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BIOMIMICRY: STUDYING NATURAL SYSTEMS FOR ACHIEVING SUSTAINABILITY

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Abstract

Systems in nature are known to be the most efficient systems and humans have been taking inspiration from nature since the beginning of time. The science of incorporating nature's highly efficient systems into human innovations is called as biomimicry. These systems also help in optimizing resource utilization and enhancing nature conservation. This study tries to understand the concept of biomimicry and find out whether biomimicry can be used a tool for achieving sustainable development. Furthermore, the study also emphasizes on the advent of biomimicry as a concept in modern technology and the trends in implementing the same in recent innovations.

Key words: Biomimicry, Sustainability, Innovation, Design, Technology

Introduction

Our planet is abundant with resources to provide for human needs. However, since the advent of the Industrial Revolution, life became modernized, automated and in turn easier. This led to development of technology at a rapid pace. Increased security of life led to a boom in the population. In a cascading manner, increasing population let to increase in consumption of resources and technology which led to stress on the natural resources. The impact of this was acknowledged in the early 1960s and the need to use resources judiciously was emphasized upon (Rees, 2002).

In order to make this concept easier to understand, the concept of sustainable development was put forth in the early 1970s. The term sustainability was first used officially by the United Nations in 1978 (Schrijver, 2008). Ever since, sustainable development has been seen as a way forward keeping both economic growth as well as environmental conservation in mind. Ever since the term sustainability was emphasized upon in the early 1970s, it has become a trending topic of research. This is because the advancement in the field of production has led to unsustainable resource consumption, social inequity and has affected the economic and ecological balance. There have been a variety of approaches in the field of design and innovation within the broad context of sustainability (United Nations, 2011).

However, the bottom line that has always been observed is to decrease the use of resources while achieving better results, viz. increasing efficiency. In the past few decades, increasing the efficiency of technology has been seen as the best way to ensure higher economic benefits as well lower damage to the environment (A.Rosen, 2008). To achieve increased efficiency, researchers have been looking for inspiration from various sources. Natural processes have always proven to be most energy efficient. And therefore, mimicking the ways of nature became increasingly popular.

Nature has been an inspiration for design since prehistoric times as man designed spears in the shape of teeth of carnivorous animals and copied their tactics to catch prey. However, the evolution of a methodical system to incorporate inspiration taken from nature into design and innovation is recent. The term 'biomimetic' was first coined in the 1960s by an American inventor by the name Otto Schmitt to refer to the integrate natural systems into technology (Kennedy E. F.-L., 2015). The term biomimicry was first used in 1982. Researcher and writer Jane Benyus made the concept popular through her book *Biomimicry: Innovation Inspired by Nature* in 1997 (Gehan A. N. Radwan, 2016).

The study and use of designs from the nature into technology is called Biomimicry. It proposes using nature as model, measure and mentor. Our way of thinking is brought closer to nature by using Biomimicry as a tool to solve our problems sustainably by taking inspiration from natural systems. The thought is that nature is innately inventive and sustainable and can be utilised as a biological norm to pass judgment on the sustainability of our progressive technologies. After 3.8 billion years of development and base up design brilliance, nature has the way to tackle a significant number of the issues that people are wrestling with on the grounds that it has learnt what works and what lasts. (Hoyos, 2016).

In her writings, Benyus describes the nine laws of nature. She contends that every characteristic ought to be of significant thought to all genuinely biomimetic structures (Benyus J. M., 1997):

- Sunlight is the ultimate source of energy
- Never use more energy than what is needed
- Energy fits form to function
- All energy is recycled
- Co-operation is rewarded
- There is strength in variety
- Local expertise is necessary
- Excess has to be curbed from within
- Power of limits is tapped

This research investigates Biomimicry as a potential methodology which helps coordinate environmental sustainability with planning by studying the common procedures to understand the structure in entirety and nature inside an ecosystem. This paper will analyse key points of applications of biomimicry in sustainable innovation better understand how the concept evolved and its applications over time and how we can pave a way for a better future.

Objectives of the Study

The study is a review of the development of technology as inspired from the nature to help in sustainable innovation and design. the research has been conducted with emphasis on the amalgamation of the approach to biomimicry with sustainable development and includes the following:

- To examine the advancing biomimicry approach, and its strategies and tools for sustainability and innovation.
- To examine the effects of use of biomimicry in modern technology.
- To understand the problems and issues faced while implementing ideas.
- To understand the scope and role of biomimicry in achieving sustainable development.

Scope

The study uses secondary data as available in the form of published articles, research papers, books, theories and miscellaneous literature from various sources. The study uses documents from old as well as new literature to

study the trends and patterns in the field of study. The study will be carried out by referencing over 40 documents.

Methodology

The study uses a data set of over 40 published documents providing secondary data from various published sources. Since itis a literature review, the study will be qualitative in nature, summarizing the data and literature available in a collated manner. The study will focus on the following points:

1. How the concept of biomimicry has evolved over the years
2. Biomimicry and its relation to sustainable development
3. How biomimicry has helped in increasing efficiency of products
4. Challenges faced during the incorporation of a biomimicry analysis into a project at the design stage

5. The advantages and disadvantages of this concept in terms of the design process and concepts of various technologies

6. Future scope for study and integration of biomimicry in modern technology to achieve sustainable development

Biomimicry:

Evolution of Biomimicry

Humans grow up observing their surroundings right from childhood and tend to imitate and imbibe these behaviours in their life and overall personality. However, using these observations to develop technology demands and keen eye and skill. Examples of these have been mentioned in several records. In the early 1500s, Leonardo da Vinci made the use of biomimicry to study birds hoping to one day enable human flight. He studied the anatomy of birds and how their flight was enabled. He noted this system in great detail including sketches of his proposed design of said 'flying machines'. Although he did not succeed in creating such a contraption, his ideas went to become the motivation for the Wright Brothers, who also took inspiration from their annotations of pigeons in flight. Finally in 1903, they succeeded in building and flying their first ever airplane (Vierra, 2011).

From concepts as old as invention of the wheel to as modern as designing modern technology, each invention and discovery has its root somewhere in the nature. Rolling logs provided an inspiration to design circular wheels, lotus leaves for umbrellas, hooked seeds of the burs for Velcro, beak of a kingfisher for designing the bullet train, resource circulation in nature for developing the concept of circular economy. In this manner, almost, every invention can be related to its inspiration drawn from the nature (Kaipel, 2017).

Impersonating nature needs an amalgamation of biological sense as well as technological data. Albeit the two frameworks have an alternate developmental timescale, the natural procedure has been advancing for as far back as hundreds of years, while technology has been developing only for a couple of hundred years. The contrasts between the innovation and the conventions that nature follows are enormous, including the genetic codes, environment, and biological clock (Knoll, 2015).

In 1989, two employees working for General Motors, Robert Frosch and Nicholas Gallapoulos, wrote an article in *the Scientific American* suggesting that industrial systems could be made more efficient by designing them in a way that their system mimicked the nature. This article attracted a lot of attention and the concept gained tremendous momentum and concepts like 'Design for Environment' were developed. The idea is presumed to be the origin of several new terms in the twenty-first century, such as biomimicry, biomimetic, bioutilisation, biophilia, bionic, biodesign, biomorphic and bioderivation. With the advancement of science, biomimicry has taken another route that associates sustainability with innovation and environmental frame of reference to assess the practicality of human inventions (Frosch, 1989).

Study of biomimicry has, over the years, become more systematic. In 2006, to make the study of biomimicry formal, Janine Benyus and Bryony Schwann started the Biomimicry Institute in Montana, USA. The institute aims to "naturalize biomimicry in the culture by promoting the transfer of ideas, designs, and strategies from biology to sustainable human systems design." With the evolution of programs, they started working with the Biomimicry Guild, their sister organization, a for-profit consulting company also founded by Janine Benyus. These institutes have made the field of biomimicry more formal and organized (Benyus J. , 2006).

Biomimetics is used widely in designs for various applications today. Biomimicry surpasses a similarity and executes on diverse stages, for example, living being, conduct, and biological system. Use of biomimicry ranges from the planning stage to design and knowledge where it keeps on inspiring new and imaginative bits of knowledge into building issues. The development of Biomimicry has escalated in the course of the most recent 30 years, roused by creepy crawlies, reptiles, mammals and other invertebrate species (Kellert, 2011).

Various approaches to biomimicry

An overall view of biomimicry includes integration of nature's overall qualities in plan and utilization of these attributes over different spatial, transient organizational scales of engineering influence. Methods to biomimicry as a design process can be categorized as: Characterizing a human need or structure issue and exploring the manners in which different life forms or biological systems understand this, named here structure looking to science, or distinguishing a specific trademark, conduct or capacity in a life form or environment and making an interpretation of that into human structures, alluded to as biology of influencing design. (John Reap, 2005).

The methodology where planners seek to life cycles of nature for answers expects planners to perceive issues followed by researchers to pair these to life forms which have worked out related problems. This methodology is successfully driven by designers defining the design objectives and factors. The plausible results of architectural plan where trademark analogues are facilitated with human-recognized issues are that the fundamental way to tackle a given problem and the issue of how plans identify with one another and the biological systems they are a piece of isn't analysed. The hidden reasons for a non-manageable or even degenerative built environment are not essentially tended to with such an approach. (Yen Jeannette, 2010).

As per an assessment carried out at Victoria University, New Zealand in 2007, there are in particular, 2 ways to deal with this concept for a structure approach: Problem-Based Approach and Solution-Based Approach. Each of the methodologies have benefits, challenges and results as far as by and large sustainability (Zari, 2007).

It was found that this Problem-Based methodology had distinctive naming in different literary works, for example, "Design looking to biology" (Zari, Biomimetic approaches to architectural design for increased sustainability, 2007), "Problem Driven Biologically Inspired Design" (Michael Helms, 2009) and "Top-down Approach" (Kinppers, 2009) all having a similar importance. Through this methodology, originators seek nature for arrangements. Where a fashioner perceives their plan issue and studies how creatures and natural systems have tackled comparative issues. A potential downside of this approach was found to be the question of how systems correspond with one another and the biological system they are a part of is not researched. Hence, the fundamental reasons for non-supportable or even degenerative assembled condition are not really tended to. Nevertheless, the Problem-Based methodology might be a decent method to start the progress of constructed condition from wasteful to a progressively green surrounding (McDonough, 2002).

The Solution-Based methodology is likewise mentioned as "Biology influencing design", "Bottom-Up Approach" or "Solution-Driven Biologically Inspired Design". Through this methodology, natural information impacts human plan. One points of interest of this methodology is that the information on science may impact the structure in manners other than the foreordained plan issue. One inconvenience is that an inside and out natural examination must be led then the data accumulated must be resolved as significant in the design context (Mwila Isabel Nkandu, 2018).

Another point to be noted is that biomimicry is not always used to design products to become more sustainable. There are two types of designs in the field of biomimicry: biomimicry-for-sustainability and biomimicry-for-innovation. This basically means that certain designs are created taking inspiration from the nature with no intention of ecological conservation. However, this does not mean that the two are always mutually exclusive. The difference between the two is that the biomimicry-for-sustainability focuses on either developing a new technology or altering old ones to decrease its ecological impacts. Biomimicry-for-sustainability is becoming increasingly popular as the state of the nature has become alarming (Zari, 2018).

Levels of Biomimicry

By directing a comparative analysis of related information on biological system standards in the controls of environment, science, mechanical biology natural structure and biomimicry, a set of ecological principles planning to catch interdisciplinary comprehension of biological system working was detailed. It is recommended that this biomimetic speculation as a lot of standards dependent on biological system capacity could be used by originators, to help in the headway of methods to enable the creation of a more economical condition (Ruxton, 2019).

The purpose of the design has to be identified first. Once this is done, a thorough study of similar phenomena in the nature must be identified and studied. The observation of this natural process must then be compared and how it can be incorporated in the design must be determined. By examining available technologies it becomes evident that biomimicry has three levels; organism, behaviour and ecosystem (D. Amaratunga, 2002).

The organism level talks about an organism in specific and might include mirroring the whole organism or just a part of it The next level indicates simulating habits, and could involve adapting to an organism's behaviour, or relates to a bigger picture. The third level talks about copying the entire ecological system and theories that allow them to operate effectively (Zari, 2007).

Through all of these levels, five measurements decide at which degree the mimicry exists. The plan is recorded as bio-mimicry of structure, mature, process and ability. These are significant and they explain entirely, the biomimicry approaches. By specifying the extent of biomimicry involved, this structure allows planners who want to employ biomimicry as a strategy for achieving sustainability in the built environment (Othmani, 2018).

Level of Biomimicry		***Example - A building that mimics termites:***
Organism level (Mimicry of a specific organism)	*form*	The building looks like a termite.
	material	The building is made from the same material as a termite; a material that mimics termite exoskeleton / skin for example.
	construction	The building is made in the same way as a termite; it goes through various growth cycles for example.
	process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behaviour level (Mimicry of how an organism behaves or relates to its larger context)	*form*	The building looks like it was made by a termite; a replica of a termite mound for example.
	material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example.
	construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	function	The building functions in the same way that it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example (fig. 6). It may also function in the same way that a termite mound does 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 kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
	function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

Figure 1 Biomimicry Application Framework (J. B. Storey, 2007)

5.4. Biomimicry and sustainability

Over millions of years, various biotic components of the nature have found a way to coexist and designing a sustainable way of life. Therefore, nature is “existence proof” of the chance of fostering sustainable and innovative technologies ourselves. Due to its wide range, biomimicry contributes to a significant number of the eco-structure ideas and designs designed over the most recent 30 years. This technique looks for nature's recommendation at all phases of design, from scoping, creation, to assessment. (Swilling M., 2013).

As per Greenbiz (2015), nature has a method of achieving several objectives through a single gesture. Leaves of the trees provide shade, and also generate energy while additionally ensuring and cooling the moving water underneath the surface. Achieving multiple functions with a single multi-functional design would be a great accomplishment for man-made systems.

Biomimicry can be applied at various levels in a system, ranging from a part of a process to the whole system. Each application helps us advance on the path of sustainable development. Although we are very far from achieving the efficiency as observed in nature, each application brings us further towards environmental conservation. Each system is multi-layered and even the smallest of changes eventually lead to a cascading effect. This is true in the case of applications of biomimicry as well. There is still however, much to be observed and inculcated in our systems (Chen, 2015).

On a large scale, imitating natural systems has led to development of the concepts such as circular economy and industrial ecology. These concepts talk about minimizing use of new resources by reusing or recycling old resources. These concepts have helped greatly in conservation of resources as well as decreasing the amount of wastage of materials. At the same time, energy efficiency and economical benefits are seen as well. Since these concepts are implemented at large scales, a huge impact is observed when it comes to making processes sustainable. These ideas are also inspired by the nature itself (Geisendorf, 2018).

For the past few decades, the importance of smart and sustainable cities has been understood and great effort has been put in developing these. The concept of developing a Low-Carbon Economy (LCE) focuses on integrating all aspects of the economy of the city to generate minimum amount of greenhouse gases (GHGs). The inspiration for this is taken from nature's method of reducing carbon in the atmosphere by sinking it in various carbon sinks and then releasing it when required. Several technologies are developed to lower the atmospheric GHGs and improve overall air quality of the cities. Similarly, technologies for enhancing the quality of other resources and their conservation are developed by taking inspiration from the nature (Spiegelhalter, 2010).

As per the Biomimicry Group, to ensure that biomimicry inspired designs result in sustainable outcomes, there are six (6) significant standards of biomimicry and their establishing twenty-three (23) standards which are as follows (Oguntona, 2017):

- Resource efficiency: Tactfully and minimalistically making the most of assets and openings. It comprises of four standards, to be specific utilizing multifunctional configuration utilizing processes using low energy, reusing materials, and optimizing work structure.

- Evolve to survive: It is an amalgamation and encapsulation of data guaranteeing execution. It comprises of three standards, to be specific repeating strategies that are effective, anticipating the unexpected and restructuring information.

- Acclimatize to changing conditions: Properly reacting to variable settings. This comprises of five standards, to be specific keeping up trustworthiness through self-restoration, exemplifying flexibility through variety, repetition, and decentralization and joining decent variety.

- Incorporate development and growth: Optimal utilization and participation in methodologies that stimulate growth and development. This additionally comprises of three standards, combining modular and nested components, building from the bottom up and self-organisation.

- Accustomed and responsive: Corresponding and coordinating with the surrounding. It comprises of five standards, in particular utilizing readily available materials, harnessing freely available energy, developing cooperative relations, utilizing cyclic procedures and utilizing feedback cycles.

- Use green chemistry: Utilization of chemistry that is friendly to life forms. It involves three standards and building with a small subset of green elements.

Biomimicry and sustainable development are very closely linked. Biomimicry, although not always used as a method for sustainable innovation has played a great role in developing technology that helps in enhancing the efficiency of the system, eventually resulting in conservation of energy, economy and resources. This in turn contributes to the higher goal, which is sustainable development. The importance of designs is considered by scientists promoting a shift to design that is regenerative in nature. The versatility of applications of biomimicry has led to its growing popularity amongst scientists as well as designers and developers (Drotleff, 2004).

Biomimetics can be used by designers and ecologists at the planning stage to gain a new perspective on their plans. Some of the advantages of biomimicry as a framework for sustainable innovation and its application in sustainable development can be understood as follows (Kennedy E. B., 2017):

- **Disruption of traditional thinking**: This framework provides a chance to explore new solutions and come up with solutions to answer problems in new and innovative ways. It is a combination of the systems thinking and design thinking and the capability to choose solutions tested over thousands of years.

- **Single step to accomplish multiple objectives**: Nothing in nature is single-purpose. For e.g., trees provide so many services at the same time. No system in nature has a single function. Development multi-functional systems can help in enhancing system efficiency.

- **Understanding the context and climate**: Using readily available resources rather than digging for new ones and thereby, decreasing the pressure on new resources. Understanding that sustainability means continuing to nourish the source while obtaining resources from it.

- **Embody resilience**: Natural systems are an epitome of resistance. Building to last and incorporating diversity and building resilience through variation, decentralization and implemeting rapid feedback loops are the key to becoming inherently resilient to change and disturbances.

- **Nurture curiosity**: Humans are inherently curious. Biomimicry provides a chance to be curious and study the functioning of the nature and look for answers to simple problems in the natural systems. This perspective increases the possibility of finding sustainable solutions to problems.

- **Avail collaboration**: Being more inclusive nature's ways and genius for developing an interconnectedness with the natural systems. This makes the system more interdisciplinary and in turn more inclusive leading to decreased costs and enhanced results.

Challenges to development of biomimicry

Biomimicry has been used in a lot of designs. But there is a lack of an organized process of studying, methodizing and documentation of the process of translating inspirations from the nature into technology. Although biomimicry shows promising results, there is lack of awareness about this concept among several researchers and remains limited among R&D professionals. There are few publications on the best practices, therefore, making it difficult to understand the depth of the field of biomimicry (Kennedy E. B., 2016).

The biggest limitation to use of biomimicry is that although designers, planners and researchers are interested in using nature as an inspiration, broad use of biomimicry as a planning strategy remains to a great extent unrealised because of this, there are barely any current ventures that have really incorporated biomimicry at a large scale in principle and practice. his is on the grounds that biomimicry as a sustainability approach is as yet an emerging discipline in development stage. All the same, there is an undeniable inspirational disposition towards biomimicry and this shows a potential for the expanded coordination of this order in compositional plan (Pawlyn, 2019).

Hypotheses, ways of thinking and thoughts of sustainability and biomimicry explicitly are to be addressed, questioned and comprehended. At a time during which a common worldview has become a standard concern, the accessible writing stays scattered and in some cases crumbled in light of the fact that the numerous partners investigate maintainability from a spread of perspectives and controls. Thus, adding in the immense potential for the machine of biomimetics its writing cuts across assortment of controls with consideration on scientific development. The application of biomimetic ideas in engineering and style has seen its application in specific settings yet regardless of everything, it holds a test quality. This point plans to require stock of the discussion and composing on legitimacy and biomimetics with thought on how it can expressly benefit engineering and style. (Gleich, 2010).

Advancement in the study of biomimicry over the years

Biomimicry is indeed a vast and relatively unexplored field of study. However, the study in this subject has risen greatly over the past couple decades. From a relatively small field of papers in the mid-1990s, biomimetics has exponentially extended from that point to now arrive at about 3000 papers for every year (Bar-Cohen, 2011). The branch of knowledge has multiplied in size every 2–3 years, far surpassing the extension of almost 6% each year for science all in all. Based on this, there is an increase in bioinspired research, which has driving revelations in biomimetics which have established the frameworks for huge regions of present and future study (Lepora, 2013).

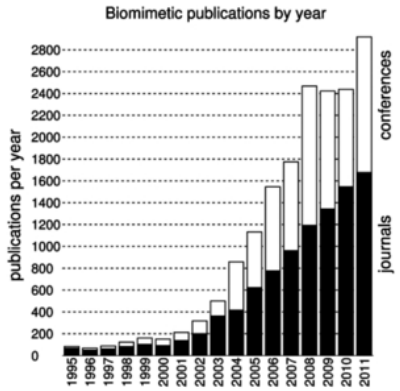

Figure 2 Number of publications on biomimicry over a period of 2 decades (Gamage, 2012)

P. S. The bar graph shows the quantity of publications distributed every year in the field of biomimicry, beginning from 1995. Black bars show the extent of articles and papers while the white bars demonstrate its extent in conference proceedings and books.

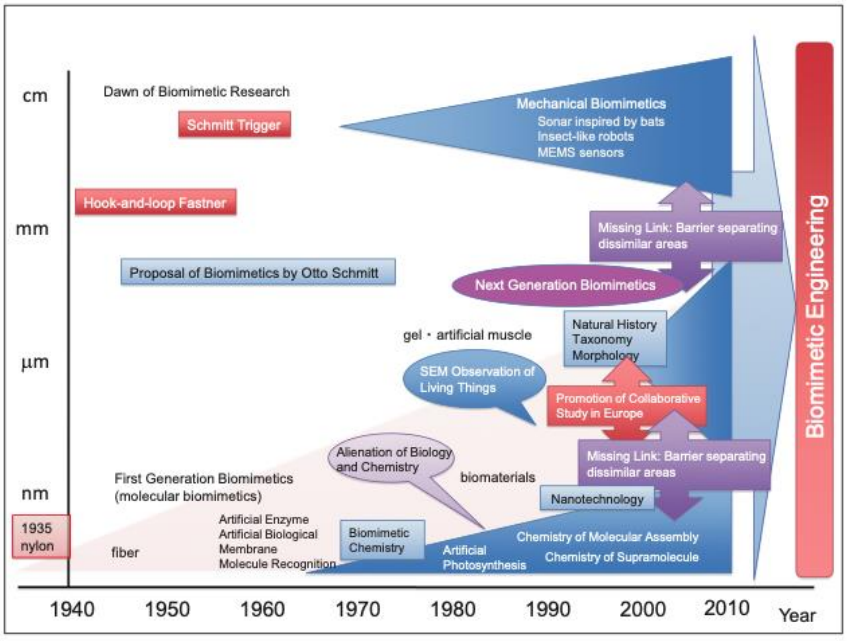

Figure 3 History of Biomimetics Research (Shimomura, 2010)

Uses of biomimetic and economical modern structure approaches change in their scale and depth of use and in this way in their dispersal and positive effect. Trial and exploratory beginnings are to be presented side-by-side

with community-oriented frameworks in this topic to decide the potential and degree of pertinence of nature's answers for the constructed situations' issues.

Conclusion:

This study reviewed the evolution of biomimicry and its role in helping sustainable development. It tried to understand the concept of biomimicry as a whole and the perception of designers and researchers towards it. Biomimicry, when included right from the planning stage of any project, offers a novel perception and helps in finding ways to optimize it to the highest degree possible. Biomimicry is a vast subject with a high potential to inspire better innovations and designs. However, the lack of awareness and R&D in this field has led to this field being left vastly unexplored.

When it comes to understanding the role of biomimicry in achieving sustainability, it was found that biomimicry can be applied at various levels of the innovation or idea to be implemented to enhance the efficiency of the system to make it resource and energy efficient, less harmful to the nature and generate lesser amounts of waste. It also helps in making systems ecologically and economically well-balanced. Use of biomimicry in sustainable innovations takes modelling the behaviour and environmental factors into consideration into consideration. This can only be done only when the complex interrelationship between form, materials and their ecosystem is understood. Some critics say that biomimicry has several uses in sustainability but is an indefinite and expansive method towards sustainability. The reason given behind such a statement is that it requires thorough study in multiple disciplines.

Although research in the field of biomimicry has been on a rapid rise, biomimicry as a concept is still in the nascent stage and is not applied widely at the design and planning level. To execute it effectively to a larger range needs collaborative functioning of various fields of study, for e.g., researcher, environmentalists and planners who can understand the connections between nature and frameworks in nature and the necessities of people with the goal for them to settle on moral choices for a more sustainable environment.

There is a growing need for newer technologies, more advanced systems and products. It has become necessary to create a regenerative environment. For this, use of nature-inspired designs has become of great relevance in order to decrease the environmental and social impacts. A clear distinction is observed between various levels of biomimicry, their effectiveness and the difference in their potentials through this study

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