Biomimicry-based approach to enhance energy efficiency in an office building

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ABSTRACT

High energy consumption is a global issue nowadays. The building sector consumes a tremendous amount of energy. Inspiration from nature (biomimicry) could be the driving force in architecture to achieve a high level of sustainability by translating biosystems into architecture. Drawing inspiration from various sources to address the challenge of the design problem, integrating the behaviour of biosystems into the building envelope could significantly influence energy performance. This paper investigates a bio-mimicry-based approach to enhancing energy efficiency in office buildings by analysing and comparing 8 projects in different climates. The result showed that the behaviour level is more applicable and functional than the organism. And ecosystem levels. Finally, the conceptual model would propose office buildings based on biomimicry strategies.

Keywords: Biomimicry Approaches, Biomimicry levels, Inspiration, Energy Efficiency, Ecosystem

INTRODUCTION

Humans have always exploited nature and destroyed the environment (Nkandu and Alibaba, 2018). There are some contradictory aspects of the human environment, by way of illustration, global warming. Architects turned to mimicry design to reduce the negative impact on the environment and create a comfortable indoor environment within buildings (Radwan and Osama, 2016b). Biomimicry is how overlapping fields of biology and architecture field can display creative potential for architectural problems. Certainly, biomimicry is not something new; it neglects knowledge to find the best solution. In 500 B.C. Greek philosophers made a natural organism model that was equivalent to the concept of beauty (Al-Assadi, 2021). In 1482 Leonardo Da Vinci, a bird-inspired inventor, invented the flying machine as an early example of biomimicry (Radwan and Osama, 2016b)(Pedersen Zari, no date). While, in the Greek and Roman eras, two of the columns' capitals were inspired by the Acanthus plant. Indeed, in 1997, a book on biomimicry was written by Benyus on how to be inspired by nature (Pedersen Zari, no date). He determined how architecture inspires a new school for studying nature and how to mimic the biosystem in architecture design. In addition, Schwan and Janine Benyus co-founded the Biomimicry Institute (Rovalo and McCardle, 2019). Thus, Biomimicry is an innovative design approach for improving energy efficiency in an office building (Sheikh and Asghar, 2019), decreasing global warming, and finding solutions for sustainable development. Increasing energy consumption is one of the fundamental problems globally faced today (Ibrahim, 2021). Currently, the building sector consumes approx. 40% of total energy is responsible for one-third of global greenhouse gas emissions (Alajmi, Aba-Alkhail and Anzi, 2021),(Hershcovich *et al.*, 2021).. The office building is one of the significant contributors to energy consumption due to the long-term occupation time of more than 8 hours a day(Masoso and Grobler, 2010). Inspiration from nature (Biomimicry) could be the best alternative in architecture to achieve high-energy performance(Radwan and Nouran, 2016). As a practical approach in office buildings, Mimicry saves energy for lighting by 82% and mechanical ventilation by 65% (Hosseini, Fadli and Mohammadi, 2021).

BIOMIMICRY APPROACH

Mimicking biology in architecture is one of the creative ways to solve the human problem in architecture (Nkandu and Alibaba, 2018),(Amer, 2019). For any architectural issue, you should ask nature. There are two main approaches (problem and solve) based on (Abdel-Rahman, 2021). The first approach is the problem-based approach, which diagnoses the human problem and tries to find a similar solution problem in the biosystem (Radwan and Nouran, 2016),(Amer, 2019). The second approach is solve- based approach. It can be defined as solving problems in the biosystem and influencing the biosystem in architecture to find a similar solution in nature (Radwan and Nouran, 2016). A key aspect of the Thermo-Bio-Architectural Framework (ThBA) is its approach to incorporating biological system into architectural design(Vitalis and Chayaamor-Heil, 2022)(Imani and Vale, 2020). For instance, an architect designs a building in a hot climate like Zimbabwe. The problem is overheating during the day (Badarnah, 2015). Thus, to avoid this issue, the architect tries to find the same problem in the biosystem to get inspiration solutions from it by mimicking termite mounds in the ventilation system, the architect can make inspiration solutions in passive ventilation (Mohamed, Bakr and Hasan, 2019). The biosystem is classified into four inspirations. First is inspiration from animals. It can be adapted for environmental change. Protect the body from overheating by maximising the surface in a hot climate. Also, minimise body surface to protect body temperature in a cold environment (Martín-Gómez *et al.*, 2019). Second is the inspiration plant; the plant can respond to environmental change by moving, changing direction, lighting, temperature, and water. The third is the human body can be inspired by structure cause of a strong skeleton (Radwan and Nouran, 2016).

Fourth is the lifeless inspiration. For instance, it inspires rock caves, when transience of water. another example is inspiring hilly rock for making a cave can be seen in the villa house hotel (Badarnah, 2015) as shown as in figure 1. Besides, biomimicry architecture can be divided into
three levels of architecture: organism, behaviour, and ecosystem (Pedersen Zari, no date)(Aziz and El Sherif, 2016). At the organism level, architects inspire nature to make an organic form to decrease environmental impact, (Aziz and El Sherif, 2016),(ElDin, Abdou and ElGawad, 2016a). Overheating and cooling can be solved by simulating all or part of the organic form to save energy passively. For instance, inspiration from durian fruits in form and skin makes a building look like this to save energy and limit sun exposure during the day (Mohamed, Bakr and Hasan, 2019). Indeed, the organism system exists for 3.8 billion years ago (ElDin, Abdou and ElGawad, 2016b). While at the behavioural level, architects mimic biological behaviour systems to solve building issues (Aziz and El Sherif, 2016). For instance, keeping bird temperature, called cuddling, in a cold environment can be used in architecture by increasing density to avoid extra heat loss in a cold climate. Behaviour systems can apply in any building form, organic or geometric (Hershcovich *et al.*, 2021),(López *et al.*, 2017a), and can be used on the building like skin or the envelope (López *et al.*, 2017a). Another study in Iraq addressed curvilinear shading devices inspired by cactus behaviour that can reduce the cooling load from 16% to 31% (Fattah *et al.*, 2024). The ecosystem level mimicking the entire ecosystem in architecture is more helpful and functional in decreasing nature's human footprint. The ecosystem level can apply on a large scale (Pedersen Zari, no date). For instance, HOK, Lavasa, India. Getting leave irrigation system for storage water and filtration (Aziz and El Sherif, 2016).

The behaviour level was applied by mimicking the adaptive strategies found in plans and animals. However it did not on physical traits but focused on how organism respond to change in their environment (Dong *et al.*, 2023)(López *et al.*, 2017b)

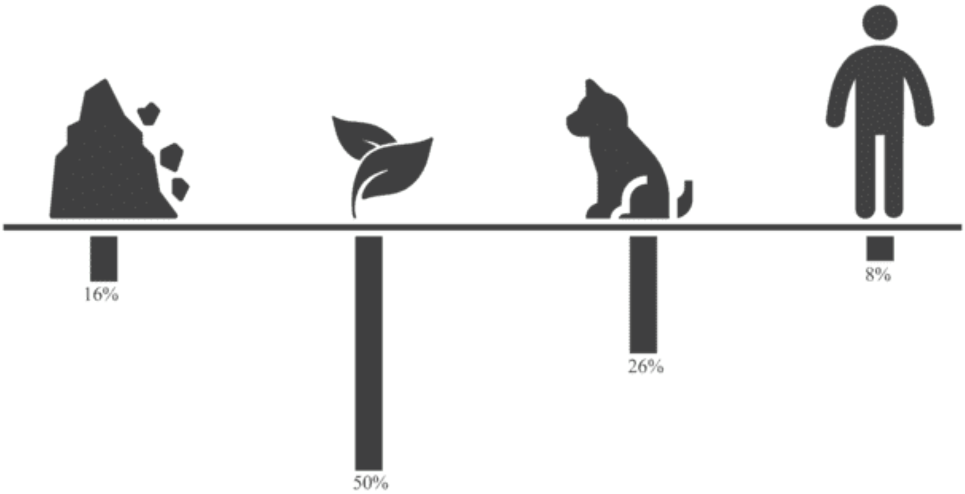

Figure 1. Cases study inspiration from (rock, plants, animals, and human)

BIOMIMICRY LEVELS AS DESIGN INSPIRATION

Organism Level

Design in architecture involves mimicking the function and forms of nature to create sustainable and energy efficient structure. This biomimetic approach draws inspiration from plants and animals to solve architectural challenges. For instance, in sngapore, the design of the esplanade theatre in inspired by structure of durian fruit to optimize and temperature control(Chayaamor-Heil, Guéna and Hannachi-Belkadi, 2018). In Senegal, a church design Mimics termite mounds to create natural ventilation systems for passive cooling (*Nianing Church*, no date). in Beijing, china's National Stadium, known as the Birds Nest emulates the form of the nest to enhance natural airflow and sustainability(Mehta, Thakur and Atha, 2019). Additionally, the national Taichung theatre in Taiwan is inspired by rocks eroded by water creating voids that enable natural ventilation. (*National Taichung Theatre*, no date). These examples illustrate how biomimicry can lead to energy saving architectureal design promoting sustainability through passive environmental control.

Ecosystem level: in biomimicry, the ecosystem level refers to mimicking entire ecosystems and their interconnected processes. An example of this is the adaptive nature of water bubbles, which can respond dynamically to environmental changes. On a larger scale, the Eden project in the UK employs active strategies to protect plant life while incorporating passive water management techniques(Singh and Nayyar, no date). In a similar approach, passive water filtration systems inspired by natural processes, such as leaf filtering, and rainwater, have been applied in India for irrigation and water purification, demonstrating how ecosystems can inform sustainable design(Shashwat *et al.*, 2023).

Behavioural Level: in biomimicry, the behavioural level refers to the inspiration drawn from the actions or functions of plans and animals. For instance, natural ventilation is a passive cooling system that prevents overheating as demonstrated by the eastgate center in Zimbabwe(Cruz, Raskin and Aujard, no date)(*Eastgate Centre*, no date). A similar strategy has been applied to council house 2 in Melborne, which utilizes natural ventilation for thermal regulation. The algae house in Hamburg integrates a shading system inspired by algae growth where algae cells are placed between two glass panels with water. Under sunlight, the algae grow and act a barrier, reducing solar radiation penetration(Ardiani *et al.*, 2019).this system is an example for active skin, contrasting with passive skins that adapt to solar radiation without requiring energy input. In temperate climates, Council House 2 employs these techniques for both ventilation and shading(Hes, Bayudi and Wakefield, no date).

MATERIALS AND METHODS

This study examines the impact of the biomimicry approach to enhance energy efficiency in office buildings (Sheikh and Asghar, 2019). The methodology begins with analysing and evaluating the energy efficiency in the different mimicked office buildings with different climates and regions. For this purpose,. Each project was investigated and analysed in terms of location, climate, function, materials, and level of inspiration, as explained below

Figure 2. Illustrates eight distinct projects located in various climates, each employing biomimicry in office building design. These projects demonstrate how biological systems can inspire innovative solutions tailored to the unique environmental challenges of different climate zones. By drawing from nature, such as efficient natural ventilation and adaptive shading systems, the designs offer sustainable strategies that improve energy efficiency and comfort within the built environment.

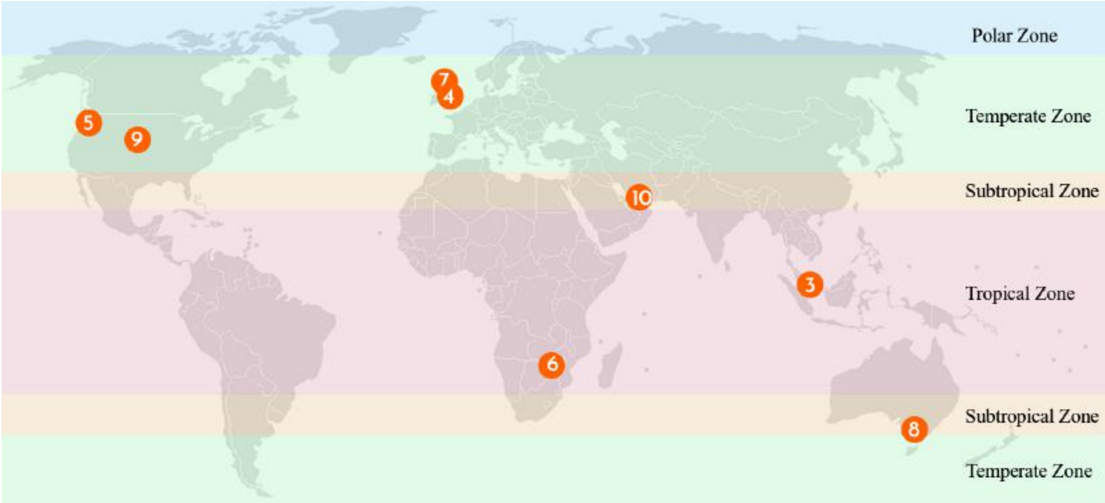

Figure 2. Climate and location of the case study project

Figure 3. Parkroyal on Pickering (Singapore)(*PARKROYAL On Pickering*, 2016)

Figure 4. One Angel Square (Manchester,

UK)('One Ange

Figure 5. The Bullitt Center (Seattle, USA)(Homchick Crowe, 2020)

Figure 6. CH2 (Council House 2, Melbourne, Australia)(Radwan and Osama, 2016a)

Figure 7. The Gherkin (30 St Mary Axe, London, UK)(*The Gherkin, London, UK*, 2019)

Figure 8. Eastgate Centre, Zimbabwe (*Eastgate Centre*, no date)

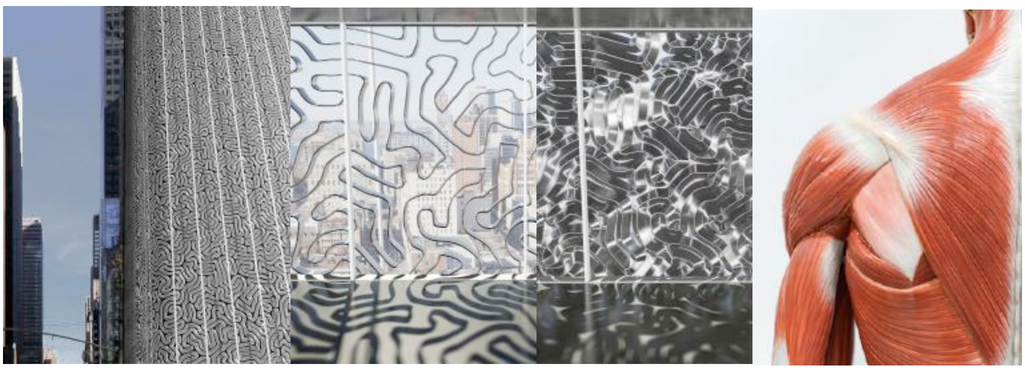

Figure 9. Homeostatic façade USA. New york (Fu *et al.*, 2020)

Figure 10. Bahr Tower in UAE (Karanouh and Kerber, 2015)

RESULTS AND DISCUSSION.

Eight projects were selected across various climate zones and categorized by name, location, climate type, function source of inspiration and energy performance; as summarized in **Table 1**, the majority of these projects draw inspiration from plants, while the remainder is influenced by human and animal forms.

Table 1. Overview of Eight Office Building Projects in Different Climates: Inspiration Sources and Energy Performance

Fig	Name and Location	Climate Zone	Function	Inspiration	Energy Performance
3	Parkroyal on Pickering (Singapore)	Tropical	Office	Terraced Rice Paddies	enhancing natural cooling and water retention
4	One Angel Square (Manchester, UK)	Temperate	Office	Human Skin	skin that regulates temperature and light levels similar to how human skin regulates body temperature
5	The Bullitt Center (Seattle, USA)	Temperate	Office	A forest ecosystem	a net-zero energy footprint, mimicking the circular processes of a forest
6	CH2, Melbourne, Australia	Tropical	Office	Termites & Trees	The building uses a ventilation system inspired by termite mounds, while its sun-shading system mimics how trees manage sunlight
7	The Gherkin - London, UK	Temperate	Office	Sea Sponges	The building's structure resembles a marine sponge, allowing for maximum natural light and ventilation, reducing the need for artificial lighting and air conditioning.
8	Eastgate Centre, Zimbabwe	Subtropical	Office	Termite Mounds	*Cool air in through the many underground tunnels *Improving air quality *Uses a fraction of the energy.
9	Homeostatic façade USA.	Temperate	Office	Muscles	**Passive** skin encourages the building of heat gain and heat loss.
10	Bahr Tower in UAE	Subtropical	Office	Lotus flower and mashrabiah	**Active** skin for east, south and west façades to protect inside from overheating during the day

To facilitate comparision, the results are presented using a numerical system. Natural ventilation is indicated by "1" if present, and "0" if absent. Similarly, shading device are marked as "1" if included and "0" if not. Active strategies are represented by "1" for presence and "0" for absence, while passive strategies follow the same format. The level of biomimicry is categorized as: "1" for organism "2" for ecosystem, and "3" for behaviour. Additionaly, the building form is classified as "1" for geometric and "2" for organic as shown in **Table 2.**

Table 2. Numerical comparison for eight office building

Fig	**climate**	**Solution**		**Strategy**			
		Ventilation	Shading	Active	Passive	Level 1,2,3	Form
3	Tropical	0	1	0	1	3	2
4	Temperate	0	1	0	1	3	1
5	Temperate	0	1	0	1	3	1
6	Tropical	1	1	1	1	3	1
7	Temperate	1	1	0	1	3	2
8	Subtropical	1	1	0	1	3	1
9	Temperate	0	1	0	1	3	1
10	Subtropical	0	1	1	1	3	1
TOTAL		3	8	2	8	8	6

Table 2 shows different solutions for different climates. Behaviour level (3) is more efficient for an office building and easy to apply in geometric form.

CONCLUSIONS

Biomimicry plays a pivotal role in enhancing energy efficiency in buildings. The three levels of biomimicry – organism, ecosystem, and behaviour each contribute to energy reduction, with the impact varying depending on the scale and function of the project. For smaller projects, the organism can be applied on a microscale, while the ecosystem level is more suited for larger, macro-scale developments.

The analysis of the eight case studies demonstrates that the behavioural level of biomimicry is most commonly used at a micro-scale as shown as in **Table 2**. Moreover, it proves to be more practical, versatile and easier to implement, particularly in geometric forms, compared to the

organism and ecosystem levels. Unlike the other two levels, the behavioural approach can adapted both passively and actively to optimize building performance.
Future research should be focused on further exploring the behavioural level in a variety of office building prototypes, given its flexibility and functionality in achieving energy efficiency.

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