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Biomimetics: An Approach to Enhance Sustainability - An Overview

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Abstract: Biomimicry is the study of natural structures, mechanisms and ecosystems to create more ecologically sustainable designs. It plays a vital role in searching for new tools and techniques to solve human problems by adopting natural phenomena. Many experts now view nature through biomimicry for motivation with its instinctive ability for sustainability and proven flexibility to interruption. Biomimetics is not a recent trend; the idea of looking into nature for inspiration is in practice for a long time. Human innovations have borrowed from nature throughout history. Essential elements of biomimicry are ethos, emulate and reconnect. Philosophies of biomimicry emphasise nature's features, thereby implying that humans have much to learn from nature with evolutionary knowledge. Biomimicry is a modelling tool; the design process is usually divided into two categories; biology to design and challenge to biology. Research folk imitate natural phenomena in three levels viz., form, process, and ecosystem level. Nowadays, biomimicry is used in almost every field, from architecture to computer science. Biomimicry can help with structural quality, water efficiency, zero-waste systems, the thermal atmosphere and energy supply. Fluid-drag-reduction swimsuits inspired by the structure of shark skin, velcro fasteners inspired by burrs, aeroplane shapes inspired by the appearance of birds and stable building systems inspired by termite mounds, honeycombs, and other biomimetic experiments are only a few examples.

Keywords: Biomimicry, Innovation, Nature, Sustainability

I. INTRODUCTION

Over the advantages of the industrial revolution, it had a negative impact on the environment. The greenhouse effects, pollution, climatic catastrophe are increased day by day, more innovations, more energy consumption leading to more pollution, in a catastrophic way. Researchers failed to adopt the technologies without creating threats or weakening the natural assets or polluting the atmosphere. Simultaneously, highly effective natural systems need to be implemented in technology to overcome the challenges. Mimicking nature helps achieve sustainability in the current situation and works as an environmental restorative approach [1].

Biomimicry is a new term to describe the old approach of imitating natural idea. Human-being started adapting the ideas of nature for the betterment and making his life easy. Biomimicry is defined as learning and emulating natural forms, processes and ecosystem for creating more sustainable designs [2]. Nature is the source of inspiration for most of the innovations. Humans copied nature's idea to solve their problems or to create new tools by combining their knowledge and creativity; this succeeded in most fields. The earth evolved around 4.54 billion years ago; between 3.9 to 2.5 billion years ago, the prokaryotes appeared, followed by eukaryotes in 1.85 billion years and most of the life forms appeared during the Palaeozoic era. All living beings underwent different conditions and stress; adaptation made them survive by adjusting themselves to the harsh conditions by changing their physical, biological and chemical activities. The permanent moulding was observed in the organisms to survive by making themselves suitable and fit for their environment. This research and development process is happening for more than 3.5 billion years in nature and it always knows to solve the problems by adapting to the prevailing situations [2]. These natures best ideas are adopted in human innovation for doing his job easy [3]. Many professionals are nowadays looking to Mother Nature for inspiration through biomimicry. Several scientific terms are known to describe this science of copying natural idea: biomimicry, biomimetic, bionic, bio-inspiration and biognosis. With the prime objective of emulating nature ideas by learning from nature, nature is considered a model, as a measure and as a mentor. The present article deals with process and popular innovations by emulating natural systems as design process and generating restorative essentials.

A. History of Biomimicry

The nomadic man was thought of by nature for the survival skills and techniques for thousands of years. Humans learned to hunt by observing the predatory animals; animals claw and teeth inspired them to make tools similar to that which facilitated hunting. The keen observation of birds and animals and the way how they protect their young ones triggered him to design the shelter to protect himself against the wind, rain, etc. [4]. Moreover, as humans began to simplify the complexity, they sustained to adopt the examples from nature.

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One of the classic examples of biomimicry is Leonardo da Vinci's "Flying Machine". Vinci got inspired by the flying birds, wrote an imaginary flying machine (Fig. 01). Late in 1903 Wright brothers succeeded in building a human flight, which was a milestone in the field of aerodynamics [5]. In 1957, Schmitt, an American biophysicist, coined biomimetics (Bion; meaning unit of life, mimic; imitating) [2,3]. Schmitt developed a trigger called Schmitt trigger by learning the nerve system of a marine animal, squid. Schmitt trigger is a bistable circuit output controlled by the input signals that permits a continuous electronic sign to be altered to an on/off state. The mimicking of the natural system is then termed as "biomimetic" to describe them. In a nutshell, biomimicry is nothing novel; it is just a forgotten insight.

In 1997, Janine M. Benyus published a book, "Biomimicry; Innovations inspired by nature". She explains that outstanding achievements with great success will be expected when technology and biology work together. She started an enterprise, Biomimicry 3.8, to share ideas and concepts of biomimicry by connecting interdisciplinary research scholars, engineers, stakeholders, designers, scientists, etc., for more sustainability.

a. Leonardo da Vinci's "flying machine" b. Wright brothers first aeroplane

Fig.01 History of Modern Airplane [6]

II. FUNDAMENTALS AND PRINCIPLES OF BIOMIMICRY

The process of imitating nature has been described with three fundamentals, *i.e.*, Ethos, Emulate, Re-connect [4,6,7]. Ethos describes the ethics, moral of life forms to study nature and nature's phenomena. Ethics deals with the base and by what means nature works and how it comes to be adopted. The emulate is imitating the natures ideas by considering nature as a model and mentor for Bio-inspired innovations. Reconnect is the way to re-experience the affiliation between the invention and nature, through which effectiveness of invention can be achieved [2]. The biomimicry is explained to work based on nature's principles (Fig.02); the biological system works on the sun's energy by utilizing minimal quantity and recycling the resources.

III. DESIGN APPROACHES

The design approaches in biomimicry are classified into two categories, *i.e.*, Problem to Biology and Biology to Design [2,8].

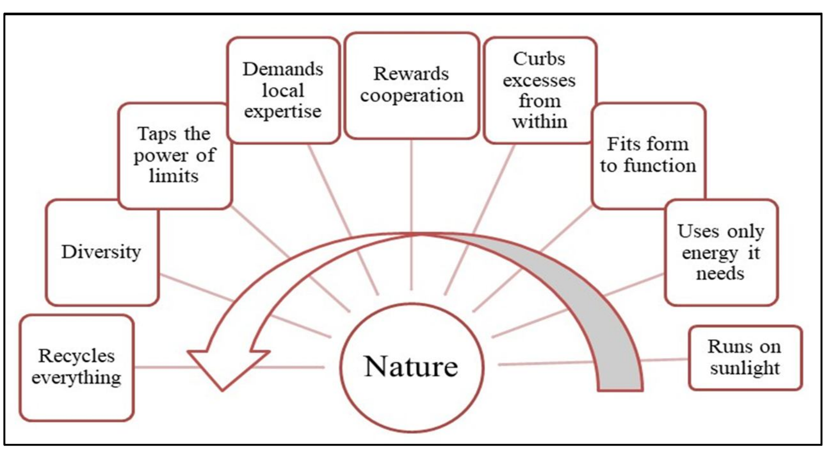

Fig. 02 Principles of Nature's biological system adopted in Biomimicry

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A. Problem to Biology (Top-Down Approach)

This approach is a problem-driven approach to imitate nature to solve the problems. When there is a problem, the designers look for nature for sustainably for getting the solutions [9]. The process involves defining and reframing the problem, searching for a biological solution by defining and extracting principles and finally applying the principles to solve the problem.

1) *Sustainable building; Learning from Termite Mound:* Ventilation and temperature maintenance were the biggest problems in huge, tall buildings throughout the different seasons, so learning to design buildings more sustainably without excess energy consumption was challenging for the engineers. Eastgate complex in Zimbabwe is an example of such a sustainable building, constructed by learning the self-cooling termite mounds with more or less constant temperature throughout the day. Engineers Mick Pearce and Arup achieved great success by studying Termite mounds. Since the termites are soft-bodied and feed on fungus, the temperature must be kept constant inside the mound throughout the day and different seasons of the year to cultivate fungus. These insects build mound using the zero-waste building method employing soil and plant residues which help in solar-powered air conditioning. The mound always constructed in the North-South direction, with a flattened conical shape to catch the sunlight during the day and heat is released during night time. The vents are continuously operated by termites through opening and closing, considering the temperature fluctuation inside the mound. These ideas are emulated and used in designing the Eastgate complex [10,11]. The complex was then designed with specially hooded windows, various width of walls and light coloured paints to decrease heat absorption. The air circulation system was adopted by using large floor openings and chimneys. The cool air enters the office room through the openings on the floor, drawn from fans outside open space and hot air escape from another channel in the ceilings, finally, exit by chimneys (Fig. 03). Furthermore, the building was constructed with excellent masonry work to minimize the solar heat gain by reducing the surface area [12]. This building uses 90% less energy for cooling the room than conventional buildings of the same size. The temperature inside the building remains 2 to 5 degrees Celsius less than the outside temperature (Fig.04).

B. Biology to Design (Down-Top or solution based Approach):

Nature influences human to imitate for innovations. Anything sustainably working in nature triggers the designer's curiosity to adapt the principles, hence encourage the inventions [13]. A benefit of this method is that it may influence the new inventory or helps in solving past unsought problems.

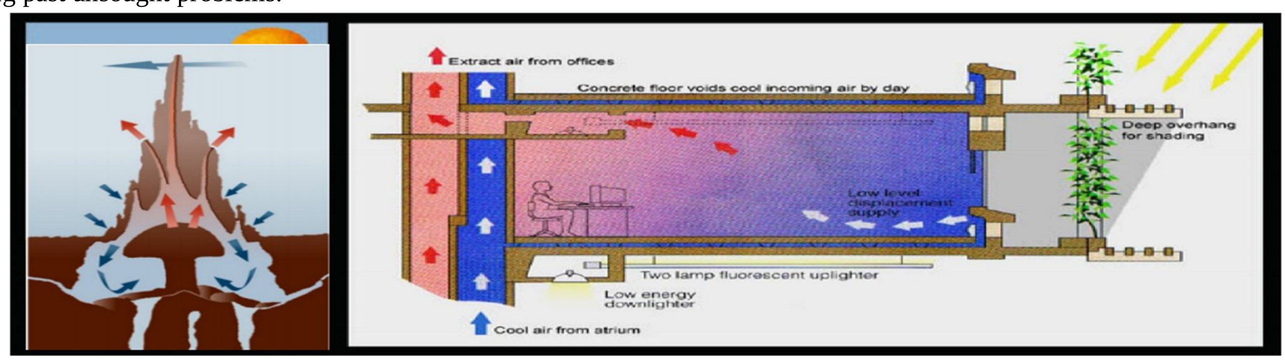

Fig. 03 Air circulation in Eastgate building chamber (Right) emulated by Termite mound (Left). (Source: asknature.org, 2008)

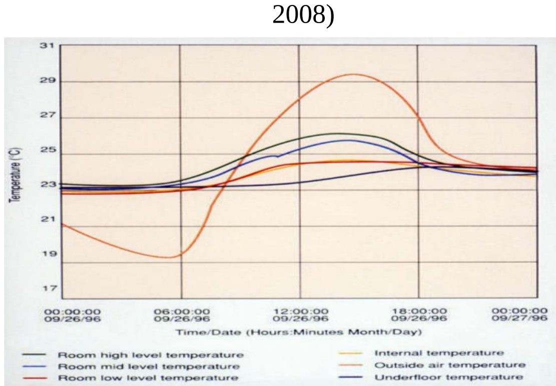

Fig. 04 Temperature variation Eastgate building to the outside [10]

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1) *Velcro; Story of Bur flower:* Velcro is a hook and loop-like structure used in the design sector, made up of two slivers with minute loops and flexible hooks, which stick when compelled and unglued once dragged apart. The innovation of Velcro brought considerable change in the design field. It is used from shoes to bags to aeroplane floatation devices. Velcro was invented in 1948 by a Swiss engineer named George de Mestral, an amateur trekker and hunter. Once, he went hiking along with his dog. Upon coming back, he observed that burr flowers clung to his cloth as well as the dog's fur. The keen observation of bur flowers showed that they were covered with a tiny hook-like structure that helps them cling to cloths and dogs fur [4]. After eight years of this fortune, he synthesised the artificial loop and hook-like structure called Velcro (Fig. 05), derived from two French word Velours and Crochet, meaning Velvet and Hooks. After a long research on loop and hook, the technology was commercialised by taking patent in Velcro in 1955.

Fig. 05 Velcro (Right) inspired by Cocklebur flowers (Left)

IV. LEVELS OF BIOMIMICRY

The information from nature can be exploited from three levels, the key biomimicry levels: form or organism level, behavioural or process level and ecosystem level [14,4]. The form or organism level focuses on an individual organism as a whole unit, whereas the ecosystem level considers the relationship between an organism and its environment by studying how it fits with the whole. Instead of an individual organism or ecosystem, a process or behaviour is adopted at the behavioural level by studying how it performs and how it is made. Levels can be categorized into five dimensions: form, material, construction, process and functions.

A. Form or Organism Level

This level deals with the individual organism or function as a unit of inspiration by studying form, texture, colour, pattern, geometric and shape. Most of the innovations inspired by the organism or form level mimic the form or function. An example of mimicking form or function may be replicating Kingfishers beak to design the tip of bullet trains.

1) *Kingfisher to Bullet Trains:* Japanese engineers stuck in a problem related to the Shinkansen trains designed as high-speed transportation in the early 1900s. The team was successfully designed the train travelling at 200 miles per hour (320 km/hr), which produced sound by low-frequency ambient pressure waves caused by fluctuations in air resistance when the trains touched subways that might be heard from 400 meters away. The problem was solved by a team led by Eiji Nakatsu, a bullet engineer and Birder, who implemented the shape of the Kingfisher bird's beak to make the train use 15 per cent less energy and travel 10 per cent faster than the previous train. The kingfisher will strike into water surface with a minute splash for hunting fishes [26]. The fact doubled the enthusiasm of Eiji Nakatsu, creating the perfect design for Shinkansen trains (Fig. 06). This kingfisher bill form trains produce 30% lesser atmospheric pressure. The Shinkansen trains are among the world's fastest, biggest, and mesmerizing to deliberate that they are assembled on the adaptations of one small bird [4].

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B. Process and Behaviour Level

Emulating the principle or process of how organism or nature works is the second level of biomimicry. At this stage of inquiry, the primary issue is, "How is it made?" and it demands in view of the assemblage or chemical methods that nature employs to make.

Fig. 06 Kingfisher beak shape inspired Shinkansen train tip. [4]

1) *Self-cleaning Lotus leaves:* Lotus plants have an unusual way of remaining dirt-free and repelling water. This benefits an aquatic plant in a muddy environment, as clean leaves mean more photosynthesis. In 1997, a German botanist named Wilhelm Barthlott investigated lotus leaves closely to solve the self-cleaning mystery. When he examined leaves under a nano microscope, he discovered that they are coated in a nanoscopic waxy texture that stops water and soil from adhering to the surface of the leaves. Papilla, tiny bumps or ridges between 10-20 microns in height and 10-15 microns in width, cover the surface. A thin film of wax covers these papillae as well (Fig. 07). He discovered that the micro and nanostructure of the leaves are responsible for the lotus super-hydrophobicity. The lotus effect occurs as water comes into contact with these waxy layers, causing it to bead up. Scientists and industry are also using the superhydrophobic composition of the lotus to develop new technology [15, 8]. Paints, fabrics, glasses and even microchips will benefit from a surface resistant to moisture. The Groasis Waterboxx Plantcocoon, for example, is a system that aids in the incubation and nourishment of a tree even in extreme or unfavourable circumstances. With a surface nanostructure similar to that of a lotus, the funnel-shaped expanding pot absorbs rain and condensation [16,17,18].

Fig. 07 Microscopically rough leaf surface of lotus leaves [8]

C. Ecosystem Level

Among the three levels, the ecosystem level is the most complex. ‘How does it fit?' is the central issue at this stage of inquiry. It is important to note that nothing happens in nature in isolation, so considering the following questions can help you imitate an ecosystem: is it appropriate, is it part of a nourishing food network of industries and can it be exported, sold, and reabsorbed in a way that mimics a forest-like economy? An eco-industrial park that mimics the mutually beneficial relationships that occur in nature, where unrelated organisms share materials to ensure that the common advantage is greater than the sum of individual profits, is an example of mimicking processes.

1) *Lavasa; the Artificial Nature Hub:* Indian hill city, Lavasa, was vulnerable to heavy rain, famine and deforestation have been built to mimic the thick forest surrounding it. Mugaon, the second town in Lavasa District, will be the world's first area to use Biomimicry principles in nature and architecture. HOK, the design team, thinks that the local environment struggles with the monsoon without losing its soil. As a result, they began to research the landscape and understand how rainwater-storage structures could be built to resemble trees that collect water during the rainy season and preserve it for later use (Fig. 08). They also considered designs that would aid in the slowing down of runoff, similar to what leaves do in a tree. They wanted to plant trees in the city to prevent rain droplets from striking each other at full velocity. Since ecosystems have a shrub layer, a mid-tree layer, and a canopy layer, they could create vegetation in heavily degraded areas, reducing soil erosion [19].

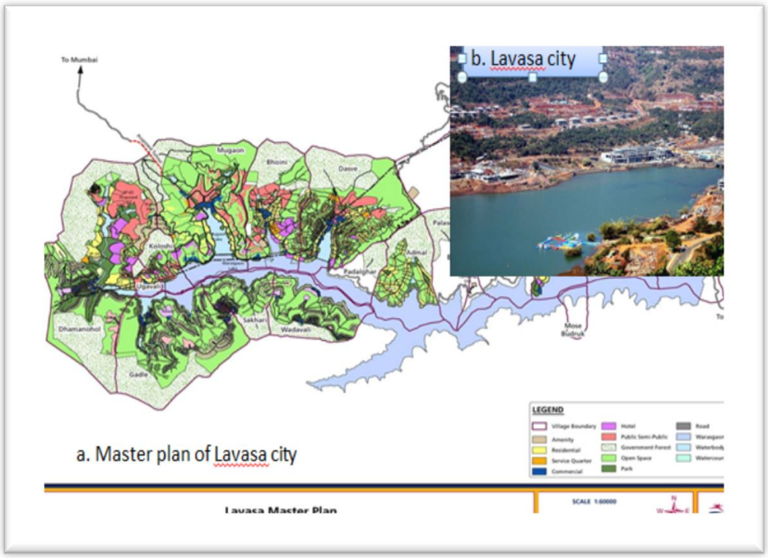


Fig. 08 Lavasa city Master Plan [19]

V. APPLICATION OF BIOMIMICRY IN DAILY LIFE

Biomimicry has been popular for centuries in most of the art, science and social fields to find solutions for problems in daily life. Biomimicry-inspired technical products and processes are claimed to make industrial and domestic life simpler and benefit the world in a positive way.

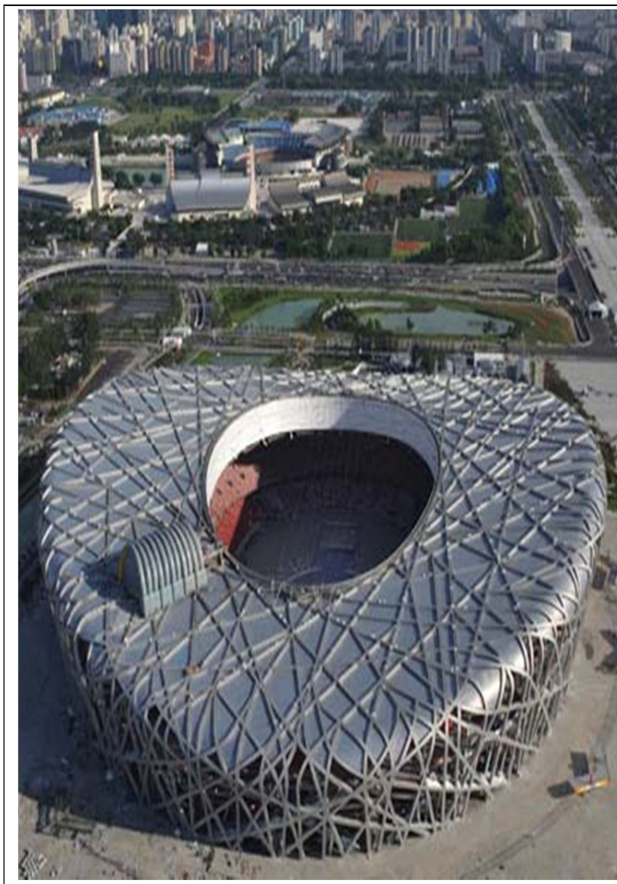
A. Biomimicry in Architecture

Nature has long assisted as a source of motivation for architects. Columns in ancient Egypt were modelled after palm trees and lotus plants and architects have since copied the designs and dimensions of natural forms to pursue artistic attractiveness. Human designs are often more geometric than natural entities and are often bigger. The majority of human manufactures are fragile and rigid and they depend on wheels for stability.

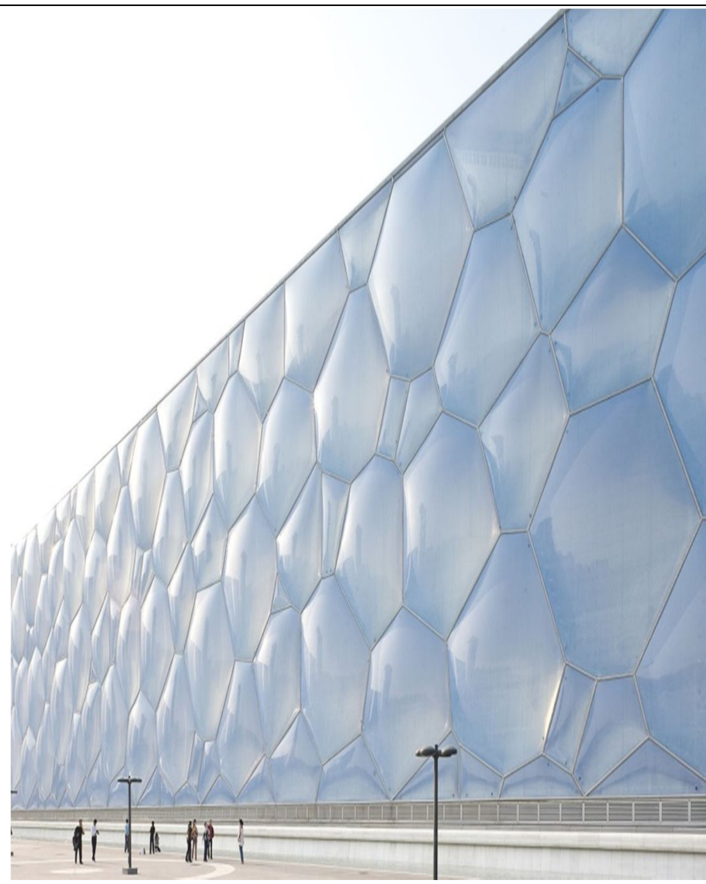
The *Gherkin tower*, modelled by architect Norman Foster, was influenced by the Venus flowers sponge [12,15,21]. The Venus Flower Basket sponge lives in an aquatic world with heavy water currents, and its lattice-like exoskeleton and circular form aid in dispersing those pressures (Fig. 09a). It is fun to witness impressive new stadiums like the *Bird's Nest* (Fig. 09c) and the *Water Cube* from an architectural standpoint [12]. These structures are not only energy-efficient and environmentally sustainable but are also influenced by nature. The architecture of the Water cube is based on water bubbles in the foam and the arrangement is derived from geometry and crystalline structures (Fig. 09d). The foundation of the firm is built of concrete, and the bubbles are made of Ethylene Tetrafluoroethylene pillows. The membrane allows more light and heat than conventional glass, keeping all five pools colder and lowering energy costs by 30%. With effective filtration and backwash systems, rainwater from the roof is stored and recycled. Vincent Callebaut's *Lily Pad* is a model for a fully self-sufficient floating community designed to provide shelter in the event of potential climate change (Fig 09b). The building Lily pad, inspired by a water lily, is designed to be a zero-emission floating city in deep water. The plan is expected to be capable of not only producing its own electricity but also coping with CO2 in the environment. The aim of a completely self-sufficient floating city was to provide shelter for incoming climate change immigrants. There are few urban planning options for accommodating the inevitable influx of homeless people that will occur as seas increase due to global warming. None, without a doubt, are as impressive as this one.

Gherkin Tower

Lily pad, a floating city



Bird's Nest stadium



Water Cube stadium

Fig. 09 Biomimicry in Architecture. [21]

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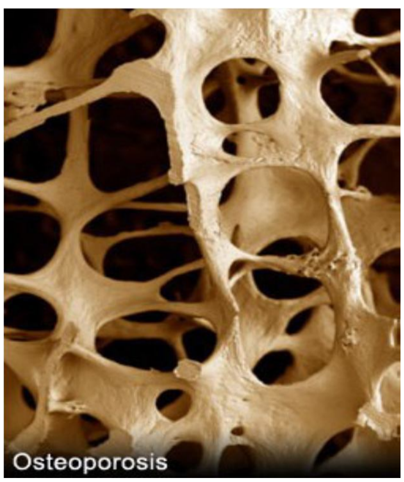
B. Biomimicry in Furniture

Furniture has long been a sign of humanity's way of life and ethnic diversity. Natural forms, structures and materials are used in furniture design for decorative and functional reasons (Fig. 10) [21].

Alvaro Uribe designed the Mantis Table, which was inspired by the mantis' body parts and joints.

Joris Laarman's "Bone Chair" was influenced by the formation of bone in osteoporosis patients.



Davide Barzaghi created the "Quartz Chair," which was explicitly influenced by quarts. The frame of the “Quartz Chair,” which has a crystalloid look, is primarily made up of smooth and curved geometric shapes.

Fig. 10 Biomimicry in Furniture. [19]

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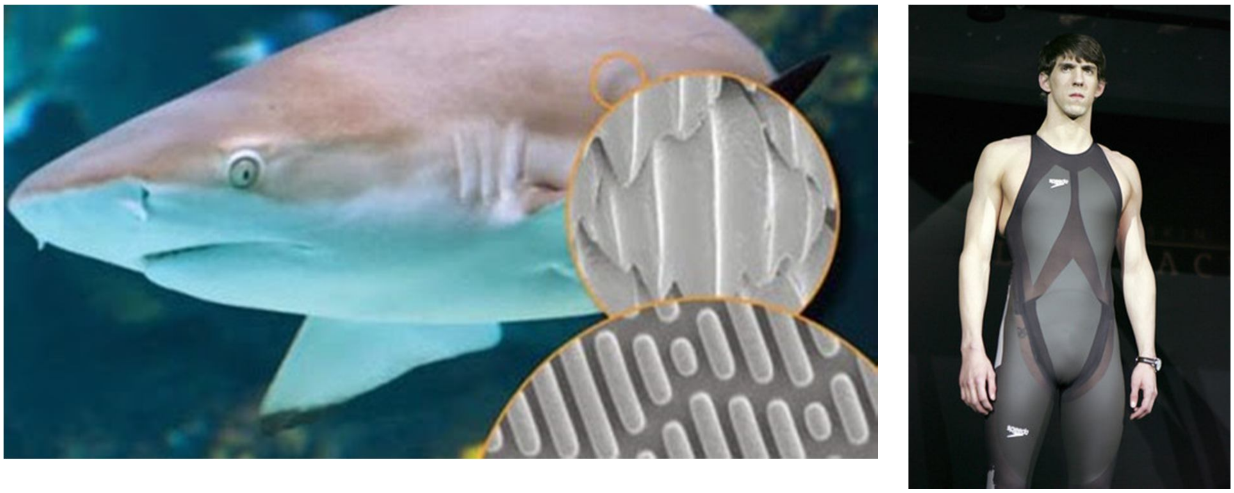
Volume 9 Issue VII July 2021- Available at www.ijraset.com

C. Biomimicry in Fashion Design

The fashion design sectors are facing two main problems, depletion of resources and increasing pollution. This scenario made the designer to turn on to nature to stimulate the characteristics of other living organisms.

1) *Sharklet skin of Shark::* Algae, seaweed, barnacles and other forms of biofouling collect on whales, ships and other objectives that move through the ocean, reducing their swimming ability. Sharks, on the other hand, despite swimming slowly across the sea, keep their skin clean. Sharks have developed with small facets in the skin, results from evolution (Fig. 11). This trend inspired our micro patterns, which we use to protect humans. The exact sequence that keeps algae from clinging to sharks' skin often keeps bacteria away from Sharklet [21]. Sharklet is only one example of biomimicry's many innovations [15,4]. The functional purpose and mechanical architecture of shark skin influenced Dr. Tony Brennan to make a Sharklet micropattern.



Sharkskin under Nano microscope   Sharklet- Swimming suit.

Fig. 11 Biomimicry in Fashion Design [4]

D. Biomimicry in Sustainability

1) *Learning from critter to make water from fog*: The Namib Desert beetle's harvesting water from fog is primarily the product of behavioural and structural adaptations to the use of an additional water supply in an area where rain is a rare event. The wing corners of this beetle have tiny bumps. Hydrophilic (water-loving) tips and hydrophobic (water-repelling) waxy sides characterise these bumps. The fog gathers in its water-loving bumps, and then water appears and slides back through its mouth from the waxy edge (Fig. 12) [27,28]. This technology could produce safe freshwater in arid areas, refugee camps and other locations. In reality, Grimshaw, one of the architecture companies, has developed synthetic surfaces that mimic this beetle for fog water harvesting, which works ten times better than any fog capturing net. The same technology was adopted in Las Palmas water Theatre (Fig. 12) [14,24,25].

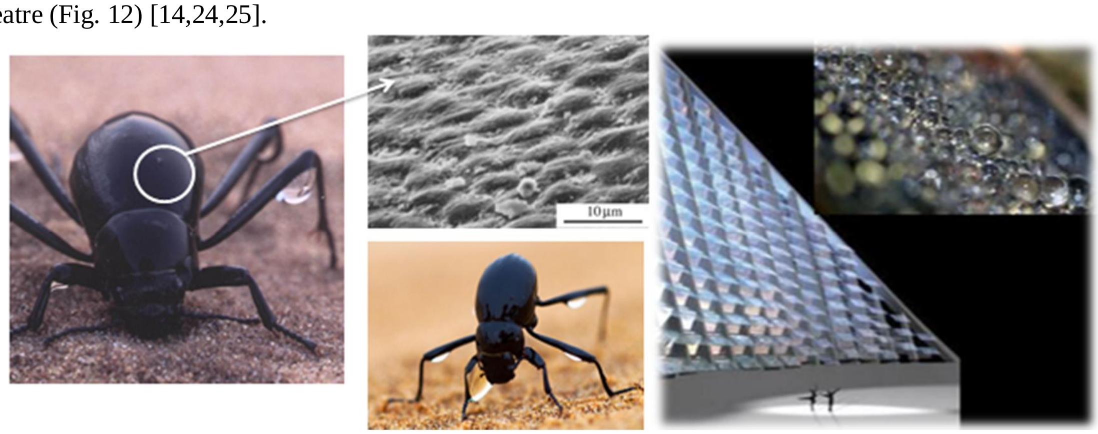
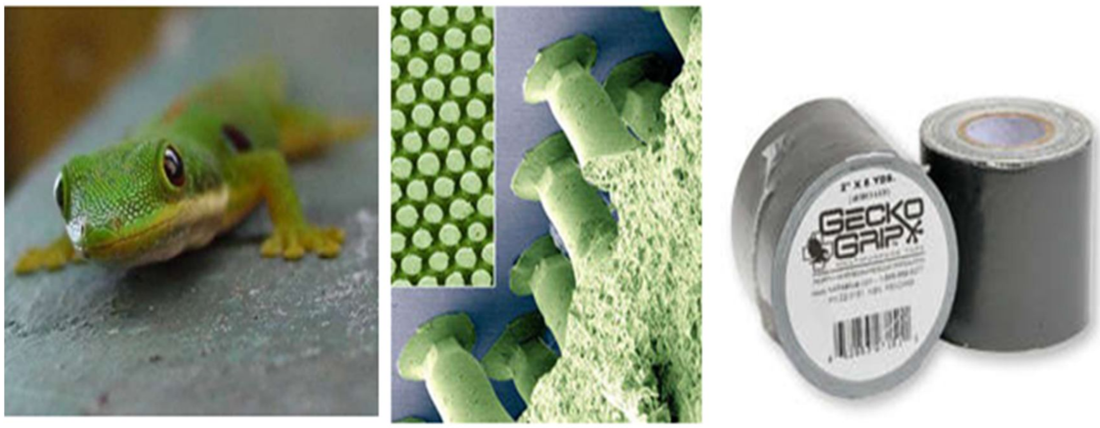


Fig. 12 Fog-basking behaviour of Namibian beetle [4]

2) *Gecko tape, Inspiration by Gecko:* The toe pads of a gecko's foot are made up of around half a million keratin setae. Hundreds of much smaller projections of nanoscale diameters called spatulae protrude from the ends of each of these fine hairs. Although several interactions, such as suction, friction and electrostatic forces, had been proposed as the cause of the adhesion, it was not until 2000 that Robert Full of the University of California, Berkeley, discovered that the adhesion was caused by Van der Waals forces formed between the spatulae and the surface. Intermolecular forces produced by induced polarization of molecules are known as Van der Waals forces. Van der Waals forces become essential on the micro and nanoscale, despite being small and negligible in most cases. Andre Geim, who is in charge of making gecko setae, discovered that capillary forces play a role in adhesion. The surface tension of a molecular film of absorbing water that forms between two surfaces creates attractive capillary forces. These techniques are adopted in the manufacture of Gecko tape (Fig. 13) [4,15,22].



Inspiration Precedence Product

Fig. 13 Gecko tape- bio innovation inspired by Gecko

E. Biomimicry in Efficiency

1) *Sustainable Engineers: Honeycomb to a Storeroom:* Though this honeycomb arrangement is well-known, the brilliance of its hexagonal pattern is relatively unknown. Scientists who researched the dynamics and structural aspects of the comb, which comprises six-sided cells, concluded that hexagonal cells are more robust and more efficient in space utilization and much lighter in weight. The honeycomb structure is very shock absorbent, resilient and wear-resistant, in addition to its strength, performance and weight [22,25]. Man has replicated God's conception by replicating the honeycomb arrangement in applications ranging from cardboard boxes to vehicle and aircraft components to window glass, floors and home insulation to sneakers and sports clothing. The hexagonal beehive is the easiest way to construct a storehouse with optimum size and the least amount of construction material (Fig. 14). This has since aided in the construction of several homeless shelters. The hexagon has proved to be the smallest two-dimensional form.

Honey Comb Building with Comb Shape.

Fig. 14 Efficiency design in Construction [23]

VI. CONCLUSION AND RESEARCH SCOPE

For millions of centuries, nature has been evolving. It had created processes that are incredibly efficient and appropriate for the activities at hand. Mimicking behaviour has been done for a long time, resulting in an extensive range of developments in various fields. This method was recently conceived and structured as biomimicry. Architecture was one of these disciplines that attempted to mimic nature to refine and expand its capabilities. Imitating figures, propositions, shapes and arrangement is the first step. It was not until the latter half of the twentieth century that we could replicate natural cycles and environments in our structures. This method aids us in the discovery of new approaches and principles that can be used to improve our construction systems. The capability of species to respond to shifting climates is one of the most remarkable biological processes.

Biomimetic architecture is a modern 21st-century style that will revolutionise the architecture landscape in every way, including the way architects design and encourage their designs, the materials used in construction and the finished materials available to the world and building consumers. Design biomimetics should prioritise ways of thought and construction that integrate architecture and industrial design into a process of environmental and biological emphasis to create more responsive, safer structures. Biomimetic science may also help us solve environmental problems, including the greenhouse effect, global warming and the ozone hole, by reducing massive CO2 emissions from construction materials and purifying the surrounding atmosphere.

In the world of biomimicry, there is much space for study. Out of 2 to 50 million, just a subset of the earth's species has been explored to date. Since there are so many areas that are yet to be investigated, there is tremendous potential for study in Biomimetics. Nature's inspiration is expected to continue to contribute to technological advancements and the effect will be felt in every part of our lives. Some of the ideas may seem to be science fiction at this time, but as our perception of nature and capacities grow, they may become a possibility that is closer than we expect. The perfect order of nature aided in the decision-making and trial-and-error process, as well as helping to animate the design in the head, giving it a shape, and find a solution through creation.

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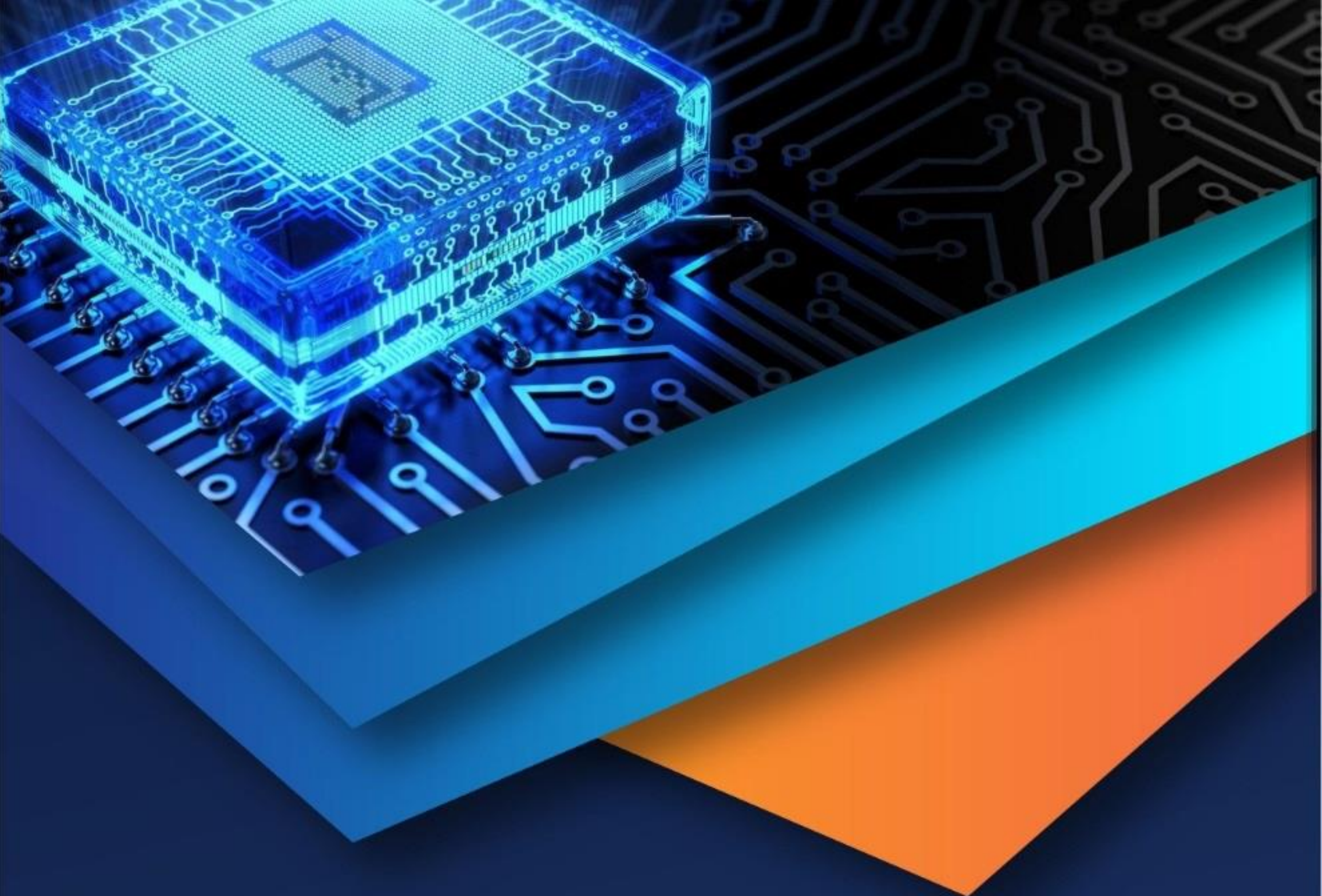

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