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Biomimicry Levels as Design Inspiration in Design

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Abstract
The relationship between design and nature has been intertwined for the past 400 years. Throughout history, designers have adopted nature to build shapes, forms, and ornamentation without understanding nature's behavior biomimicry. Nature's behavior biomimicry is a method that applies solutions to human problems by analyzing natural designs, processes, and systems. This innovative method refers to nature as an inspiration to solve design challenges. The method is the new science that studies nature as a model and inspiration to imitate the design and process of solving human problems. However, there is a lack of widespread and practical application of biomimicry as a design method; architecture commonly uses biology as a library of shapes, which is not biomimicry. Among the levels of biomimicry, the organism level is widely applied as a design tool to achieve a design solution. This paper reviews published research on the applications of biomimicry level, including its formative elements. Organism, behavior, and ecosystem level are mostly inspired or applied in the biomimicry concept. The content analysis was carried out to examine the published research articles on different perspectives of biomimicry and its application in design. The findings produce three levels of biomimicry that can serve as a regenerative design. There is a growing need for designs that work with nature to create a regenerative built environment, and designers can no longer ignore the relevance of bio-inspired theories and approaches to achieve a more sustainable future.
Keywords: Biomimicry, Biomimicry Levels, Formative Elements, Biomimicry Concept

Introduction
Although researchers and experts mention various biomimicry or bio-inspired designs in sustainable architecture (McLennan, 2007), biomimicry's widespread and realistic application as an architectural design method remains unrealized. It is evident by the small number of built case studies (Faludi, 2014). For instance, successful biomimicry that has improved beyond the concept and development stage are usually products or materials instead of buildings or building systems. It also imitates an aspect of a single organism.

A growing international field of biomimicry work with the built environment recognizes various obstacles to applying the method. One of the limitations is the lack of a clearly defined biomimicry approach that architectural designers initially used (Blok & Gremmen, 2016).

Nature has solved many mechanical and structural problems without generating residual and active wastes (Al-Obaidi et al., 2017). Mimicking nature requires an understanding of the differences between biological and technical systems. Their evolution is different where the biological systems have been evolving for millions of years, while the technological systems have been emerging for just a few hundred years. Biological systems evolved based on their genetic codes controlled by natural selection, while technological systems are built on human nature to perform functions (Al-Obaidi et al., 2017). In general, functions in technical systems tend to create a system due to design, whereas functions in biological systems may sometimes be unsystematic due to evolutionary genetic changes that lead to a specific feature that is not pre-arranged. Their differences are vast: technical systems function within extensive environments, while biological systems work within restricted living constraints.

The design from nature in the built environment can be understood in various terms, such as biomimicry, biomimetic, bionic, bio-design, biomorphic, bio utilization, biophilia, and bio derivation. Introduced biomimicry and they presented a unique concept of resembling ecosystems by creating a balance between nature and humankind (Versos & Coelho, 2011). Biomimicry is a new direction in science that links sustainable solutions and innovation based on an ecological criterion to evaluate the sustainability of the inventions and to appreciate the applicability of biomimicry in architecture and one of the approaches was the investigation of terminologies by Gruber on the relation of biomimicry in biology, which has shared use in built environments (Arnarson, 2011). Pawlyn explored notions from nature, while Gamage, Hyde, and Zari investigated biomimicry based on ecosystem interactions (Nkandu & Alibaba, 2018). Biomimicry ranges from architecture to material science and chemistry, where it continues to provide new and innovative insights into engineering problems (Blok & Gremmen, 2016). Biomimicry development has advanced and inspired over 30 years from insects, reptiles, mammals, and other organisms. From the engineering perspective, biomimetics works as an instrument to solve specific problems at the conceptual levels of design (Dash, 2018). Biomimicry and biomimetic are interchangeable terms. However, the latter focuses more on the technical aspect.

Biomimicry architecture seeks to remedy errors in designing efficient systems and products. For instance, Myers presented a dramatic technique by incorporating living materials into elements and structures. Myers' approach pushes the concept of mimicking to integrate biology within buildings to create new forms. Mazzoleni explored ways of utilizing animal skins for performative buildings. However, biomimetics research faces challenges in creating practical design tools in the built environment (Mirniazmandan & Rahimianzarif, 2017).

Literature Review

What is Biomimicry

The term "biomimicry" was introduced by Otto Schmitt in 1982 and rediscovered by Janine Benyus in 1997, an innovation consultant and co-founder of the Biomimicry Institute (Peters, 2011). The concept of biomimicry is sometimes misrepresented as creating buildings that look like natural organisms, i.e., buildings shaped like shells, which is another different approach in the design called morphology. Mimicking natural systems or processes can affect the form, but it is not the fundamental point in biomimicry (Benyus, 1997).

Therefore, biomimicry is not the simple imitation of nature in material and function nor in creative regards. It is grasping natural principles to aid the comprehension of analogous and technological questions that the applications of optimized technologies can solve. Biomimicry is practiced through learning from nature for the improvement of technology. It is exciting for the designers to explore the wealth of living nature, but one must be cautious of the direct interpretation. Inspiration from nature for architecture will not be functional if architects do not follow the in-between step of abstraction. The application of biomimicry is a 3-step process: Research–Abstraction–Implementation (Amer, 2019). There are two main approaches to the design process in biomimicry: problem-based and solution-based approaches.

Biomimicry Approaches

In the Biomimicry approach, there are two categories: defining the human needs or design issue and searching for solutions for other organisms or ecosystems, termed here design looking to biology, or defining a particular characteristic, behaviour, or function in an organism or ecosystem and translating that into human designs, referred to as biology influencing design (Shahda, 2018).

Design Looking at Biology

The approach where designers look for alternatives to identify problems and biologists match these with organisms that solve similar problems. This approach is effectively guided by designers who identified the initial design goals and parameters. The designer in this approach starts with identifying the problem, followed by searching for solutions from natural organisms. The biologists and designers match the problem to an organism that solves a similar problem. This approach can also be called a "challenge to biology," seeking answers in biology for human problems. The designer enhances a specific design or solves a design problem by exploring and looking at nature. The following is an example of this approach:

An Example of a Design Looking at the Biology

An example of the approach is Daimler Chrysler's prototype of a bionic car (fig. 1). To create a large volume and small wheelbase car, the design for the car is based on a boxfish (ostracon Meleagris), an aerodynamic fish with a box-like body. The chassis and structure of the car are also biomimetic, which are designed using a computer modeling method based on how trees can grow in a way that minimizes stress concentrations. The resulting structure looks almost skeletal as the material is allocated to places where it is most needed (Blok & Gremmen, 2016)

Figure 1: Daimler Crysler's Bionic Car is Inspired by The Boxfish

Source: https://featuredcreature.com/yellow-boxfish-who-knew-cubes-could-be-so-cute/ and https://www.motor1.com/news/299424/mercedes-bionic-concept-we-forgot/

Biology Influencing Design

The solution-based approach is a "biology to design," used when the biological principle is the source for design ideas (Borgh, 2006). The design process depends on the scientific knowledge of biologists and scientists instead of human design problems. The designer identifies a useful characteristic from nature, which is abstracted and translated to a technological context before the goal of the design is defined (Lepora et al., 2013). If biological knowledge influences human design, the collaborative design process is dependent on people's knowledge of applicable biological or ecological science rather than deciding on human design problems.

An Example of Biology Influencing Design

One of the examples is the scientific analysis of a lotus flower emerging cleanly from swampy waters, which led to many design innovations (El-Zeiny, 2012), including Sto's Lotusan paint which enables buildings to be self-cleaning (fig. 2).

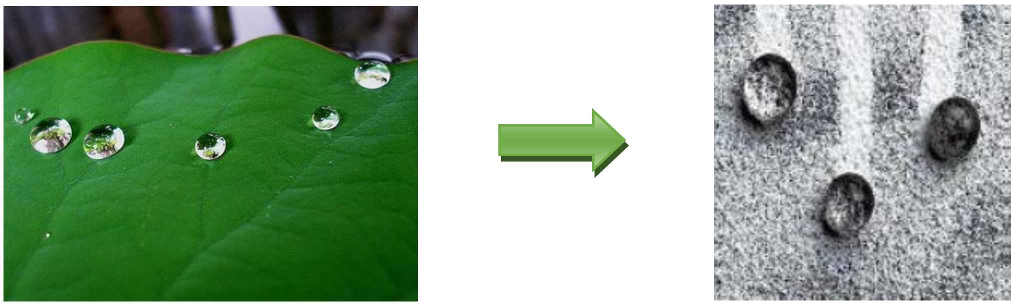

Figure 2: Lotus Inspired Lotusan Paint

Source: https://www.assignmentexpert.com/blog/lotus-effect-or-self-cleaning-leaves/ Biomimetic Approaches to Architectural Design for Increased Sustainability

Biomimicry Levels

Three levels of biomimicry that can be applied to a design problem are typically given as the forming process and ecosystem within the two approaches discussed (Peters, 2011). In studying an organism or ecosystem, the form and process are the elements of an organism or ecosystem that could be mimicked. Nonetheless, the environment can be researched to replicate specific aspects. There are three primary levels of biomimicry: organism, behavior, and ecosystem. Firstly, buildings may imitate an individual organism's characteristics at the organism level. Secondly, behavioral level, the design may be inspired by how the organism behaves or relates to its larger context. Thirdly, at the ecosystem level, design may be drawn from the entire ecosystem of an organism and its surrounding.

It emphasizes the natural process and cycle of the greater environment (Shahda, 2018). There are five possible dimensions of mimicry that happens within each level. For example, the design may be biomimetic in terms of what it looks like (form), what it is made out from (material), how it is made (construction), how it works (process), or what it can do (function). Table 1 describes the differences between each type of biomimicry and how different aspects or parts of a termite or ecosystem could be mimicked (Zari, 2015). The design could be biomimetic in terms of its form and what it looks like, its material and what it is made out from, its construction and how it is made, its process and how it works, and its function and what it can do (Shahda, 2018). The most apparent dimension of biomimicry is the emulation of nature's function.

Table 1
A Framework for the Application of Biomimicry Source: An Approach towards Sustainability of High-rise Buildings

Level of Biomimicry	Criteria	An Example-Building that Mimics the Termite
Organism level (mimicry of a specific organism)	Forms	The building looks like a termite.
	Material	The building is made from the same material as the termite, mimicking the termite's exoskeleton/skin.
	Construction	The building is made the same way as a termite; it goes through various growth cycles.
	Process	The building works the same way as an individual termite; it efficiently produces hydrogen through meta-genomics.
	Function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil.
Behaviour level (mimicry of how an organism behaves or relates to its larger context)	Form	The building looks like a termite constructs it, a replica of a termite mound.
	Material	The building is made from the same materials used by a termite in a building; it uses digested fine soil as the primary material.
	Construction	The building is made in the same way that a termite would build its nest, piling Earth in certain places at certain times.
	Process	The building works the same way as a termite mound by careful orientation, shape, materials selection, and natural ventilation, or the building mimicked how termites work together.
	Function	The building functions similarly to termites; internal conditions are regulated to be optimal and thermally stable. It may also function similarly to a termite's mound in a larger context.
Ecosystem level (mimicry of an ecosystem)	Form	The building looks like an ecosystem (a termite would live in).
	Material	The building is made from the same materials that a termite's ecosystem is made from; it uses naturally occurring common compounds and water as the primary chemical medium.
	Construction	The building is assembled in the same way as a termite's ecosystem; principles of succession and increasing complexity over time are used.
	Process	The building works the same way as a termite's ecosystem; it captures and converts energy from the sun and stores water.

	Function	The building can work in the same way as a termite's ecosystem and would be a part of a complex system using process-to-process relationships; it can engage in hydrological, carbon, and nitrogen cycles in the same way as an ecosystem.

Biomimicry in Education

On the other hand, biomimicry has been introduced into architectural programs in some universities globally in the past few years studied the impact of teaching biomimicry as a tool for enhancing thinking skills among students in art education (Amer, 2019). They studied a sample of 30 students in the third level at the University of Khartoum in 2012/2013. Their research findings showed that biomimicry has several major benefits. It offers spiritual development by allowing them to meditate and appreciate God's creation. It awakens the students' perceptions of nature by realizing that everything in nature has a purpose and function. Moreover, biomimicry can positively impact the early years of education. The results also showed that biomimicry has long-lasting effect skills. Students can develop their self-reflection, critical and creative thinking, and problem-solving techniques.

The recommendations include considering this topic as the main component of the design education system and considering design and nature concerning architectural design education (Stevens et al., 2020). They delivered an architectural design course for second-grade students at Karandeniz Technical University in Turkey on the concept of biomimicry. They indicated that analogies attract interest and wonder and increase motivation. Students can develop their analytical ability and learn that many problems have a solution in nature (Amer, 2019). University of Dammam in Saudi Arabia taught interior architects how to open their eyes to the natural world by inspiring them with new directions for a better life on Earth. She said that teaching students how to use biomimicry would increase the integration of the built environment with nature in a sustainable manner (Yurtkuran et al., 2013). A Russian State Vocational-Pedagogical University mentioned that biomimicry principles can help provide more innovative design and connect the work with the natural environment. They stated that biomimetic design is becoming more popular in the field of architecture in the future. They also stated that applying biomimetic principles and adaptive strategies of natural organisms can improve the adaptive behaviors of building skins (Stevens et al., 2020).

Biomimicry and Sustainability

The range of applications of biomimetics is wide and fosters innovation (Dash, 2018). Since 2000, biomimetics has been progressively applied beyond conventional chemistry and expanded into material science and engineering, mainly at the centimeter scale (Maglic, 2014). Furthermore, biomimetics is increasingly applied to design in areas at the meter or kilometer scales (Maglic, 2014) (Figure 3).

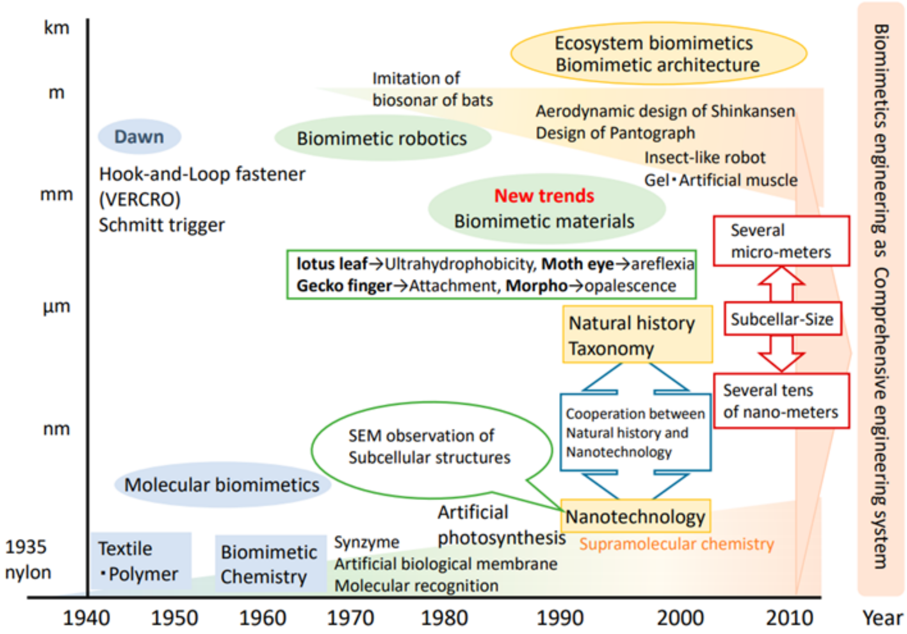

Figure 3: Historical Trend of Biomimicry
Source: Shimomura (2015)

Biomimicry is an approach toward the sustainability of the whole system's design (Uchiyama, Blanco & Kohsaka, 2020) that has the potential to develop ecological solutions. However, it does not necessarily lead to environmental solutions (Borgh, 2006). The production of sustainable products is independent of the basic design process. Scientists and designers mentioned that biomimicry innovation must be pursued to achieve the objective of a sustainable society (Royall, 2017). The contribution of the biomimicry approach is not only for environmental sustainability but also for economic sustainability (Marshall, 2010). Sustainability, as a concept, cannot easily be changed from biology to innovation; living systems have characteristics that can assist in sustainability if they are systematically researched and transferred (Garcia, 2019). Pedersen Zari listed three critical reasons for using biomimicry approaches in the design process. The first is related to the production of new technologies and products without the link to ecological performance, and it is called "biomimicry-for-innovation." The second is in line with previous considerations that enhance environmental performance, called "biomimicry-for-sustainability." The third is the least explored and linked to the growth of human psychological well-being. It is often related to biophilic design theories.

Previous Research on the Biomimicry Level

Many research papers and studies on biomimicry summarise the multidisciplinary epistemological and ontological grounds. Hence, the biomimicry literature has flexible boundaries; its depth depends on the topic of inquiry. This paper focuses on the literature on biomimicry and its applications in the architecture's design processes. This research focuses on some literary works to explain the word "biomimicry" and its use in design. The literature summary presents the most efficient architectural design from the three levels.

- Published Paper - 1

Maibritt Pedersen Zari presented how biomimicry approaches to architectural design can lead to greater sustainability and the development of a regenerative built environment. A framework is used as a design methodology for exploring various advantages and disadvantages through different forms of biomimicry. She also suggested various approaches as the design process and method based on the literature review and analysis of current biomimetic technologies (Zari, 2017).

- Published Paper – 2

Maibritt Pedersen Zari supported the 'biomimicry's role of climate change in the built environment. In this paper, several architectural concepts of ecosystem biomimicry were explored. Besides that, adaptation and mitigation methods were also explored to address climate change. This paper concluded that integrating biology and ecology into the architectural design is significant in creating a sustainable built environment (Zari, 2016).

- Published Paper – 3

Stylianos Yiatros, M. Ahmer Wadee, and Gary R. Hunt studied how biomimicry principles can be applied in structural design. Principles have been used in compression structures. The potential use of tessellation and the possibility of a modular building on the micro and macro scale were studied with the help of model testing, structural analysis, fluid dynamics experiments, and computer modeling (Yiatros et al., 2007).

- Published Paper – 4

Elghawaby Mahmoud introduced a new concept called façades of breathing. A design for the breathing wall was created by mimicking the skin's characteristics of flora and fauna. It improves the cooling and ventilation systems and achieves thermal comfort in hot-climate buildings. A case of the triangular-shaped Sinai Peninsula is discussed in this article (Mahmoud, 2010).

- Published Paper – 5

J Scott Turner and Rupert C Soar revealed how termite mounds function and how this concept is applied in the design of buildings. This paper addressed two topics: the termite mound that inspired the Eastgate center and how a termite mound is like a lung (Turner & Soar, 2008).

- Published Paper – 6

Oguntona, Olusegun Aanuoluwapo, Aigbavboa, and Clinton O studied the mathematical patterns and structures in biology and nature to find their applications in construction technology. This paper explored the possible use of human bone in structure. The paper discussed using concrete in a building to achieve load-bearing capacity and the possibility of reinforced concrete with fiber (Oguntona & Aigbavboa, 2019).

Methodology

This paper used content analysis to identify the biomimicry level applied in the design. The selected content was from the case studies. The case studies were chosen based on the study about the biomimicry approach and the three levels of biomimicry: organism level, behavior level, and ecosystem.

Trends of the Application of Biomimicry in the Design Field

For the analysis of the study, relevant papers were collected using Google Scholar using the keywords; architecture and biomimetics/biomimicry in 2019. A total of 107 articles, including the proceedings and the chapters in books, were listed, and 77 papers from the total discussed biomimicry's application in the design field. The remaining papers did not focus on the field of interest but focused on the general trends of biomimicry design. At first, the researcher identified the research topics of the papers, and a second researcher identified the most discussed topic in the selected journals.

Papers on the research topics are classified into three topics: biomimicry concept, biomimicry levels, and biomimicry design. The examples of the subjects addressed in each topic are related to biomimicry concept: bio-inspired biomimicry concept; biomimicry levels: bio-inspired biomimicry levels as the organism level, ecosystem level, and behaviour level; biomimicry design: the use of natural patterns and systems on buildings to improve the users' well-being and foster a sense of nature. Figure 2 shows the number of papers published each year and their study topics. The bar chart shows that the topic "Biomimicry Concept" was frequently discussed, and "Biomimicry Level" appeared in the sample recently. The trends of the articles on "Biomimicry Concept" and "Biomimicry Design" are slightly similar. However, the number of papers for "Biomimicry Levels" is the lowest compared to "Biomimicry Concept" and "Biomimicry Design".

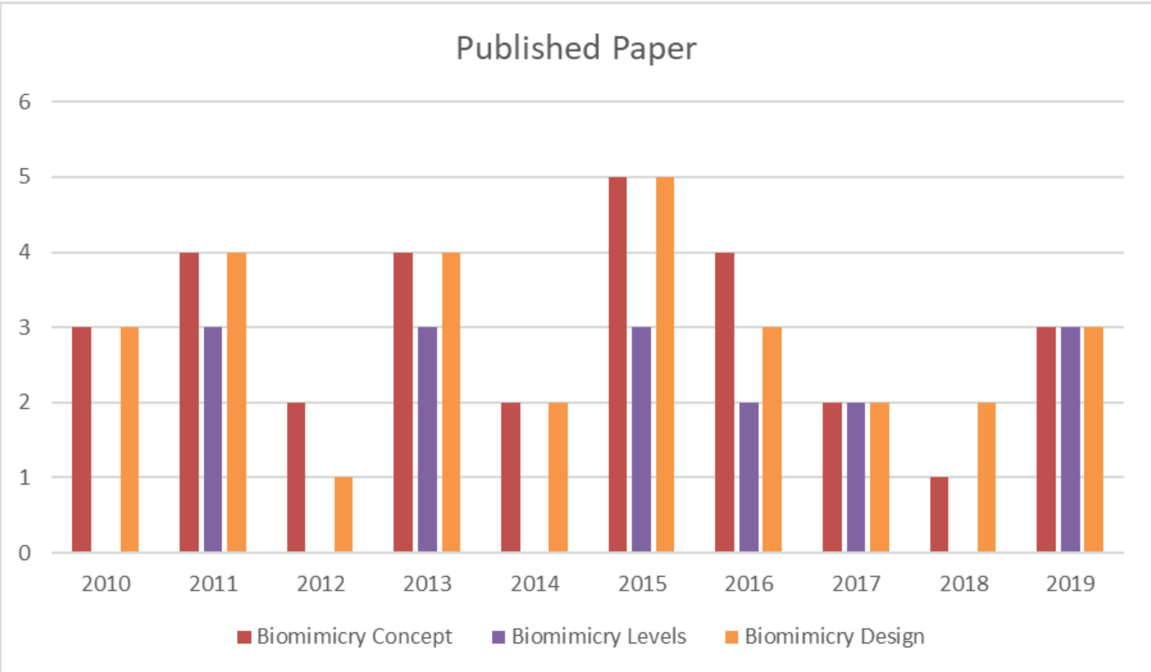

Figure 4: Number of Papers in Individual Years and the Research Topics
Source: Author 2021

The concrete keywords in the research topics and subjects such as "Biomimicry Concept" and "Biomimicry Design" were frequently mentioned and studied. For example, the concept of plants was mimicked in several studies to design a building envelope. Regarding the number of reviewed papers, Figure 4 shows the publication trend. The papers focused on "Biomimicry Concept" and "Biomimicry Design," with more published papers than "Biomimicry Level".

Papers that address both scales are frequently discussed. However, there are limited papers that discussed and analyzed the application of biomimicry.

Summary of the Reviewed Papers

Table 2

Shows the studies on several topics for each level

Research Papers	Categories	Study Focus	Highlights
1	Design Elements	Organism Level Behaviour Level Ecosystem Level	A framework is used to discuss various forms of biomimicry as the design methodology.
2	Design Elements	Ecosystem Level	The 'biomimicry's role in addressing climate change in the built environment.
3	Design Elements	Organism Level	Bullet trains inspired by kingfisher birds.
4	Design Elements	Organism Level	How the termites' mounds work and the application of this concept in building design.
5	Design Elements	Organism Level	The pattern of walk inspired by flora.
6	Regenerative Design	Organism Level	Breathing façade. It enhances the cooling and ventilation systems and achieves thermal comfort in the building.
7	Regenerative Design	Ecosystem Level	Ecosystem-based design theory.
8	Regenerative Design	Organism Level	Dealing with the ability to collect water, sunlight, and wind.
9	Application Field	Engineering (transportation) Organism Level	Designing the front of the train inspired by kingfishers. It is a bird that dives into the water with minimal splash and high speed. As a result, the train becomes quieter and uses 15% less electricity, although it travels 10% faster than usual.
10	Application Field	Medicine Behaviour Level	Researchers observed the chimpanzees and discovered how they seek the plant *Vernonia genus*, as a remedy.
11	Application Field	Architecture Ecosystem Level	An architect, Mick Pearce, studied the termites and how they can keep the temperature in their nest within one degree.

Source: The Incorporation of Biomimicry into an Architectural Design Process: A New Approach towards the Sustainability of Built Environment

Result

This paper used the result from previous studies on biomimicry. Previous studies revealed that biomimicry implementation is only explored for the current object design. The design of the biomimicry realization is still unexplored. The literature findings showed that only the organism level is used for architectural solutions from the three levels of application of biomimicry. The application of two other levels remained unexplored. Linda Groat and David Wang explained that the analysis of literature is a continuous and never-ending process and should be undertaken throughout the research process to explore any possibility (Linda, 2002).

Discussion

Implementing the concepts of biomimicry levels in designs can become a reality by exploring practical ways. Biomimicry can be considered as a design solution for realization. This design can become a process of awareness for a sustainable built environment. Although university students are aware of biomimicry, the widespread and practical application as a design method remained unrealized. The shapes of biology inspire designers, but this aspect alone is not biomimicry because it should have some biology.

There are many studies on biomimicry. Hence, there is a need to discuss how the ideas and principles can be applied and used in the design processes within the design discipline. The literature review showed the need to understand the phenomenology behind science and design. Besides that, there is a need to step away from improving prediction, control, and exploitation of nature as a resource. Biomimicry solutions can become one of the most sustainable ways of producing an efficient and productive built environment.

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