows for the design of façades that are aligned with the movement of forces according to the structure's existence. Many structural systems have been affected by design throughout history. Natural prototypes of structural systems can be found everywhere, from cave houses to tensile structures. These are taken into account in some of the earlier structural system classifications. Insect mounds are used in masonry structures such as pyramids, eggshell shell structures, web tensile structures, honeycomb cell structures, and pneumatics in soap bubbles, according to the biomimetic approach.

C. Energy Efficiency Considerations-

Even though scientific evidence indicates that anthropogenic carbon emissions are at the root of global warming, carbon is a necessary component of living organisms in nature. One of the most critical aspects of architectural processes is the effective use of energy, which results in smaller environmental footprints. Furthermore, there is no waste in nature since the output of one phase is used as the input for another. Furthermore, natural chemical reactions do not require high temperatures or toxicity.

Another point to consider is that, while man-made environments depend heavily on external energy sources, nature's primary energy source is the sun and gravity. Nature has numerous clues to give humans a more sustainable existence in this way. Air quality, water efficiency, carbon capture, use of non-toxic materials, low embodied energy, low material consumption, biological activity, responsiveness, adaptability, breathing, and sensing are all factors that the façades cover.

Indoor air quality, in addition to thermal comfort, is linked to health and productivity problems in buildings. The façade of Mick Pierce's Council House 2 in Melbourne employs a variety of biomimetic concepts to control the building's heating, lighting, air quality, and water. With eco-tech architectural technology, every part of the building has been reevaluated to act like a tree. The façade is multi-layered, similar to human skin, with a semi-enclosed microclimate created by the outer skin (dermis), which includes stairwells, balconies, ducts, sunscreens, and foliage for solar and glare control.

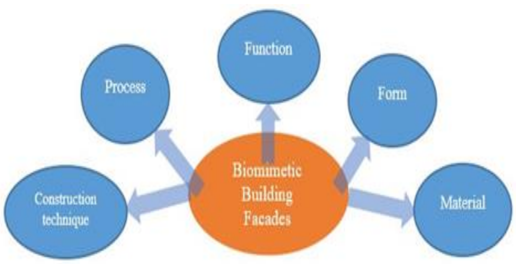
Although water is the source of life on Earth and the living medium for many species, water considerations in a building are twofold. The first is water preservation, and the second is efficient freshwater usage for resource management. For the generation of biomimetic design concepts, Badarnah and Kadri propose the Biogen methodology. It focuses on the investigation of incorporating a range of techniques to produce better results. They apply this approach to the problem of designing a water-harvesting façade in arid areas. They start by plotting their findings in a graph for four hierarchical levels: function, process, factors, and pinnacles.

Then, to reduce complexity, they define paths on the map, choose from pinnacles, evaluate, and classify the chosen pinnacles. The design paths are overlaid over the dominant features in each category. The Thorny Devil, one of the several pinnacles in the structure, inspired the resulting preliminary design. A bumpy surface attracts water molecules, and grooves between the mounds facilitate capillary action into storage chambers. After that, the water in the chambers is transported and evaporated within the wall. They estimate that for one-third of the year, the wall would keep the interior cool.

VII. BIOMIMETIC BUILDING MATERIALS AND TECHNIQUES FOR FAÇADE APPLICATIONS

The building façade is no longer just a cover to keep the structure protected from the environment. A façade's architecture seeks to have both practical and aesthetic qualities, as well as considering how to prolong the life of the building by using more durable materials. As a result, a façade can be modified as an adaptive layer that has a significant effect on the building's energy efficiency and thermal comfort. Building facades that are more functional, durable, and energy-efficient can be built using an interdisciplinary approach. Bio-inspired manufacturing, whether at the micro, nano, or macro scale, produces materials or structures that are derived from biological self-organization methods, such as self-healing, self-cleaning, and self-assembly.

Bioinspired climate adaptive building skins that function as living organism could help to create an ecosystem that has a mutual relationship with the surroundings. Biological materials, such as greenery is a material that can be used to cover a façade and control temperature changes, as an example of green walls. When inspiration comes from nature, it can be expressed in several ways in the building of façades: designing a functional or aesthetic form; creating a functional material for the façade; incorporating a new feature, such as self-cleaning or energy conservation; and constructing the façade with a new technique. Façade-making materials are often made using a biomimetic process.



VIII.ANALYTICAL STUDY

A. The Council House 2 (CH2), Melbourne

(CH2) is a ten-story sustainable structure situated in Melbourne, Australia. It was constructed between 2004 and 2006, and it was built by the City of Melbourne in partnership with Mick Pearce in design Inc. The building's architecture was rather innovative because it challenged conventional approaches to sustainability and building design by mimicking the bark of a tree. Design to biology was the biomimetic approach. The building has a 6-star Green ranking. The CH2 is an amalgamation of art and science. It was focused on connecting the building to its external environment and living organisms around it to achieve the goals. As a consequence, it reacts to its environment holistically.

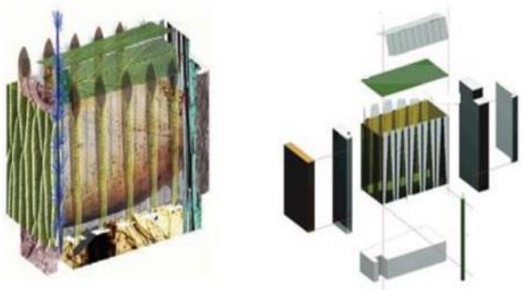
The use of biomimicry was evident in the structure. The west facade, for example, is the tree's epidermis.

Mimicry of the epidermis of tree

It was inspired by how the exterior climate would be moderated by the facade. The north and south facades were designed after the tree's bronchi. These were used as windpipes and allowed for air ducts to be installed on the exterior of the CH2. The service core and toilets, which made up the eastern core and facade, were designed to look like tree skin (bark). In the ventilated wet area spaces behind, the skin served as a protective barrier, absorbing light and air. Finally, perforated metal with polycarbonate walling is used to construct the overlapping layers of the facade.

The design process was beneficial because it resulted in the separation of conventional industry solutions. Although future buildings do not look like the CH2, the CH2 reflects a living form of architecture14. As a result, it was determined that future systems should include the following features:

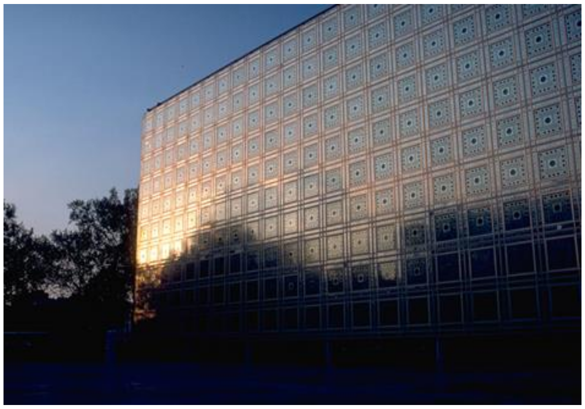
- Interact with the environment.
- Express climate and culture.
- Facades should express orientation



Wind pipes on the north façade & overlapping layers of façade

B. Institute du monte Arabe, Paris

The Arab World Institute (Institut du Monde Arabe in French) was established in Paris by eighteen Arab countries in 1980 in collaboration with France to conduct research and disseminate knowledge about the Arab cultural and spiritual values. The Institute was established in response to a perceived lack of Arab representation in France, and it aims to create a secular space for the promotion of Arab civilization, art, literature, and aesthetics.

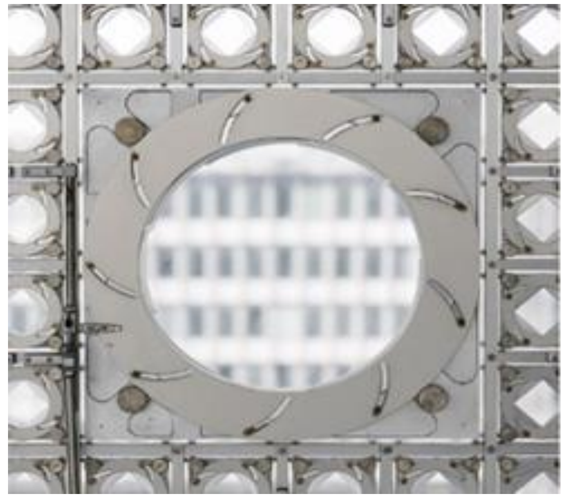


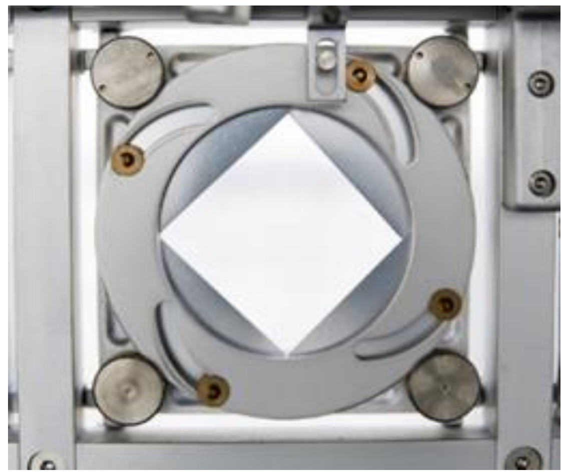
South façade mimicking Iris of an eye

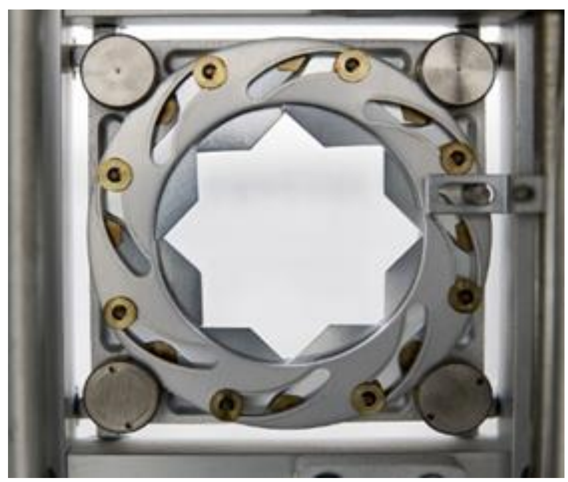
Light patterns inside AWI

The steel carvings or mashrabiya on the south façade represents the Iris part of a human eye. It is designed in such a way that it captures sunlight inside the building and has an open-close mechanism that forms interesting light patterns inside the institute. There are a total of 240 mashrabiyas, of which half is composed of mobile apertures.

The attention to façade details is typical of Jean Nouvel's work, and this design is no exception. The advanced responsive metallic brises Soleil on the south façade is a key feature and creative element of the IMA. The mashrabiya, an archetypal element of Arabic architecture, was reinforced by Nouvel's proposal for this scheme, which was well-received for its originality and reinforcement of an archetypal element of Arabic architecture. He was inspired by the traditional latticework that has been employed in the Middle East for centuries to provide privacy and shield the inhabitants from the sun.







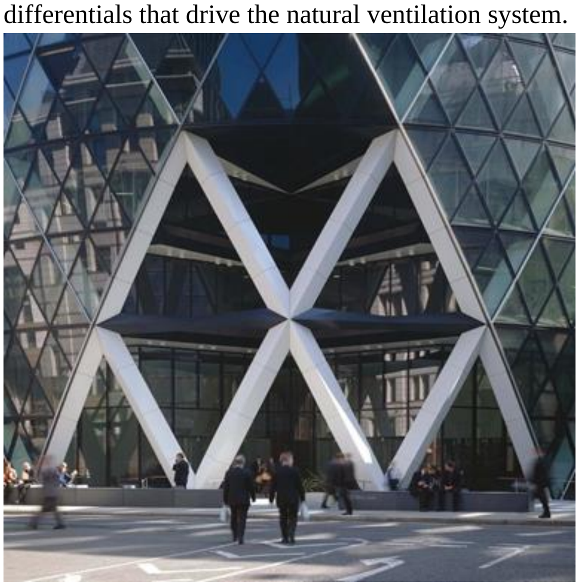
Shows the open-close mechanism of the carvings

Several hundred light-sensitive diaphragms are used in the device to control the amount of light that enters the building. A changing geometric pattern is created and shown as both light and void during the different phases of the lens. Light is modulated in parallel to form squares, circles, and octagonal shapes in a fluid motion. The interior spaces, as well as the external appearance, are dramatically changed. These ocular devices are not only aesthetically beautiful to look at, but they are also useful for controlling the environment. The amount of solar gain can be easily reduced by closing or reducing the aperture sizes.

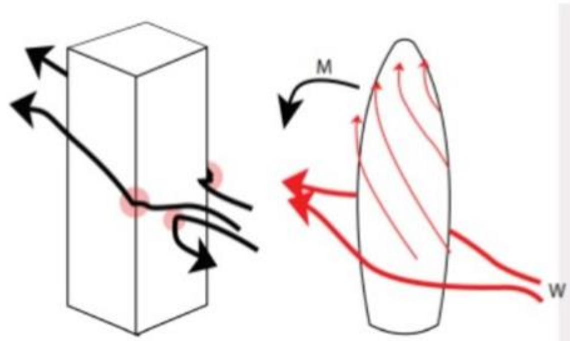
C. The Gherkin, London

The Gherkin, or 30 St Mary Axe, is a commercial skyscraper in London's main financial district, the City of London. It first opened in April 2004 after being completed in December 2003. It stands 180 metres (591 feet) tall and has 41 floors. The Venus' flower basket sponge, a form of glass sponge, served as inspiration for The Gherkin's structure. The sponge's lattice-like exoskeleton and circular shape provide stiffness and disperse forces from strong currents, allowing it to survive at great depths. The shape helps the structure with wind loads by decreased buffeting, reduced vibrations and diminished fluttering.

The Gherkin mimics the sponge's shape and lattice structure to perform the same functions in the air as it does in water. The building's circular shape reduces wind deflections and generates external pressure differentials that drive the natural ventilation system.



In comparison to the rectilinear form of a typical office tower, air can flow more freely across the building. The exterior is enclosed by a lattice-like, diagonally braced framework that allows for an open floor plan without interior columns. The transparency also allows for a lot of natural light to penetrate.



Wind movement around the building

For sustainability, the Gherkin was designed with natural ventilation and the ability to "breath" like a lung. By circulating air between floors, gaps in the floors provide natural ventilation. There are six of these atria on each floor, which stretch through several floors at once, following the diagonal lattice structure. As a firebreak, there are just interruptions on the sixth floor. The air between an extra set of glass in the double-skin façade creates a double-glazing effect, insulates the office room by passive heating and cooling, and creates a double glazing effect. This natural ventilation and insulation design enable the building to use half the energy that a similar-sized tower would.

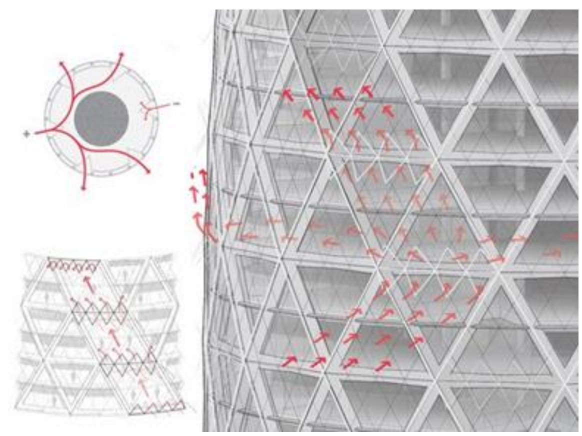


Diagram of airflow in and around the structure

The atria have opening panels in the façade that allow fresh air to flow in. Through pressure differentials, the air is distributed between the connected floors for natural ventilation. Depending on the season, this mixed-mode ventilation system provides passive cooling and heating effects. In the winter, the insulating effect uses passive solar energy to keep the building warm. External pressure differentials force warmer air out in the summer. The house, in turn, breathes in and out through the passage of air through it. This air movement into and up through the building is modelled after the flow of water and nutrients through Venus' sponge.

VII. CONCLUSION

For billions of years, nature has been self-sustaining and energy efficient. To be energy-efficient, natural organisms have evolved and established strategies. Human problems can be solved by incorporating these characteristics into architecture. Despite technological advancements and environmental debates, the human race's and buildings' environmental footprint continue to grow. This is largely due to the growing population and increased comfort demands. Since it has worked for centuries to perfect solutions, nature produces healthy ecosystems and surrounds us with answers to most of our questions regarding energy efficiency.

Some designers have adopted this viewpoint. On the path to being more energy efficient and having a lower environmental effect, they draw inspiration and learn from nature. Formal and functional biomimicry are the most common approaches; some building elements and materials are also referred to as biomimetic in façades. The definition of biomimicry is compatible with that of energy-efficient buildings; however, there are different levels of energy efficiency, and not all biomimetic application is energy efficient. To achieve a new solution for energy-efficient building envelopes, mimicking nature has considerable potential. A large amount of energy is used in the building envelope. Using the biomimicry method, it is possible to minimize energy consumption by discovering and emulating natural strategies.

This paper has demonstrated biomimetic design approaches in the sense of three major aspects of designing an energy-efficient façade: energy requirements, form, and structure; and energy considerations. One of the obstacles to using the behaviour level of biomimicry is its broad reach, which requires a multidisciplinary approach. Biomimicry's behaviour level work goes beyond the organism mimicry of biomimicry and incorporates an innovative way of looking at and working with nature; as a result, their implementations will possibly become more common in future façade designs. Structures that will incorporate the behaviour level of biomimicry would be more energy-efficient than structures incorporating the organism level of biomimicry.

REFERENCES

[1] Dr. Gehan.A. N. Radwana & Arch. Nouran Osama, 2016. Biomimicry, An Approach, For Energy Efficient Building Skin Design, Elsevier

[2] Thomas Button, 2016. Biomimicry: A Source for architectural innovation in existing buildings. RIT Scholar Works.

[3] Ayça Tokuç, Fatma Feyzal Özkaban and Özge Andiç Çakır, 2018. Biomimetic Facade Applications for a More Sustainable Future, Intech publication.

[4] Thomas Button, 2016. Biomimicry: A Source for architectural innovation in existing buildings. RIT Scholar Works.

[5] Ajla Aksamija, 2013.Sustainable Façades: Design Methods for High-Performance Building Envelopes, Wiley.

[6] Michael Pawlyn, 2011. Biomimicry in Architecture, London. RIBA publishing.

[7] Jonathan Massey (November 2013), The Gherkin: How London's Famous Tower Leveraged Risk and Became an Icon (Part 2) (Online)

[8] Available- https://www.archdaily.com/447205/the-gherkin-how-london-s-famous-tower-leveraged-risk-and-became-an-icon-part-2

[9] Vikram Bengani (October 2015), The Gherkin: Case Study (Online)

[10] Available- https://www.slideshare.net/VikramBengani/the-gherkin-case-study

[11] Snaves (2019), Biomimetic Architecture: The Gherkin (Online)

[12] Availablehttps://steemit.com/architecture/@snaves/biomimetic-architecture-the-gherkin