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The Impact of Applying Biomimetic Mechanism in Achieving the Sustainability of Architectural Design: A Review

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ABSTRACT

Biomimicry is a newly emerging science that relies on inspiration and innovation to solve human problems by studying the systems, forms, and relationships found in nature. This research examines more than 50 studies, each addressing the concept of biomimicry in a specific field. Despite the novelty of this concept, it still requires detailed and extensive studies to achieve comprehensive sustainability in architectural designs. This research aims to build a comprehensive theoretical framework for sustainable biomimicry mechanisms in architecture. Accordingly, the concept of biomimicry in architectural design will be addressed on two levels. The first includes the concept within the field of architecture: the exterior structure, high-rise buildings, and interior design, as well as the concept of urban mimicry in urban environments and projects, and concepts of biomechanical design. The second level examines the impact of this concept in making these projects more energy- and resource-efficient, achieving environmental balance, and thus achieving more sustainable projects. The research concludes that the most important axes of these mechanisms include: biological analysis as a basis for architectural design; biomimicry as a philosophical approach that understands nature as a complex, closed system; smart cities and high-rise buildings; and smart materials and technologies, including green buildings. Achieving design aesthetics and environmental balance, and a future-oriented educational approach by integrating biology and architecture with biomechanical design curricula and training future generations to draw inspiration from nature in solving problems.

Keywords: Biomimicry, Innovation, Environment, Integration with nature, Sustainability.

1. INTRODUCTION

Most studies agree that the concept of biomimicry involves studying the best ideas of nature and then simulating designs and processes to solve human problems.
The main goal of biomimicry is to create beautiful designs by drawing inspiration from the form, functions, and processes of various living organisms to achieve more sustainable designs. It is a concept derived from two words: bio, meaning "life," and mimesis, meaning

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"imitation" **(Mirniazmandan and Rahimianzarif, 2017)**. Biomimicry, bionics, biomimicry, biomorphism, organic design, and similar terms all refer to imitating nature in some way. Although there are words and concepts associated with the general term "biomimicry," they all mean "design from nature." It is a holistic approach based on making buildings sustainable by emulating life **(Verbrugghe et al., 2023)**. Biomimicry is an environmental concept that encourages the creation of environmentally friendly designs through organic systems, and nature is a source of innovative design (technological mimicry) **(Fish, 2017)**. **(Hammond, 2024)** defined the concept of biomimicry through four concepts: Biomimetics, Biomorphism, Biophilia, and Bioutilization. He classified each concept into its most prominent associated concepts, as illustrated in **Fig. 1**.

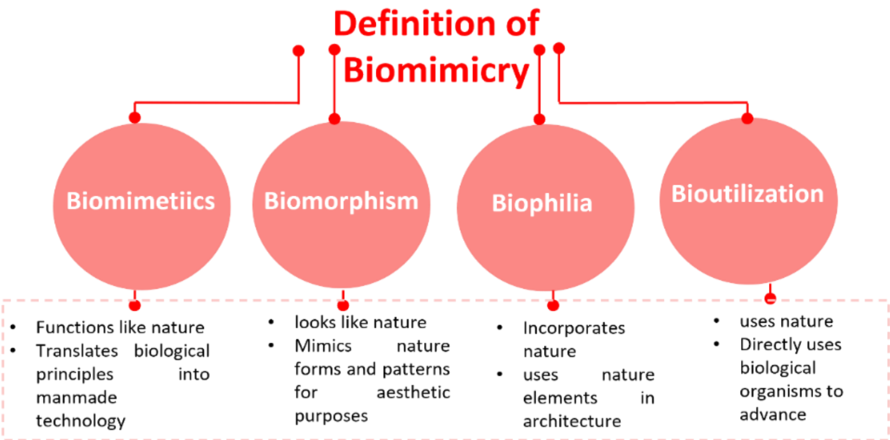


Figure 1. The concept of biomimicry **(Hammond, 2024)**

Biomimicry was first coined in 1997 by Professor Janine Benyus, who proposed it as a science that studies natural models. Some of the most famous biomimicry inventions are the flight mechanism of birds, such as Leonardo da Vinci's attempt in 1482 or the Wright brothers' 1948 invention of the airplane **(Mirniazmandan and Rahimianzarif, 2017)**. The resulting design therefore reduces environmental damage by integrating ecological processes that rely on sunlight, growth, recycling, and self-healing **(Buck, 2017)**.

Since nature recycles and is a source of design inspiration, the idea of biomimicry has emerged, contributing to the expansion of sustainable thinking through the principles of integration and interconnectedness between systems. This mimicry relies on biological strategies to solve problems and produce flexible, sustainable buildings with lower energy requirements that adapt to the environment through external facades and technical systems such as natural ventilation. In other words, biomimicry is a system that mimics nature to find solutions and make them more sustainable and flexible (adaptation in design) **(Verbrugghe et al., 2023)**. It encompasses various disciplines, requiring an understanding of the relationship between humans and nature to make them more sustainable **(Ilieva et al., 2022)**. Today, we see that the built environment has used biomimicry in the natural ventilation system, the provision of control systems, and the aesthetic factor; therefore, it is necessary to increase environmental awareness in construction and contribute to solving climate change problems **(Sun, 2024)**. Studies **(Barthlott et al., 2017; Li et al., 2022; Chen et al., 2022)** have shown that simulation stimulates environmental conservation, energy efficiency, and the achievement of sustainable buildings.

Biomimetic project features are:

1 .Nature as a source of inspiration and problem-solving.
2 .The goal of the projects is to create a mutual relationship between humans and nature.
3 .These projects must go beyond aesthetics by design and aim to focus on natural processes and systems.
4 . Projects that promote sustainability and are environmentally friendly.
5. Encouraging the positive role of these projects by teaching this curriculum **(Hammond, 2024).**

The most important advantages of biomimicry are: Firstly, evolutionary design and natural selection to ensure optimal adaptation (universal adaptation is adaptation in all aspects of an organism's life). Secondly, the durability of biological materials is very strong and performs as well as any standard engineering material, including metals. Thirdly, sustainability: the possibility of recycling biological materials and returning them to the soil from which they were taken **(Vincent and Mann, 2014)**. The study **(Chakraborty and Shaw, 2010)** identifies two types of research supporting biomimicry: descriptive versus prescriptive research, divided into two categories:
-Design methods and research that represent biological phenomena.
- Studies that support the application of biological phenomena in design. The two categories are interconnected, as the former is essential for the implementation of the latter.
The biomimicry institute design spiral refers to the Biomimicry Institute indicates that the design process includes several concepts. design spiral that the research illustrates in sequence in **Fig. 2**.

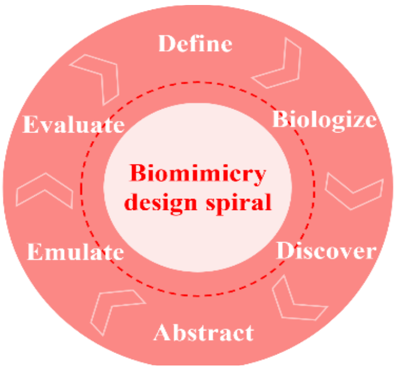


Figure 2. The design process. Source author based on the Biomimicry Institute.

Biomimicry is not limited to living organisms and their systems, but includes the results of their biological behavior, such as the way they build nests **(Royall, 2010; Zare, 2013; Fujii et al., 2016)**. Biomimicry constitutes a promising framework for understanding the intellectual structure and research trends in landscape architecture, guiding future studies toward innovative environmental solutions **(Ali and Dinçer, 2025)**. Designing a good architectural project requires taking into account key quality-of-life factors, such as sustainability, resources, and building materials **(Fadhil and Hinthel, 2024)**. Technological applications contribute to achieving a sustainable urban environment, thus making cities more sustainable **(Hinthel, 2025)**. Modern sustainable architecture relies on nature in our time **(Sugár et al., 2017)**. Stimulating collaboration between architecture and biology helps accelerate the implementation of solutions into the real world **(Kennedy et al., 2021; Vincent and Mann, 2002)**, and this stimulation is a necessary global requirement that has been emphasized by both studies **(LaVan and Cha, 2006; Bruck et al., 2007; Gebeshuber and Drack, 2008; Miray and Timur-Öğüt, 2015)**

From the previous theoretical frame, the research presents the operational definition of biomimicry as follows: " It is one of the strategies that has recently emerged in the field of architecture. Its goal is to achieve creativity and innovation by drawing inspiration from nature for the forms and practical systems to achieve flexible, sustainable, and environmentally friendly buildings", as shown in **Fig. 3**. Hence, the general problem of research is to build a comprehensive conceptual framework for sustainability mechanisms using biomimicry in architecture.

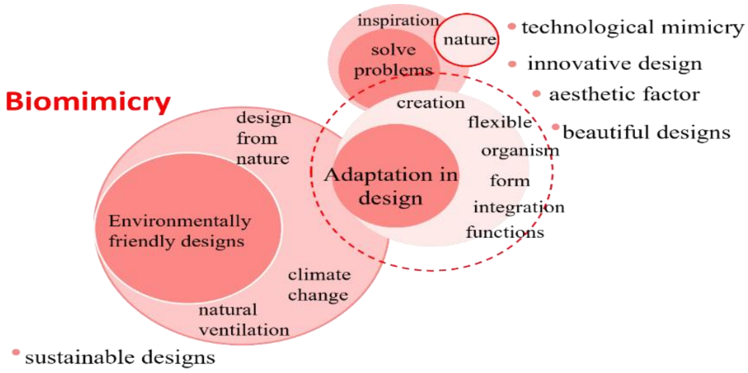


Figure 3. The most important terms extracted from the concept of biomimicry.

2. RESEARCH METHODOLOGY

The research relies on a narrative review approach, which includes a presentation and analysis of the methodology and applied mechanisms adopted for 50 recent studies from research databases (Google Scholar, Scopus, Web of Science, Clarivate). This review aims to build a comprehensive conceptual framework for sustainability mechanisms using biomimicry in architecture, through the research question that will be answered in this review: What are the mechanisms of sustainability in biomimicry in architecture and urban design? **Fig. 4** illustrates the research methodology.

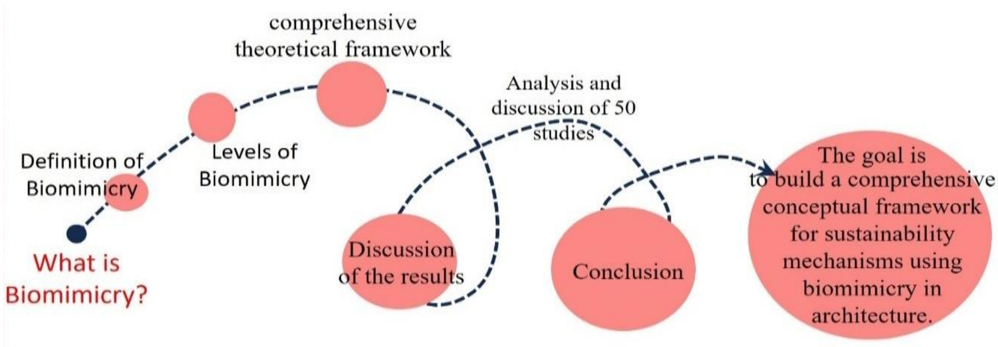


Figure 4. The Research Methodology.

3. BIOMIMICRY: LEVELS AND CLASSIFICATION

After defining the concept of biomimicry and the vocabulary associated with it, it is necessary to explore the levels specific to this concept.

There are three levels of biomimicry (the levels may overlap) to solve design problems: form, process, and ecosystem **(Zari, 2007; Sun, 2024; Benyus, 2008; Verbrugghe et al., 2023)**. The study of **(Halford, 2021)** indicates that there are levels of biomimicry:

1-Behavioral level, which examines the interaction between an organism and its environment.
2-Ecosystem level, which mimics the conditions of different organisms, often in mutually beneficial relationships.
3- Innovation in future design from nature, so design problems are solved in innovative ways through the use of structures, forms, and programs inspired by nature.

(Hu, 2017) refers to five dimensions of biomimetics: form, material, construction method, operation, and function. Structure is the primary factor determining the performance and levels of these dimensions. Within these same dimensions and levels. **(Sun, 2024)** indicates that biomimetics may encompass certain aspects, behaviors, natural elements, or environmental impacts. It supports collaboration between the disciplines of architecture and biology to produce innovative and creative ideas. Form is a clear element of nature, and biomimicry, at its three levels mentioned above, requires more than just design (green or sustainable). It is the study and application of natural solutions to design challenges. It is nature's creativity that solves today's problems **(Benyus, 2008)**.
Biomimicry can be broadly classified into two approaches: design that looks to biology (the direct approach) and biology that influences design (the indirect approach). Innovative solutions are among the most important ways to solve architectural problems, and models inspired by nature (the best model for adapting to the environment) have achieved creativity and innovation **(Mirniazmandan and Rahimianzarif, 2017)**. A design may mimic some parts of an organism, its context, or the function of an ecosystem. Biomimicry includes applications in form, material, construction, process, and function. Inspiration is at the level of form and structure, but behavior and interaction with the environment are most important. Inspiration may be to identify biological strategies: identify the biomimetic aspects, translate the principle, and assess the level of adaptability **(Verbrugghe et al., 2023)**. Several biologists and design researchers **(Benyus, 1997; Vincent and Mann, 2002; Bar-Cohen, 2006)** have suggested that natural language text is a rich and flexible means of representing and communicating biological knowledge (computational linguistic tools can aid in cognitive studies) and thus support biomechanical design. The research concluded that it is possible to identify the levels of biomimicry, as shown in **Fig. 5,** which contribute to determining the level of sustainable mechanisms used in architectural applications in the following paragraphs.

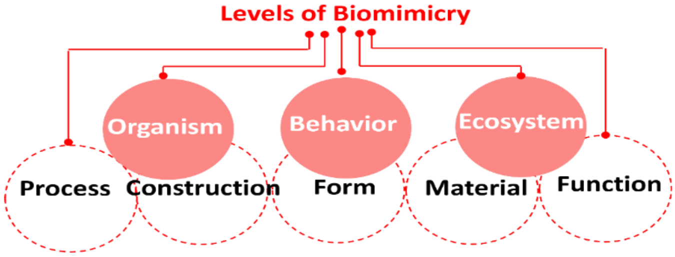


Figure 5. The levels of biomimicry

4. COMPREHENSIVE THEORETICAL FRAMEWORK FOR BIOMIMICRY

The research will address a group of studies, more than 50 studies, on the concept of biomimicry in the field of architecture and its impact on the environment, and achieving sustainability through sequencing this impact to explore the mechanisms used in architectural applications as follows:

4.1. Biomimicry in Architecture and Urban Design

4.1.1 Biomimicry in Architecture

Biomimicry is used in architecture and urban design by mimicking ecosystems to reduce environmental impact and improve well-being. Therefore, concepts such as biophilia and sustainable design must be integrated into research, particularly in the field of biomaterials, urban design, and planning, as this application remains limited **(Uchiyama et al., 2020)**. **(Helms et al., 2009)** identified two trends in biomimetic design:

-Solution: When a biological event or phenomenon arouses interest, the search begins to translate this event into architectural applications.

- Problem: When a specific problem is encountered, biological phenomena are sought to solve it.

However, studies show significant growth in research in countries such as Germany, the United Kingdom, and Australia. Most studies focus on designing architectural envelopes using solutions inspired by nature, highlighting the importance of integrating architecture, biology, and technology, as biomimicry can contribute to more energy-efficient architectural designs **(Varshabi et al., 2022)**.

Biomimicry has the potential to provide sustainable solutions in design and construction, through the development of materials and technologies inspired by nature. These materials provide efficient building models that rely on renewable energy and resource recycling in building design to increase efficiency and sustainability, and encourage intelligent interaction with the surrounding environment **(Jami and Versilj, 2021)**.

The study **(Chayaamor-Heil, 2023)** highlights the evolution of bioinspiration in architecture from aesthetic approaches to scientific biomimicry (understanding nature to produce sustainable solutions) and the importance of cultural and technical context in selecting natural models. Biomimicry holds promising potential for establishing a new field known as "biomimicry architecture," based on collaboration and integration across multiple disciplines to provide innovative environmental solutions.

Among these projects is the Esplanade Theatre in Singapore, as shown in the **Fig. 6**.

Figure 6. The Esplanade Theatres building in Singapore. Analyzed by the author according to **(Chayaamor-Heil, 2023)**.

While the study of **(Hu, 2017)** showed that Levels and dimensions are very important to the biomimetic approach, and they exist in the context of structure design as well, the three levels of inspiration from nature: The first level: the organization through biomimetic techniques, by simulating the entire organization or specific parts of it. The second level includes the behavior, such as shrinkage rates and others. third: The system level is the most difficult. The project was also cited as an example of biomimicry in architectural applications, as shown in **Fig. 7**.

A B

Figure 7. Biomimicry in architectural applications, (A): Munich Olympic Park, (B): Casa Batlló – spider web. Analyzed by the author according to **(Hu,2017)**

Since biomimicry is one of the most sustainable methods for producing highly efficient and productive built environments, when studying an organism or ecosystem, form and process are two elements of the organism or ecosystem that can be mimicked across the levels of mimicry: organism, behavior, and ecosystem. First, mimicry may be at the level of the entire organism or part of it. Second, at the behavioral level, mimicking the behavior of the organism or its relationship to its context. Third, at the ecosystem level **(Othmani et al., 2022)**. In the same context, **(Vincent, 2014)** pointed to the role of technology in changing our understanding of events and the way things work. To improve our lifestyles, we must delve deeper into biology, consider the foundations of engineering, design, and cost, extract vitality from biomimicry, and attempt to formulate biological ideas in comprehensive engineering terms acceptable in the age of technology. **(Oguntona and Aigbafobowa, 2019)** reviewed patterns and structures in nature and biology and their applications in construction technology. While **(Al-Ahmar's, 2011)** study pointed to the technological development of living systems, their physical properties, nutritional processes, and environmental adaptations, this represents a response to architects' design of "organic" curved surfaces using computer programs and techniques far removed from biological processes and biomimicry. **(Al-Zaini, 2012)** also noted that these biomimicry techniques are used to solve problems in interior design (natural lighting, thermal comfort, energy efficiency, durability, and productivity) and can contribute to creating a new sustainable standard that improves the quality of life for interior spaces, buildings, and cities.

4.1.2 Biomimicry in the City

In the context of cities, **(Buck, 2017)** reviewed the role of biomimicry in urban design and city design as a mechanism to stimulate creativity in planning and designing future urban infrastructure and its role in improving the quality of life. In the same vein, **(Helms and Goel,**

2009) called for the systematic integration of biomimicry into the design and management of future cities. The adoption of such solutions requires fundamental changes in city governance and cooperation between city systems. **(Goel et al., 2013)** also pointed out the importance of teaching biomimetic design and applying environmental data in urban planning by architects and urban planners to achieve more sustainable cities. He noted that bringing together biologists (biomimicry) and designers is an important part of delivering bioinspired design.

To achieve bioinspired designs, the subject thesaurus must be studied as a versatile design tool in bioinspired design (as these designs provide insight into adaptive designs and achieve more efficient, elegant, and sustainable designs). The adoption of a biological thesaurus achieves the following:

- Reducing the workload in the biological field by providing a link between engineering and biological terminology.
- Helping designers find connections between the two fields.
- Facilitating bioinspired design through diverse applications.

Both **(Nagel, 2013; Oliveira, 2025)** refer to the biological terminology dictionary in functional design as a first step in bridging the terminological gap between engineering and biology. This dictionary increases user interaction, encourages association, and enhances the designer's ability to leverage biological information.

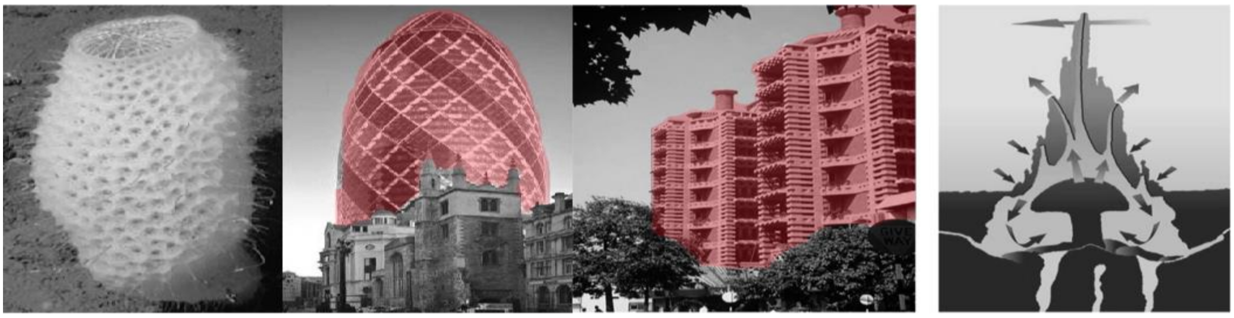
The Biomimicry Institute serves as a clearinghouse for biomimicry researchers through an online database of biological solutions, information, and experiments made available on the AskNature.org platform. In a similar vein, BioTRIZ also supports knowledge transfer from biology to engineering by analyzing more than 500 biological phenomena. Because biological solutions consume less energy, the use of bioinspired design holds promise for developing new and sustainable engineering solutions **(Xu and Cheung, 2013)**. Classifying data according to biomimicry on AskNature.org offers four important benefits:

- First, AskNature is a design tool for practicing biomimicry design.
- Second, to support biomimicry design, we need inspiration, and AskNature provides over 1,600 strategies for this.
- Third, AskNature content is free, licensed, and accessible to all.
- Fourth, AskNature is an ongoing experiment toward strategies for adapting to the future **(Deldin and Schuknecht, 2013)**

Mechanical methods may sometimes be more appropriate for solving design problems when using biomimicry, because the similarity between natural phenomena and architectural problems can be deceptive. Living organisms, for example, are capable of regeneration, while building materials cannot. Although biomimicry is a relatively new field, future research will provide designers with a deeper understanding of nature and greater opportunities to apply it to construct more sustainable buildings **(Okeke et al., 2017)**. The study pointed to a group of architectural buildings based on biomimicry, as shown in **Fig. 8**.

(Han et al., 2025; Metwally, 2025) combined the integration of biological processes into construction to enhance energy efficiency, urban environmental quality, and resilience, as well as green architecture that supports sustainable development goals by reducing the ecological footprint and promoting urban sustainability. In the same study, **(Zalekis et al., 2025)** argued that biomimicry has broad potential for developing psychologically and environmentally sustainable urban environments by adapting to diverse urban contexts. It contributes to enhancing social cohesion in cities.

A



B C

Figure 8. (A): The Eastgate Center, Harare, demonstrates biomimicry, drawing formal inspiration from nature. (B): Foster's Gherkin Tower in London. (C): The Eastgate Center functions; this diagram represents the direction of air movement from bottom to top. Analyzed by the author according to **(Okeke et al., 2017)**.

4.1.3 Biomechanical Design

In the context of improving environmental performance and sustainability through biomimicry, the biomechanical approach achieves this. Several biologists and design researchers **(Benyus, 1997; Vincent and Mann, 2002; Bar-Cohen, 2006)** have suggested that natural language text is a rich and flexible means of representing and communicating biological knowledge (computational linguistic tools can aid in cognitive studies) and thus support biomechanical design. A study by **(Alevizos et al., 2025)** demonstrated that the biomechanical approach enhances sustainable design by extracting effective solutions from living organisms, leading to improved thermal efficiency, optimal lighting, and the use of environmentally adaptive materials. The results demonstrate the ability of this approach to reduce energy consumption and improve thermal comfort through adaptive systems such as kinetic and smart facades. **(Keshmiri, 2025)** adds that the role of the biomechanical approach enhances sustainable design by drawing inspiration from natural processes to improve architectural performance in energy efficiency through the use of nature-inspired shading systems. The study confirms that biomechanics opens promising horizons for designing buildings that combine environmental efficiency and aesthetics, enhancing the potential of sustainable architecture in the face of contemporary environmental crises. In the same context, **(Foroughi and Daneshgar, 2025)** support the transformative potential of biomechanics in sustainable planning and design, as the former relies on natural solutions, while the latter relies on enhancing human interaction with nature. The study indicates that current design models lack clear practical steps for achieving sustainability. **(Kolivand and Saluki, 2025)** highlights the role of biomechanics in enhancing the sustainability of residential buildings by adopting a descriptive and analytical approach. It identifies seven key indicators, most notably: composition, modeling, process, and function. It recommends future studies to gain a deeper understanding of the relationships between these indicators and their role in designing sustainable buildings using biomechanical principles. **(Badarneh and Waman, 2025)** share a convergent approach to biomechanics, presenting a transformative educational framework that combines innovation, sustainability, and systems thinking. This framework is grounded in natural principles such as adaptation and self-organization, fosters critical thinking and creativity, and relies on experiential learning, real-world projects, and interdisciplinary collaboration. It uses a modified Bloom's taxonomy and the "function-structure-behavior" model to support the transition from knowledge to innovation, contributing to building a sustainable and resilient future inspired by nature. The research extracts the most important sustainable mechanisms followed and the level of simulation in the field of architecture, cities, and biomechanical design according to the studies analyzed above. Studies are classified from oldest to newest, as will be explained in **Table 1** below:

Table1. The most important sustainable mechanisms and the level of simulation in the field of architecture

No.	Reference	Sustainable mechanism	Level of biomimicry
1	**(Benyus 1997; Vincent and Mann 2002; Bar-Cohen 2006)**	-Mechanism of computational tools and languages to transfer biological knowledge to biomechanical design via perception and design	Biomechanical Design
2	**(Helms and Goel, 2009)**	-Drawing inspiration from biological phenomena for architectural applications -Researching a specific design problem and solving it with biological systems -Mechanism for integrating biomimicry into city design and management	City level
3	**(Al-Ahmar, 2011)**	-Digital simulation mechanism (technology) for using curved shapes in simulation	Architecture in general
4	**(Al-Zaini, 2012)**	-Adoption of a sustainable standard in interior spaces, such as lighting, thermal comfort, energy efficiency, durability, and productivity	Architecture in general
5	**(Shu and Cheong, 2013)**	-BioTRIZ analysis mechanism to provide sustainable solutions	City level
6	**(Deldin and Schuknecht, 2013)**	-Simulation mechanism via the Ask Nature platform to support sustainability	City level
7	**(Goel et al., 2013)**	-Mechanism for integrating biomimicry with urban environments in design and planning	City level
8	**(Nagel, 2013)**	-The mechanism of the conceptual link between biology and architecture	City level
9	**(Shu and Cheong, 2013)**	Understanding biomechanical design through classification tools and databases such as AskNature	Biomechanical Design

10	**(Vincent, 2014)**	-The mechanism of analyzing biology in an engineering manner to develop sustainable designs.	Architecture in general
11	**(Buck, 2017)**	-Using biomimicry to stimulate innovation in infrastructure and improve the quality of life	City level
12	**(Okeke et al., 2017)**	-Mechanical solutions (alternative techniques) for architectural materials and structures	City level
13	**(Hu, 2017)**	-Simulation mechanisms at the structural, behavioral, and systems levels of biological systems to achieve sustainability	Architecture in general
14	**(Oguntona and Aigbafobowa, 2019)**	-A mechanism for linking nature and construction materials through techniques and technology to achieve sustainable mechanisms.	Architecture in general
15	**(Uchiyama et al., 2020)**	-Imitation - Mimicking the ecosystem to improve human well-being -Integration and connection mechanism - Integrating nature into designs to achieve sustainable designs	Architecture in general
16	**(Jami and Versilj, 2021)**	-Mechanism for developing nature-inspired materials to achieve sustainable technologies	Architecture in general
17	**(Varshabi et al., 2022)**	-Smart facade design mechanism (architectural envelopes inspired by nature) to reduce energy consumption in buildings	Architecture in general
18	**(Othmani et al., 2022)**	-The mechanism of imitation at the level of the organism's form or part, or the imitation of the organism's behavior with its surroundings, or the mechanism of imitation of the ecosystem as a whole.	Architecture in general
19	**(Chayaamor-Heil, 2023)**	-A mechanism for drawing inspiration from the aesthetics of biological systems -A mechanism for understanding the functioning of biological systems to achieve sustainability	Architecture in general
20	**(Dixit and Stefanska, 2023)**	-Digital mechanisms and technological techniques to improve topology and achieve environmental, social, and economic balance.	Biomechanical Design
21	**(Alevizos et al., 2025)**	-Inspire solutions from living organisms to improve thermal performance, lighting, and the use of environmentally adaptive materials such as smart facades and kinetic systems.	Biomechanical Design
22	**(Keshmiri, 2025)**	-Mechanism for improving energy efficiency using shading systems inspired by natural processes (aesthetics and environmental efficiency)	Biomechanical Design
23	**(Foroughi and Daneshgar, 2025)**	-A mechanism for achieving comprehensive sustainability through human interaction with nature.	Biomechanical Design
24	**(Kolivand and Saluki, 2025)**	-Biomechanical mechanisms such as structure, patterning, function, and process of living organisms.	Biomechanical Design
25	**(Badarneh and Waman, 2025)**	-Mechanism for developing a sustainable curriculum from nature using the “function-structure-behavior” model and modified Bloom’s taxonomy	Biomechanical Design
26	**(Oliveira, 2025)**	-The mechanism of the conceptual link between biology and architecture	City level
27	**(Han et al., 2025; Metwally, 2025)**	Integrating bio-processes into construction, applying green architecture, and adapting biomimicry to the urban context	City level

4.2 Biomimicry Towards Sustainability

Several studies have explored the role of biomimicry in preserving the built environment within the framework of trends toward achieving sustainability in architecture. Among these studies is **(Watchman et al., 2020)**, which explored the relationship between biophilic design principles and well-being by creating healthier and more comfortable environments that facilitate communication among its members. Reference was made to school environments and the role of natural landscapes, daylight, variable lighting, natural ventilation, and temperature to achieve better social behavior and maximize the relationship between architecture and bioclimatic biophilia, generating enjoyable architectural experiences that enhance well-being and achieve sustainability. In the same context, **(Fish, 2017)** pointed to two approaches to dealing with nature: mimicry and inspiration (that mimicry is not inspiration). The first approach: biomimicry of nature (within an ethical framework), within the idea that it is a complex, dynamic, self-organizing network. In contrast, inspiration is linked to concepts of authenticity and attractiveness. What results from this is a process that cannot be classified as belonging to nature, man, or technology, but is something that calls for a charged common potential that motivates everyone towards a new arrangement (as confirmed by the study **(Matthews, 2011)**, relying on ecosystems to achieve human purposes, and that biomimicry is a key to sustainability if biomimicry is applied from the mindset of nature and not from imitating nature..
(Yasser, 2025) The applications of plant-inspired architecture, focusing on its formal, functional, and environmental aspects, explore its role in improving architectural design by mimicking natural light, reducing energy consumption, and enhancing aesthetics. It also highlights the need for further research to develop this approach, leverage its untapped potential, and integrate it with building technologies to achieve energy-efficient green buildings. **(Begary et al., 2025)** .Architecture must contribute to solving the problems of pollution, energy, and resources. Biomimicry is based on nature's closed system, leaving no waste and creating environmentally friendly buildings that are sustainable, efficient, and innovative **(Hammond, 2024)**. Therefore, the basic sustainability principles of the biomimicry concept in architecture are: Local conditions determine functional, structural, and site-specific solutions, optimize space utilization and avoid excess space, encourage the use of renewable energy sources, and ensure that buildings are environmentally friendly through eco-friendly construction methods **(Mirniazmandan and Rahimianzarif, 2017)**.
Biomimicry plays an important role in improving the urban environment and its quality by connecting with nature and achieving environmental performance standards. It is an effective tool for guiding and developing future cities. There is a strong convergence between prevailing "future city" models, such as the smart city, and biomimicry. Biomimicry can contribute to guiding strategies for analysis, communication, and infrastructure design, as many algorithms that make cities smarter rely on biomimicry strategies **(Batty et al., 2012)**. In the same context, **(Zari, 2016)** addressed the role of biomimicry for climate change in built environments. Several (architectural) concepts were discovered for biomimicry of the ecosystem (methods of adaptation and mitigation to address climate change). This study also addressed that to create a sustainable built environment, biology and the environment must be integrated into architectural design. The study refers to the St. Pancras International Terminal project as an example of inspiration from nature, as shown in **Fig. 8**. The study explains the inspiration from the flexible structure of the scaled exterior of an animal, as shown in **Fig. 9**.

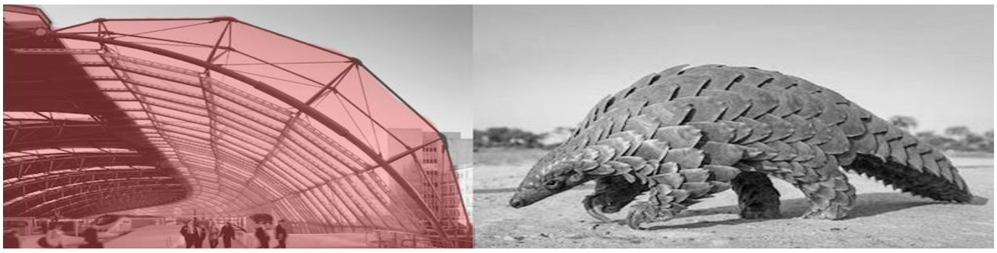
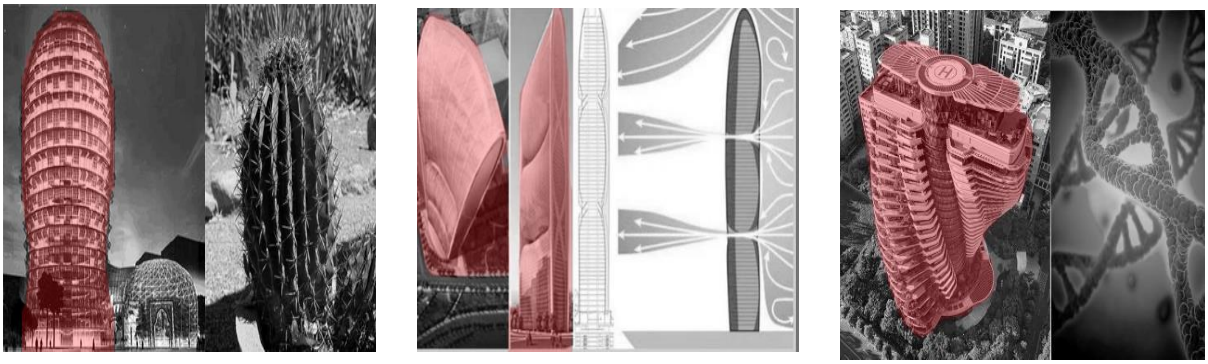


Figure 9. The St. Pancras International Terminal. Analyzed by the author according to **(Zari, 2016)**

Also **(Zari, 2017)** addressed the role of biomimetic methods in the architect's design and achieving a sustainable, renewable built environment through a design methodology inspired by different forms of biomimetics and proposed different construction and design methods based on previous literature and analysis of biomimetic techniques. the study refers to New Zealand's capital city of Wellington. **(Mirniazmandan and Rahimianzarif, 2017)** refers that Biomimicry is one of nature's strategies to maintain the sustainability of tall buildings through its analysis of three high-rise buildings and the application of different levels of biomimicry. These buildings are: (MMA office building, Pearl River Tower, DNA Towers). They believe that the comprehensive sustainability of buildings is through applying the behavior and work of living organisms and not through the imitation of form. In order to enhance the role of biomimicry in achieving comprehensive sustainability in buildings, there must be a deep understanding and cooperation between engineers, architectural designers, environmental scientists, and biologists to integrate the principles of simulation into designs and not just add them formally, as shown in **Fig. 10**.



A: B: C:

Figure 10. The buildings: (A) MMA office building, (B) Pearl River Tower, and (C) DNA Towers. Analyzed by the author according to **(Mirniazmandan and Rahimianzarif, 2017).**

Both **(Zari, 2015; Zari, 2018)** had similar opinions in that biomimicry produces more sustainable designs if it is at the ecosystem level (particularly when the simulation distinguishes between ecosystem functions and processes) as well as Biomimetic innovation can be studied within the framework of: component, product, service, system Because it is linked to sustainability challenges, human participation and society as a whole in the design process can also be studied.

The study **(Bensaude, 2019)** indicated that the concept of bioeconomy promoted by the OECD and the European Commission is strongly supported by biomimicry, which aims to reconcile economic and environmental sustainability. The concept of the bioeconomy is the basis of the philosophy of biomimicry and bioelectronic technologies, which supports the use of biotechnology by imitating nature's capabilities to create new resources and generate machines capable of organizing themselves, self-reproducing, and continuous expansion and accumulation of capital. In the same field the study of **(Ilieva, 2022)** clarified the relationship between biomimicry and sustainability, especially the built environment, to stimulate bio-inspired innovation, the level of biomimicry (i.e. form, process, ecosystem) as there is much debate in the relationship between different levels of biomimicry and the promise of sustainability, the study also showed that the biomimetic design experience can be considered as a stimulating practice for thinking across the dualities of nature and culture and thus moving towards achieving sustainability. Biomimicry is an important key to achieving transformative change.

In addition, the study of **(Verbrugghe et al., 2023)** indicated that the concept of biomimicry is new and so far, not all the details and possibilities have been revealed, so it requires more studies and training on techniques for adapting to the environment to achieve sustainable development. The research extracts the most important sustainable mechanisms followed and the level of simulation in the field of Sustainable architecture according to the studies analyzed above. Studies are classified from oldest to newest, as will be explained in **Table 2**.

Table 2. The most important sustainable mechanisms and the level of simulation in the field of Sustainable architecture

No.	Reference	Sustainable mechanism	Level of biomimicry
1	**(Matthews, 2011)**	-Sustainable design is achieved by understanding nature as a self-organizing network -Biomimicry as a means of achieving ecological balance	Sustainable
2	**(Batty et al., 2012)**	The intersection of biomimicry and smart cities through design, analysis, and communication mechanisms in smart cities (smart biological tools)	Smart cities.
3	**(Zari, 2016)**	Ecosystem mimicry as a mechanism to address climate change through adaptation and mitigation, inspired by animal organisms.	Climate adaptation of buildings
4	**(Zari, 2017)**	Developing new design and construction methods based on multiple forms of biomimicry	Sustainability
5	**(Mirniazmandan and Rahimianzarif, 2017)**	-Enhancing the sustainability of tall buildings by mimicking the behavior of living organisms, not just their shape. -Green building mechanisms as sustainable environmental practices, as well as reusing resources.	Sustainability
6	**(Fish, 2017)**	-Biomimicry as an ethical approach based on understanding nature as a complex system -Inspiration as an aesthetic process (stimulating creativity) through the joint interaction between nature, humans, and technology	Sustainable structures
7	**(Zari, 2015; Zari, 2018)**	Distinguishing between ecosystem functions and processes to produce more sustainable designs (biomechanical innovation)	Ecosystem-level Sustainable

8	**(Bensaude, 2019)**	Bridging the bioeconomy and biomimicry as a means of combining environmental and economic sustainability	Bioeconomy and Innovation
9	**(Watchman et al., 2020)**	Integrating natural elements (landscape, lighting, natural ventilation) into architectural environments to enhance social well-being and comfort.	Sustainable Design
10	**(Ilieva, 2022)**	Achieving sustainability through biomechanical design: A thought-provoking practice across the "nature-culture" dichotomy	Sustainability
11	**(Verbrugghe et al., 2023)**	Enhancing adaptive capacity to achieve sustainable development.	Sustainability
12	**(Hammond, 2024)**	Mechanisms for mimicking natural closed systems to reduce pollution and resource consumption, making them efficient and sustainable buildings.	Principles of sustainable architecture
13	**(Yasser, 2025)**	A mechanism for harnessing plant functions to improve lighting, reduce energy consumption, and enhance aesthetics.	environmental
14	**(Begary et al., 2025)**	Integrating biomimetic designs with technological techniques to expand the potential of biomimicry.	green buildings

5. RESULTS AND DISCUSSION

After applying the extracted mechanism in **Tables 1 and 2** on the selected Previous studies, the results were as follows:

First: bioimimetry in architecture: the research notes the multiplicity of common mechanisms inspired by nature in the field of architecture, cities, and Biomechanical Design, including:

- Drawing inspiration from nature to develop architectural and engineering designs in terms of efficiency, effectiveness, and aesthetics. These studies range from inspiration based on external form to inspiration based on the relationship of the organism with its surroundings, and inspiration based on the ecosystem as a whole.
- Analytical mechanisms using technical methods and technology, including: BioTRIZ: to generate sustainable innovative solutions; digital platforms such as AskNature: to facilitate access to solutions inspired by nature; and digital simulation: specifically for shaping curved shapes and analyzing environmental performance.
- Mechanisms for integrating architectural designs (exterior facades and interior designs) and urban designs (future smart cities) with nature to achieve sustainable environments, and attempts to link biology and architecture to enhance the performance of biological systems in architectural applications.
- Biomechanical design mechanisms (biomechanics are the basis for understanding the interaction between humans and nature in a sustainable manner), including: understanding living organisms through classification tools and databases such as AskNature. The use of computer models and programming languages to transfer biological knowledge and analyze their systems to develop sustainable solutions.
- Creative and aesthetic design mechanisms: bioinspiration through interaction with nature, humans, and technology.
- Considering nature as a complex system of ecological balance relationships (achieving ecological, social, and economic balance through digital mechanisms and technological techniques). Incorporating natural elements (lighting, ventilation, landscapes) into

design for environmental adaptation, as well as developing smart interfaces inspired by biomimicry to improve thermal performance and reduce energy consumption.
- Digital design mechanisms: Digital modeling to achieve precise environmental solutions, as well as efforts to link these techniques to educational curricula to support sustainability in design.
- Integrating bio-processes into construction, applying green architecture, and adapting biomimicry to the urban context

Second: sustainability in biomimicry :sustainable mechanisms inspired by nature in architectural applications can be summarized in **Table 2** as follows:
- The mechanism of biological analysis as the basis for architectural designs: by analyzing form and function and transforming them into more sustainable design solutions. Knowledge platforms such as AskNature can be used.
- The mechanism of achieving balance with sustainability by adopting biomechanics to understand nature and arrive at innovative solutions by focusing on the structure and behavior of living organisms about their surroundings, not just form.
- Integrating nature into smart cities and high-rise buildings using analytical tools based on smart biotechnology and computer simulations in the design of smart facades with sustainable technologies.
- The mechanism of green construction and reuse as sustainable methods is inspired by ecosystems.
- Integrating biomimetic designs with technological techniques to expand the potential of biomimicry.

6. CONCLUSIONS

This comprehensive review of studies has developed a comprehensive theoretical framework for the most important sustainability mechanisms in architectural applications, which contributes to bridging the knowledge gap identified at the beginning of the research. The most important aspects of these mechanisms include: biological analysis as a basis for architectural design; biomimicry as a philosophical approach that understands nature as a complex, closed system, and attempts to leverage these natural systems to find design and environmental solutions that reduce energy consumption, whether aesthetically, through solar breakers or inspired by the philosophy of living organisms in maintaining climatic conditions. This includes architectural designs, high-rise buildings, and smart cities, in addition to smart materials and technologies, including green buildings, and achieving design aesthetics and environmental balance. The theoretical framework emphasizes the need to provide a future-oriented educational curriculum that integrates biology and architectural engineering (biomechanical design curricula and training future generations to draw inspiration from nature in solving design problems). The study concluded the importance of relying on technological techniques and tools, computer simulations, and cognitive platforms such as AskNature and BioTRIZ, which include previous project experiences and applied models to facilitate the formal simulation process of building envelopes and complex biological systems, and translating them into realistic solutions to achieve an integrated, smart, adaptive, and sustainable urban and architectural environment.

Declaration of Competing Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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أثر تطبيق آليات المحاكاة الحيوية في تحقيق استدامة التصميم المعماري: مراجعة

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الخلاصة

المحاكاة الحيوية هو علم ناشئ يعتمد على الإلهام والابتكار لحل المشكلات الإنسانية من خلال دراسة الأنظمة والأشكال والعلاقات الموجودة في الطبيعة. لذا يتناول هذا البحث أكثر من خمسين دراسة، تناولت كل منها مفهوم المحاكاة الحيوية في مجال محدد. وعلى الرغم من حداثة هذا المفهوم، إلا أنه ما يزال يتطلب دراسات تفصيلية وموسعة لتحقيق الاستدامة الشاملة في التصاميم المعمارية. يهدف هذا البحث إلى بناء إطار نظري شامل للآليات المستدامة المحاكاة الحيوية في العمارة وبناءً على ذلك، سيتم تناول مفهوم المحاكاة الحيوية في التصميم المعماري على مستويين:يشمل المستوى الأول المفهوم داخل مجال العمارة، مثل الهيكل الخارجي، والمباني العالية، والتصميم الداخلي، بالإضافة إلى مفهوم المحاكاة الحضرية في البيئات والمشاريع العمرانية، ومفاهيم التصميم الميكانيكي الحيوي. أما المستوى الثاني فيتناول أثر هذا المفهوم في جعل تلك المشاريع أكثر كفاءة في استخدام الطاقة والموارد، وتحقيق التوازن البيئي، وبالتالي الوصول إلى مشاريع أكثر استدامة.ويخلص البحث إلى أن أهم محاور هذه الآليات تشمل: التحليل البيولوجي كأساس للتصميم المعماري، والمحاكاة الحيوية كمنهج فلسفي يفهم الطبيعة كنظام معقد ومغلق، والمدن الذكية والمباني العالية، والمواد والتقنيات الذكية بما في ذلك المباني الخضراء، وتحقيق الجماليات التصميمية والتوازن البيئي، إضافةً إلى تبني منهج تعليمي مستقبلي يدمج بين علم الأحياء والعمارة عبر مناهج التصميم الميكانيكي الحيوي، وتدريب الأجيال القادمة على استلهام الحلول من الطبيعة.

الكلمات المفتاحية: المحاكاة الحيوية، الابتكار، البيئة، التكامل مع الطبيعة، الاستدامة.