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A Systematic Design Technique of Biomimicry to Correlate and Integrate Architecture and Biology to Attain Green Buildings

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Abstract
Nature embraces enormous resources for biomimicry yet faces many challenges, including embodying and simulating environmental systems and processes into technical systems within the built environment. Also, imitation and mimicry strategies focus on separate parts rather than a complete system as an organism as a single unit in its environment. Therefore, the research aims to reduce the harmful effects of buildings and preserve biodiversity and energy through a systematic design technique for biomimicry to identify appropriate adaptation mechanisms from nature and inspire their functions, processes, and forms to integrate architecture and biology. Accordingly, the study addressed biomimicry through its entrances, classes, and levels depending on the desired result. The problems encountering biomimicry application and its adaptation mechanisms were explained. Then, the information and characteristics required from nature were classified according to three biomimicry classes to implement environmental concepts and treatments. Likewise, the study compared the biomimicry strategies to choose the most suitable one for the design processes. Thus, it confirmed the correlation between green buildings and biomimicry. Finally, a systematic technique was derived and established to incorporate and collaborate between two approaches for simulating nature to identify the appropriate biological systems for attaining green building, improving design processes, and making decisions.

1. Introduction

In developed nations, a sizable portion of overall energy use is accounted for by the building industry, which is responsible for 16% of all water use, 40% of all raw material consumption, 40% of all energy produced, and 25% of all timber used [1], [2]. It is significant that develop more sustainable and resilient solutions given the rising environmental consciousness and the requirement to minimize energy demands [3]. A further approach, including energy-efficient buildings, must be used because energy efficiency is an obligatory positive trend that imposes itself on a global scale. Engineers and designers must draw inspiration from organisms and living things

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on the micro and macro scales to mature and develop solutions to deal with energy efficiency to attain green buildings (GBs) [4]–[6]. This issue is dealt with by employing adaptation techniques in nature, whereby the process of an organism becomes more suitable to its environment and is essential for usefulness and survival over short and long durations [7], [8]. For concerned engineers and experts in various sectors, nature offers an infinite supply of inspiration. Every organism is distinct and perfectly suited to its environment. Nature changes due to responding to its necessities and devising efficient solutions [9]. The ability of an element to bounce back after a change or react correctly to a group of multiple circumstances is often referred to as resilience [6], [10]. That endures for numerous eras, succeeding through the survival test of time to reach the subsequent age. The practice of biomimicry, in which plants, animals, or whole ecosystems are imitated as a design inspiration, has universally sparked attention in architecture disciplines. Natural systems offer a vast repository of tactics and techniques. Besides, it serves as a source of inspiration for possible contemporary innovations that can be included through biomimetic creations to create a successful design and build an environment that is more sustainable and green, which is faced with significant challenges and contentious issues [11], [12]. It is now widely acknowledged that the twentieth century was the era of physics, and the twenty-first century will be the biology era. Almost everyone agrees on two aspects of the 21st century. When comparing budgets, workforce sizes, and the number of significant discoveries produced, biology has surpassed physics in scale. This trend is anticipated to continue into the 21st century. Also, biology is more significant than physics in terms of its impact on the economy, morality, and human welfare [10], [13]. So, as a relatively new model for the design process in applied practice, the biomimetics approach can utilize various and varied mechanisms, methods, and strategies in nature [14]. Because of this, it is challenging to practice and use biomimicry in the field of sustainable or GBs and construction, although it looks for sustainable solutions to difficulties and concerns imposed by circumstances or faced by humans. Today, applying biomimicry to solve indoor space issues is required rather than desirable to meet human demands and improve the quality of life [15]. One of the meaningful design solutions, whether in architecture or other arts and sciences, has been modeling and imitating nature [5]. All around us, nature impacts everything and is the source of all life. Shaping and mimicking nature are two keys to approaches to design, whether in construction or other fields of the sciences and arts [16], [17]. The three inferred classes of biomimetic design, namely form, process, and ecosystem, demonstrate that design can mimic a process, replicate form or shape, or even imitate at an ecosystem level. Only creative solutions may address a combination of issues in architecture; models drawn from nature can spur the imagination and ingenuity of an architect. The optimal sort of adaptation has been demonstrated by natural models in a mixture of settings across time, making the shift from nature to architecture logical [2]. The shortcomings in creating effective systems and products are addressed by biomimetics. Also, Myers demonstrated a striking design strategy involving combining live materials into elements and structures. Myers' technique drives the idea of mimicry to incorporate life within formations to generate new forms in practice and investigated how used animal skins were for high-performance projects [18]. However, developing appropriate design tools for the built environment presents difficulties for biomimetics research. A strategic methodology was established in many academic studies along this line, including "BioSkin," "Towards the Living Envelope," and "Architecture Follows Nature." [17], [19]. Although interior architecture frequently uses biology as a library of shapes or decorations (Jugendstil, the like, and Art Nouveau). The general and practical use of biomimicry as a design methodology is still largely unrealized. Hence, it requires a systematic design technique of biomimicry to correlate and ingrate architecture and biology. Imitating or being inspired by natural-looking forms, textures, and colors alone is not biomimicry; it must also contain some biology. That indicates that a design must be inspired by nature's science in other ways, not merely by aesthetics, to be truthfully biomimetic. The natural environment has a lot to teach architects, designers, and engineers to achieve GBs.

2. Research Problem

Biomimetic design strategies are available and numerous today. However, formulating an efficient design concept is the most significant challenge, requesting a selective design methodology or mechanism that can identify relevant systems and processes and then derive their strategies and mechanism [8], [11]. Also, regarding the issue of the complete separation when handling two biomimicry approaches, although possible to integrate and be compatible between them in facing the same design problem or challenge simultaneously, the benefit will be more general and comprehensive. Furthermore, to go beyond the belief that mimicry of nature is only at the level of the organism's appearance or shape, it must be at the level of the ecological processes and systems of the organism and its environment [6], [20]. On the other hand, biomimicry faces two main obstacles, the biggest of which is when designers translate concepts, systems, natural processes, and biology into technical systems in the built environment or design to achieve standards and principles of sustainability, or GBs [12]. Furthermore, the second obstacle is that many biomimetic methods focus on the design process as separate parts instead of dealing comprehensively as a complete system, such as the living organism as a single unit in its environment. Besides, simulating all its vital properties, processes, and form is in an integrated design [19], [21].

3. The Aim and Objectives of the Research

The research aims to reduce the harmful effects of buildings becoming GBs and preserve biodiversity and energy by structuring a systematic design technique of biomimicry to correlate and ingrate architecture and biology. It also meets the designer's demand for support with decision-making and independence without mandating the use of a particular tactic. The following objectives can achieve this aim:

1) To demonstrate the concept and principles of biomimicry as a creative approach through nature imitation in form, processes, and ecosystems, and learn how to apply biomimicry in design and interpret the problems of its implementation.
2) To provide solutions and examples of adapting mechanisms based on required information and characteristics concerning biomimicry classes obtained from nature and biological systems; thus, choosing the biomimicry design approach that is most suitable to correlate the GBs principles to biomimicry; and
3) To derive a systematic technique to incorporate and collaborate between two biomimicry approaches to simulate nature in the design and achieve comprehensive GBs harmonizing with nature.

4. Methods and Tools

The study used the inductive method, as shown in **Fig. 1**, to explain and clarify the meaning and role of biomimicry as a creative approach that seeks environmental solutions by imitating nature in form, processes, and ecosystems. Furthermore, shedding light on the principles of biomimicry as sources of inspiration and deduction from nature and biological systems. In addition, biomimicry's

role in the design or the way nature is understood. Besides, how to apply biomimicry in design through approaches, classes, and levels depending on the desired result.
The study relied on the analytical method to collect, inventory, and reveal the problems facing the employment or activation of biomimicry in design as a newly emerging field. The solutions and examples of adaptation mechanisms in nature and architecture were presented, which describe and are equivalent to the three possible classes of imitation during the implementation of any of the two biomimicry approaches as a design process. Then, analyzing an adaptive envelope as a design example was to identify the usage aspects of biomimicry in architectural design. Therefore, the difference between the information and characteristics required according to three biomimicry classes, which can be learned from and utilized in design concepts and environmental treatments, was demonstrated. Thus, the biomimicry design approach that is most suitable for the design processes was identified and selected through an analytical comparison of its application strategies and showing the possibilities for improving the design processes.

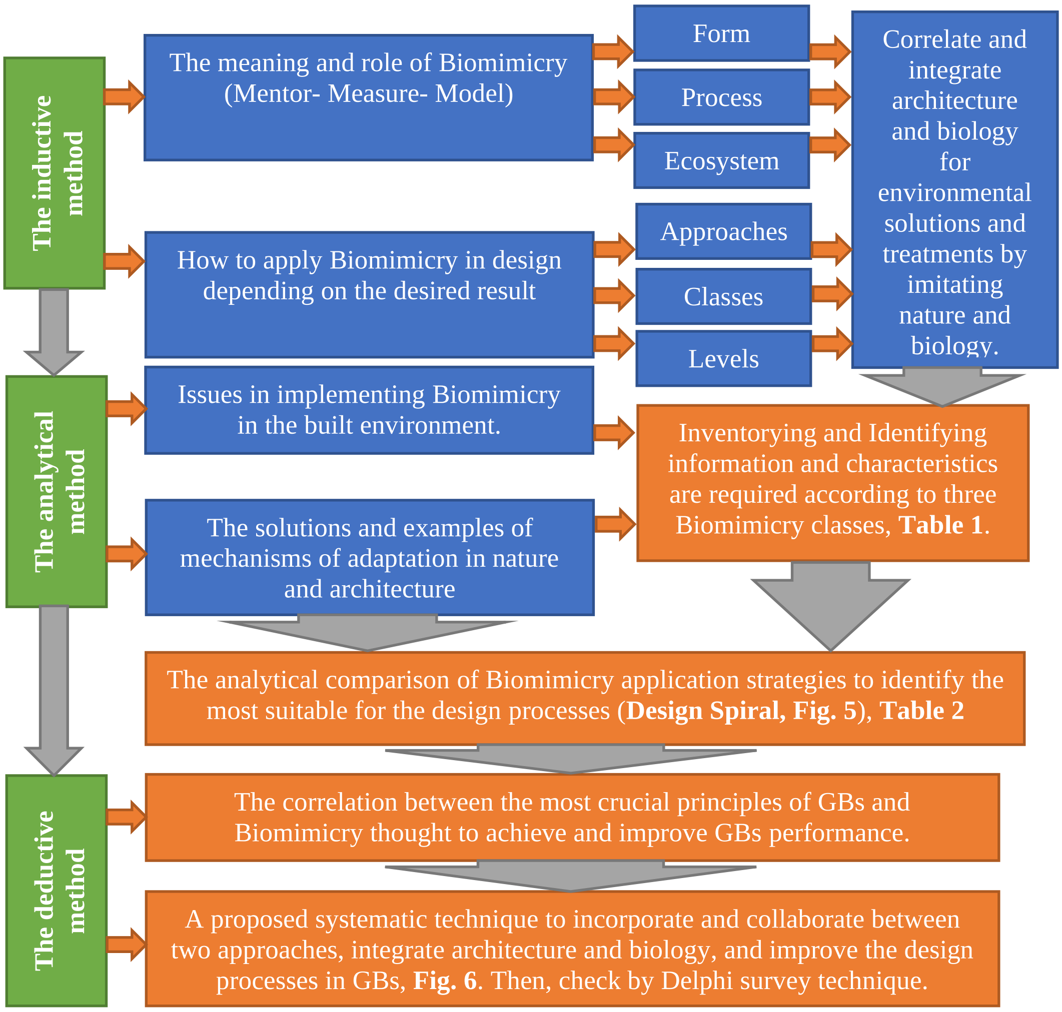

Fig. 1. The research methods.

Based on the above, the study employed the deductive method to correlate and integrate the most crucial principles of GBs that the thought of biomimicry could achieve, improve their performance, and contribute to biodiversity through distinct designs. The transition from nature to architecture is a logical attitude because natural models have made the best adaptations under various conditions over the years. Finally, a systematic technique was derived and established for integrating and collaborating between two approaches to mimic nature in GBs, improve the integration of architecture and biology, and help the designer make decisions during the design processes. Then, ensure and verify the effectiveness (importance -uniqueness) of such systematic technique by the Delphi survey technique.

5. Biomimicry Definitions

Biomimicry is a creative approach that studies natural systems, processes, and designs for inspiration to find new ways to address issues. Biomimicry is a newly developed field of study that refers to imitating nature's tried-and-true patterns as an innovation process in searching for sustainable solutions [3], [10], [22]. Biomimicry is the evolution of copying or drawing ideas from natural systems to address human challenges. Janine Benyus, a biologist and pioneer of the growing subject of biomimicry, gives one basis for this discipline; in her defense of the necessity of mimicking nature to secure a more sustainable future [23]. Benyus and other proponents of biomimicry underline that while replicating natural form is significant, doing so solely misses the objective. Benyus contends that a complete imitation of nature involves at least three layers of mimicry (appearances, processes or functions, and ecosystems) to solve issues [20], [24]. Replicating an organic system or thing is only one aspect of biomimicry. It also goes beyond only creating something to be "green" or sustainable. A creature or ecosystem is closely examined, and the underlying design ideas present in the natural solutions are mindfully applied. Understanding nature is one thing; taking lessons directly from it is another [21]. Time-tested patterns and solutions from nature surrounded humans. Biomimicry is the realization and use of these patterns and answers to address design problems. According to Janine Benyus, the founder and head of the biomimicry Institute, "Nature is innovative by condition and has already resolved many of the issues humans are facing today." Our living environment is a dynamic encyclopedia of inventiveness [5], [9]. Architecture, material science, and chemistry are just a few of the enormous fields where biomimicry is used to solve technical difficulties. It has evolved and been inspired by insects, reptiles, mammals, and other living things over the past 30 years. From an engineering standpoint, biomimetics can be used to address issues in the conceptual design phases. Although "biomimicry" and "biomimetic" are frequently used interchangeably, the latter emphasizes the technical side more. The available strategy for creating a more robust biological system is biomimetics as an emerging discipline [19], [25]. Thus, it is also known as bio-mimicry. It imitates tactics employed by living creatures to carry out tasks that our technology must complete. Every facet of biomimicry is covered, from producing energy to creating color. There are three basic imitation classes, and this will also demonstrate different approaches to using and enhancing high-rise buildings. Hence, following the sustainable design fundamentals, engineers consider mimicry at the organism, behavior, and ecosystem level. It was found that every creature in nature avoids excess and overbuilding, so it achieves optimum efficiency with the least number of resources. Furthermore, techniques for addressing the sources of creativity [3], [22]:

1) Duplicating, including imaging: its aim is scanning anything with the brain, a detector, or an electromagnetic beam to create a visual depiction of it.
2) Abstraction: a pyramid shape is a concept simplifying the mountain.
3) Inspiration: demonstrates the capacity for original thought to develop compositional ideas, as in the production of buildings in the form of shells from seashells.

5.1. Biomimicry principles

Biomimicry principles are modeled, such as nature's principles. They run on light from the sun, use only the energy and resources needed, adapt forms to functions, recycle and find uses for everything, encourage cooperation, and rely upon and foster diversity. Furthermore, they seek local knowledge and resources, prevent internal excesses, and harness the limited force [15]. Understanding the distinctions between biological and technological systems is necessary for mimicking nature. Technical system functions typically attempt to create a system as a design result, regardless of the natural system functions that may result from an ad hoc genetic development creating an unplanned purpose. They must operate within the confines of the physical world, but technical systems operate in vast environments [9]. The following are examples of ecosystem principles [16], [22]:

1) Everyday Sunshine is necessary for an ecosystem. The sun is an organizing device for space and time (daily sunlight creates energy).
2) An ecosystem maximizes the whole system rather than just its parts.
3) An ecosystem harmonizes with and depends on regional conditions.
4) An ecosystem has a variety of parts, connections, and data.
5) An ecosystem fosters conditions that allow for the continuation of life; and
6) An ecosystem accommodates and changes at varying rates and levels.

5.2. The influential role of biomimicry in mentoring, measuring, and modeling.

Nonetheless, this is not biomimicry when mimicking biological forms; the architect did not use biology as a tool to address issues or fulfill a purpose. Questioning how nature does things is a significant part of the biomimicry design operation. Simply copying a natural system or object is not what biomimicry entails. One might argue that learning about nature is one thing, but learning from nature is another. It begins with conducting an in-depth analysis of a specific organism or ecosystem, then the deliberate application of the fundamental design principles included in nature's answer [6], [20]. To comprehend nature's role as follow [6], [15]:

1) Mentor: refers to a new perspective on nature that bases evaluations on what we can discover from it rather than on what we can get out of it.
2) Measure: to determine the "rightness" of our innovations, we use the rules, tactics, and principles of nature as a benchmark.
3) Model: to solve human crises, models are used to study and imitate natural phenomena.

5.3. Biomimicry through the design processes (two approaches, three classes, five levels)

There are numerous methods and categories for applying biomimicry in architecture design. The research outcome often is what determines this [3], [9]. In design, the advantages of using biomimicry are enabling the development of new and efficient goods and processes that are intrinsically more sustainable, effective, energy-efficient, waste-free, and lightweight [8], [15]. Two approaches to biomimicry as an architectural design process are classified scientifically; In general, bottom-up (indirect) and top-down (direct) design approaches were the fundamental methods used by earlier scholars and practitioners [1], [19], [24]:

1) Because "Biology Influencing Design" necessitates a rigorous examination of biological systems, biologists and designers must work together. Bottom-up, biomimetics by induction, solution-based, and biology to design are all influenced by observations of nature and result in technological designs. In this study, this methodology is referred to as solution-based [2], [12]. This approach depends on the ecologist or biologist first adapting bio-logical qualities into a man technology to find solutions and then identifying human design issues. It is necessary to pinpoint specific traits or behaviors in an ecosystem or organism before molding them into rules for creating architectural designs or manufacturing products [6].
2) The concept of "designs looking to biology" entails developing new designs by considering the biological behavior, structure, and function of natural ecosystems and organisms to learn how they solve the same design challenges that designers encountered [5]. The challenge to biology,

top-down, analogous biomimicry, problem-based, and biomimetics is to look to nature for a solution for the specific technical problem. It is known as a problem-based approach. The second strategy uses analogies to look to nature for a solution to the distinct challenge. Solutions can be reached without the assistance of biologists or ecologists or the need for a thorough scientific understanding through such methods and feasible biomimicry. Due to the nature of scientific thought (partial and superficial), the ability to translate biological information into technological systems is constrained [12], [19], [25]. Designs could be biomimetic within these two paradigms or approaches in terms of three potential classes: form, process, and ecosystem. It is crucial to identify whatever component of biology is imitated for this application [15], [22]:

- Form: there are the physical components (shape, material, and construction method). The structure draws its influence from nature.
- Process: how something is done-and function-what it can do, behave, mimicking an organism's strategies for adjusting to its environment.
- Ecosystems: while it is challenging to locate design examples in ecosystems, the plurality of the current design examples is connected to form, structure, material, and, to a lesser extent, functional activities; degrees of ecosystem simulation.

Each class has five levels that can be accessed, which control how much mimicking occurs. The style is defined [11], [13]:

1) Biomimicry as it appears in form and appearance.
2) The material from which it is formed, more specifically.
3) Manufacturing methods (construction).
4) The method (process); and
5) The functions it can perform (about what it is capable of).

The three imitation classes were described in **Table 1**, as will be seen later, after issues and adaptation mechanisms related to biomimicry. These highly significant classes satisfy the biomimicry paradigms or approaches.

6. Issues in implementing biomimicry in the built environment.

Architecture's emerging discipline of biomimetics confronts many problems that prevent its progress. For example, biomimicry in technology and engineering has only been developed at particular sizes to translate technological characteristics from biology to design [7], [26]. Due to these restrictions, the applicability of biomimicry in sustainable design has been reduced. Nature embraces numerous systems and tactics that can be employed in biomimicry approaches. Many different kinds of biomimicry designs are available, and it is hard to create an effective design in architecture [9]. The main flaw in biomimicry design has been identified as the absence of an apparent structured method; this prevents the delivery of distinct mechanisms and strategies from the chosen systems [19]. Form and morphology are current tendencies in architecture that imitate nature. Such an advantage, however, hardly ever has any ability to mimic natural systems, making it difficult to call it a good biomimicry design. The use of biomimicry in architecture is constrained by three factors [16], [21], [26]. The first factor is scaling issues since some functions operate at specific scales (such as nano to micro), the second factor is the conflict between integrated design conception elements, and the third factor is the investigation and selection of natural strategy. Executing biomimetics faces several challenges, such as the isolation of the technique from fundamental problem-solving and the tendency for biomimetics to be oversimplified into a linear sequence. Besides, it has been shown that copying biological technology without modifications leads to many failed initiatives [11], [24]. Biomimetics has many drawbacks: The first one, numerous specialized information, abilities, and instruments are needed for biomimetics. The second one, computer software plays a significant role in design methodology. The difficulty stems from the discrepancy between human and computer recognition abilities. The third one, selecting the best material for a system, necessitates a substantial number of physical tests and geometric descriptions. Finding the connection between components is the fourth issue. The choice of appropriate algorithmic growth procedures comes in at number five. The sixth is the ongoing fusion with suitable analysis software. The continual evaluation and feedback system comes in seventh [3], [6]. The beneficial execution of biomimicry techniques recognized in architecture remains a challenge.

6.1. Mechanisms of adaptation in nature and architecture

The correctness of the modeling methods employed for decision-making is the critical limiting factor for applying adaptation. So, when implementing these systems, improving the choice of the optimal corrective action is essential. Additionally, it was mentioned that three considered factors characterize an adaptation: (1) assumptions are made about how the environment has changed while adaptations are being carried out; (2) ambiguity in the consequences of adaptation acts; and (3) variability due to context [9]. Self-adaptation is divided into two categories: (1) the behavior of the system and its environment with a lower degree of abstraction to distinguish component and connection kinds; and (2) the method approach to illustrating the impact of singular adaptation actions [10], [11]. Unique adaptation techniques (behavior, morphology, and physiology) have had to evolve in nature due to changing environmental conditions to survive [15]. Thus, the adaptation mechanisms that represent, clarify, and explain the three potential classes to be imitated by two biomimicry approaches or paradigms as a design process are as follows:

1) A reaction of an organism to an exterior impulse for preserving homeostasis is known as a physiological adaptation of ecosystems [7]. Mangroves, which live in intertidal zones along the coast, can endure high saline levels, for instance, thanks to specific biochemical and molecular processes, as shown in **Fig. 2** [27].

Fig. 2. (From left to right) Costa Rican mangrove ecosystem [27]. Mangrove roots are directly in touch with saltwater in the middle. Crystallized salt deposits on elder leaves are about to fall.

2) A structural or geometrical characteristic, such as size, form, or pattern, facilitates an organism's adaptation to a specific environment and provides improved functionality for survival as a morphological adaptation [28]. **Fig. 3** shows several illustrations of the morphological adaptations in desert plants, such as the unique stem shape, the tiny and thin leaves, and the immense root system. Small leaves help prevent water loss; such stems enable water storage, and vast root systems improve water absorption in plants.

Fig. 3. (From left to right) Cacti exhibit morphological diversity [15]. As an adaptive reaction to harsh conditions.

3) An organism's activity takes to survive, such as swarming bees and bird migration, are behavioral adaptations as processes or functions. Moreover, the physiological and morphological mechanisms and organisms also act and respond in specific ways to adapt to changing environmental situations [7]. Huddling is one way; penguins living in the harsh environment of Antarctica complement their physiological adaptation methods, as in **Fig. 4**.

Fig. 4. (From left to right) a group of huddling penguins consisting of about 2500 men [4]. Penguins converge to raise their body temperature as behavioral adaptations as processes or functions.

Furthermore, there are two pillars (Natural -Architecture) of adaptation mechanisms to succeed [11], [16], [19]:

- Nature is the perfect place to study adaptation since natural systems have evolved the best defenses against shifting environmental conditions. Thermodynamics, optics, and other continuous processes are self-organized, and examples of iterative feedback loops happen in natural systems. One of the primary dynamic and adaptive processes for complex adaptive systems is self-organization. It is a process wherein a system's internal structure adjusts to its surroundings to develop a particular function without external management or direction. Nature roles: (1) generates a level of redundancy; (2) self-organizes; (3) evolves at different levels and different rates; (4) creates favorable conditions for sustained life; (5) has a diversity of elements and relationships, besides information; (6) depends on local situations and conditions; (7) optimizes the system rather than its elements; and (8) depends on current sunlight.
- When used in an architectural context, the terms "adaptive" or "self-adaptive" refer to systems that may modify their behavior in response to changing work circumstances. These systems can only change their performance in response to changes in their operational environment to fulfill specific needs while using less energy. These systems' corrective actions depend on sensors that provide information for dynamic settings. Architecture involves incorporating system knowledge into the systems and developing precise analytical techniques for decision-making. Also, it requires choosing the most suitable remedial action, assessing the likelihood that

adaptation actions will be successful, adjusting for context, and monitoring the environment as adaptations are carried out.

A design example of the building envelope adapting to adjust carbon dioxide, humidity, temperature, and light. Dynamic mechanisms include those that move, fold, crease, expand, roll, hinge, fan, inflate, rotate, or curl. Static techniques include changes in material qualities such as reflecting, absorbing, or the transfer of energy from one form to another, as well as geometric properties such as density, pattern, or geometrical methodologies [9], [10], [17]. The adaptation of the environment for applications involving biomimicry has two main aspects. It is possible to carry out the complex abstracting and shifting from the natural sector to the architecture sector by defining essential categories such as anatomy, behavior, and ecology. It's crucial to recognize the aspects in which bio-mimicry is used in architectural design since these are areas where data from an organism, its behavior, or an ecosystem might be valuable [1], [5], [7], [17], [28]:

- Convergence of function, the first step, represents a considerable language link between two disparate fields that infrequently interact and communicate. It is possible to conduct a more targeted and directed search for natural strategy by outlining the appropriate functions. Buildings and nature share many crucial environmental jobs and objectives, and these shared core functions of biology and construction that control these challenging objectives have been sophisticated and identified.
- Processes in the environment are the specified main functions that numerous processes carry out, resulting in adapting and executing the indicated primary functions, which frequently depend on fundamental physical laws.

Hence, adaptation mechanisms encourage us to summarize, collect, and identify information classes and characteristics obtained from nature and biological systems that can be learned from and used in solving design concepts and environmental treatments.

6.2. The information and characteristics concerning three biomimicry classes.

As shown in **Table 1**, the information contained in each creature is divided into three classes to fulfill and examine the biomimetics of an organism, a biological system having potential features, and its surrounding nature. Each one focuses on a particular layer of an organism's characteristics; the first class entails the characteristics and traits of the taken creature as a whole entity. The second class has additional components emphasizing the connections between living things and their living environment. The third class focuses on ecological systems and solutions drawn from interactions between a creature and its context or surroundings [9], [11], [20].

Table 1. The information and characteristics concerning three biomimetic classes [4], [20].

The biomimicry classes /Adaptation mechanisms		**The information and characteristics of the class**
Creature characteristics (characteristics of the organism itself).	**Form - Appearance - Morphology**	Color, shape, rhythm, transparency, and volumetric treatment are examples of formal qualities.
		Pieces and system hierarchy and organization.
		Structure, sturdiness, and resistance to gravity.
		Fabrication methods and materials.
		Growth, mutagenesis, and life cycle.
		Both behavior and function.
		Aerodynamics and motion.
		Anatomy, modularity, patterns, and morphology.

The biomimicry classes /Adaptation mechanisms		The information and characteristics of the class
		Mobility and portability
		Self-Synthesis.
		Recovery, recuperation, survival, and upkeep.
		While external influences fluctuate, homeostasis keeps the internal system balance.
		Organ, circulatory, digestive, skeletal, respiratory, muscular, neurological, excretory, sensory, and locomotive systems are among the systems mentioned.
Relationships between a creature and its society of other species share characteristics and may interact.	**Ecosystems - physiology**	Existence strategies.
		Interspecies communication.
		Knowledge transfer and training between generations.
		Group members' social standing.
		Coordination and leadership of a group.
		Contacts.
		Coordination and cooperation
		Self-defense
		Observation, reaction, and interaction.
		Risk control.
Biologically-environmentally interactions (how a creature conforms to its major life zone (biology) and environment).	**Process – Function -Behave**	Contextual relevance.
		Adaptability to change
		Solutions for cooling, heating, and ventilation in reaction to the conditions.
		For instance, camouflage, self-defense, and self-cleaning are adjustments to the surroundings.
		Adjusting to different light or noise levels, shade, and self-illumination are all examples of ecological adaptation.
		Shelter construction.
		Managing resources Restricted, such as modifications to cope with the shortage of food, light, or water.
		Waste organization.
		A cycle of the input/output operations.

7. Biomimetic methods and tools in environmental design

The advantage of ecosystems and other biomimicry levels, such as behavior and organism form, is their ability to be applied at a wide range of spatial and temporal scales. Such strategies can be applied on both a practical and metaphoric level. Designers with less ecological expertise might still increase a building's sustainability by using metaphors [3], [29]. On the other hand, employing an ecosystem requires a thorough understanding of ecology and biology, making it difficult for designers to apply this sophisticated biomimicry level [2], [9]. Over the last two decades, different biomimetic techniques have been created, but they are still difficult to apply reliably in projects. The primary flaw is the absence of a distinct design selection process and the practical deployment of an architecture-specific design methodology [6], [12]. Numerous methods discussed above are theoretical, particularly in the architectural design field. The previous sections investigated several biomimetic adaptation mechanisms, pillars, and aspects and pointed out potential ways to improve the design process. The development of an appropriate biomimicry systematic technique requires an examination of the similarities, differences, and unique importance of various equivalence translation systems: BT, DS, TA, and NSA, as shown in **Table 2**. All four translations aid in examining and comprehending the degree, order, and parallel application of natural to artificial systems. That entailed locating the connections between each stage and mapping each equivalence translation. Any system is individually used at various levels of hierarchy, from macro to micro, besides utilizing all the systems as analytical tools to identify the imitating process in transferring strategies primarily at three levels (formation, behavior, and ecological system). However, the drawback is the connection challenge of these levels into a sequential design [4], [25].

Table 2. Comparative analysis of equivalence translation systems [4], [19], [24], [30].

Equivalence Translations	**Features**		
	Application Scales	**Process Overview**	**Biomimicry Design Method**
Nature Studies Analysis (NSA)	Ecosystem, Process, and Form	Classification, Scientific Reasoning, Functional and Contextual Adaptation, and Aesthetic Formation	Building Natural systems Built and systems. Systems to biological
Bio-TRIZ (BT)	Supersystem, System, and Subsystem	Identification of the Issue, Understanding of the Issue, Logical Solutions, and Biomimetic Answers	Solution-driven approach and Problem driven. approach
Design Spiral (DS)	Form, Process, and Ecosystem	Identify, Interpret, Discover, Abstract, Emulate, and Evaluate	Biology looks at design and designing while examining biology.
Typological Analysis (TA)	Creature, Behavioral, and Ecosystem	Form, Process, Material, Construction, and Function	Design is affected by biology, and design considers biology

7.1. Design spiral (DS) as the most suitable biomimicry approach

The study focuses on this approach while dealing with design and addressing the challenges, problems, and issues encountered during the design process. Using this approach, the designer can determine what he wants from the surrounding nature of environmental solutions for such dealings and treatments in his design, which varies depending on the environment in which he designs and builds. Carl Hastrich developed the design spiral as a representational translation mechanism [9]. It makes it possible to add a designer's sensitivity to a process. Adopting it is advisable; he contends that spiral-shaped methodologies would be comfortable for designers and the entire design process to visualize. Janine Benyus and Dayna Baumeister instruct and engage in biomimicry using this technique. It is beneficial for innovators to approach a problem biologically, look to nature for ideas, then assess to ascertain the final design corresponds to nature at all scales: ecosystem, process, and form [2]. Hence, based on the previous comparative analysis as in **Table 2**, for new people to biomimicry or the design process in general, the Biomimicry Design Spiral is very helpful. Adopting it is advisable as the foundation for the entire design process or as a comprehensive guide for incorporating the biomimicry-related findings into another design technique you employ. A followed design process can be immensely beneficial when addressing a design difficulty [5], [11]. The Biomimicry Design Spiral gives a clear explanation of the essential components of a design procedure that makes use of nature as a model for developing solutions. It outlines the six crucial actions a design team should take when looking for biomimetic answers to a design problem. The first step is a sequential description of the steps. But design teams sometimes find themselves going back and forth or duplicating procedures. That is a wise course of action because each phase usually reveals emerging data that can either confirm or refute established hypotheses previously [3], [15].

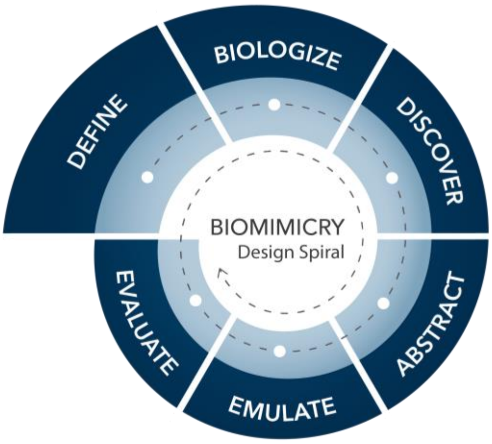

Fig. 5. The design process by the Design Spiral of biomimicry [9].

The design process outline of biomimicry provided by the Design Spiral [15], [19], [22]:

1) Define: To explain the design's intended influence on the world (the problem seeking to solve) and the standards and limitations that determine its viability.
2) Biologize: To analyze the context and fundamental requirements that the design solution must meet. Reframe problems in biological terms so the designer can "consult nature."
3) Discover: To encounter examples from the natural world (ecosystems, processes, and forms) that deal with the same issues and situations as the intended design solution. To determine the tactics employed to ensure their success and survival.
4) Abstract: To study the fundamental components or mechanisms giving biological tactics their success in detail. Rephrase them as "design techniques" to avoid using biological terminology.
5) Emulate: To search for patterns and connections among the tactics discovered to focus on the most important lessons that should guide the solution. Creating design ideas depends on those components.
6) Evaluate: To inspect how well the design concept complies with the requirements and limitations of the design challenge and integrates with Earth systems ecologically; keep technological and business model viability in mind; refine and review earlier processes as necessary to come up with a workable answer.

7.2. The correlation between GBs and the thought of mimicking nature and biology

The only way to solve various architectural issues is by offering novel ideas. The models of nature can spur an architect's imagination and lead to new ideas. The optimal sort of adaptation has been demonstrated by natural models in some settings across time, making the shift from nature to architecture logically [5], [8]. Thus, architects have incorporated biomimicry into designs to reduce the harmful environmental effects of buildings and achieve overall architectural sustainability [11]. New environmental ideas, regulations, and programs have been developed in response to climate change concerns to lessen the detrimental consequences of buildings. That has already started to affect buildings' form, fabric, and microclimate. As a result, designers today have to combine merged efficiency initiatives with innovative design to accomplish ecologically sustainable design [12], [24]. Through innovative designs and concepts, employing intelligent materials, and energysaving practices, sustainability is being pursued in numerous ways; there are multiple initiatives to create international sustainability standards, but not all these architectural approaches are sustainable. Leading biomimetic theorist Bill Reed (who co-chaired the creation of LEED standards from the beginning) claimed that being able to "have a world full of LEED platinum buildings and still kill the earth ." [16]. Even though they are more environmentally friendly, these designs frequently adhere in ways being "less awful" than the current norm. According to Bill Reed, regenerative design refers to the idea that our creations must support biodiversity [21], [22]. Environmentally friendly green building practices are valuable for the environment and people's health. It has been demonstrated that supporting sustainable design results in a 2% increase in the original investment cost resulting in a nearly 20% reduction in the overall cost of the building [8], [25]. The following are the most crucial principles of GBs, as it became clear from this study and previous studies that biomimicry thought can achieve them and improve their performance by mimicking nature's thought:

1) The operation of the building must also take environmental considerations into account for ventilation, energy use, and material usage.
2) Environmentally friendly building materials and ecological construction theories should be considered when creating alternative construction methods, sanitary engineering systems, and structures.
3) It is crucial to choose locational, functional, and structural solutions adhering to the regional characteristics, such as terrain, water surfaces, soil composition, microclimate, flora, etc.
4) Reusing and recycling materials, besides preserving water in various ways, such as collecting rainfall and reusing gray water.
5) Utilizing sustainable energy sources, such as solar, biomass, wind, etc., will help preserve and enhance the environment.
6) A structure must have been thoughtfully planned and organized for everyday use to qualify as ecologically; and
7) The footprint must also be kept to a minimum or increase the amount of utilized green space.

Achieving these principles and basics is through adaptation mechanisms representing, clarifying, and explaining the three possible biomimicry classes by the two biomimicry approaches as a design process previously addressed. Then a proposal is formulated for a systematic design technique for GBs that achieves biomimicry's thought, concept, and principles.

8. The proposed systematic technique of biomimicry to design GBS.

The proposed systematic technique aims to reduce the harmful effects of buildings to be green buildings, preserve biodiversity, and rationalize energy use. These would be achieved through identifying the appropriate adaptation mechanisms from nature to solve design problems, inspiring and eliciting the functions, processes, and forms of these biological systems to correlate and integrate architecture and biology through incorporating and collaborating between two biomimicry approaches. Supporting the designer's demands during decision-making and independence to use whatever tactic, the proposed systematic technique begins with defining the level and scale of biomimicry application or dealing with all levels as a design process in any of its two approaches and during each of the four proposed technique stages. Then, interrelationships and correlations are identified, such as nature strategies and biology, based on understanding the ecological features of behavioral, morphological, and ecosystem theories. As shown in **Fig. 6**, each of the four stages of the proposed technique is dealt with through three questions to determine the classes of imitation or emulation of nature that help in solving the design problems and challenges facing the designer, which are as follows:

- Form: What shape does it have?
- Process: How is it made, behaves, and works?
- Ecosystem: How does the ecosystem relate to everything else?

Hence, the design phase begins as follows:

1) To work on the two independent approaches of biomimicry design together in the first phase (Classification), Design Spiral (DS) can be relied upon as in **Fig. 5**, where:

- The first approach based on the problem works by defining the problem or challenge. Then, it begins to find solutions by searching for the natural and ecological systems in the environment surrounding the project; and
- The second approach is the solution gets ideas, principles, and concepts from nature, the environment, and living organisms without linking to the surrounding environment. It possibly means to inspire processes, ecosystems, and forms across another environment to solve the same challenge, issue, or design problem.

2) Then, the integration between the two approaches in the second stage (Hierarchy of Functions); is the phase of supporting functional integration between the environment and design besides the interrelationship between solutions, challenges, and design issues in the face of the environmental processes, forms, and ecosystems.
3) After the previous union or merger of the two approaches, the third stage (Adaptation Strategies) is to imitate nature's existing forms, functions, and ecosystems more sustainably and effectively in addressing the design challenges.
4) Reaching the fourth stage (Expressive/Creative Form) is the stage of embodying the characteristics of natural systems in terms of quantity and quality in the form of building systems; and tangible architectural form and imitating them as found in nature, their functions, and environmental systems in a way that confronts design challenges more sustainably and effectively, it is also a stage for defining the work systems of nature and then a productive and inspiring tool for reimagining the built world; and
5) Finally, how to take advantage of valuable lessons, models, and systems that can be transferred from the natural environment based on balance and complete sustainability to environments designed and built to be green as possible.

The role and function of each stage, as shown in **Fig. 6**, are as follows:

1) The first stage (Classification) works to understand the rationale behind the similarities and differences, the foundations and rules that distinguish (systems, shapes, and processes), which is the stage of identifying challenges and design problems within projects and buildings.
2) The second stage (Hierarchy of Functions) is the stage of supporting functional integration after building a hierarchy of functions and operations. It determines the required information, summarizes, collects, and defines information and characteristics that could be obtained from nature and biological systems according to three biomimicry classes that can be learned from and used in solving design ideas and ecological treatments, as in **Table 1**. What strategies do natural systems, forms, or processes rely on, and how can these strategies be transferred or reformulated into buildings, projects, or parts of them for improvement and their internal systems?
3) The third stage (adaptation strategies) illustrates and shows the differences between adaptation strategies to make the biological system chosen more suitable for the project environment or more viable. Besides, determine how species differ on the scale (systems, shapes, and processes) concerning their physical and physiological characteristics, processes, and behavior. Thus, imitating them since they are more sustainable and effective when addressing design

challenges. Despite the agreement of two biomimicry design approaches, starting from the second stage, and

4) The fourth stage (Expressive/Creative Form) is the translation and embodiment of behavioral, physical, and psychological characteristics based on the biological systems, emphasizing the synthesis method among the parts in a coherent quantitative and qualitative way. Such a way supports the strategies of functional integration and environmental adaptations used to survive and translates them into images of geometric shapes and configurations of the building, its parts, and internal systems to achieve the principles of GBs previously mentioned in this study.

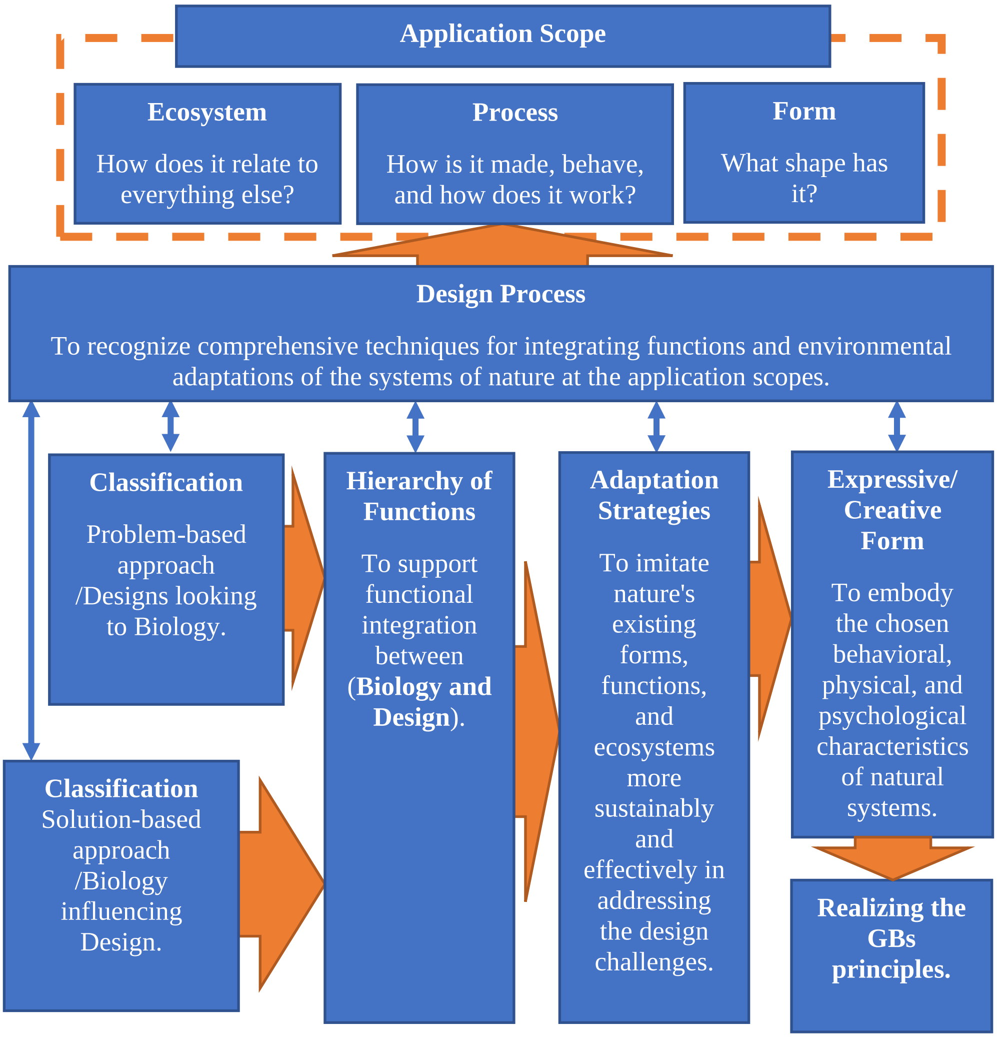

Fig. 6. The proposed systematic technique of Biomimicry to design GBs.

9. Ensure and verify the effectiveness (importance -uniqueness) of proposed systematic technique.

A survey study was conducted using the Delphi survey technique based on interviews and questionnaires, where 94 specialists in the scope (architecture, building design, green buildings, and sustainability) were invited, and 70 specialists responded. The study was conducted in two phases, as shown in **Table 3,** as follows:

1) The first phase was conducted in two rounds to review the importance of the proposed technique in the design discipline and link architecture, nature, and biology to benefit from them. Besides, finding architectural solutions, treatments, and dynamic systems for buildings to

be environmentally friendly and sustainable in all aspects of the construction industry. Also, make sure of the components, points, and foundation questions of the proposed technique.

2) In the second phase after the first phase's completion, the study has a form and structure that can be relied upon in mimicking or imitating nature and biological systems from the environment around a project. Comes the second phase to review and verify the procedure and method of application and implementation and conduct this proposed technique to achieve the desired aims.

Table 3. displays the findings of the Delphi survey technique through four rounds to ensure and verify the effectiveness (importance -uniqueness) of the proposed Systematic technique.

Test Statistics	**Survey phases**			
The survey study phases	**The first phase (importance – structure)**		**The second phase (application method - achieve the desired aims)**	
Test Statistics	**Rounds**		**Rounds**	
Kendall's (W) Test	First	**Second**	**First**	**Second**
N (No. of questionnaires)	70	70	70	70
(W)	0.524	.714	.531	.789
Chi-Square	256.849	349.730	111.504	165.780
df (degrees of freedom = n-1)	7	7	3	3
Asymp. Sig.	.000	.000	.000	.000
(W): The concordance coefficient for Kendall. A strong agreement or consensus exists for W>= 0.7, a moderate agreement for W = 0.5, and a weak agreement for W 0.3 in nonparametric statistical tests.				
n: The total number of Delphi survey technique questions or interview questions.				
Significance level (Asymp. Sig.): The p-value is less than 5%.				

Accordingly, at the end of the two phases, the study outcomes (the form, structure, and application method) are reliable and consensus-based, as shown in **Fig. 6**.

10. Discussion and results

The proposed systematic technique aims to advance a comprehensive approach by discovering systematic functional integration and environmental adaptation techniques in natural systems. From the survey study by the Delphi technique, its steps follow a pattern like traditional and contemporary architectural design processes; hence, nature studies analysis was applied primarily to structure this technique. This systematic technique offers the designer a prominent framework for looking for and choosing answers in the vast database of nature by incorporating and collaborating between two biomimicry approaches for simulating nature to identify the appropriate biological systems and help the designer while emulating and making decisions. Ecological and biological functions highlight the usefulness of environmental adaptation. That is a crucial finding to believe in the design process since it shows how controlling one environmental component can affect other aspects of an environment. The focus is on numerous natural systems and creatures that adopt innovative strategies to resist extreme circumstances of the environment, where similar architectural applications are pertinent. Natural systems adhere to specific ecosystems and biological arrangements to develop the best potential contact with their immediate surroundings. It turns out that biology effectively contributes to how environmental adaptation is carried out in nature and serves as a multi-functional interface to control the elements of forms, ecosystems, and organisms.

It can be said that processes and forms are a convenient starting point for biomimicry uses in building design for environmental adaptation. Functional convergence is a crucial language link between two disparate fields that infrequently interact and communicate, where a more precise definition of functions facilitates the looking for pertinent tactics within nature. The results of biomimicry are highly efficient buildings, sustainability, and a reduction in the use of materials and energy. Also, attention to biomimetics isn't just about looking for new forms of inspiration. Through biomimetics, it is possible to create entire cities that function like intricate ecosystems, waste management, and water while producing electricity. Desert communities will be planned to collect water as much as possible, just like desert plants perform and conserve it.

Because biomimicry is interdisciplinary, engineers frequently face challenges as they work on designs in situations where it is difficult to get biophysical knowledge. Searching for and choosing acceptable strategies from the extensive database of natural methods is one of the difficulties in putting biomimetics into practice. It depends on creating biomimicry designs that can control the elements of nature, biology, and ecosystems. It is essential to establish a systematic method for developing adaptation solutions. The study demands emulating natural systems and creatures that will function sustainably throughout time and in harmony with the environment. It also addresses the most recent and effective ways to do this. A solution to the issues affecting our environment is provided by biomimetics. Because of its potential to produce a better regenerative built environment, biomimetics acts as a source of inspiration for emerging future innovations. A significant scientific research team with diverse specialties and effective potential is needed for the second approach. This team should investigate ecosystems and organism behaviors that are well-adapted to their surroundings in closed systems with no flaws and then apply this knowledge to human problems and society. The first approach is better appropriate for architects who describe problems in terms of architecture, the environment, buildings, and solutions found in nature.

Although the sciences are increasingly looking to nature for answers or comparisons, there are currently few real-world applications to buildings that can help them adapt to their environment [22], [31]. This study is a component of a broader research project that attempts to create new technological solutions that are nature-inspired to improve the ability of building systems to adapt to their environment. There are not enough studies to draw conclusions or create natural solutions [10]. These were utilized to systematize the proposed systematic technique's structuring.

However, there are numerous challenges that biomimicry investigations must overcome, especially when converting natural ideas into technical systems. Most imitation techniques don't consider the entire system, only specific components. The technical and functional aspects of biomimetic studies' methodologies have not been identified or reviewed in terms of architecture [3], [7], [19], as the study attempted. Moreover, what was verified by the Delphi survey technique.

11. Conclusions

The key conclusion of this study was to derive and create a systematic biomimicry design technique for incorporating and collaborating between two approaches to mimic nature in designing buildings. Consequently, reducing their harmful effects on the environment and humans, improving the integration of architecture and biology, and helping the designer make decisions during the design process by identifying appropriate natural systems for design challenges, besides being inspired by them by understanding their functions, processes, and mechanisms entirely. Hence, the correlation and integration between the GBs principles and biomimicry’s thought to preserve biological diversity and association with nature were clarified and confirmed. The analytical comparison of the various strategies and methods for applying biomimicry in design was significant for selecting the most appropriate design approach for simulations and imitation of nature through forms, processes, and ecosystems. The Design Spiral that is best suited for designers, and the design process revealed possibilities for improving the design process. Also, the three adaptation mechanisms equivalent to the three biomimicry classes were exemplified, depending on the differences between the information and characteristics required from nature and living organisms to implement design ideas and environmental treatments. Then, emphasize the success of adaptation mechanisms across two pillars, namely architecture and nature, and the transformation process has two aspects (functional convergence and operation in the environment). Therefore, it became clear, understood, and explained the problems and obstacles facing the activation of biomimicry in design as a newly emerging field. Hence, the importance of the role and principles of biomimicry was confirmed as a creative field in design through the two approaches or paradigms, the three classes and five levels of it, which depend on the targeted result. Finally, the Delphi survey method was utilized to verify the systematic technique effectiveness (importance and uniqueness). Thus, the harmful effects of buildings on nature and organisms will be reduced, besides preserving biodiversity, participating in it, and conserving energy. Also, the challenges and obstacles that hinder designers when embodying and simulating environmental systems and processes will be overcome to be technical systems in the built environment. Additionally, the imitation and mimic methods will focus on design by treating the whole as a complete system, such as an organism as a single unit in its environment rather than separate parts. Nature contains and embraces enormous forms, processes, and strategies that could be employed in the biomimicry approach as an emerging design thought to achieve sustainability, resilience, and GBs.

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تقنية تصميم منهجي لمحاكاة الطبيعة لربط ودمج العمارة والبيولوجي لتحقيق المباني الخضراء

تحتضن الطبيعة موارد هائلة لتقليد الطبيعة، ولكنها تواجه العديد من التحديات، بما في ذلك تجسيد، ومحاكاة النظم، والعمليات البيئية في الأنظمة التقنية داخل البيئة المبنية. أيضًا تركز استراتيجيات تقليد، ومحاكاة الطبيعة على أجزاء منفصلة بدلاً من نظام كامل ككائن حي كوحدة واحدة في بيئته. لذلك يهدف البحث إلى تقليل الآثار الضارة للمباني، والحفاظ على التنوع البيولوجي، والطاقة من خلال تقنية تصميم منهجي لمحاكاة الطبيعة؛ لتحديد آليات التكيف المناسبة من الطبيعة، واستلهام وظائفها، وعملياتها، وأشكالها؛ لدمج الهندسة المعمارية، والبيولوجيا أو علم الاحياء عموماً. وبناءً على ذلك تناولت الدراسة التقليد الحيوي او محاكاة الطبيعة (**Biomimicry**) من خلال مداخله، وفئاته، ومستوياته اعتمادًا على النتيجة المرجوة التي نريد الحصول عليها. وتم تفسير المشاكل التي تواجه تطبيق، وتوظيف التقليد او المحاكاة الحيوي للطبيعة، وآليات التكيف الخاصة به. بعد ذلك تم تصنيف المعلومات، والخصائص المطلوبة من الطبيعة وفقًا لثلاث فئات للمحاكاة الحيوية؛ لتنفيذ المفاهيم، والمعالجات البيئية. وبالمثل قارنت الدراسة استراتيجيات التقليد الحيوي او محاكاة الطبيعة لاختيار أنسبها لعمليات التصميم. وبالتالي أكدت العلاقة بين المباني الخضراء، وتقليد ومحاكاة الطبيعة. وأخيرًا تم استنباط، وإنشاء تقنية منهجية للدمج، والتعاون بين نهجين محاكاة الطبيعة؛ لتحديد النظم البيولوجية المناسبة لتحقيق المباني الخضراء، وتحسين عمليات التصميم، واتخاذ القرارات.