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Biomimetic Approach for Thermal Performance Optimization in Sustainable Architecture. Case study: Office Buildings in Hot Climate Countries

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Biomimetic Approach for Thermal Performance Optimization in Sustainable Architecture. Case study: Office Buildings in Hot Climate Countries

Azza Elsakksa[1], Ola Marouf[2,3], Mai Madkour[4]

[1] Associate professor, Department of Architectural Engineering, Faculty of Engineering, Tanta University, Egypt.
[2] Master of Science candidate, Department of Architectural Engineering, Faculty of Engineering, Tanta University, Egypt.
[3] Demonstrator, Department of Architectural Engineering, Faculty of Engineering, Delta University for Science and Technology, Egypt.
[4] Associate professor, Department of Architectural Engineering, Faculty of Engineering, Tanta University, Egypt.

E-mail: olamarouf390@gmail.com

Abstract. Biomimicry is an applied science that mainly depends on deriving inspiration from various natural solutions to human problems for making practical applications through the study and examination of natural phenomena, designs, systems, and processes. Historically, designers have dealt with nature as an essential source of innovation and inspiration. In future architecture, biomimicry will be applied to achieve sustainable design. Thus, the paper assumes that biomimicry is an environmental solution for optimizing the thermal performance of office buildings through the building's skin. The purpose of this paper specifically is to determine and clarify the effective indicators of applying biomimicry to the skins of office buildings in hot climate countries. This will be accomplished by discussing the general concept of biomimicry and its definitions, approaches, and levels. Then, selected examples of biomimetic skin of office buildings in hot climate countries will be shown, analyzed, and compared to determine the most effective biomimetic indicators that will be suggested to be applied to the office building skin. As a result, the effective use of biomimicry as a tool for sustainable design leads to optimizing building thermal performance, optimum thermal comfort for users, and increased productivity for employers in office buildings. Based on indicators, biomimicry as a creative approach to achieving sustainable design will support architects, students, and scholars in achieving sustainable office building design.

Keywords: biomimicry, office buildings, sustainable design, thermal performance, building skin.

1. Introduction

Nature is an endless source of inspiration and creativity for designers, planners, and scientists across all disciplines [1]. Biomimicry (from the Greek words: bios "life" and mimesis "to imitate", the word means "to imitate life") is the study of mimicking and emulating nature to solve human problems. It is a relatively new field that studies nature's best ideas and then applies these designs and processes to solve problems. Biomimicry and its applications trace back to the fifth century BC when natural elements were inspired as ideal models by mimicking proportions among their parts that are reflected on classical aesthetic elements [2].

Most biomimicry attempts are based on taking inspiration from external forms and elements while ignoring the internal behavior and systems of living organisms that lead to sustainability. Biomimicry can be used to achieve sustainable design. It is becoming increasingly important as buildings become inefficient, consuming a great deal of energy, materials, and resources. Furthermore, design processes are becoming less sustainable [3]. It is also about fully comprehending the philosophy of natural life and how it affects design to solve a specific problem. The building can be adapted to surrounding conditions such as organisms.

Buildings are the major consumer of global final energy use by a ratio of up to 40%. Building skin is the main contributor to this percentage as it is responsible for direct heating and cooling loads through the building. According to the International Energy Agency, applying passive systems on the building skin is among the key global considerations set to meet net-zero carbon emissions in the building sector by 2050 [4]. The thermal performance of building skins has sparked widespread interest around the world. In this regard, buildings' skins have become a growing field of research in the last decade, but a comprehensive review of studies investigating their design is still lacking. In this paper, biomimicry will be studied as a method for designing a sustainable building skin that optimizes thermal performance, reduces energy consumption, and achieves thermal comfort for users.

1.1 Research Problem

In light of climate issues and rising energy consumption in buildings, particularly office buildings, thermal comfort could be reached by a variety of factors, including a mechanical design of the HVAC system, as feeling comfortable in such an interior space has a direct impact on people's mood. Working in optimal settings allows us to think and work better in office buildings, and thermal comfort adds not only to well-being but also to productivity.

1.2 Research Aim

The main purpose of this paper is to highlight biomimicry as an approach to the design of a building skin by identifying the most important indicators that achieve thermal comfort, optimize thermal performance, and reduce energy consumption in office buildings in hot climate countries.

1.3 Research Methodology

To achieve the aim, the theoretical and analytical methodology will be used in this paper, beginning with a review of the theoretical framework for biomimicry, focusing on the approaches, levels, and sub-levels of biomimicry to aid in the following stage. Several examples of biomimetic buildings' skins will be carefully analyzed after their selection based on common conditions as all examples are office buildings in similar hot climate conditions. The analysis will aid to deduce the most effective indicators and considerations for applying a biomimetic approach to the building skin (Fig. 1).

Figure 1. Research methodology. Source: researchers.

2. Biomimetic Approach Background

Biological ideas were embraced in the writings of great architects such as Le Corbusier and Frank Lloyd Wright. Le Corbusier (1452–1519) declared that "biology is the great new world of architecture and planning". Since the early nineteenth century, architects, scientists, and designers have looked to biology for inspiration. Over the years, the term "biomimicry" has evolved significantly.

Designers and architects have given many definitions and concepts to biomimicry over the past years. Otto Schmitt, an American biophysicist, and polymath coined the term "biomimetics" in the

1950s. According to Otto Schmitt, biomimetics is "the transfer of ideas and analogs from biology to technology" [5]. In 1960, the term "Bionics" was introduced by engineer Jack Steele as "The science of systems that has some functions copied from nature".

The term "Bionics" entered Webster's dictionary in 1960 with the concept of "a science concerned with the application of data on the functioning of biological systems to solve engineering problems"[6]. The term "Biomimetics" only entered webster's Dictionary in 1974 and it is defined as the study of the formation, structure, or function of biologically produced substances and materials (such as enzymes or silk).

The term "biomimicry" then appeared in 1982 by scientist and author Janine Benyus in her book Biomimicry: Innovation Inspired by Nature, which is published in 1997, as a "new science that studies nature models and then imitates or takes inspiration from these designs and process to solve human problems" [7].

In 2006, scientist Julian Vincent defined biomimicry as "a reflection of nature's tremendous design" [8]. In 2011, Petra Gruber defined biomimicry as "Nature's blooming field of behavioral analogies, functions, processes, or data offered by live biological models". In 2019, Michel Pawlyn defined it as "mimicking the functional basis of biological forms, processes, and systems to generate sustainable solutions" (Fig. 2).

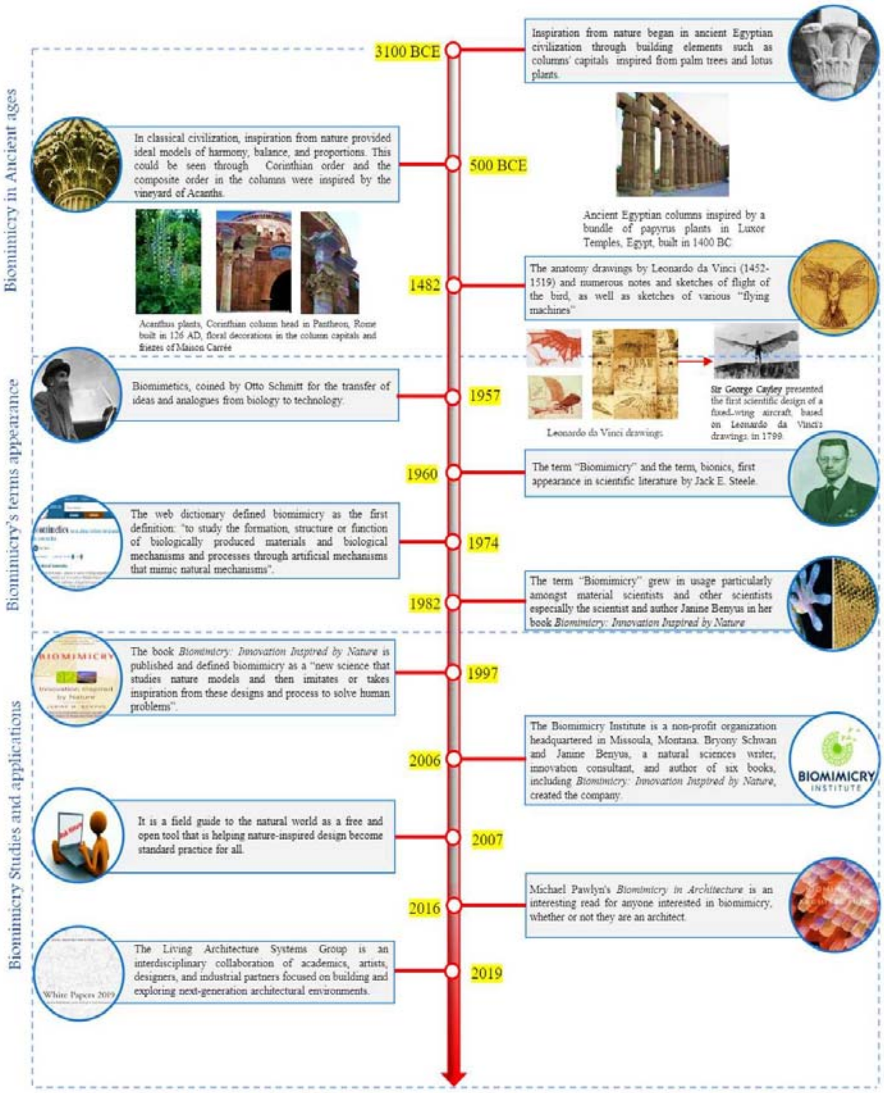


Figure 2. The prevalence of biomimicry, and its milestone. Source: researchers

3. Framework of Biomimicry

3.1 Approaches to biomimicry

There are two approaches that researchers and designers can take to the biomimicry-based design process. The approaches are known as "bottom-up" or "solution-driven biologically inspired design", and "up-down" or "problem-driven inspired design" [9] (Fig. 3).

3.1.1 The problem-based approach (Design looking to Biology)

This approach is also known by various names, such as "Design looking to Biology", "Direct approach", "Top-down", and "Problem-driven". This approach takes the problem as a starting point, with designers defining the exact design problem to set specific goals [10].

3.1.2 The Solution based approach (Biology to Design)

This approach is also known as "Biologically Inspires Design", "Biology Influencing Design", "Biology to Design", "Indirect approach", "Bottom-Up Approach", and "Solution Driven". This method is used when the design process is initially based on the scientific knowledge of biologists and scientists rather than human problems [11].

3.2 Levels of biomimicry

Maibritt Pedersen Zari, a professor at Victoria University in Wellington was able to categorize biomimicry into three different categories or "levels" which are Organism, Behavior, and Ecosystem [12]. Through each level, five dimensions or sub-levels determine the extent to which the mimicry exists. These dimensions are form or appearance, material, construction or how it works and process or what it can do, and function or capability [13] (Fig. 4).

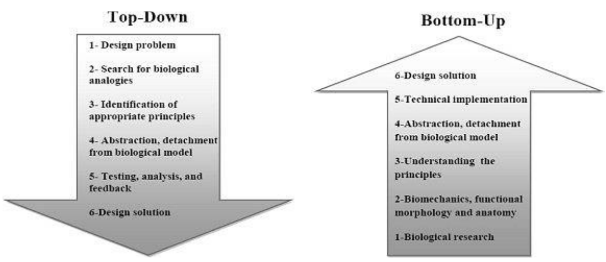


Figure 3. Biomimicry approaches. Source: (Moheb Sabry Aziz, Amr Y. El sheriff,2015)

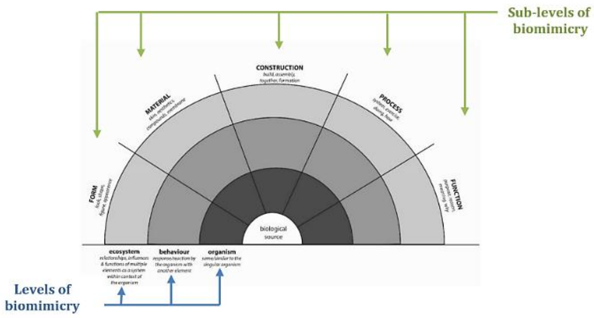


Figure 4. Biomimicry levels. Source: (Harris D, 2016). Developed by researchers.

3.2.1 Organism level

Buildings at the organism level mimic the characteristics of an individual organism (a plant or an animal), including some of the organism's overall form, material, function, construction, and process [14].

3.2.2 Behavior level

On the behavior level, the design will be inspired by how the organism behaves, conducts, and relates to its larger context, as well as how the organism acts and behaves to survive or reproduce regularly, and how it functions [15].

3.2.3 Ecosystem level

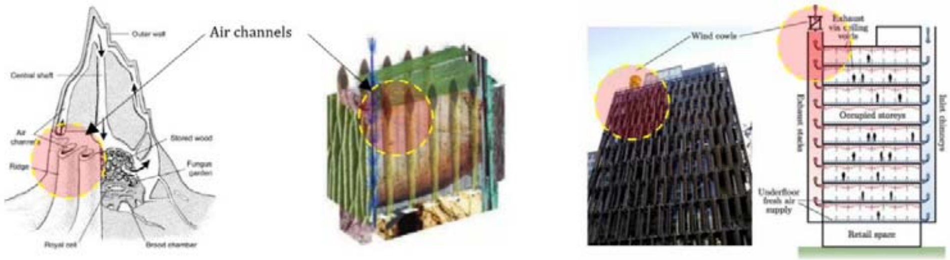
On the ecosystem level, the design depicts the entire ecosystem of the organism and its surroundings. It emphasizes the natural processes and cycles of the larger environment to achieve a sustainable environment [16].

4. Analysis

Eight examples of biomimetic skins of office buildings located in various hot climate countries (Fig. 5) have been selected and analyzed (see Table 1). The scarcity of those kinds of examples of buildings will allow results to be considered as a measure.

Figure 5. The office buildings' countries' locations. Source: researchers.

A Melbourne City Council building's fresh air is dripping down through the wall ducts and pushing out through the ground vents into the interior spaces. The stack effect, inspired by termite mounds, is the mechanism used by the architect to direct the hot and exhausting air out of the building through roof gaps of shafts up to the wind turbines (Fig. 6). To avoid the unwanted hot sun on the western façade, automatic shading louvers are installed [2].



a b c

Figure 6. The biomimetic concept of the CH2 building skin. a) Termite mounds. Source(Jeanne RL, 2009). b)Windpipes on the façade. Source: (Gehan.A.N.Radwan,2016). c) Building skin of the CH2 Building. Source: (Dutta Pramanik P, 2019). Developed by researchers.

Qatar's giant cactus is the new Minister of Municipal Affairs & Agriculture building that features a cactus-inspired design that is the epitome of biotic adaptation to its environment (Fig. 7). The sunshades on the windows are designed to open or closed depending on the temperature mimicking the activity of the cactus which performs transpiration at night rather than during the day to retain water [17].

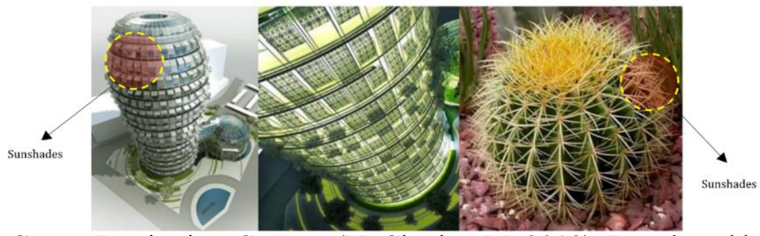
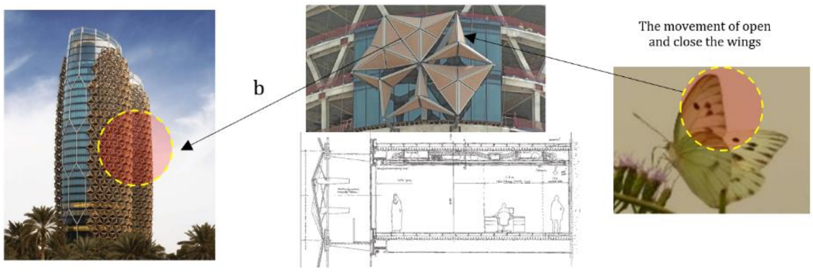


Figure 7. Cactus Inspiration. Source: (N. Charkas M, 2019). Developed by researchers.

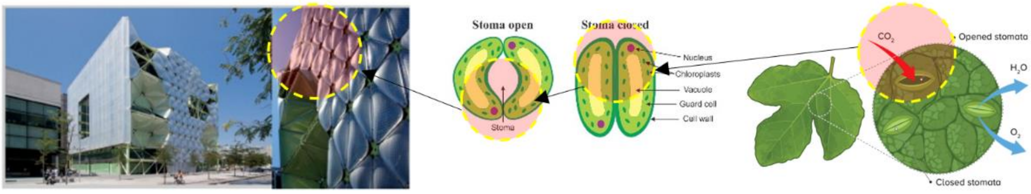
To avoid the desert's scorching sun, Aedas Architects designed a double façade system for Al Bahar Towers. The exterior façade is kinetically designed to open and close in response to sun movement. The design of photovoltaic panels was influenced by white butterfly wings. The shutters, according to Peter Koch, open and close like butterfly wings in response to heat and light levels inside the building (Fig. 8). It makes use of natural light and aids in energy conservation [18].



a c d

Figure 8. The biomimetic concept of Al-Bahr Towers. a) Al-Bahr Towers. b) part of the building's façade. c) The schematic section. Source: (Karanouh A, Kerber E. 2015). d) white butterfly. Source: (https://butterfly-conservation.org/butterflies/green-veined-white. Developed by researchers).

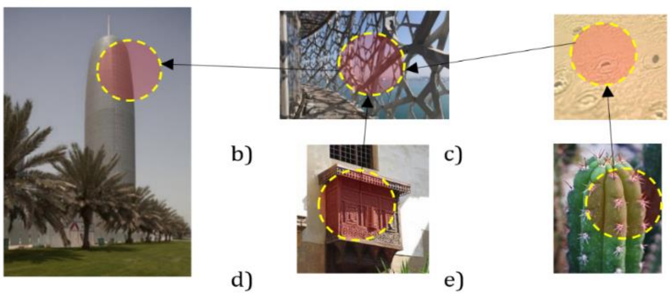
The idea of a biomimetic facade in the TIC - Media building in Barcelona is based on a network of inflatable pillows-based stoma of the plant. Each stoma of a plant is made up of a guard cell and an auxiliary cell (Fig. 9). The hole is opened and closed by the guards by absorbing or releasing water in such a way that they either fill up or drain out like a water balloon, as the plant regulates its temperature by opening its stomata [19].



a) b) c)

Figure 9. The biomimetic concept of Tic-Media building. a) Tic-Media building in Barcelona. Source: (Hadeer Samir MohamedShahin, 2019), b) Stomata climate cycles. Source: (www.grasscity.com). C) Opened and closed stomata. Source: (theconversation.com)

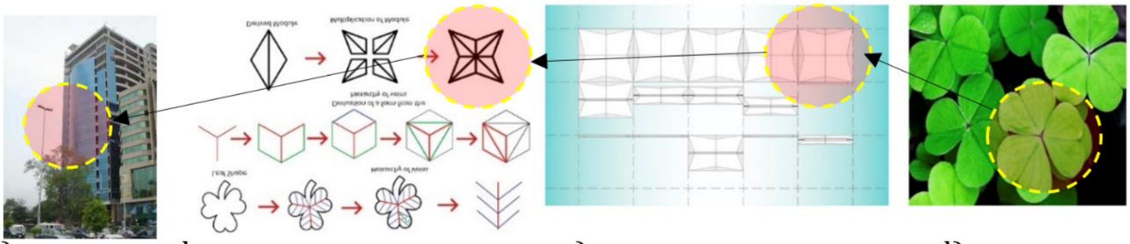
Doha Tower's façade system is dependent on the kinetic screen and the curtain wall, made of reflective glass. The facade screen is a reference to the ancient Islamic design, Mashrabiya, and it is also inspired by the open and darkening surface pores of the cactus plant[20](Fig. 10).



a) d) e)

Figure 10. The biomimetic Doha tower concept. a) Doha tower. b) The skin of Doha towers. c) The pore of the cactus. d). Source: (https://www.archdaily.com/). e) Cactus plants. Source: (sacredsucculents.com). Developed by researchers.

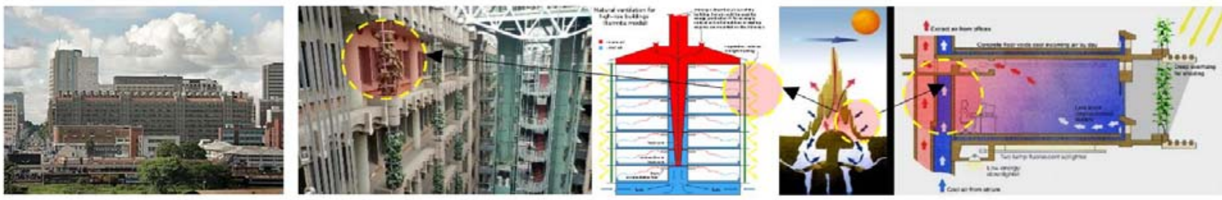
The skin of the Tricon Corporate Centre is designed by mimicking a combination of the organism and behavior levels of the Oxalis oregana plant [21]. The photoreceptors in the Oxalis oregana plant allow it to track the intensity of sunlight (Fig. 11). Its leaf can change its angle from horizontal to vertical in just 6 minutes [22].



a) b c) d)

Figure 11. The biomimetic concept of Tricon Corporate center. a) Tricon Corporate Center. b) Stages of inspiration. c) Folding of the module into shading position. d) The Oxalis oregana plant. The source of b, c, and d: (Wajiha Tariq Sheikh, 2019). Developed by researchers.

The Eastgate office building was inspired from termites that can maintain an internal temperature of 30 degrees C while daily temperature fluctuations the ranging from 40 degrees C to less than 0 degrees C. The biomimetic skins of the building are thick with insulating walls creating and constantly maintaining a draught of air from low openings to top holes (Fig. 12). Designers take advantage of the stack effect, or convective airflow from cool to warm [23].



a) b) c) d)

Figure 12. The biomimetic concept of the Eastgate building. a) Eastgate building. b) The façade of the Eastgate building. Source of a and b: (https://en.wikipedia.org). C) The section of the Eastgate building. Source: (https://asknature.org). d) The inspiration of The Eastgate building skin. Source: (https://www.mickpearce.com). Developed by researchers.

According to architect Michael Pawlyn, the glazed glass exterior of the Biomimetic Office Building nods to a mollusk's iridescent shell, while our double-duty spinal column is echoed in support columns that also encase the building's energy systems. The Biometric Office Building design is inspired by the foliage that closes at night and reopens in the morning, efficiently capturing and utilizing sunlight (Fig. 13). The building design needs identical shades, like plants like the mimosa pudica [24].

a) b) c) d)

Figure 13. The biomimetic concept of the biomimetic building. a) The section of the biomimetic building. b) Mollusk's iridescent shell. c) The mimosa pudica plant. d) The biomimetic office building. Source: (exploration-architecture.com). Developed by researchers.

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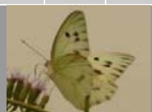
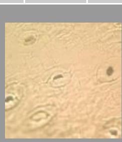
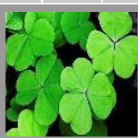
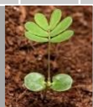
Table 1: The analysis of biomimetic skin of office buildings. Source: researchers.

Case study / The analysis criteria		Biomimetic Sector: Biomimetic approach: The problem-based approach	Biomimetic approach: The solution-based approach	Biomimetic level: Organism level	Biomimetic level: Behavior level	Biomimetic level: Eco-system level	Biomimetic sub-level	Architecture Sector: Building Skin: Protective skin	Building Skin: Shading system	Building Skin: Double-wall	Skin materials: Recycled	Skin materials: Non recycled	Environmental Sector: Energy savings	Natural ventilation and lighting	HVAC level lowered
Project (1)	**The Council House 2, Melbourne** 		√				Form	√	√	√	√	-	%95	√	√
					√		**Function**								
				√			**Construction**								
							Material								
					√		**Process**								
				 **White ants**			**Biological Source**								
Project (2)	**The new Minister of Municipal Affairs & Agriculture (MMAA) building** 		√				Form	√	√	-	-	√	50%	√	√
							Function								
				√			**Construction**								
							Material								
							Process								
				 **Cactus**			**Biological Source**								
Project (3)	**Al Bahar Towers, The United Arab Emirates** 	√			√		**Form**	-	√	√	-	√	50%	√	√
							Function								
							Construction								
							Material								
							Process								
				 **White Butterfly**			**Biological Source**								
Project (4)	**The Media-TIC Building, Barcelona** 	√					Form	√	√	-	-	√	95%	-	√
							Function								
							Construction								
							Material								
					√		**Process**								
				 **Opened and closed stomata**			**Biological Source**								
Project (5)	**Doha Tower, Qatar.**		√				Form	√	√	√	-	√	25% north façade, 40% south	-	√
							Function								
							Construction								
							Material								

					√		**Process**						façade, and 60% on both the west and the east façades		
				 **The pore of the cactus plant**			**Biological Source**								
Project (6)	**Tricon Corporate Centre** 	√		√			**Form**	√	√	-	-	√	32%	-	√
							Function								
							Construction								
							Material								
					√		**Process**								
				 **Oxalis oreganada leaf**			**Biological Source**								
Project (7)	**Eastgate Building in Harare, Zimbabwe** 		√				Form	√	√	√	-	√	35%	√	√
					√		**Function**								
				√			**Construction**								
							Material								
					√		**Process**								
				 **termite mounds**			**Biological Source**								
Project (8)	**The Biomimetic Office Building, architect Michael Pawlyn**  	√					Form	√	√	-	-	√	expect to be saved by up to 25%	-	√
							Function								
				√			**Construction**								
							Material								
							Process								
				 **mollusk's iridescent shell**			**Biological Source**								
		√					Form								
							Function								
							Construction								
							Material								
					√		**Process**								
				 **the mimosa pudica plant**			**Biological Source**								

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5. Results

The cumulative points gained by each level and sub-level will be signed based on the previous analysis will be shown below (Fig. 14).

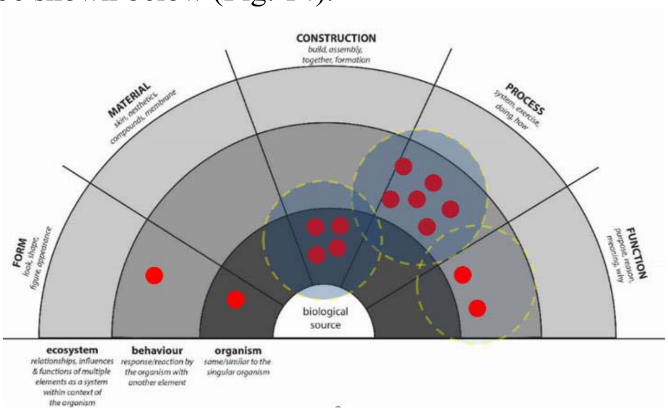

Figure 14. parameters of biomimicry signed with points deduced from analysis

The cumulative points scored by each main level and sub-level and the average of energy-saving percentage according to previous analysis will be shown below (see Table 2).

Table 2. Cumulative points and the average of energy saving percentage.

Level	Sub-level	Points (the number of projects used at the sub-level)	Total Points in each level	The percentage of sub-level (%)	Average of energy saving percentage in each sub-level	The average of energy-saving percentage in each
Organism	**Form**	1	5	7%	**32%**	**42%**
	Material	0		0%	**0%**	
	Construction	4		28.5%	**50%**	
	Process	0		0%	**0%**	
	Function	0		0%	**0%**	
Behavior	**Form**	1	9	7%	**50%**	**56%**
	Material	0		0%	**0%**	
	Construction	0		0%	**0%**	
	Process	6		43%	**54%**	
	Function	2		14.5 %	**65%**	
Eco-system	**Not applied to the examples**					
	Total Points			**14**		

The graph shows that many designers and architects are following the design of biomimetic skin of office buildings at the behavior level with a sub-level of the process, and then the organism level with a sub-level of the construction (Fig. 15).

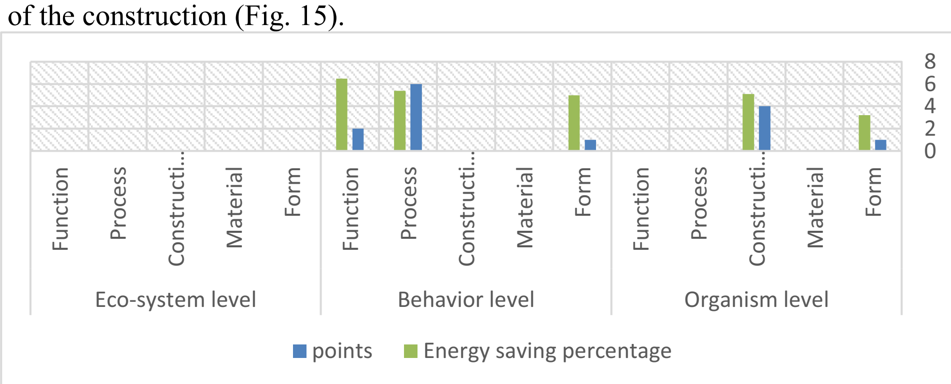

Figure 15. The graph of points and energy-saving percentages in the analyzed examples.

Biomimetic building skin design at the level of behavior with a sub-level of function achieves 65% and with a sub-level of process achieves an average of 54% of energy savings. There is the most collectible to save energy in office buildings, followed by an organism with a sub-level of construction at 51% and form at 32%.

6. Conclusion

The following indicators are inferred by analyzing previous examples of office buildings' skins and analyzing the comparative and numerical results of the most used levels by architects for optimization of thermal performance and saving energy.

- The Biomimetic approach at levels of organism and behavior as a sustainable skin design approach in office buildings has proved effective in thermal performance optimization in terms of energy conservation, providing natural lighting and natural ventilation, providing thermal comfort to users, and less consumption of HVAC loads.

- The biomimetic approach was used at the organism and behavior levels, and examples lacked the application of the third level, as well as the methodology for applying the ecological level to the skin of the building. Based on the analysis of examples, it was discovered that the behavioral level achieves better thermal outcomes than the organism level. It is predicted that the ecological level will achieve more effective outcomes than the behavior and organism levels based on building and climate conditions. It is preferable to conduct studies on the application of the ecological level to the building skin.

- Biological processes and functions are the best sub-levels that can be followed to achieve a biomimetic skin that optimizes thermal performance. This, as well as a solution-based approach, necessitates biological knowledge.

- Biological knowledge is critical in applying sustainable principles. Biologists and architecture specialists must collaborate to create a mutual database or platform for the study of organisms and their behavior which can be reflected in building skins depending on climatic regions to provide immediate solutions to thermal performance problems.

- Recycled, local, and smart materials aid in the design of the most successful biomimetic skin, which optimizes the thermal performance of the building.

- Biomimetic skins are essential in office buildings because they provide thermal comfort within the building, reduce energy consumption, reduce HVAC loads, add an aesthetic element and a good view for users, and improve indoor environmental quality, increasing employer productivity in office buildings.

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