e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:04/Issue:08/August-2022 Impact Factor- 6.752 www.irjmets.com

BUILDING ENVOLOPE THROUGH BIOMIMICRY: A STUDY ON BIOMIMETIC BUILDING ENVELOPE AND THE AFFECTED PARAMETERS

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ABSTRACT

Aside from humans, every other living thing has the capacity for adaptation and evolution over time, and we can undoubtedly learn from them. Approximately 8.5 million species, all of which have developed ways to survive on earth, are known to exist, according to the Board of Innovation. It's interesting to note that 99.9% of all species that have ever existed on Earth are now extinct. The startling statistic that 99.9% of species were unable to innovate in a way that would be future-proof serves as a reminder of how simple it is to fail at the harsh test of evolution. The 0.1 percent of species that are still alive must have developed effective strategies to deal with disruption, especially the primitive ones that have endured for millions or perhaps billions of years. As they say, nature finds a solution. Biomimicry is one such concept to adapt nature's form, function and behaviour into objects, product, building, etc. So the research is based on the study of biomimicry examples adapted by various buildings and their envelope. It also includes the study of different types of building enveloped that can affect the parameters.

Keywords: Building Envelope, Biomimicry, Biomimetic Architecture, Thermal Comfort, Ventilation, Daylighting, Levels Of Biomimicry, Esplanade Singapore, Louvre Abu Dhabi, Milwaukee Art Museum.

I. INTRODUCTION

1. BACKGROUND

Biomimicry can be define as a study of imitating and adapting the practical use of form and structure and mechanical and functions of the living (such as plants, animals, organism) and non-living things (such as habitat of the animals, birds and other organism) in nature.

According to the article on the website Environment and Ecology, "Biomimicry or biomimetics is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. The words "biomimicry" and "biomimetics" are adaptations of the Greek words "bios" (life) and "mimesis" (to imitate). The phrases bionics, bio-inspiration, and biognosis are also commonly used."

All living beings have the tendency to evolve, adapt and learn from the nature and according to the Biomimicry institute, "Biomimicry is a practice that learns from and mimics methods inspired by nature to address problems with human creation and discover hope along the way. We as architects and designers can also be inspired and learn from nature to solve our problems". Nature can provide numerious shapes, forms, structures, mechanism and functional features to incorporate in the field of architecture.

1.1 Need for the study

Apart from humans, all living organism have the ability to adapt and evolve through time and we can definitely learn from them. According to Board of Innovation, "approximately 8.5 million species currently live on our planet, all of which have created solutions to enable them to thrive on earth. Interestingly, 99.9% of the organisms that have lived on our planet are now extinct. This mind-blowing fact reminds us how easy it is to fail at the unforgiving test of evolution – 99.9% of species were incapable of future-proof innovation. The 0.1% of organisms that remain (especially the primitive ones that have been around for millions, sometimes billions of years) must have found successful ways to deal with disruption. Nature, as they say, finds a way." (Board of Innovation, n.d.)

1.2 Aim

To study biomimicry and the parameters like thermal comfort, natural ventilation and daylight and analyse how it affects biomimetic building envelope.

1.3 Objectives

- To study the concept of biomimicry and its approach in architecture.

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- To study the parameters that can affect biomimetic building envelope and the building envelope that can affect dayligh, thermal comfort and ventilation.
- To compare the case studies to analyse the effectiveness of the parameters on building envelope.

1.4 Limitation

1. This dissertation is based on literature study only.
2. Literature study is restricted to those study which involve the implementation of organism and behavioural level.
3. The case studies are limited to building envelope through biomimetic architecture.
4. All the case studies are institutional building.

2. DIFFERENT LEVELS OF BIOMIMICRY

There are three ways to approach biomimicry, first is organism level which is copying form and shape, second is behavioural level which is copying a process (method), and the third is imitating at an ecosysten level like building a nature inspired campus and city.

Taking termite mound as the prime example because of its relevance to all three level of biomimicry. (Science Direct, n.d.)

2.1 Organism level:

- Species of living organisms have typically been evolving for millions of years.
- The species that have survived and adapted to constant change over time are still present on Earth today.
- On the organism level, the architecture looks to the organism itself, applying its form and/or functions to a building.
- Since organisms are a component of an ecosystem, it is also important to consider their functions and responses to a wider context.

Table 1: Organism Level of Biomimicry

LEVEL OF BIOMIMICRY	EXAMPLE- A building that mimics termites	
ORGANISM LEVEL (Imitation of a certain creature)	FORM	The structure resembles a termite.
	MATERIAL	The structure is constructed of termite, a substance that, for example, resembles the exoskeleton or skin of termites.
	CONSTRUCTION	The structure is constructed similarly to a termite, going through numerous growth stages, for instance.
	PROCESS	The structure functions similarly to a single termite, producing hydrogen effectively, for instance, via meta-genomics.
	FUNCTION	In a broader sense, the building performs similar tasks as termites, such as recycling cellulose waste and producing soil.

Figure 1: Organism Level - Lotus temple inspired by lotus flower.

2.2 Behavioural level:

- Structures imitate how an organism acts or interacts with its environment.
- A building replicates the natural processes and cycles of the larger environment at the level of the ecosystem.
- The organism's behaviour is imitated, not the organism itself.
- When behaviour level mimicry occurs, moral judgments must be formed regarding whether the duplicated behaviour is appropriate in a human context.
- Not all species have traits that are appropriate for humans to imitate.
- There is a risk that consumption or exploitation paradigms could be supported by the actions of another species.
- For the construction of passively regulated, thermally comfortable buildings, it might be suitable, for example, to emulate the building behaviour (and results of that behaviour), of termites.

Table 2: Behavioural Level of Biomimicry

LEVEL OF BIOMIMICRY	EXAMPLE- A building that mimics termites	
BEHAVIOURAL LEVEL (Imitation of an organism's behaviour or interaction with its environment)	FORM	The structure, such as a reproduction of a termite mound, gives the impression that it was constructed by termites.
	MATERIAL	The construction is based on its intended the same resources that termites use to construct their structures, such as digested fine dirt as the main component.
	CONSTRUCTION	The structure is constructed similarly to how a termite would construct one, such as by piling earth in specific locations at specific times.
	PROCESS	The building functions similarly to a termite mound might, for example, through precise alignment, design, material selection, and natural ventilation. Perhaps it imitates the way that termites cooperate.
	FUNCTION	The structure operates similarly to how a termite-made structure would; for instance, inside conditions are controlled to be ideal and thermally stable. In a broader sense, it might have the same function as a termite mound as well.

Source:

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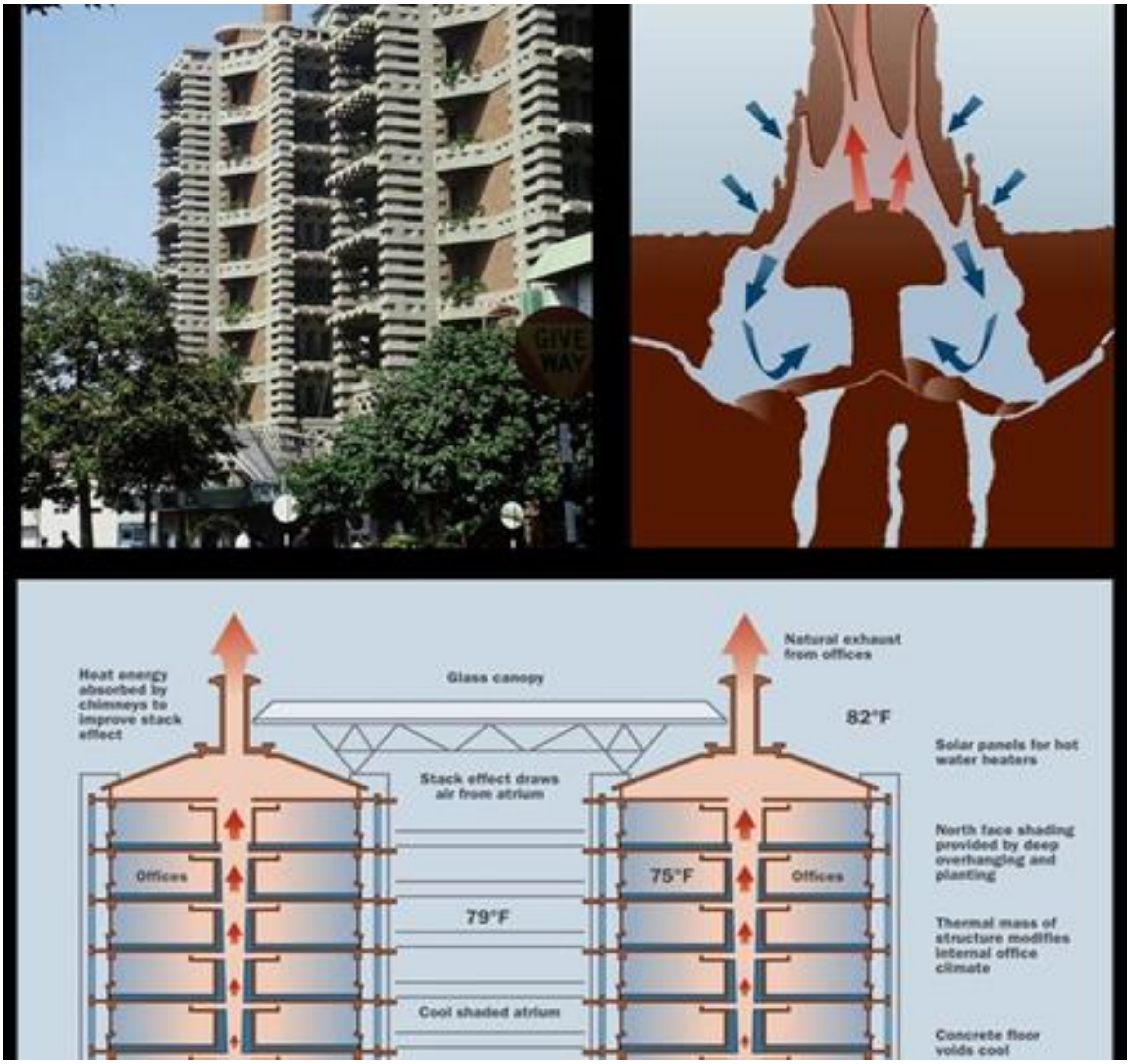

Figure 2: Behavioural Level - Eastgate Centre inspired by termite mound

2.3 Ecosystem level:

- Building mimics the natural occurrences in the surrounding environment..
- Ecosystem principles follow that ecosystems

1. dependent on contemporary sunlight;
2. maximize the system as a whole rather than just its parts;
3. sensitive to and reliant on regional circumstances;
4. diverse in components, relationships and information;
5. construct environments that support prolonged life, and
6. adapt and change at various speeds and levels.

- In essence, this means that a variety of elements and procedures come together to form an ecosystem, and that for the ecosystem to function well, they must cooperate rather than compete.
- ADVANTAGE - possible enhancements to the functioning of the environment as a whole. Operates at both metaphoric levels and at a practical functional level.
- METAPHORIC LEVEL – Designers without extensive ecological expertise can nonetheless apply general ecosystem concepts (based on how most ecosystems function).
- FUNCTIONAL LEVEL – Designing a built environment that can take part in the main biogeochemical material cycles of the planet requires a thorough understanding of ecology.

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Table 1: Ecosystem Level of Biomimicry

LEVEL OF BIOMIMICRY	EXAMPLE- A building that mimics termites	
ECOSYSTEM LEVEL (Imitation of an ecosystem)	FORM	The structure resembles an ecosystem (a termite would live in)
	MATERIAL	The building is constructed using the same ingredients that make up a termite habitat; for instance, water serves as the construction's main chemical medium.
	CONSTRUCTION	The building is put together using concepts of succession and escalating complexity over time, similar to how a (termite) ecosystem is put together.
	PROCESS	The structure functions similarly to a (termite) ecosystem; for instance, it collects and transforms solar energy and stores water.
	FUNCTION	The building is able to function similarly to a (termite) ecosystem and contribute to a complex system by making use of the connections between different processes. For instance, similar to an ecosystem, it can take part in the hydrological, carbon, and nitrogen cycles.

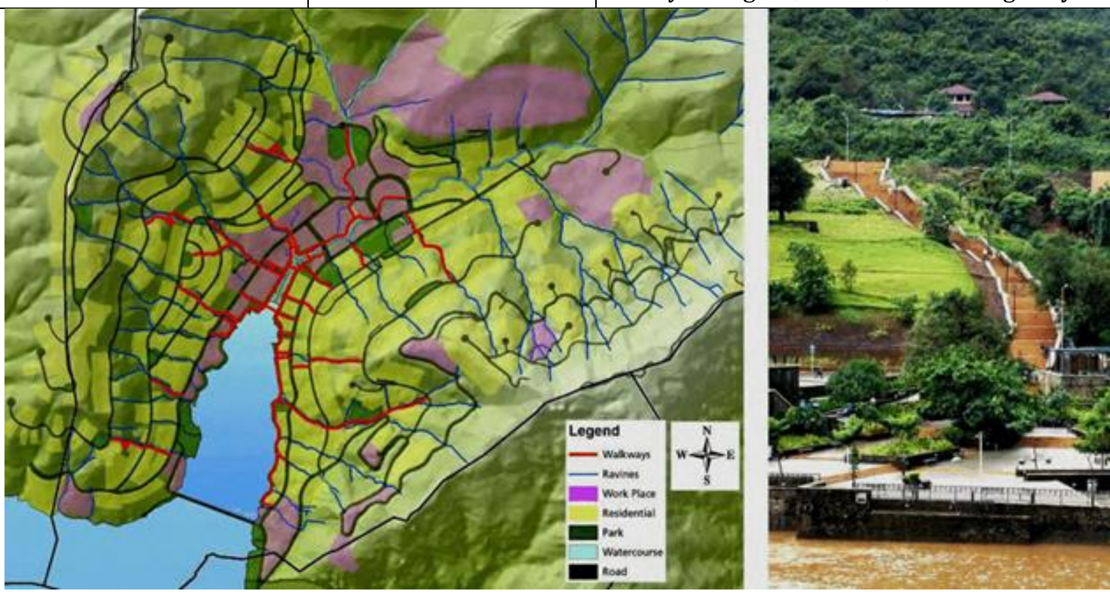

Figure 1: Ecosystem Level - Lavasa township inspired by roots of a trees.

II. BIOMIMICRY IN ARCHITECTURE

Through mutation, recombination, and selection, living things have evolved to adapt to a continuously changing environment. The core tenet of the biomimetic philosophy is that nature's occupants, such as animals, plants, and microbes, have the most experience in problem-solving and have already figured out the best strategies for surviving on Earth. In a similar vein, biomimetic architecture looks to nature for inspiration when developing sustainable structures.

Due to inefficient building designs and excessive energy use during the operational stage of a product's life cycle, the 21st century has seen widespread energy waste. Parallel to this, new opportunities to emulate nature at various architectural sizes have emerged as a result of recent developments in fabrication methods, computational imaging, and simulation tools. As a result, the development of novel design strategies and solutions to address energy issues has grown quickly. One of these multi-disciplinary approaches to sustainable design is known as "biomimetic architecture," which adheres to a set of principles rather than stylistic norms. Rather than drawing inspiration from nature for the built form's aesthetic elements, biomimetic architecture seeks to use nature to solve problems related to the building's functionality and energy efficiency.

Two fundamental methods within biomimetic architecture can be distinguished: the bottom-up approach (biological push) and the top-down approach (technology pull).

The line separating the two methods is hazy because it's possible to switch between them based on the circumstances of each particular case. Biologists and other natural scientists frequently work with engineers, material scientists, architects, designers, mathematicians, and computer scientists in interdisciplinary teams to develop biomimetic architecture.

In the bottom-up method, a fresh finding from basic biological research that holds promise for biomimetic application serves as the starting point. Creating a biomimetic material system, for instance, following a quantitative investigation of a biological system's mechanical, physical, and chemical qualities.

The top-down strategy looks for biomimetic innovations for already developed products that have been successfully marketed. The collaboration is centred on enhancing or expanding a current product. (Science Direct, n.d.)

"Biomimicry in architecture fosters innovative thinking in architects in addition to producing inventive systems. Carl Hastrick developed a biomimicry spiral demonstrating a step-by-step process to turn natural strategies into creative design solutions: (How Biomimicry Enhances Creativity in Architecture, n.d.)

1. Establish a list of the purposes your structure will serve.
2. Interpret - put it in biological terms; that is, consider how nature performs this function.
3. Find - Locate the unsung heroes who overcome your problems.
4. Abstract - Reframe the strategies that have been discovered in terms of architecture.
5. Create a design solution by imitating the strategies.
6. Assess - Compare your design response to the previous brief from step 1 and the natural laws you identified in step 3.

3.1 BUILDING ENVELOPE

The building envelope is the physical separator between the exterior and interior environments enclosing a structure to withstand air, light, heat and noise.

“The building envelope or building enclosure is all of the elements of the outer shell that maintain a dry, heated, or cooled indoor environment and facilitate its climate control. Building science and indoor climate control are all applied to the specific field of building envelope design in architecture and engineering.” (Syed, 2012)

There are three general categories that can be used to classify the building envelope's numerous uses:

- Support (to withstand and transfer dynamic and structural loads)
- Control (the flow of matter and energy of all types)
- Finish (to meet desired aesthetics on the inside and outside)

The core of effective performance is the control function, which in reality prioritises the control of rain, air, heat, and vapour in that order of significance. (Eric F. P. Burnett, 2005)

Building envelope can be designed around four major climate:

- Arid
- Tropical
- Cold
- Mixed

3.1.1 Building envelope categorised by their mechanism:

1. Fixed building envelope
- It is a fixed facade all throughout the year.
- Building envelope of the building never changes.
2. Mechanical Building Envelope
- This type of mechanical facade which are managed by artifical intelligence and can change throughout the day according to the requirement like thermal comfort, ventilation and daylighting.
- Building envelope keeps changing.

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3. Manually Controlled Building Envelope

- These facades are controlled manually. It can also be changed according to the requirement like thermal comfort, ventilation and daylighting..
- Facade doesn't remain the same.

3.2 Parameters which can be controlled by Building Envelope

3.2.1 Thermal comfort

In terms of whether they feel too hot or too cold, a person's mental state is referred to as their "thermal comfort."

The best you can realistically expect for is a thermal environment that is comfortable for the majority of workers. The number of workers reporting thermal discomfort, not the temperature of the room, is used to measure thermal comfort.

Thermal comfort is important because it improves morale and productivity as well as improving health and safety. People who labour in extremely hot or cold conditions are more prone to act unsafely because their judgement and/or manual dexterity suffer.

- Individuals might take shortcuts to escape chilly conditions.
- In heated situations, employees might not properly wear personal protective equipment, increasing the dangers.
- A worker's ability to focus may begin to wane, which raises the possibility of mistakes being made.

3.2.1.1 Factors affecting thermal comfort

Six variable elements that are primarily responsible for affecting thermal comfort must be balanced in order to retain occupant contentment with their surroundings.

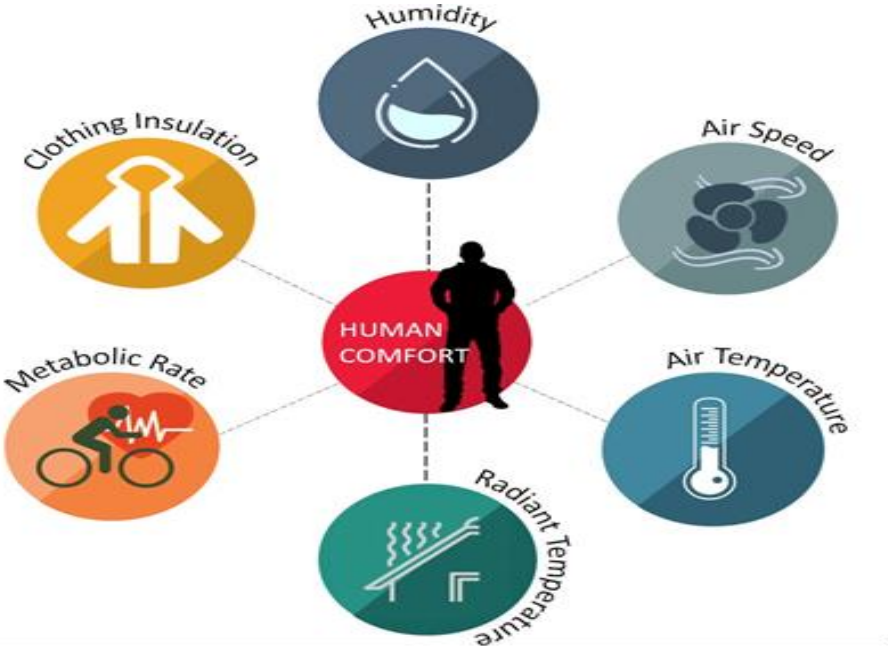

Figure 2: Factors affecting thermal comfort - Source: **(Simulation Hub, n.d.)**

3.2.2 Ventilation

The purposeful introduction of external air into a place called ventilation. Ventilation can be used to regulate indoor temperature, humidity, and air motion to improve thermal comfort, contentment with other aspects of the indoor environment, or other goals. Ventilation is primarily used to control indoor air quality via dilution and displacement of indoor contaminants.

This can be divided into three categories:

1. Mechanical ventilation is the purposeful movement of outside air into a structure powered by fans. Supply fans push outdoor air into a building, exhaust fans pull air out of a building to create an equal ventilation flow

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into a building, or a mix of supply and exhaust fans may be used in mechanical ventilation systems. In many cases, equipment that is also used to heat and cool a place also provides mechanical ventilation.

2. Natural ventilation is the deliberate passive entry of outside air into a structure through designed vents (such as louvers, doors, and windows). Mechanical systems are not needed for natural ventilation to transport outdoor air. It completely depends on inert physical events, such as the stack effect or wind pressure. Openings for natural ventilation may be fixed or movable. Adjustable apertures can be operated manually by occupants, automatically (operated), or both automatically and manually. A characteristic of natural ventilation is cross ventilation.

The benefits of natural ventilation include:

- Improved Indoor air quality (IAQ)
- Energy savings
- Reduction of greenhouse gas emissions
- Occupant control
- Reduction in occupant illness associated with Sick Building Syndrome
- Increased worker productivity

3. Mixed-mode ventilation: systems use both mechanical and natural processes The usage of the mechanical and natural components is possible at any given time, as well as at various times throughout the day and throughout the year.Since natural ventilation flow depends on environmental conditions, it may not always provide an appropriate amount of ventilation. In this case, mechanical systems may be used to supplement or regulate the naturally driven flow.

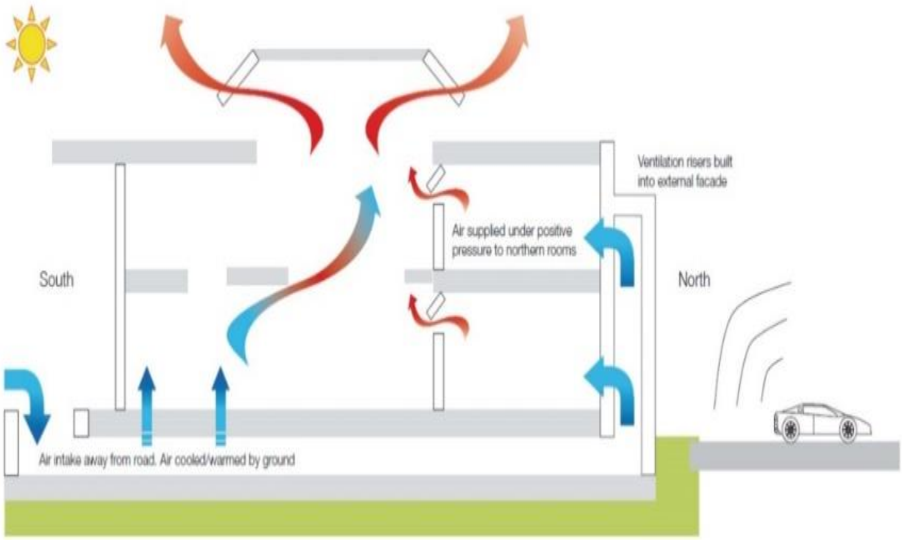

Figure 5: Image Showing natural ventilation – Source **(Designing Buildings, n.d.)**

3.2.3. Daylighting

In order to reduce the need for electric lighting and save energy, daylighting is the controlled entry of natural light, direct sunlight, and diffused skylight into a building. In addition to lowering energy costs by up to one-third, daylighting helps create a visually engaging and productive environment for building occupants by establishing a direct connection to the dynamic and constantly changing patterns of external illumination. Natural light is a powerful architectural tool. Passive techniques like daylighting have become increasingly important in decreasing the influence of the built environment as the significance of sustainable design increases. Additionally, over the past ten years, research has shown that daylighting has significant benefits for users' health and wellbeing.

There are also a number of health and wellness benefits when you allow more natural light into your building. Exposure to natural light improves:

- Mood
- Employee and visitor satisfaction

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- Student performance and learning
- Healing (especially in hospital environments)
- Productivity
- Cognitive function
- Circadian rhythms

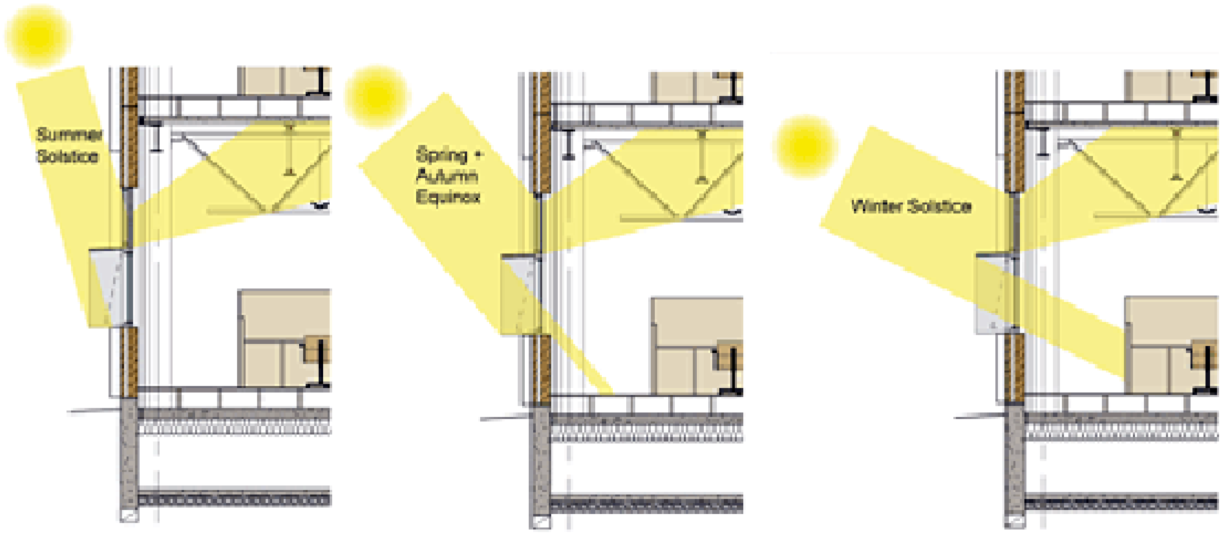

Figure 6: Indirect Daylighting – Source (Whole Building Design Guide, n.d.)

III. COMPARATIVE ANALYSIS

Table 4: Comparative study.

Builidng Information			
Name	**Esplanade Theatre**	**The Louvre**	**Milwaukee Art Museum**
Architect	DP Architects and Michael Wilford & Partners	Ar. Jean Nouvel	Ar. Santiago Calatrava
Building Type	Institution Building: Theatre	Institution Building: Art Museum	Institution Building: Art Museum
Image			
Area	60,000 m2	95000 m2	
Building Location	Singapore	Abu Dhabi, United Arab Emirates	Milwaukee, Wisconsin
Orientation	East- West axis	-	East-West axis
Climate type	Tropical climate	Sub-tropical, Arid Climate	Humid Continental Climate
Form	Hemispere	Dome structure	Prow of a ship
Design Challenge	The building is a theatre which needed an envelope keeping in mind the form and space of the theatre. So, to avoid having a basic oval envelope the designers	Collaboration between traditional design and contemporary building methods. (Louvre Abu Dhabi, n.d.)	The footing's design presented one of the project's initial difficulties. The site of the development was a defunct landfill by the lake. a pavilion-like building situated

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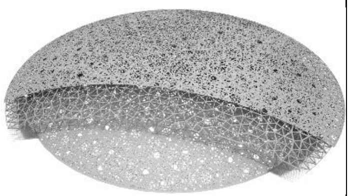
	adapted the concept of the skin of durian fruit which is spiky or fibrous husks that protect the fruit or the seeds inside.		on Wisconsin Avenue's axis on the major thoroughfare of the city. (Re-thining Future, n.d.)
Biomimetic Application			
Biological Inspiration	Durian fruit	Oasis in the Deserts and the stars are repeated by various sizes and angles in eight different layers.	The wings of a bird due to its opening and closing mechanism. (Re-thinking Future, n.d.)
Biomimetic Envelope	On the roof	On the roof	Roof Structure
Shape of the Envelope	Curved along the oval roof	Curved like dome.	Structure of the wings.
Visual Appearance			
Adaptation of the Envelope	Giving a covering to the theatre just like the durian fruit.	The museum creates a welcoming environment. Because of passive cooling, which mimics how an oasis in a desert functions, and traditional regional architecture and designs. (The dunes of Saadiyat Island and the seas of the Arabian Gulf meet the Arabian sky.) (Louvre Abu Dhabi, n.d.)	A movable sunscreen with a 217-foot wingspan that unfolds and folds twice daily.
Key Features	Natural light with a responsive shade system (louvres that change to the sun's location and angle throughout the day)	The dome lowers the amount of energy used by the structures below. It provides protection from the sun's heat for the open plaza. Walking through the "shower of light" between the buildings is a truly unique experience. (Arch Daily, n.d.)	While glass is used in locations like the windows and the glass dome above the main hall, metal is employed in components like the moveable sunscreen.
Parameters Adapted	Daylighting	Daylighting, Thermal Comfort, Ventilation	Daylighting

IV. CONCLUSION

The aim of this study was to study biomimicry and the parameters like thermal comfort, natural ventilation and daylight and analyse how it affects biomimetic building envelope in commercial buildings. Through literature review following points was concluded:

- Recently, biomimicry has inspired many designers to learn from nature and adapt them into their designs.
- By modelling nature's time-tested patterns and tactics, the innovation strategy known as "biomimicry" aims to find long-lasting answers to human problems.
- Applicablity of biomimicry is stated to be a fundamental change in approach in designing for resilient buildings.
- Biomimicry not only imitates forms or function in nature into design but also their behaviour and systems.
- Plants have features that help them adapt to improper weather condition which makes them an inspiration of adaptive movements for building envelope.
- Building envelope is designed around keeping in mind the climate.
- Building envelope can be of three types, which are fixed building envelope, mechanically controlled or artificially controlled and manually controlled building envelope.
- Buildings made through vernacular materials can not be designed for high rise buildings.

Conclusions from the case studies are as follows:

- Building envelope through biomimetic architecture was found to be helpful in designing with respect to thermal comfort, ventilation and daylighting
- Biomimetic envelope can be cost effective if it is designed using local building materials.
- Building envelope in the case studies not only served the parameters like thermal comfort, daylight or ventilation but also enhanced the aesthetic beauty of the building.
- Biomimetic envelope can be both fixed and moving, adapting according to the external factors.

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