Biomimicry as an Approach to Create Architectural Resilient Projects

[1*] **Dr. Shaimaa H. Zaki**
Department of Architecture, Modern Academy for Engineering and Technology, Cairo, Egypt
Emails: SHAYMAA.ZAKY@eng.modern-academy.edu.eg & shaimaa.hassan.zaki@gmail.com
ORCID: https://orcid.org/0000-0001-9646-3242

Abstract

Nature is the primary mentor and source of instruction for scientists and architects alike. Biomimicry is a design methodology that combines nature and technology. It uses the principles of nature as a way of thinking to create a resilient and sustainable built environment. In addition to, it is an innovative approach that simulate biological process, shapes, and systems to reach sustainable and resilient solutions. In the other hand, resilience in buildings is the ability to meet the human needs and provide for safe, steady, and comfortable use to change conditions outside. The term "resilience of design building" refers to its resistance, recoverability, and adaptability, the latter of which is generally associated with outside circumstances.

This research aims to engage in design using biomimicry methodologies and resilience principles. Also answering the following question: How can use biomimicry for achieving and creating resilient buildings?

The research also emphasizes how to access the principles of resilient design in biomimicry buildings by studying biomimicry approach meaning, levels of biomimicry, inspiration methodology in biomimicry approach, and resilient buildings meaning.

Finally, the basic points and principles for the design of resilient buildings are applied to engage them with design by using biomimicry methodologies by analysis and discussing of 4 biomimicry projects. The projects are Beijing National Aquatic Center “the water cube”, Milwaukee Art Museum, Beijing National Stadium “Bird’s Nest Stadium”, and Tao Zhu Yin Yuan “known as Agora Garden”. The research concluded that biomimicry approach achieves resilience principles in buildings.

Keywords

Biomimicry, Inspiration, Resilient buildings, Biomimicry levels, Nature.

Introduction

The most significant source of creativity and inspiration for architects is nature. It can inform us about systems, components, methods, frameworks, and aesthetics. Janine Benyus asserts that many issues that society is currently confronting have been resolved by nature. Plants, animals, and microorganisms have a history of engineering. They are familiar with what functions, is suitable, and—most importantly—what endures on earth. According to architects and builders, nature contains various degrees of complexity, and its shapes have been used as an inspiration for architectural design and building construction. Additionally, many concerns about how to balance the link between nature and architecture have been posed by architects and designers. Thus, the word "biomimicry" and its connection to the built environment emerged.

Biomimicry is a creative methodology for problem-solving that draws inspiration from the study of natural systems, processes, and designs. By observing how nature resolves issues that we now face, biomimicry design can be used to explore and extract suitable answers and new paths for our built environments. Biomimicry is a comprehensive approach that includes environmental design and technological innovation. In simulation process for any nature element by the designer, it simulates a specific aspect of this element as its shape, behavior, physiological function, and adaptation to the surrounding environment, whether this element is an animal, a plant, or an ecosystem. Resilience is about the environment having a law impact on building. It is the ability to face change, and the process of creating products that can withstand economic, social, and physical stress. Resilient buildings are which can meet human needs and provide for a safe, steady and comfort. Human productions will be able to be more effective, resilient, and sustainable with designs based on biometrics. There are numerous initiatives to achieve resilience through innovative concepts and materials, disaster preparedness, adaptation to climate change, and energy-saving.

This research aims to engage in design using biomimicry methodologies and resilience principles. Also answering the following question: How can use biomimicry to achieve and create resilient buildings?

1- Biomimicry Approach Meaning

The term "biomimicry" first appeared in scientific literature in 1962; it began to gain popularity in 1980, especially among material scientists; and in 1982, renowned scientist Janine Benyus coined the term and published it in her book, "Biomimicry Innovation Inspired by Nature," describing it as a new science that draws inspiration from nature to create designs that address problems in society [1]. To create sustainable design solutions, biomimicry is employed. It strives to provide ideas for solutions that draw from nature, are adapted by nature, and apply guiding principles to human engineering. Biometric-based designs will make human productions more productive, durable, and sustainable [2].

There are three ways to deal with the source of creativity in the biomimicry approach. inspiration, abstraction, and imitating [3]. Biomimicry has been outlined by several academics. Benyus, for instance, defines a new discipline as one that analyzes nature's concepts and then draws inspiration for designs and methods to solve human issues [4]. Guber, on the other hand, described it as the study of areas where the fields of biology and architecture cross and have creative potential for solving architectural challenges. It can also be described as an innovation strategy that imitates nature's time-tested patterns and tactics to find long-term answers to human problems. According to biomimicry theories, nature serves as a guide, a standard, and a teacher [5], as illustrated in Figure (1).

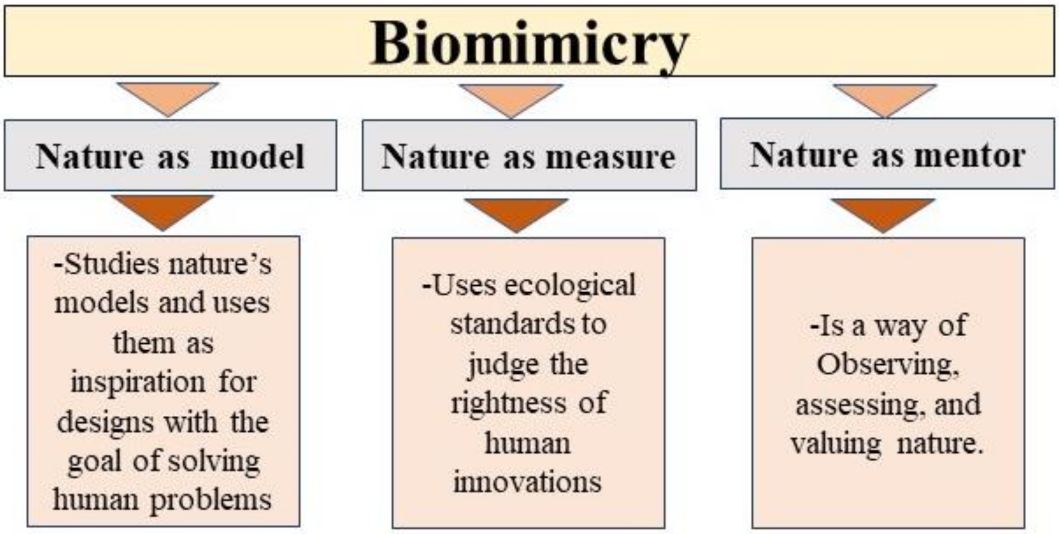

Figure (1) Theories of Biomimicry

It can also be described as a strategy for finding inspiration for tackling human challenges by looking at natural designs, systems, and processes. We can learn from nature about architecture, materials, processes, systems, and aesthetics. To provide sustainable solutions, it is also described as imitating the functional foundation of biological forms, processes, and systems. Therefore, the guiding principle of biomimicry is proposed to be a paradigm shift of imaginative and problem-based learning required for education toward sustainability [6]. For example, Frank Lloyd Wright used mushroom structural principles to create the interior pillars for Johnson Wax's executive offices in Racine, Wisconsin, between 1936 and 1939, as illustrated in Figure (2), and Guggenheim Museum spiral ramp idea was inspired by seashells 1943 [7], as illustrated in Figure (3).

Figure (2) Mushroom Structural Hall

Figure (3) Guggenheim Museum

By observing how nature resolves issues that we now face, biomimicry design can be used to explore and extract suitable answers and new paths for our built environments. Biomimicry is a comprehensive approach that includes environmental design and technological innovation [8].

2- Levels of Biomimicry

In simulation process for any nature element by the designer, it simulates a specific aspect of this element as its shape, behavior, physiological function, and adaptation to the surrounding environment, whether this element is an animal, a plant, or an ecosystem [9].

There are two classifications of Biomimicry levels, as follows: ***First:*** Ganine Benyus classification of Biomimicry levels, ***second:*** Maibritt Pedersen Zari classification of Biomimicry levels [10], as illustrated in Figure (4).

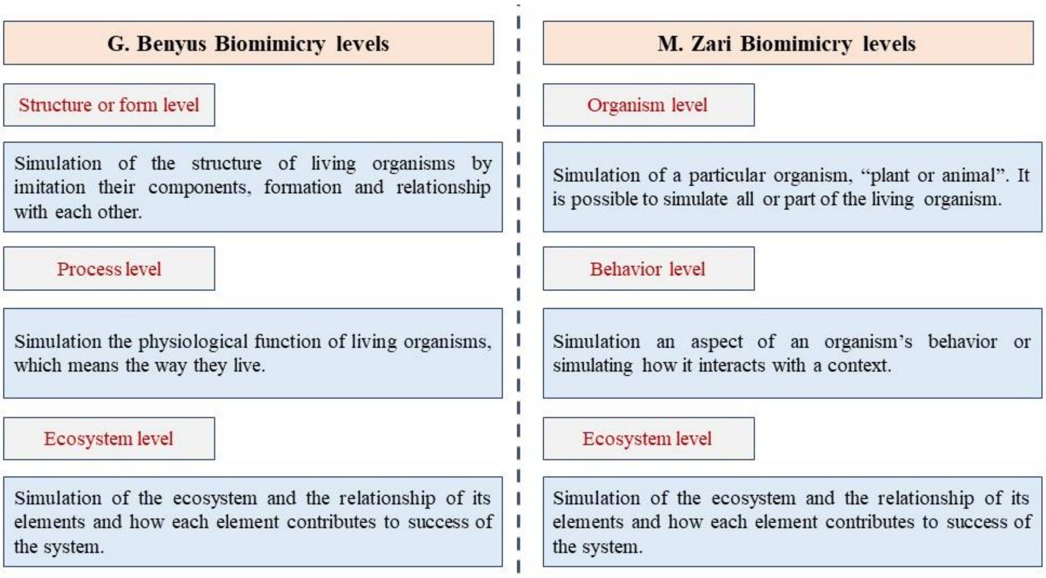

Figure (4) Classifications of Biomimicry Levels

3- Inspiration Methodology in Biomimicry Approach

As a design methodology, biomimicry approaches often fall into two categories: Design looking to biology is the process of defining a problem in human needs or design and seeking solutions from other organisms or ecosystems. Biology influence design is the process of identifying a specific characteristic, behavior, or function in an organism or ecosystem and applying it to human design. [1], [11], as illustrated in Figure (5).

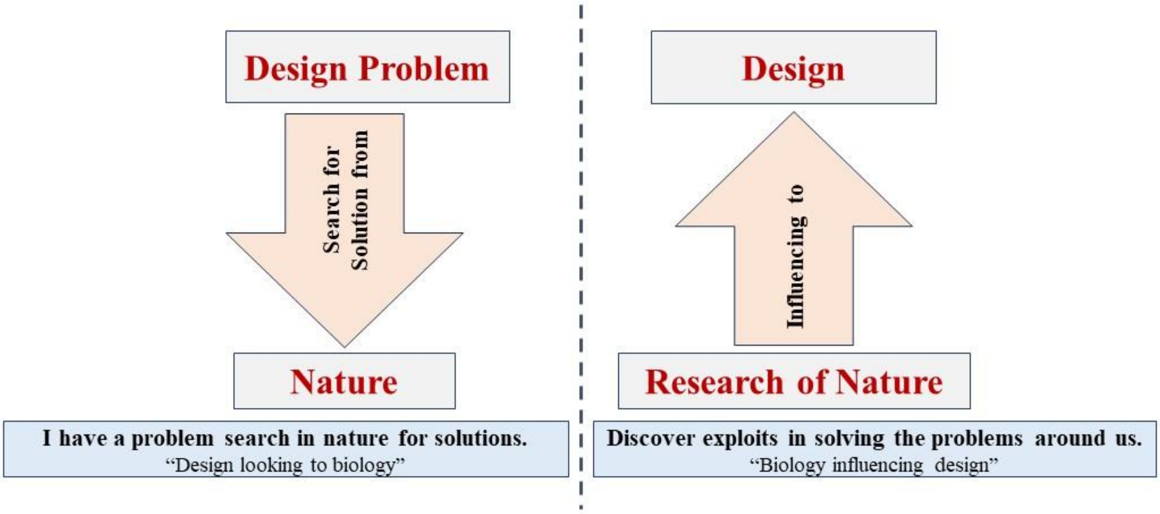

Figure (5) Comparison of biomimicry techniques

In design looking to biology approach [12]**,** Designers search the living world for answers to their challenges, matching them with species that have found solutions to a related difficulty. Designers who establish the project's initial goals and parameters effectively lead this strategy. For example, a robotic arm inspired by the elephant's trunk. When scientists tried to design a robotic arm, there was a problem for achieving free movement. In nature, the elephant can move its trunk in any direction. The robotic arm that was constructed at Rice university in the U.S simulates the elephant trunk design, as illustrated in Figure (6).

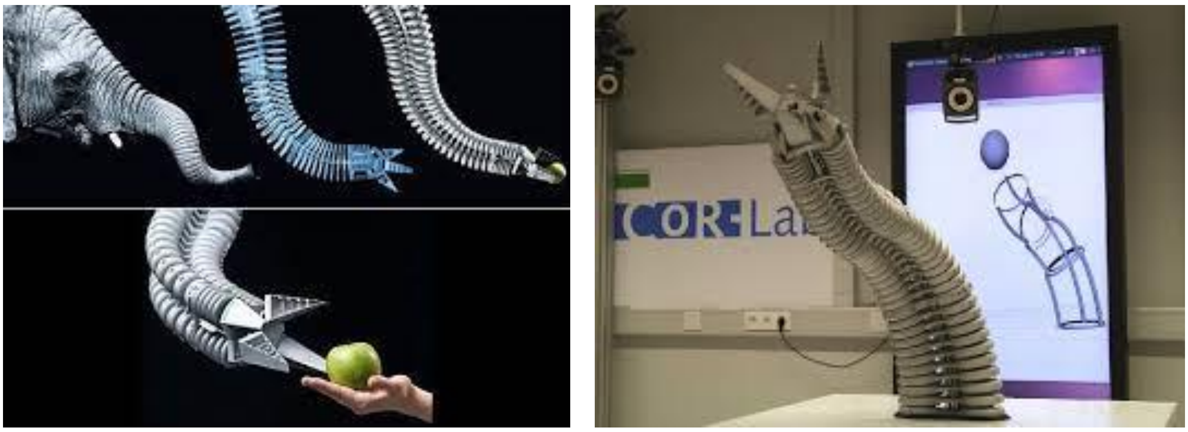

Figure (6) Robotic Arm Modeled after an Elephant's Trunk

And, in biology influence design approach [13]**,** When biological information affects human design, the collaborative design process initially depends on people being familiar with pertinent biological or ecological research rather than on difficulties with identified human design. For example, Scientists in China and Japan have developed a more effective solar cell that could be used to power mobile devices because of the connection between butterfly wings and solar cells. Butterfly wings include scales that serve as small solar collectors, as illustrated in Figure (7)

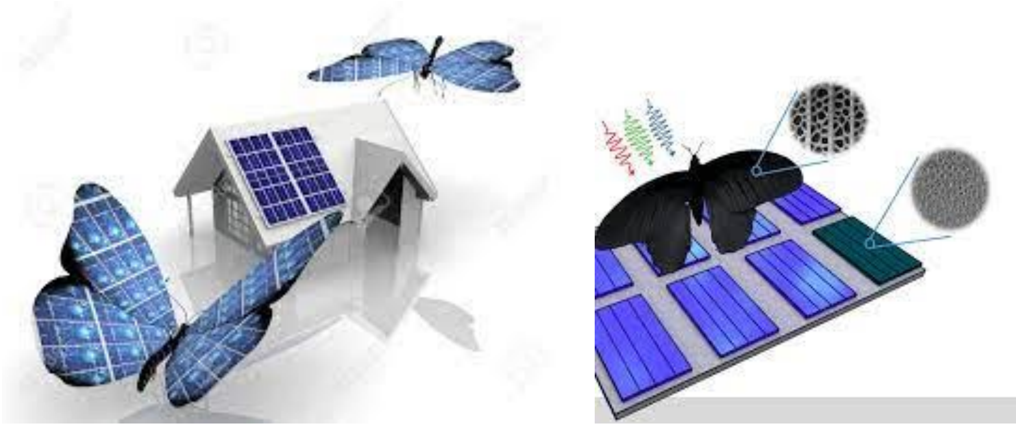

Figure (7) Butterfly Wings and Solar Cells

Designers follow several Biomimicry inspiration methodologies as [14]:

1- Biomimicry design spiral.
2- Biologically inspired design.
3- Typological analysis.

By using design looking to biology approach, or biology influence design approach.

In each methodology, there are some steps which are followed by designers to provide design solutions inspired by nature. Biomimicry inspiration methodologies were illustrated in table (1).

Table (1) Biomimicry inspiration methodologies

3-1 Biomimicry Design Spiral

This methodology is a tool that helps designers in creating designs inspired by nature and enables them to evaluate these designs to ensure their compatibility with nature principles and criteria at the level of shape, process, or ecosystem. The two approaches can be used design looking to biology, and nature influence design [15], as illustrated in Figures (8, 9).

a- Design Looking to Biology

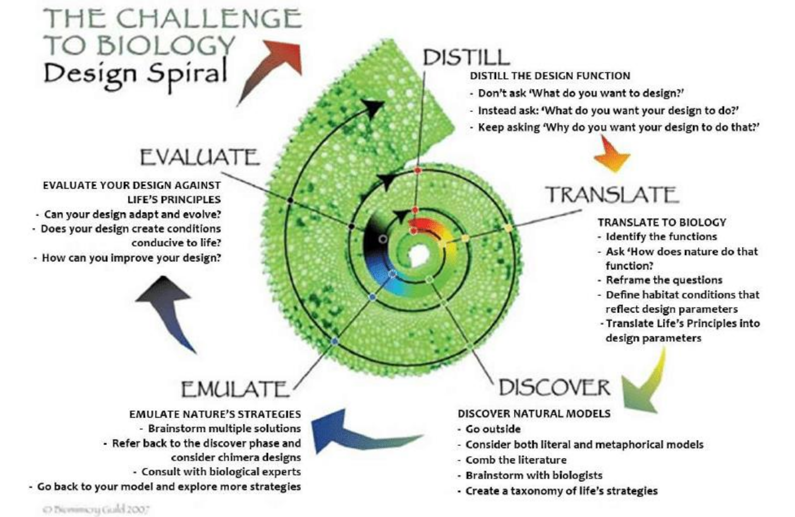

Figure (8) Design Spiral Steps (a)

-Distill:
Determine the problem.
-Translate:
Interpretation of identified problem.
-Discover:
Discovering nature models and searching for the ideal solution for the design problem from these models.
-Emulate:
Simulating nature models to develop solutions and ideas that depend on nature.
-Evaluate:
Evaluation of the design and its conformity with principles of nature.

b- Nature Influence Design

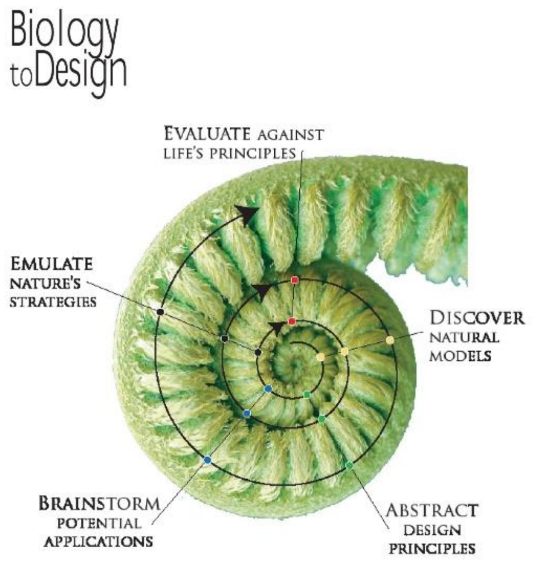

Figure (9) Design Spiral Steps (b)

-Discover:
Discovering nature models.
-Abstract:
Summarizing principles and models of design from nature.
-Brainstorming:
Trying to find ideas from nature through discussions between designers and biologists.
-Emulate:
Simulating nature models to develop solutions and ideas that depend on nature.
-Evaluate:
Evaluation of the design and its conformity with principles of nature.

3-2 Biologically Inspired Design

In this methodology, designers use the similarities in functions between engineering designs and biological systems to develop solutions for engineering problems and creating sustainable design. The two approaches can be used design looking to biology, and nature influence design [16], as illustrated in Figures (10, 11).

a- Design Looking to Biology

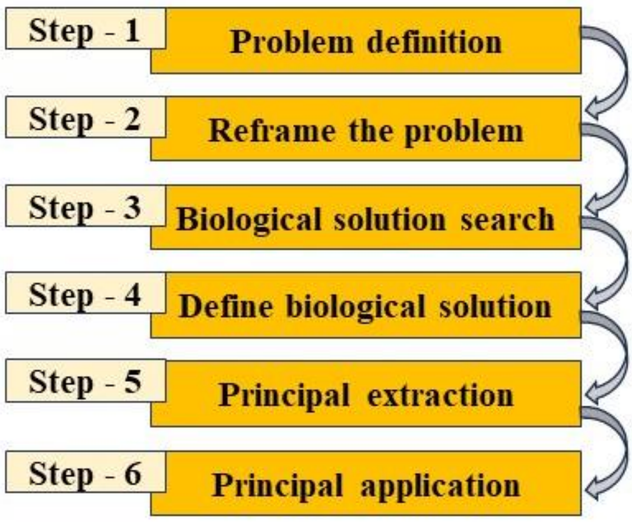

Figure (10) Biologically Inspired Design (a)

-Problem definition:
Determine the design problem that designer wants to solve.
-Reframe the problem:
Redefining the issue such that it is more biologically relevant.
-Biological solution search:
Searching for nature models that solve the same problems.
-Define biological solution:
Choosing the best biological solution model for the design problem.
-Principal extraction:
Extracting the principles and strategies of the biological solution model.
-Principal application:
Transferring and simulating of nature strategies to different design fields.

b- Nature Influence Design

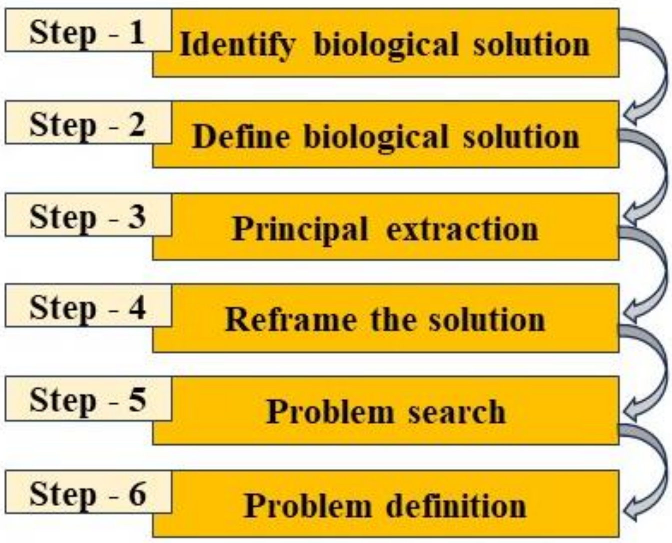

Figure (11) Biologically Inspired Design (b)

-Identify biological solution:
Determine the phenomena, functions, and characteristics that exist in nature.
-Define biological solution:
Doing a detailed study of the biological solution.
-Principal extraction:
Extracting the principles and strategies of the biological solution model.
-Reframe the solution:
Reframing forces designers to consider how people would evaluate the value of the biological function being achieved at this stage.
-Problem search:
Instead of searching through a finite space of known biological answers as is the case in the biological realm, problem search may involve creating brand-new issues. Compared to the problem-driven process's solution search step, this is very different.
-Problem definition:
Determine the design problem that designer wants to solve.
-Principal application:
Transferring and simulating of nature strategies to different design fields.

3-3 Typological Analysis

It is a methodology that was developed by Maibritt Pederson Zari to understand applying biomimicry in its three levels organism, behavior, and ecosystem, to use it as a tool to improve the built environment. In each level, there are five dimensions through which the building can simulate nature as shape/ form, materials, construction, process, and function [17], as illustrated in Figure (12). The two approaches can be used design looking to biology, and nature influence design.

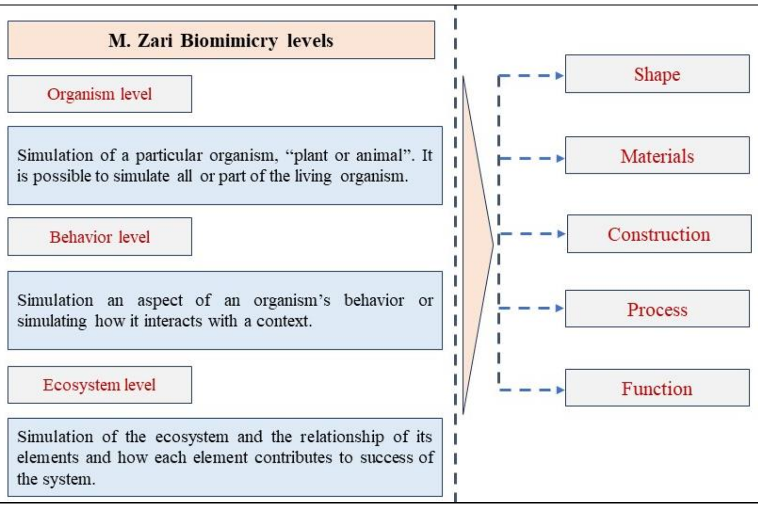

Figure (12) Typological Analysis Methodology

-Shape/ Form: What does it look like? **-Materials:** Which material is it made of? **-Construction:** How was it constructed?	**-Process:** How does it work? Which processes take place inside it? **-Function:** Which function can the building perform?

4- Resilient Buildings Meaning

Life may not come with a map. People will experience their challenges in life. Each event and change have a different effect and brings a unique flood of thoughts. However, people adapt well overtime to life challenges and stresses. It all comes down to resilience.

After natural disasters around the world, there have been some resilient buildings to protect the people and cities that depend upon them for survival [18].

Sustainable and resilient buildings and built environment is a multi-layered and multi-disciplinary construct. There is a difference between sustainability and resilience [19]. Sustainability is about having a low impact on the environment. It is the ability to continue important functions, and to be maintained at a certain level. In addition, sustainability is the practice of reducing environmental impact and improving quality of life [20]. But resilience is about the environment having a law impact on building. It is the ability to face change, and the practice of designing things to endure physical, social, and economic shocks and stress [21].

Sustainability and resilience employ many of the same methods to raise standards of living, lessen environmental impact, and boost spatial resilience. For instance, solar energy systems and energy efficiency increase a city's environmental impact reduction and supply chain disruption or shocks to the energy supply resilience.
Resilience focuses on disaster preparedness. Disaster resilient architecture means city services such as buildings, public transit, power system, internet, and communication services. There can face natural disasters. According to WHO, natural disasters include earthquakes, tsunamis, volcanic eruptions, floods, and so on. Resilience can be defined as the ability to adapt and respond changing conditions while maintaining functionality. According to psychologists' definition, resilience is the process of good adaptation in the face of adversity, threats, or sources of stress. Based on the urban land institute definition, resilience is the ability to prepare and plan for absorbing, recovering, and adaptation to adverse events [22].
Resilient design is the process of designing buildings, landscape, and entire communities to mitigate the impact of weather and other threats. It focuses on practical and realistic solutions.
Resilient design in buildings is studied according to several basic points, including resilience features, construction materials, key issues of design, resilience principles and strategies, as illustrated in table (2)

Table (2) Basic Points of Resilient Design in Buildings

Resilient Design in Buildings	
Features and key issues of resilient buildings [22], [23]	• Law carbon input resilient. • Highly insulated building envelopes. • Flexible, multi-use buildings • Water efficiency. • Land efficiency. • Material efficiency. • Energy futures and human needs. • Reducing the effect of the environment on a building. • Considering the use and maintenance phases. • Prediction of future behavior based on projected climatic conditions. • Contribution to adaptation to climate change. • Recoverability of building operability • Adaptability and transformability.
Disaster resilient construction materials [18], [24]	• Flood resistant buildings. • Earthquake resistant buildings. • Fire resistant buildings. • Heavy snow resistant buildings.

Resilient design principles [22]	• Human needs are met by resilient systems. • Systems that are passive, and adaptable are more resilient. • Resilience is strengthened by durability. • Resilience prepares for disruptions and a changing future. • Discover and encourage resiliency in nature. • Building design and structure can accommodate the anticipated changing impacts. • Using future climate conditions to create design solutions. • Optimizing on-site renewable energy supply. • Selecting materials and components that will not present a hazard in the event of damage.

5- How can Use Biomimicry to Create Architectural Resilient Projects?

Biomimicry can be utilized to create resilient and adaptive buildings. The features, key issues, disaster materials, and principles of resilience can be used to assess the performance of buildings which were designed by biomimicry approaches and methodologies. In this part of the research, the basic points, and principles for the design of resilient buildings which were presented in the previous part are applied to engage them with design by using biomimicry methodologies by analysis of 4 biomimicry projects. The projects are Beijing National Aquatic Center "the water cube", Milwaukee Art Museum, Beijing National Stadium "Bird's Nest Stadium", and Tao Zhu Yin Yuan "known as Agora Garden", as following:

5-1 Beijing National Aquatic Center "the water cube" [25]

Location	Olympic Green, Beijing, China.
Project purpose	Held water activities for the Summer Olympics.
Project concept	• Soap bubbles are the inspiration for the project's concept. • The architects created ordered models in the shape of cells with 12 to 14 faces to mimic the haphazard appearance of clinging soap bubbles.
Project description	• The bio-mimic approach is design looking to biology. • Structural form: 3D Vierendeel space frame. • The building's shape is based on a repeating unit that is tiled in three dimensions. • The building skin combines the enigma of the bubble system with the transparency of water.

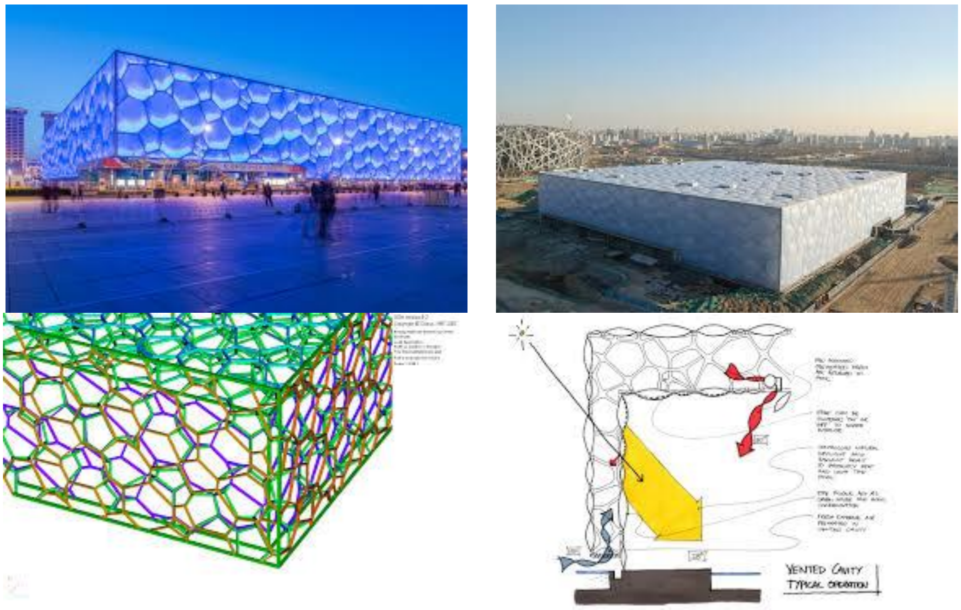

Figure (13) Beijing National Aquatic Center "the water cube"

How design achieve resilience

Resilience features and key issues of design for resilience

Using ETFE material as smart material and skin:

- The building skin absorbs solar energy and has energy efficient which appears in:

- Reduced energy costs by 30%
- Reduced artificial lighting by 55%
-Water transparency to the visitors which engages people inside and outside experience water through.
-Rainwater is collected and recycled.
- 20% of the solar energy used to heat swimming pools is captured by the bubbles.

- Using fluoropolymer which is plastic material with several advantages:

-Its weight is 1/10 of glass.
- It is clearer and more flexible.
- A greater amount of light can pass through it.
-It is a good insulator.

Construction materials

- ETFE material is a fire resistance system.
- It doesn't burn, but when the flame is there, it melts.
- Melting stops when fire is avoided.
- Its melting point is 270^{o}.
- ETFE's ability to shrink away from heat, effectively self-venting and releasing smoke out of the building, is its greatest firefighting advantage.

Resilient design principles

This project has achieved many resilience principles. The building was designed to simulate the environmental and structural characteristics of the accumulation and collection of soap bubbles. The building structure and skin resist and adapt to climate change. A high fire resistance material was used. Usage of light and flexible materials with high transparency that allow the passage of natural light and communication between indoor and outdoor, in addition to be energy-saving materials with high insulating properties.

5-2 **Milwaukee Art Museum** [26]

Location Milwaukee Wisconsin USA

Project purpose Museum

Project concept

- The proposal reflects the lifestyle of lake yachts, the environment, and a sense of motion and transition.
- The architects modeled the pavilion after a large bird with wings that could open and close.

Project description

- Calatrava created a project as an As an independent, ship-like structure made of white steel and concrete, the pavilion mixes in with other structures in terms of shape and building materials.
- The Milwaukee Art Museum is home to these enormous white wings constructed of glass, concrete, and steel.

Figure (14) Milwaukee Art Museum

How design achieve resilience

Resilience features and key issues of design for resilience

- The mobile sunscreen is one of its environmental features.
- The fins' sensors are always tracking the direction and speed of the wind.
- The green roof, which has aesthetic and environmental advantages such as extending the life of the roof, reducing energy use, and managing storm water.

Construction materials

- The wings are moved and modified in response to the wind, as well as the needs for light and shade, making it responsive to the weather. "*Adaptation with climate*"

Resilient design principles

This project has achieved many resilience principles. The building was designed to simulate the structural characteristics of the wings of a great bird. The building structure and skin resist and adapt to climate change. Usage of green roof which is a source of energy savings, aesthetic benefits, and environmental benefits.

5-3 **Beijing National Stadium** "Bird's Nest Stadium" [25], [27]

Location	Beijing city, south part of the Beijing Olympic Green, China
Project purpose	Host the 2005 Summer Olympics and Paralympics
Project concept	• The name of the stadium refers to how the iron bars resemble a nest of birds. • The architects emulated the project from bird's shelters made of natural materials like grass and branches.
Project description	• The original inspiration was from a combination of local Chinese art forms. • The design of a bird's nest incorporates innovative structural systems and load-distribution strategies.

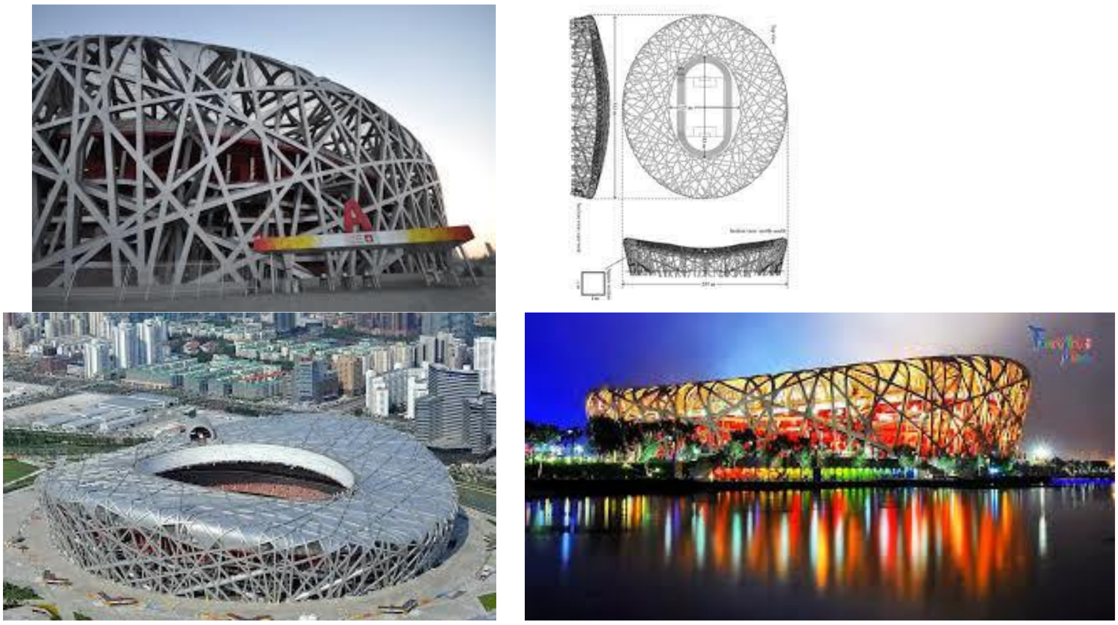

Figure (15) Beijing National Stadium "Bird's Nest Stadium"

How design achieve resilience

Resilience features and key issues of design for resilience	• The project was inspired from the bird's nest to simulate temperature, Wind, electricity, and humidity inside the bird nests. "*Adaptation with climate*" • A distinctive architectural formation with aesthetic value. • Modeling natural lighting and ventilation systems to assist rationalize energy use and lower operational costs. • Reducing the amount of pollution, the building emits.

Construction materials	• The project was inspired from use of the bird's nest to create a robust structural system which resists earthquakes.
Resilient design principles	This project has achieved many resilience principles. The building was designed to simulate the structural characteristics of the bird's nest. The building structure and skin resist earthquakes. This building has achieved aesthetic value and energy-saving.

5-4 **Tao Zhu Yin Yuan** "known as Agora Garden" [28]

Location	Taipei, Taiwan's Xinyi district and Xinyi special district
Project purpose	Residential high-rise building
Project concept	• The architects emulated the project from DNA strand. • This building has a unique appearance and is a distinctive twisting structure that is shaped like a double helix that rotates 90 degrees from top to bottom.
Project description	• The DNA double helix, which is a structure, served as inspiration for the skyscraper. • In the project, each double helix is represented by two housing units that make up a full floor. • In double helix, the 20 occupied levels stretch and twist at 90 degrees from bottom to top.

Figure (16) Tao Zhu Yin Yuan project

How design achieve resilience

Resilience features and key issues of design for resilience	• The architectural concept is to eco-design an energy self-sufficient building, whose energy is electric, thermal, and so on. • Carbon-absorbing ecosystems and anti-global warning systems that work in harmony with the environment. • It covers its open spaces with trees, planting, shrubs, and plants on the ground floor garden. • The annual carbon absorption reaches around 130 tons. • Planting multi species of trees with better carbon absorption.

	• Plants on balconies purify the air, keep the area moist, and reduce noise. • Providing fresh air in Summer, warmth, and ventilation in Winter. • To accomplish energy savings and carbon reduction, it blends natural ventilation, rainwater recycling, wireless monitor control of LED lighting, fiber optic connection, light guiding system, and solar/wind power. • Structure is designed to find its inspiration in the body structure of the tower. • The human body serves as the tower's structural core.
Construction materials	• In order to combat the crisis of global warming and climate change, the initiative has been devoted to promoting carbon-absorbing architecture. • The goal of the project is to promote carbon-absorbing architecture in order to lower the earth's temperature and combat climate change and global warming.
Resilient design principles	This project has achieved many resilience principles. The building was designed to simulate the DNA strand. The building structure and skin resist earthquakes and climate change. Usage of green roofs has achieved aesthetic value, environmental benefits, and energy-saving.

Discussion and Conclusion

Nature can offer creative ideas and solutions to structural problems, energy efficiency, and human needs. For that, nature has inspired a lot of the most beautiful architectural projects in the world. It was then that the word "biomimicry" and the associated scientific field of study first surfaced. Simulated natural environment. Biomimicry is a cutting-edge technique that imitates nature to produce resilient and sustainable solutions. This research highlights the role of biomimicry approaches and methodologies in creating resilient projects. 4 biomimicry projects are discussed. The projects are Beijing National Aquatic Center “the water cube”, Milwaukee Art Museum, Beijing National Stadium “Bird’s Nest Stadium”, and Tao Zhu Yin Yuan “known as Agora Garden”. These projects have achieved many resilience principles.

For Beijing National Aquatic Center “the water cube”, it was designed to simulate the environmental and structural characteristics of the accumulation and collection of soap bubbles. The building structure and skin resist and adapt to climate change. A high fire resistance material was used. Usage of light and flexible materials with high transparency that allow the passage of natural light and communication between indoor and outdoor, in addition to be energy-saving materials with high insulating properties. In the Milwaukee Art Museum project, it was designed to simulate the structural characteristics of the wings of a great bird. The building structure and skin resist and adapt to climate change. Usage of green roof which is a source of energy savings, aesthetic benefits, and environmental benefits. In addition, Beijing National Stadium "Bird's Nest Stadium" was designed to simulate the structural characteristics of the bird's nest. The building structure and skin resist earthquakes. This building has achieved aesthetic value and energy-saving. And Tao Zhu Yin Yuan "known as Agora Garden" was designed to simulate the DNA strand. The building structure and skin resist earthquakes and climate change. Usage of green roofs has achieved aesthetic value, environmental benefits, and energy-saving.

The projects were designed to simulate nature to present the environmental and structural characteristics and solutions. These buildings' structure and skin resist and adapt to climate change. A high fire and earthquake resistance materials were used. Usage of light and flexible materials with high transparency that allow the passage of natural light and communication between indoor and outdoor, in addition to be energy-saving materials with high insulating properties.

The research concluded that biomimicry approach achieves resilience principles in buildings.

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