Exploring biomimicry in agriculture focuses on how insights from natural systems can revolutionize farming practices and enhance food security

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Abstract. Biomimicry, a design philosophy that is based on the principles of nature, presents a promising solution to the sustainability challenges faced by modern agriculture. Biomimicry agriculture endeavours to replicate the efficacy, resilience, and sustainability of natural systems by drawing inspiration from ecosystems. By analysing agricultural challenges and identifying the biomimicry approach in previous research, this study investigates the alternative method in biomimicry to ensure a sufficient food supply for agriculture. This document examines the adoption of biomimicry in the agricultural sector. A comprehensive content analysis of four case studies that concentrated on biomimicry farming systems and their integration with agricultural design was conducted. The case study selection was determined by the concept of biomimicry, which involves the transfer of inspiration from nature to the commonplace built environment. The results indicate that the design of Biomimicry is anticipated to enhance the efficacy of agriculture and technology in terms of environmental sustainability and well-being. The urban environment can be transformed through the application of biomimicry, as evidenced by this agricultural study. In summary, biomimicry has the potential to significantly improve the sustainability and resilience of agriculture. It has the potential to create innovative solutions that improve food security, conserve natural resources, and reduce the environmental effects of cultivation.

1 Introduction

Food security, as defined by the Food and Agriculture Organization (FAO), refers to a state where individuals have consistent and unrestricted access to an adequate supply of food that is both safe and nutritious, satisfying their dietary requirements and preferences, and enabling them to lead an active and healthy life [1]. Food security encompasses four fundamental components in the realm of food supply: availability, stability, accessibility, and usage. The components within the food security pillars serve as a standard for assessing food security, as they enhance people's comprehension of the significance of a stable food provision. Ensuring food security is currently a significant concern since the global community must find a way to allocate natural resources for other economically advantageous endeavors [2].

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The competition for natural resources for development and food is intensifying due to the annual increase in population numbers. Climate change exerts a substantial influence on the agriculture sector. Yields crops grown in Malaysia such as durian, rice, cocoa, bananas, coconuts pineapple and other primary crops may probably see reduced yields in the next twenty years due to rising temperatures and decreasing rainfall in semiarid regions [3]. The issue has a substantial influence on the entire food supply and results in a problem of food insecurity. If this issue is not adequately handled, malnutrition and farmers' well-being will be jeopardized.

The Biomimicry Institute defines biomimicry as the science and art of emulating nature's best biological ideas, processes, and ecosystems, which it was used to solve human and environmental problems [4]. This research asserts that the built environment practice should embrace the biomimicry method to determine the best techniques to make designs part of the ecosystem rather than an outsider, causing environmental imbalance. To comprehend such a situation, relevant answers and new possibilities for built environments can be explored by understanding nature and mimics form, systems, materials, function, process, aesthetics, and ecosystems [5].

2 Methods

The method used in this study is by defining a case study. The selected case studies are based on agricultural issues and how the designers solve the problem using biomimicry. Four case studies were selected, which are Prospero: The Robot Farmer, Agrowormbots, Warka Water and Biomimetic Dew Harvesters. The case studies were selected based on the design solution of using biomimicry for agriculture. Next, case studies will be assessed by different design focuses, which revealed that the design emphasized different biomimicry approaches, levels, principles, and sustainable solutions. To explore the differences in the type of approaches and principles, the third method addresses the kind of application that the Biomimicry Institute suggests. Finally, case studies will be analysed using comparative analysis. A comparison table that compares two or more items on different parameters. The parameters used in this study are biomimicry approaches, principles, nature as a teacher, and measurement of sustainability in agriculture.

2.1 Biomimicry Approaches: Solution-based (Indirect) and Problem-based (Direct)

Numerous methods are available through biomimicry. It is important to note that the Biomimicry design process is used as a whole rather than as individual components [4]. Two methods have been found for using biomimicry: 1. Problem-Based Approach: focuses on the design issue and investigates how ecosystems or animals resolve it. 2. Solution-Based Approach: locates the design issue that could be solved by first identifying a specific trait, behavior, or function within an organism or ecosystem.

2.2 Biomimicry Principles

They are essential checklists to be adhered to in ensuring the application of biomimicry, resulting in sustainable outcomes. According to the Biomimicry Group [6], the four (4) significant principles are:

2.2.1 Evolve to Survive

This is the ongoing integration and application of knowledge to ensure long-term efficacy. It is based on three (3) main principles: information rearranging (changing and rearranging information to produce new alternatives), integrating the unexpected (incorporating errors in ways that can lead to new shapes and functions), and reproducing tactics that work (repeating successful techniques) [7].

2.2.2 Adapt to Changing Conditions

This adapts to changing circumstances properly. It is composed of five (5) principles: incorporating diversity (include multiple forms, processes, or systems to meet a functional need), maintaining authenticity through self-renewal (persist by constantly adding energy and matter to heal and improve the system), and demonstrating resilience through variation, redundancy, and decentralization (preserving function after disruption by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together)[6].

2.2.3 Use Life-Friendly Chemistry

To achieve this, life-supporting chemicals must be used. It also consists of three (3) guiding principles: conducting chemistry in water (using water as a solvent), disassembling products into benign constituents (using chemistry in which decomposition yields no hazardous by-products), and building selectively with a small subset of elements (assembling relatively few elements in sophisticated ways) [7].

2.2.4 Energy Efficient

Utilizing resources and opportunities wisely and proficiently. The four guiding principles are as follows: recycling all materials (maintaining a closed loop of all materials), utilizing low-energy processes (minimizing energy consumption by reducing necessary temperatures, pressures, and reaction times), and fitting form to function (selecting a shape or pattern based on the need) [7].

2.3 Biomimicry Principles

A newly developed perspective on nature and its potential for use is biomimicry. According to Benyus [4], humans must deliberately adopt a new perspective to imitate nature's genius. People look to nature as a guide, standard, and model in biomimicry. Using life's genius to consult applies nature's wisdom [4] to today's difficult, complex issues.

2.3.1 Nature as a model

People used natural phenomena as models for innovative behavioral patterns. There are lessons to be learned from nature in pursuing new perspectives on daily existence. There are no boundaries or waste in the natural world. Only nested systems exist, in which every component of the system is necessary for the existence of every other component [8].

2.3.2 Nature as Measure

A natural ecosystem is filled with mature living things that act in ways that uphold the nine laws of nature and indicate an ecosystem functioning correctly. Living in a group is one way to gauge one's righteousness. An ensemble is a set of complementary elements that create a single effect. Living in groups requires organisms, including humans, to develop the ability to maintain dynamic stability [9].

2.3.3 Nature as Mentor

Nature would no longer be seen as a master but as a teacher and mentor to humans. Humans will need to take care of nature if they hope to have it as a resource for knowledge, creativity, and inspiration in the future. Nature provides wisdom that can be emulated. Nature has evolved and gained experience with living systems, enabling it to create sophisticated, robust, and adaptive systems. Instead of exploiting, humans would be better off observing and learning [10].

2.4 Contributions to Food Scarcity

Agriculture plays a critical role in addressing food scarcity, which refers to the lack of sufficient food to meet the nutritional needs of a population or region. Several factors contribute to food scarcity, including natural disasters, climate change, economic instability, conflicts, and inefficient agricultural practices [11]; climate change is a global phenomenon that significantly impacts various aspects of the natural environment. Moreover, climate change exerts extensive repercussions on urban areas [12]. as shown in Table 1 below:

Table 1. Causes of food scarcity and how to mitigate the strategies

Causes of Food Scarcity	Mitigation Strategies
Climate change Shifts in weather patterns, extreme weather events, and rising temperatures can disrupt agricultural production, leading to crop failures and reduced yields	**Polyculture and Agroforestry** Mimicking natural ecosystems where diverse species coexist can enhance soil fertility, reduce pests and diseases, and improve overall ecosystem health
Natural disasters Floods and droughts can devastate crops and infrastructure, leading to immediate food shortages.	**Water Management** Learning from natural water systems such as wetlands or mangroves can inspire water-efficient agricultural practices.
Land degradation Poor land management practices, including deforestation, overgrazing, and soil erosion, can degrade soil fertility, reducing agricultural productivity over time.	**Soil health** Emulating the nutrient cycling and soil-building processes seen in forests or grasslands can improve soil health. Methods like composting mimic natural decomposition and nutrient cycling, reducing the need for synthetic fertilizers and enhancing soil structure.
Water scarcity Insufficient access to water for irrigation and drinking purposes can limit agricultural production, especially in arid and semi-arid regions.	**Energy Efficiency in Farm Design** Designing farm infrastructure based on natural energy-efficient structures like termite mounds can reduce energy consumption.

[11]

3 Results

3.1 Case studies

The selected case studies are based on designs that use the concept of biomimicry to ensure the continuity of food sources in different contexts:

3.1.1 Case Study 1: Prospero: The Robot Farmer (Biomimicry for harvesting)

Biological domain: Ants

Abstraction Phase: Taking inspiration from ants, Prospero illustrates three basic biomimicry qualities. With its six legs, Prospero has an extremely stable locomotion system that is ideal for difficult agricultural terrain, making its design obviously biomimicry.

Reaction to the environment: Reaction to the surroundings: The remaining three stages comprise farming and harvesting autonomous robots, and the last one is a plant-cultivate-harvest robot that can move autonomously from one procedure to another. The robot can determine whether the seed has been put in the area at the ideal depth and spacing thanks to the underbody sensor array. Prospero can dig a hole, plant a seed in it, then cover the seed with dirt, add a marking agent, and any pre-emergence fertilizers or herbicides [5].

Food security solution: This innovation will raise productivity per acre, enable the conversion of less land to agriculture, feed more people, and improve the standard of living for all of these people by reducing their expenditure on food [5].

3.1.2 Case Study 2: Agrowormbots (Biomimicry for reducing carbon footprint)

Biological domain: Worms
Abstraction Phase: Agrowormbots do agriculture by imitating worms.

Reaction to the environment: They fail to provide any compounds, such as nitrogen, that are needed for farming. Agrowormbots may help in plant growth by utilizing alternate agricultural methods, as previously demonstrated. By identifying the roots of these plants, they can locate the sources of residual nitrogen in the soil and provide them with care rather than plough them under with the other weeds. It will help lower the amount of nitrogen used, which was previously thought to be harmful to the environment and remove the need to transport any nitrogen fertilizers [13].

Food security solution:
The "agrowormbots" remove the need for nitrogen fertilizers by identifying remaining nitrogen-producing plants and nurturing them instead of pulling them out. These robots assist plant development and preserve an ecosystem's equilibrium by using artificial intelligence and soil residue. In addition to treating parasitic plants, this method uses less toxic nitrogen fertilizers [11].

3.1.3 Case Study 3: Warka Water (Biomimicry for water harvesting)

Biological domain: Warka tree (Ficus vasta)
Abstraction Phase: A water drop is composed of water molecules that like to stick together- an example of the property of cohesion. The water droplets are stuck to the web, which is an example of the property of adhesion.

Reaction to the environment: Observation of the process of how plants such as cactus and lotuses, as well as organisms such as Namib beetles and spider webs, extract moisture from the atmosphere led to the development of biomimicry technology.

Food security solution: The real-world impact of Warka Towers is astounding. They provide safe drinking water for people, helping reduce the risk of waterborne diseases. Warka Towers delivers a reliable water source for small-scale irrigation, vegetable gardens, and livestock. Installing one or more Warka Towers in a remote village creates a sustainable foundation to alleviate poverty, foster self-sufficiency, and improve the health and well-being of the community. The Warka Tower can also be an invaluable source of potable water anywhere in the world [14].

3.1.4 Case Study 4: Biomimetic Dew Harvesters (Biomimicry for water harvesting)

Biological domain: Stenocara beetle
Abstraction Phase: The research showed that these insects were also capable of collecting dew on their backs.

Reaction to the environment: The water yield of artificial dew condensers that imitate the beetle's back nanostructure. Scientists discovered that this beetle's back features, when examined under an electron microscope, make it an ideal model for water-trapping tents, building coverings, water condensers, and engines.

Food security solution: Although fog water harvesting is most suited for supplying water to rural and developing areas, it is still a vital water source that should be considered in other areas. Fog water harvesting is a renewable energy source useful for remote settlements that have grown reliant on outside water sources and rarely or limited rainfall [14].

The criteria analysis is illustrated in Table 2. In this section, the research utilised criteria to assess the degree of benefit from imitation in two primary domains: the biological domain and the food security domain. Then, it was subdivided into four dimensions. Consequently, the most suitable criteria will be the most significant design that satisfies the dimensions [15]. The requirements are implemented in specific case studies, including the Domain of biology a. Biomimicry methodologies: Solution-based and problem-based b. Biomimicry principles: Energy efficiency, evolve to survive, Adapt to changing conditions, and Resource material c. Nature as a teacher: Measure, Mentor, and Model d. Biomimicry levels: Organism, Behaviour, Ecosystem.

Table 2. Criteria analysis

Measuring Criteria \ Case Studies			Project 1	Project 2	Project 3	Project 4
			Prospero: The Robot Farmer	Agro-wormbots	Warka Water	Biomimetic Dew Harvesters
Biological domain	Biological Role model		Ant	Worm	Spiderweb collecting dews	Steno Cara beetle
	Biomimicry approaches	Solution - based	✓		✓	✓
		Problem - based		✓		
	Biomimicry principles	Resource material	✓		✓	
		Energy efficient	✓	✓		
		Evolve to survive			✓	✓
		Adapt to changing condition	✓			✓
	Nature as teacher	Mentor	✓	✓	✓	
		Measure	✓	✓		
		Model	✓	✓		
	Biomimicry levels	Organism				✓
		Behaviour	✓	✓	✓	
		Ecosystem				
Food	Sustainable in Agriculture					
	Measurement of Sustainability in Agriculture	Environmental health (agri-ecological)	✓	✓	✓	✓

		Economic profitability	✓		✓	✓
		Social and economic equity (social-territorial)	✓	✓	✓	✓

4 Discussion

Based on the analysis, a set of criteria is used to determine the extent of their impact on the design, using the concept of biomimicry to achieve the desired innovation design goals for food security through biomimicry principles and laws [15]. The analysis shows that all the criteria are critical and influence the design produced but in different proportions so that they can be divided into two domains. Projects 1, 3, and 4 were created utilising solution-based approaches to meet the first requirement. This method finds a design problem that can be solved by first identifying a certain trait, behaviour, or function found in an organism or ecosystem. Project 2 employed problem-based design approaches, in which the designer first considers the design challenge and then looks at how creatures or ecosystems resolve the issue.

Projects 1 and 3 successfully addressed the second requirement, biomimicry principles (resources materials), by utilising locally available, environmentally friendly materials. (Projects 1 and 2 effectively met the energy-efficient requirements since they addressed the building's entire system, which can use solar panels, shades, and other methods to lower energy use. Projects 3 and 4 successfully meet the Evolve to Survive criterion by duplicating effective tactics and integrating the unexpected by incorporating failures in ways that can lead to new shapes and functions. Projects 1 and 4 that successfully adjust to changing conditions do so by employing various strategies, such as climate adaptation.

The third requirement is the utilisation of Nature as a teacher. Most of the projects incorporate practical applications by emulating nature's structure, patterns, and behaviour, and by employing its fundamental principles. The fourth criterion evaluates the Biomimicry levels of projects 1, 2, and 3, which include nature's performance by imitating behavioural aspects in their design. The second area is to food security, which is influenced by factors such as climate change, population increase, escalating food costs, and natural calamities. It is crucial to implement policies and tackle the factors that contribute to global food security. The Sustainable Development Goal 2 (SDG2) aims to eradicate hunger, achieve food security, improve nutrition, and promote sustainable agriculture. It acknowledges the interconnectedness between sustainable agriculture, empowerment of small farmers, gender equality, rural poverty eradication, healthy lifestyles, climate change mitigation, and other issues addressed in the 17 Sustainable Development Goals [16].

The idea of sustainability is based on three fundamental principles of sustainable agriculture, which encompass the economic, social, and environmental aspects.The ecological (agri-ecological) scale promotes a farming method that prioritises environmental sustainability, minimising pollution and the use of non-renewable resources.The social (social territorial) scale prioritises the provision of sufficient food for the global population and the promotion of equitable employment and development for local communities.The economic scale guarantees the sustainability, effectiveness, and profitability of the farming activity. The research demonstrates that all of these designs meet the initial criterion, which pertains to the environmental (agri-ecological) aspect, by promoting a sustainable and harmonious approach to agriculture.

5 Conclusion

Food security is crucial today for food production to sustain the world's population. The science and art of mimicking the most advantageous biological concepts, systems, and ecosystems found in nature is known as biomimicry, and it is applied to address both environmental and human issues. Utilizing biomimicry a method that emulates nature can support the more environmentally friendly food manufacturing sector [17].

Sustainable agriculture integrates management practices with natural processes to promote resource preservation, waste reduction, environmental protection, issue prevention, and the resilience, self-regulation, evolution, and sustained production of agroecosystems for the benefit and fulfillment of all. The chosen case studies suggest that this design nearly satisfies sustainable agriculture and biomimicry requirements. To sum up, biomimicry has a lot of potential to make agriculture a more resilient and sustainable system. It can create novel solutions that improve food security, protect natural resources, and lessen farming's negative environmental effects. For future research, researchers can explore how this biomimicry system or concept can help urban farming and can also help the B40 group to apply this design for dense housing areas and at the same time can generate their income.

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