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Biomimicry: Journey to the Future with the Power of Nature

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Abstract

Biomimicry involves studying and imitating nature's strategies and features in man-made design and technology. This approach fosters innovation in industrial, scientific, and design projects, drawing inspiration from the exceptional adaptations, processes, and structures of organisms. The primary goal of biomimicry is to comprehend the complexity and efficiency of natural ecosystems, leveraging this understanding to develop sustainable technologies and utilize natural resources more effectively. While humans have drawn inspiration from nature for thousands of years, the modern term gained popularity in the mid-20th century. Biomimicry is integral to sustainability, offering solutions in harmony with nature by integrating its balances into man-made systems. In medicine, biomimicry taps into the characteristics and processes of natural organisms to inspire innovative treatment methods and materials. In education, it equips students with the skills to comprehend and replicate nature responsibly, inspiring future designers and scientists. Ethical considerations emphasize that learning from nature should occur without causing harm to the natural environment. To unlock its full potential, biomimicry requires broader acceptance, integration into industrial applications, and technological advances for sustainable resource use. The energy sector, for instance, can benefit from biomimicry by enhancing the efficiency of solar panels through inspiration from photosynthesis, offering environmentally friendly energy production solutions. In essence, biomimicry is the key to discovering sustainable, innovative, and ethical solutions inspired by nature. As we delve into the richness of the natural world, this approach plays a pivotal role in shaping future technology and design. This review focuses on current biomimicry research, particularly highlighting its potential in the energy sector. The paper aims to serve as a blueprint for future achievements while shedding light on the unseen limitations of biomimicry.

Keywords: "Nature, biomimicry, energy, future."

1. Introduction

For centuries, people have improved their lives by observing nature, being inspired by it and consciously or unconsciously using its wisdom. Nature has provided the most appropriate solutions to the challenges that humans face and people have used these solutions to better their lives. This view has been the basis of human innovation and problem solving since their historical existence. With the development of science and technology, great progress has been made in the fields of design and engineering inspired by nature. This approach has been called biomimicry since the 19th century. Biomimicry has gone beyond using the results of observation and has inspired a number of disciplines that study the genetic, functional, biological and physiological processes of observed organisms.

Today, biomimicry offers environmentally sensitive and sustainable solutions as well as making life easier with innovative designs inspired by nature. Biomimicry is a science that integrates the perfect designs of nature into human engineering and design. Derived from the Greek words "bios" (life) and "mimicry" (to imitate), biomimicry refers to learning from and imitating nature [1]. This approach shows that designs that combine functionality and aesthetics are also based on a scientific basis [2]. Throughout history, people have been inspired by nature to discover innovations and solutions that improve quality of life. Biomimicry takes this process of learning from and imitating nature even further, opening the door to more innovative designs and sustainable solutions in the future.

While explaining the basic principles of nature, Benyus emphasizes saving energy, maximizing the use of solar energy, recycling and creating a suitable form to fulfil the function [1]. Primlani, as one of the principles of biomimicry, suggests adapting to different conditions, solving problems, continuous development and obtaining the materials needed from nature [3]. Nature is defined as the totality of living and non-living things that are constantly changing within its own rules. The way nature

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works is characterized by using solar energy, adapting form to function, recycling, rewarding cooperation, increasing diversity, favouring regional expertise, and using scarcity in the most effective way [1].

In this study, the concept of biomimicry, the basic principles, history, main application areas and future potential of biomimicry are examined. Furthermore, it focuses on recognizing examples of biomimicry, its current uses and future potentials by addressing the relationship of biomimicry with energy. The aim of this review is to contribute to the exploration of innovative ideas and solutions to be used in future design and engineering projects inspired by nature.

2. How Does Biomimicry Work?

Biomimicry involves understanding the solutions that organisms in nature have developed over years of natural selection and applying these solutions to man-made problems. Scientists and engineers are inspired by plants, animals, microorganisms and ecosystems to develop man-made technologies and designs.

3. Importance of Biomimicry

Sustainability: Biomimicry helps us use natural resources more effectively and minimize waste. This increases environmental sustainability.

Innovation: Excellent designs and processes in nature inspire people to develop more effective and innovative products.

Energy Saving: Biomimicry contributes to energy conservation by using principles learned from nature to improve energy efficiency.

Health and Medicine: Biomimicry enables the development of new treatments and medicines by understanding the defence mechanisms that organisms in nature develop against disease.

4. History of Biomimicry

Biomimicry is a concept that dates back thousands of years, but the emergence of biomimicry as a modern scientific discipline is more recent. Here are some important periods in the history of biomimicry:

Antiquity: Ancient civilizations created many designs inspired by organisms and natural phenomena in nature. For example, ancient Egyptian architects were inspired by nature when they built irrigation canals and dams to control flood levels in the Nile River. The ancient Greeks designed unmanned aerial vehicles inspired by the principles of bird flight.

Middle Ages: In the middle ages, the trend of design inspired by nature continued. Arab mathematicians and engineers in particular made important discoveries in astronomy and mathematics inspired by nature.

Renaissance Period: During the Renaissance, interest in the natural sciences increased and works of art and design inspired by nature emerged. Leonardo da Vinci left important notes on airplane design by studying birds.

18^{th} and 19^{th} Century: With the industrial revolution, inspiration from nature and interest in natural sciences increased. For example, the design of trains and ships was inspired by the morphology of fish. However, during this period, such designs were often random experiments, and biomimicry as a systematic scientific discipline had not yet developed.

20^{th} Century: In the twentieth century, the concept of biomimicry began to emerge more prominently. Biologist Janine Benyus popularized biomimicry in 1997 with the publication of her book “Biomimicry: Innovation Inspired by Nature”. This book explained how biological organisms generate solutions in the natural world and showed how these solutions can be applied to human problems. Janine Benyus and others have taken steps to organize a social enterprise, Biomimicry 3.8, to share biomimicry ideas and concepts, as well as to connect interdisciplinary researchers, scientists, artists, engineers, business leaders and stakeholders.

5. Technology and Design Inspired by Nature

Biomimicry has been a source of inspiration in many fields of technology and design. In this section, innovative solutions in aerodynamic designs, materials engineering, architecture, robotics and healthcare will be examined in detail. Some examples of technology and design inspired by nature:

Aerodynamic Design: Birds, insects and sea creatures in nature have excellent aerodynamic properties for flight and swimming. Inspired by these organisms, aerodynamic designs of vehicles such as airplanes, drones and submarines have been developed. For example, the wing structure of birds has influenced the design of airplane wings. In Demir's (2020) [4] study, an attempt was made to design the rim wing.

Materials Engineering: Organisms in nature, especially insects and plants, use natural methods to produce durable and lightweight materials. Inspired by these properties, engineers have developed strong, lightweight and flexible materials. Durable materials inspired by spider webs are used in many fields, from construction to sporting goods. Excellent examples of biological optical systems and clues to their potential applications in textiles can be found in studies involving anatomical basis of photonic crystals in nature. Photonic crystals (also known as photonic band-gap materials) are periodic structures that have a band gap that forbids the propagation of a certain frequency range of light. As a result, photonic crystals always reflect only that specific band width (colour) of visible light [5]. Such structures are found in nature in butterfly wings, some plant species (bracts of edelweiss), marine creatures (e.g. brittlestar, *Ophiocoma wendtii*), opals [6], etc.

Robot Technology: The movement mechanisms of organisms in nature have played a major role in the development of robotic systems. For example, the movement mechanism of snakes has been a source of inspiration for robots that can work in narrow and difficult spaces. Also, swarm robots have been designed inspired by the behaviour of insects. These robots can perform complex tasks together, mimicking social insect organizations in nature. Many of the advancements made in the field of computers and robotics have been made possible due to an inspiration from nature. Observing the way insects behave gave us swarm algorithms, observing structure of neurons gave us Artificial Neural Networks etc. Biomimicry has been practiced since ancient times, and we are still learning from nature, whether in the field of robotics and smart systems, or in algorithms and networks [7].

Health and Medicine: The physiology and defence mechanisms of organisms in nature have led to significant advances in medicine and healthcare. Prosthetic limbs and artificial organs have been developed inspired by the body structures of organisms in nature. Material scientists have tried to emulate the nanofibrous structure and hierarchical architecture of fibrous tissues like tendon. Techniques usually combine a biomimetic scaffold with biological factors, such as cells and growth factors to provide physical and biochemical cues for tissue growth [8].

Energy Generation: Solar panel technology was inspired by photosynthesis mechanisms in nature. The design of wind turbines has also been optimized, inspired by bird wings. Novel strategies based on nature-inspired design will play a major role in future photovoltaic solar cells as a sustainable energy resource [9].

6. Biomimicry and Sustainability

Biomimicry aims to minimize the environmental impact of products inspired by nature. In this section, the importance of biomimicry in terms of sustainability will be discussed and the positive effects of products designed with biomimicry on nature will be emphasized. The relationship between biomimicry and sustainability is very important.

Optimizing Resource Use by Taking Lessons from Nature: Biomimicry is an important resource for understanding how organisms in nature effectively use resources and efficiently convert energy. With this knowledge, industrial processes and product designs can be optimized. In this way, more efficient products and processes can be developed using less energy and raw materials. Structure built by animal, or animal architecture is bound with nature, unlike human-made. Animals create their construction with sophisticate features that allows them to survive, such as, ventilation, temperature regulation, structural strength, multiple escape routes, traps, bait, special-purpose chambers and many other features. Animals build their constructions with a limited energy and within an eco-system. For example, Termite's mound is one of a perfect natural construction, with efficient passive ventilation system that can keep the interior temperature always stable whatever exterior temperature would be. Termites make their mound from wasted materials of plants and animals around their local area, the process of their construction produce nitrogen, phosphorus and organic materials that help to enrich the soil, fostering more plant and animal grow in the area. This is the best example to show that apart from the termite mound construction is efficient, the process of their construction also gives a positive impact to their environment. This is an important lesson for us, to learn and improve our construction design process and industry [10].

Waste Reduction and Recycling: Organisms in nature are excellent examples of waste minimization and recycling. Biomimicry takes inspiration from nature to develop new approaches to waste management and recycling. For example, fungi rapidly break down and recycle organic materials in nature. This can be applied to design and manufacturing processes in ways that help waste to quickly disappear in nature.

Sustainable Material Development: Biomimicry is used to understand how organisms in nature produce durable, lightweight and environmentally friendly materials. For example, materials inspired by spider webs have biodegradable properties while being strong and lightweight at the same time. Such materials can be used to replace single-use plastics and offer an environmentally friendly alternative.

Sustainable Agriculture and Plant Breeding: Biomimicry can also be applied to agriculture and plant breeding by studying how vegetation and ecosystems in nature are sustainably managed. Inspired by the way organisms in nature naturally protect themselves from pests, agricultural practices can be developed that reduce the use of chemical pesticides and do not harm ecosystems. Biomimicry seems to resonate quite well with some of the main issues around recent agricultural Technologies [11].

Green Energy Generation: Refers to the generation of electricity using environmentally friendly and sustainable energy sources. Such energy sources help to reduce greenhouse gas emissions while reducing the danger of natural life depletion, such as fossil fuels. In green energy production, more efficient energy production techniques can be developed by taking inspiration from energy conversion processes in nature and the way organisms store energy. Organisms in nature often use energy very efficiently. This feature can be studied with biomimicry to develop new ideas on energy efficiency. In green energy production, technologies inspired by organisms in nature can be developed to increase energy efficiency. Biomimicry can offer solutions for using renewable energy sources more effectively. For example, the design of solar panels can be inspired by plant leaves that capture sunlight most efficiently. Similarly, the design of wind turbines can be inspired by birds in nature that are capable of flight. Organisms in nature are organisms that can adapt to their environment and are made using sustainable materials. Biomimicry shows how sustainable materials can be learned from nature. Biomimicry principles can be applied in the production of green energy, the use of environmentally friendly materials and the development of recycling processes. Biomimicry encourages drawing inspiration from nature for creative design. When designing green energy technologies, it is possible to develop creative and sustainable solutions by studying the complexity and optimized structures of nature. For these reasons, biomimicry plays an important role in the process of finding innovative, environmentally friendly and sustainable solutions in the field of green energy production. This approach can shape the future of energy production technologies by drawing inspiration from the fact that natural systems and organisms are in harmony with nature. Plants use sunlight in a chemical process called photosynthesis to convert carbon diox-ide into sugars whose solutions act as liquid fuel. Any artificial route to harvest solarenergy through a chemical process is bioinspired. Some biological structures such as theeyes of many species possess excellent anti-reflection coatings, and their implementationin conventional solar cells can enhance the light-harvesting efficiency, thereby providingan example of biomimetic methodology [12].

7. Biomimicry and Medicine

Biomimicry also has a great impact on the medical field. In this section, we will examine the uses of biomimicry in the medical industry and provide information about the treatment methods and medicines developed by taking inspiration from nature. In the future, biomimicry will have a greater impact through the combination of medicine, science, and biomedical engineering to treat diseases, physical disabilities, and wounds. Regenerative medicine and tissue engineering are particularly promising fields. Principles and functions of biomimetics that can be applied in biomedical engineering are derived from many sources, including how a lizard regenerates its tail and a buckhorn regenerates its horns every year, the adhesive, plegmatical, and regenerative properties of a spider web, and leukocyte adhesion/migration in inflammation [13].

Drug Development: Organisms in nature inspire us to develop drugs using the defence mechanisms they have naturally developed over the years against diseases. For example, peptides found in jellyfish venom have pain-relieving properties and can be used to treat severe pain. Likewise, the naturally occurring compounds produced by some plants could lead to drugs used to treat diseases such as cancer.

Wound Healing and Tissue Engineering: Biomimicry leads to important innovations in the fields of wound healing and tissue engineering by taking inspiration from the tissue healing processes of organisms in nature. For example, specialized cells in the skin of amphibians can help skin wounds heal faster. Furthermore, natural materials such as spider silk can serve as inspiration to produce durable and flexible materials for artificial tissues and organs used in tissue engineering.

Bacterial Resistance and Antibiotics: Organisms in nature have developed natural resistance mechanisms against bacteria. Inspired by these resistance mechanisms, a new generation of antibiotics can be developed to treat superbugs. In addition, natural antibiotics produced by organisms in nature can be used to treat diseases without harming human health.

Prosthetics and Artificial Organs: Biomimicry is used to develop prosthetic limbs and artificial organs inspired by the body structures of organisms in nature. The movement mechanisms of organisms in nature are studied to make artificial limbs work in a more natural way. In addition, the shapes and structures of organs in nature can be used as a basis for making artificial organs more compatible with the human body.

Research on Neurological Diseases: By studying the nervous systems of organisms in nature, biomimicry can work on the understanding and treatment of neurological diseases, and thus new treatment methods can be developed that can be used in the treatment of neurological diseases.

8. Biomimicry and Education

In this section, the place and importance of biomimicry in education will be discussed and information about biomimicry-oriented educational programs and projects will be provided. Biomimicry offers students the opportunity to understand the complexity of the natural world, develop problem-solving skills and promote scientific thinking. Biomimicry addresses sustainable methodologies into design education by following three essential elements: nature as model, nature as measure, and nature as an intrinsically valuable mentor. Laura et al. (2019) [14], researches examines, analyses and verifies biomimic educational processes considering its use of analogical reasoning, determining which elements are fundamental when incorporating biomimicry into design education. Here is the relationship between biomimicry and education:

Promotes Scientific Thinking: Biomimicry requires using scientific methods to study the structures and functions of organisms in nature. This allows students to develop scientific thinking in the natural sciences. Scientific methods such as making observations, conducting experiments, analysing data and drawing conclusions are taught as a basis for biomimicry projects.

Develops Creative Problem Solving Skills: Biomimicry offers students the opportunity to develop creative problem solving skills. Understanding how organisms in nature develop appropriate solutions to various problems encourages students to generate creative ideas. This gives students the ability to find innovative and sustainable solutions to real world problems.

Promotes an Interdisciplinary Approach: Biomimicry promotes an approach that brings together different disciplines such as biology, physics, engineering, design and mathematics. It gives students the ability to address problems by building bridges between different disciplines and integrating knowledge. This gives students the ability to more effectively approach complex problems they will face in real life.

Environmental Awareness and Sustainability: Biomimicry means understanding nature's design principles and developing sustainable solutions inspired by nature. This gives students an environmental awareness and understanding of the principles of sustainability. In this way, future leaders can develop environmentally friendly and sustainable projects.

Opportunity to Get to Know Nature Closer: Biomimicry offers students the opportunity to understand the complexity of nature and the amazing harmony of organisms in nature. The design, function and adaptation of organisms in nature allow students to learn more about the natural world. This builds a love of nature and awareness of environmental protection.

9. Biomimicry and Ethics

Biomimicry should also be considered from an ethical perspective. Biomimicry practices have a responsibility to respect organisms and natural ecosystems and minimize the risk of harm when designing with inspiration from nature. Here is the relationship between biomimicry and ethics:

Respect for Natural Organisms: Biomimicry practices require respect for the natural habitats and life cycles of organisms when drawing inspiration from nature. Mimicking the natural behaviours or structures of organisms should be done without threatening their lives and disrupting natural balances.

Sustainability and Environmental Sensitivity: Biomimicry projects should be based on the principle of sustainability. When designing inspired by nature, it is important to minimize environmental impacts and conserve natural resources. Biomimicry practices should be environmentally friendly and energy efficient, reducing the risk of damaging natural ecosystems.

Risk of Damage to Organisms: There may be a risk of harming organisms during biomimicry practices. Therefore, biomimicry projects should prioritize ethical values and the welfare of organisms. While experiments on organisms should be ethical, the risk of harm should be minimized.

Social Benefit and Justice: It is important that biomimicry projects contribute to social benefit. These projects should benefit the wider society and comply with the principles of justice. Biomimicry applications should aim to increase social benefit in areas such as health, education, environment and economy.

Knowledge Sharing and Collaboration: It is important that the information obtained in biomimicry projects is clearly and accurately presented to the scientific community and the public. Information sharing and collaboration ensure that biomimicry projects contribute to scientific progress.

Rights of Future Generations: It is important that biomimicry practices carry the responsibility to protect the rights of future generations and natural resources. Biomimicry projects should aim for a sustainable future and leave natural resources available for future generations.

10. Future Potential and Challenges

Biomimicry has a lot of potential for the future, but challenges in this field should not be ignored. Here are the future potential and challenges of biomimicry:

Future Potential:

1. Development of Innovative Technologies: Biomimicry enables the development of innovative technologies inspired by nature. It can open the door to important innovations in areas such as more efficient energy production, sustainable materials, pharmaceuticals and health technologies, inspired by the excellent design of organisms in nature.

2. Environmentally Friendly Products and Processes: Biomimicry can help develop environmentally friendly products and production processes. Products and processes inspired by nature can use natural resources more efficiently and minimize waste generation, thus increasing environmental sustainability.

3. Innovations in Health and Medicine: Biomimicry enables the development of new treatment methods in health and medicine. Drugs, prostheses and treatment methods inspired by organisms in nature can improve the quality of life of patients and improve treatment processes.

4. Advances in Education and Science: Biomimicry can be used in education to understand the complexity of the natural world and provide students with the opportunity to study nature more closely. Furthermore, biomimicry can encourage collaboration between biology, physics, engineering and other disciplines, which can lead to more comprehensive and innovative solutions.

Challenges

1. Lack of Scientific Understanding: The complex structure and functions of organisms in nature may not be fully understood. This can complicate the application of biomimicry because it can be very difficult to design around a feature that is not fully understood.

2. Ethical Issues: Biomimicry practices may risk harming organisms while taking inspiration from nature. Therefore, it is important that biomimicry studies comply with ethical standards. It is a challenging task to develop biomimicry applications without harming the natural habitats of organisms or disrupting natural balances.

3. Technological and Financial Challenges: Developing and commercializing biomimicry applications can be costly. Moreover, designing inspired by nature can sometimes bring complex technical challenges. Therefore, adequate financial and technical resources are needed for the development of biomimicry applications.

11. Biomimicry and Energy Examples

Ecological architecture aims to minimize the energy consumption of a building and to ensure that the design and material selection are in line with this goal. With the application of passive design principles, it is aimed to contribute to the energy production of the building through material selection and systems to be integrated [15]. Michael Pawlyn argues that a radical change is required for energy saving and sustainability. This change includes a radical increase in resource efficiency, the use of resources in a linear and non-polluting way, and the transition from fossil fuels to solar energy. Biomimicry plays an important role in realizing these innovative solutions. Because this approach supports energy efficiency and sustainability by mimicking the natural cycles in nature and the functioning of living organisms [16]. When ecological architecture and biomimicry come

together, there is the potential to develop ground-breaking solutions in the design of environmentally friendly buildings and energy systems. In this way, by taking inspiration from the natural processes of nature, a step is taken towards a greener and more energy efficient future.

-*Eastgate Center Building:* This building stands out as an example inspired by the thermoregulation ability of organisms in nature. This feature was used in the design of the building to ensure energy savings and sustainability. Located in Zimbabwe and built by architect Mick Pearce, this building mimics the natural ventilation system of termite towers [17]. When building their nests, termites manage to control the temperature inside, regardless of the temperature outside. This control is achieved by maintaining optimum humidity levels and temperature regulation.

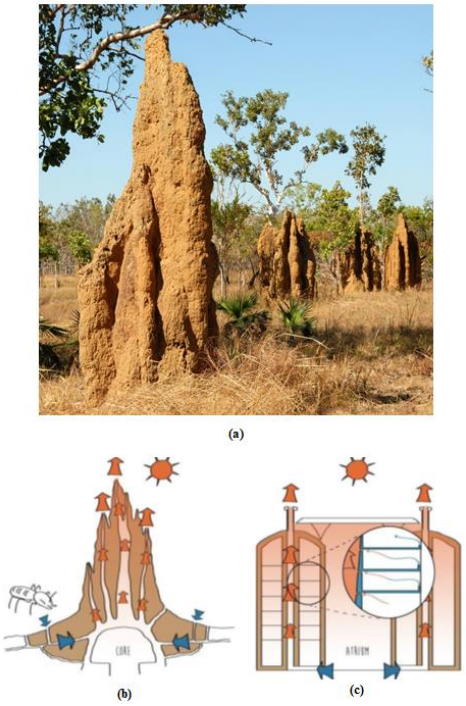

Fig. 1. (a) Termite mound [18]; (b) Termite mound architecture; (c) Eastgate Center [17].

Inspired by the excellent engineering skills of termites, the Eastgate Center building minimizes energy costs by implementing a natural ventilation system. The building manages natural ventilation with holes that can be opened and closed like termite nests. This planning principle developed by termites ensures a constant flow of air inside the building and effectively regulates energy use. This natural air movement, supported by fans in the design of the building, plays an important role in energy efficiency and reduction of greenhouse gas emissions [17]. The Eastgate Center building is a pioneering example of modern architecture inspired by nature's perfect adaptation, providing an inspiring model for energy conservation and environmentally friendly practices (Fig. 1).

-*Fish House:* Tsui designed this unique structure in response to his parents' request for a house that would be safe from natural disasters, protected from termites and offer a peaceful life. While researching these qualities, Tsui was inspired by the miracles of nature and discovered these qualities in a durable microscopic creature called the "Water Bear" [19]. This microscopic organism, known as a water bear, belongs to the invertebrate family and is known as one of the smallest animals in the world. They are characterized by their cylindrical body and four pairs of legs, as well as their extraordinary endurance (Fig. 2). Usually living in freshwater and humid areas, water bears are extremely resistant to extreme conditions. They can withstand radioactive rays, starvation and dehydration for long periods of time and are almost impossible to exterminate naturally. They can live all over the world, from the cold polar regions to tropical rainforests, from the ocean depths to the summit of the Himalayas. In addition, their ability to survive even in space has been discovered [20]. The design of the Fish House is inspired by this endurance and adaptability, creating a robust, aesthetic and environmentally harmonious living space. This building is a unique example of bringing nature's elegant and durable design to modern architecture.

(a)

(b) Fish House

Fig. 2. (a) Water bear (Tardigrade) [21]; (b) Fish House [22].

Fascinated by the unique resilience of tardigrades, Tsui meticulously studied the properties of these microscopic creatures and applied this knowledge to the Fish House project. Tsui was impressed by the fact that tardigrades do not have hard edges and their ability to spread the impacts they receive in their bodies, and made the structure ovoid (egg-shaped) to protect it against external impacts [19]. In order to increase stability against earthquakes and minimize the horizontal resistance created by wind and water, Tsui designed the walls of the building with a slight slope, adopting the sloping surfaces of the tardigrade's body structure. Large domed windows provide natural heat and light into the house, while the west-facing façade creates a natural air conditioning system to harness the wind. This design allows the building to remain stable, offering a high level of resilience against natural disasters. He also created a self-contained design to maximize energy savings, greatly improving the energy performance of Fish House [23]. In this way, Tsui has developed a unique house concept inspired by nature that combines sustainability, durability and energy efficiency in modern architecture.

-*San Leandro Civic Center:* Another design that Tsui created with micromorphic formation is the "San Leandro Civic Center" building he designed in 2014 (Fig. 3).

Fig. 3. Eugene Tsui's DNA-like tower design for a business and public building [24].

This public and office building has a design that is strikingly reminiscent of the DNA helix and is therefore also known as the DNA Tower. The spaces between the floors are carefully designed to reduce horizontal pressure from the wind and provide natural ventilation. In the center of the building is a core that connects the floors. In addition, the balconies on each floor have gardens that allow for the cultivation of crops. A wind turbine placed on the ground to meet the energy needs of the building supports the self-sufficient energy production of the building. This unique structure, reminiscent of a DNA helix, has a special structure to ensure maximum efficiency from the wind [23]. By combining aesthetics and functionality, this design offers an example of a sustainable building that mimics nature.

-*LAVA-Energy Storage Center:* It is a cylindrical structure that functions as a public sustainable energy information center (Fig. 4).

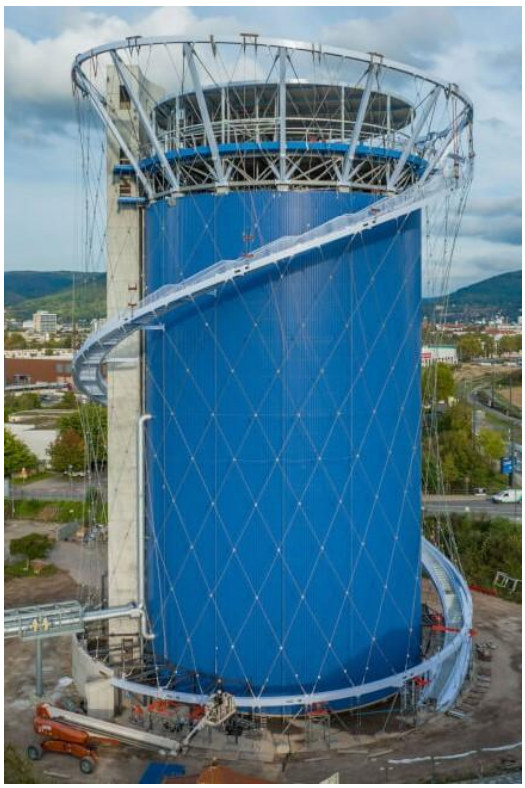

Fig. 4. Energy Storage Center (Stadtwerke Heidelberg-Model) (Germany) [25].

This unique building is characterized by its layered façade design. Its design is inspired by nature - spider webs, leaves and reptile skins - and focuses on flexibility, adaptability, energy transition, decentralization and networking. This design approach creates a dynamic and ever-changing play of light and shadow that animates the building with the wind. The building thus comes to life as a symbol of a new energy regime [16]. This building stands out as a unique energy storage center that combines the concept of sustainable energy with aesthetics and functionality inspired by nature.

-*Mandai Facility* is an innovative project in Singapore, realized by WOW Architects. The primary goal of this facility was to minimize its environmental footprint, with minimal impact on local wildlife. To achieve this goal, the main element of the facility is the tree houses raised off the ground. The design of these houses is inspired by the shape of a seed pod, giving them an aesthetic appearance in harmony with nature. In order to be in full harmony with the natural environment and to preserve the natural balance, the project has planned to plant native tree species. In addition, the roofs and facades of the resort's buildings are planted with plants that are in harmony with the environment. The interior design of the tree houses is inspired by natural flora and fauna, reflecting Mandai's rich biodiversity. This represents not only biomimicry design but also an approach that prioritizes energy efficiency. Energy saving measures to be used in the project include various technologies such as natural ventilation, mixed-mode air conditioning and solar panels. By saving energy through these methods, the facility is the first Super Low Energy facility in Singapore. Inspired by nature, the Mandai Facility is both aesthetically and environmentally remarkable because it is based on the principle of adapting to the natural environment without harming it.

- *The Heliotrope House* is a remarkable solar house built in Germany by architect Rolf Disch in 1990 (Fig. 5). This innovative design maximizes energy production with a system that follows the movement of the sun. The building has a circular floor plan and a cylindrical structure, which allows it to adapt to the movement of the sun and adapt to different thermal characteristics [26].

Fig. 5. Heliotrope House (Germany) [27].

The front façade of the building consists entirely of glass, while the rear façade is highly thermally insulated. This feature is utilized by enclosing the insulated rear side to keep the house cool on hot summer days. The roof of Heliotrope House features a large-scale photovoltaic system positioned in line with the sun. In addition, vacuum tube collectors on the balcony parapets provide energy for hot water and indoor heating [26]. This design not only maximizes energy production, but is also aesthetically pleasing because it combines sustainable living and energy efficiency, inspired by the power of nature.

- *Jellyfish Lodge:* A unique concept project inspired by nature. This house (Fig. 6) is inspired by the ability of special cells in jellyfish bodies to convert solar energy directly into electricity. This extraordinary structure, also known as Jellyfish Lodge, is not only aesthetically pleasing but also functional.

Fig. 6. Jellyfish Lodge [28].

The jellyfish-shaped structure filters polluted water with its long “tentacles” and collects the garbage in the water without harming wildlife. In addition, microbial digestion chambers measure the toxicity of the water and take an eco-friendly approach to the purification process. The cleaned water is pumped back into the river, supporting the natural cycle. The aquaponics garden

within the building provides a self-sufficient, productive and sustainable agricultural system where fish, plants and beneficial bacteria live in a symbiotic relationship. In addition, Jellyfish Lodge's retractable glass walls create an electrostatic field that repels mosquitoes and other microorganisms, creating a healthy indoor environment. This project stands out as an example that reflects the perfect balance of nature and sustainability using the principles of biomimicry.

- In a perfect example of nature, *the sunflower (girasol) grows* best by following the sun throughout the day. This natural behaviour is the inspiration Massachusetts Institute of Technology students found to improve the efficiency of solar panels. These students improve solar panels by utilizing the natural ability of sunflower flowers to change direction. The new model solar panels contain particles that can sense the sun. They sense the temperature difference between sunny and shady areas and orient themselves. This impressive system works without the need for any external energy source. Inspired by the fact that nature only uses as much energy as it needs, this system offers a more efficient way of energy production.

Since the sun is the main source of all energy on Earth, it is an ideal solution to utilize direct solar energy in designs. This is a reflection of the biomimicry approach, which respects the natural balance of nature and aims to use energy efficiently. Biomimicry offers important lessons on how living things in nature use energy efficiently. These examples show that biomimicry applications have the potential to create significant value for human societies in the future.

12. Conclusion and Evaluation

Biomimicry is an important approach that can provide innovative solutions to many challenges faced by humanity in the field of design and technology by taking inspiration from nature. This approach has great potential for future technological innovations and sustainability efforts. The topics covered in this study cover the broad spectrum of biomimicry, revealing the various application areas and potential in this field.

Biomimicry means understanding nature's perfect systems that have evolved over millions of years and using these systems in man-made solutions. This approach supports sustainability, as products and processes inspired by nature enable more efficient use of natural resources. Biomimicry also opens the door to innovation in the medical field; treatment methods and medicines inspired by the characteristics of organisms in nature can revolutionize the healthcare industry. In education, biomimicry offers students the opportunity to understand the complexity and harmony of nature. In this way, future designers and scientists can be inspired by nature and develop their solution-oriented thinking skills. However, it is of great importance that practices in the field of biomimicry are compatible with ethical values. Design processes based on learning from nature should not harm the natural environment and disrupt the natural balance. In the future, biomimicry will become even more important and has the potential to revolutionize many industrial sectors. Examples used in the energy sector will enable technologies such as solar panels and wind turbines to become more efficient and environmentally friendly by taking inspiration from nature.

In conclusion, biomimicry is an important tool for understanding the richness of nature and creating sustainable solutions for the future by taking inspiration from nature. Further exploration of this approach, supported by scientific research and industrial applications, will strengthen humanity's efforts to build a sustainable future in harmony with nature.

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