Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 10, October-2023

Bio-Mimicry Based Architectural and Vehicular Design - Development and Applications

Devanarayanan M Kurup*(1)
I Sem EEE, Christ University, Kengeri Campus, Bangalore
Bangalore, India

Mahadev Manoj*(2)
I Sem CSAI, Christ University, Kengeri Campus, Bangalore
Bangalore, India

***Abstract*: Versatility of biomimicry has acted as a motivation for various innovations and designs in all fields of engineering. Solutions to multitude of engineering problems are motivated from nature from ages, this has become more prevalent in current era as adoption of various natural techniques is made possible with advancement in technology. Biomimicry is considered as sustainable solution to today's environmental, technological, and economic challenges. This paper intends to explain the history and development of application biomimicking in modern architecture and vehicular engineering. The discussion considers adopting biomimetic principles, and discusses some problems such as physical constraints and architectural constraints .This paper attempts to provide insights into the current state of biomimicry in architecture and automotive design and scope for futuristic projects**

HISTORY OF APPLICATION BIOMIMICKING

Biomimicry is a fascinating and multidisciplinary field that talks about innovations which are inspired from nature's processes, designs and strategies and has led to multitude of innovations and provided solutions to many challenges. Flying machines like Ornithopter with flapping wings were designed by Leonardo da Vinci Centuries inspired by the ability of birds. This topic gained its popularity in the 1940s, with the invention by George de Mestral's of Velcro , a portmanteau of "velvet" and "crochet". While in Swiss Alps, he noticed the burdock seeds that stuck to the clothes and dog's fur and further investigation revealed the structure which includes little claws or tiny hooks on those burrs catching onto fabric loops. That organic process gave rise to the Hook-And-Loop Fastening System; a term that Mr. de Mestral combined from the French word for hooks – 'croc-hay' + the French word for velvet- 'velor' = V. Since its invention, Velcro too has proven an adaptive technique for bonding and is now very popular as a securing method, showcasing how nature-inspired approaches can be implemented to engineer items.

In the latter part of the twentieth century, researchers discovered the 'lotus effect' –water repelled by lotus leaves that remained clean. The self-cleaning property of ultra hydrophobic micro-nanostructured surfaces was studied by Wilhelm Barthlott and Ehler in 1977, who described such self-cleaning and ultra hydrophobic properties for the first time as the "lotus effect". Self-cleaning glass, also known as "smart glass," is widely used in modern architecture. It employs a special coating that uses the sun's UV rays to break down and remove organic dirt and grime. This technology is applied in the construction of skyscrapers, residential buildings, and public spaces, reducing the need for manual cleaning, and ensuring unobstructed views. Self-Cleaning Facades are Building exteriors which are subject to environmental pollutants, which can mar their appearance. Self-cleaning coatings on building facades help maintain the aesthetics and cleanliness of structures. Self-Cleaning car exteriors, Self-Cleaning Train Windows etc are inspired by the lotus leaf's water-repelling properties, they help vehicles stay clean for longer periods by repelling dirt, water, and other contaminants. Train operators have adopted self-cleaning window technologies to improve visibility and reduce maintenance. These coatings help prevent dirt, water spots, and contaminants from adhering to the windows, ensuring a clearer view for passengers, and reducing cleaning costs.

The use of the kingfisher beak design for bullet trains was discovered in the early 21st century. This innovative application of the kingfisher's beak design to reduce noise and improve aerodynamics in high-speed trains was a product of research and development conducted in the mid-2000s. This technology was developed to make the Shinkansen (Japanese bullet trains) more efficient, quieter, and environmentally friendly

Sharkskin-inspired swimwear, also known as "fastskin," was first introduced in the year 2000. The innovative design of these swimsuits, which draws inspiration from the texture of sharkskin, was created to enhance the performance of competitive swimmers by reducing drag and optimizing hydrodynamics in the water. These suits gained popularity in the early 2000s. Gecko-inspired Adhesives is an imitation of gecko's adherence on surface. Such adhesives bond very tightly due to microscopic hairs which can be used in different areas like robotics, medicine etc. One of the early pioneers in this field was Dr. Kellar Autumn, a biologist at Lewis & Clark College though this technology has evolved through the collaborative efforts of many scientists and research teams. Termite-inspired Ventilation design relies on active airflow and temperature modulation principles found by wind patterns on these mounds. The Eastgate Centre in

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 10, October-2023

Zimbabwe, was designed by architect Mick Pearce inspired by the natural air conditioning of termite mounds in early 2000s. Camouflage Technology adopted in Military uniforms and tools used in warfare are based on camouflage strategies observed among animals and plants. Blending techniques exhibited by chameleons, and disruptive coloration for instance among zebras are some of the influences. Designs for wind turbine blades have been inspired by the shape and structure of bird wings and fish fins. Such designs help in effective energy collection, high efficiency, and low sound levels. Bionic eyes have been designed along biomimetic principles to mimic the structure and functions of the human eye thereby helping to restore sight for visually impaired people.

Mimicking Nature's Structural colour: The consequence of nanoscale sub-micron scale surface topology and architecture has been attracting much interest in materials science, chemistry, engineering, and physics, thanks to its investigation. Scientists are trying to recreate these effects, described as shimmering pearl-like surfaces with metallic highlights, through concepts such as diffraction, interference, and scattering. Artificial structural colour development is guided by nature's inspiration on its different application.

Here are some examples of bio-related architectural designs:

Green Roofs and Living Walls: Such are covering the building surfaces by vegetation. Green roads such as living walls and green roofs have benefits as they offer beauty in nature, contribute towards reduction of excess temperatures by retaining rain water as they also allow for absorption of some carbon dioxide.

Bioclimatic Design: When it comes to designing a building, an architect has in mind the typical climatic and environmental conditions that exist in a location. For instance, passive solar design increases natural light and heat which reduce the necessity of employing artificial heat and lighting.

Daylighting: Bio-Inspiration- using Natural Light to Light Interior Spaces. it does not only lower energy consumption, but it also links inhabitants with rhythm of the nature.

Biomimetic Facades: Using natural patterns and textures like tree bark and animal skins in building facades could enrich the appearance of structures and offer shading, insulation, and energy-efficient designs.
Biodegradable and Sustainable Materials: Using such eco-friendly materials as recycled or biodegradable ones results in mitigation of the environmental effect of the construction process.

Solar Leaf Facades: These are facades which include photoelectric solar panels which mimic the shape and functionality of plants in which plant cells convert sunlight into energy for growth.

Natural Ventilation: Provision of adequate indoor air through creation of various designs such as atriums, courts' yards, and operable window in a building makes it unnecessary use of machine system.

Eco-Pods and Biodome Structures: They emulate such environments; for instance, to do research, agriculture or any other reasons that require a sealed environment within the space.

Habitat Integration: However, architects, when coming up with their design concepts, strive to make sure they do not harm the natural environment. Often these schemes create structures which become part of the ecosystem, for instance treetop walkways, cliffside retreats and so forth.

Bio-Responsive Buildings: They include technology that responds to environmental changes like open-up/close-down-ventilation system which opens or closes according to temperature, lighting, or air conditions.

Bioluminescent Lighting: Architects are getting inspired from Bioluminescent Organism and planning to incorporate inbuilt light sources as natural and soothing.

Vertical Farms: Such designs include vertical farming in skyscrapers meaning that people grow their own foods with reduced distance to transport.

Here are some real-life examples of biologically-inspired architectural designs:

Eden Project, United Kingdom: This iconic project features a series of massive geodesic domes that house different ecosystems, including rainforests and Mediterranean biomes. The design draws inspiration from the way soap bubbles form, creating sustainable, energy-efficient structures that provide educational and recreational spaces.

Bosco Vertical (Vertical Forest), Milan, Italy: Designed by Stefano Boeri, this residential complex consists of two tower blocks covered in a lush forest of trees and shrubs. The buildings not only provide greenery in an urban setting but also help improve air quality and reduce the urban heat island effect.

California Academy of Sciences, San Francisco, USA: The building's undulating green roof design imitates the hills of San Francisco. It features over 1.7 million native plants and offers natural cooling and insulation, as well as habitat for local wildlife.

Singapore's Super tree Grove: These towering artificial trees are part of the Gardens by the Bay project. They resemble natural trees and are equipped with photovoltaic cells to harvest solar energy and act as air exhaust receptacles. They also support a variety of plant life.

The Bullitt Centre, Seattle, USA: This commercial building is designed to be one of the greenest in the world. It

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 10, October-2023

incorporates natural ventilation, solar panels, a green roof, rainwater harvesting, and a composting toilet system to minimize its environmental footprint.

Sustainable Treehouse, Alnwick Garden, UK: It provides a platform for children, which has been constructed using eco-friendly raw materials such as sustainably harvested timber. This creates a more enmeshed experience of nature.

Aga Khan University Hospital, Nairobi, Kenya: This design of the hospital came from Baobab tree that has thick trunks and branches and is an indigenous tree of Africa. The hospital's architectural layout is built on sustainable practices of open space, green spaces and ample natural lighting and cool breezes.

The Water Cube, Beijing, China: The Water Cube, which is a national aquatics center located at Beijing, bears structural resemblance to the soap bubbles. The ETFE cushions of this structure are engineered for capturing and dispersing natural daylight resulting in an economical ventilated façade as well as an attractive architectural creation.

The Sainsbury Laboratory, Cambridge, UK: The building for this research facility was designed taking after the plant cell's form and functions, with the pattern of plant cells and leaves being used in its appearance. Designed on Energy Efficient Principles with Sustainable Materials.

The Gherkin (30 St Mary Axe), London, UK: The unique shape of the gherkin was inspired by a species of sea sponge called Venus flower basket sponge. This praised for its low energy consumption and negligible environmental effects.
Management and Reduction of CO_2: About half of greenhouse effect is caused by CO_2emissions which are mainly generated through fossil fuels burning for electricity purposes. To replicate nature's carbon dioxide absorption, various applications have been developed:

Nano Vent-Skin (NVS): In addition, there is a form of bio-mimetic technology mimicking human and animal skins for creating building surfaces which can absorb carbon dioxide. The skin has turbines of about 25mm length and 10mm width covered with photovoltaic materials. The turbines derive solar and wind energy as well as convert carbon dioxide to oxygen.

TecEco Eco-Cement: A special cement kind absorbing CO_2 from the atmosphere. It contains magnesium-based compounds that trap CO_2 and harden, like what happens in the shell building of marine organisms. They use this innovation as a part of making building materials and helps with lowering carbon dioxide content in the build environment.

Examples from everyday life demonstrate how architects and designers have learnt from nature in creating eco- friendly and aesthetically appealing architecture.

SUSTAINABLE BUILDING DESIGN THROUGH BIOMIMICRY:

Key factors in eco-architectural design include building efficiency, water conservation, waste minimization, temperature control, and power supply. This section of the paper demonstrates how nature has evolved highly effective strategies for challenges like those confronted at the intersection of social and environmental responsibility, specifically through biological systems that have been subject to significant selective pressures.

CONSERVATION OF RESOURCES

Energy conservation through natural methods of ventilation and maintaining temperature and lighting is adopted by many architects. Shahda, Abd Elhafeez & Asharaf, (2014) mentions about natural ventilation inspired by natural cooling seen that simulates termites, natural lighting facilities arranged in many foreign building complexes, adopt proper shading to avoid excess sunlight, use of dye-sensitized solar cells as an alternative for power generation, building is provided by solar power, wind turbines and 160 (geothermal wells), and is an environmentally friendly energy source (green electricity) that does not have an impact on the environment to support the clean environment

Zuhri S (2020) explains the use of locally found materials that can last the surrounding environmental degradation as the need less maintenance like the Birds Nest stadium in China. This stadium has adopted almost all concepts from nature to enable Natural lighting, minimise light pollution, conserve energy, provide easy access for visitors,

Kasi(2011) mentions about Re utilization of sewage water like that in the council house of Melbourne draws inspiration from termites who use ground water to regulate nest temperature. These designs can advance to systems like the chaac-ha : a system that is used to collect the atmospheric dew and rain water it has a spider web like structure and draws water from the hydrophobic nature of plant leaves like lotus . The study also mentions about an architecture developed in 2004 in Swiss Re Headquarters Building designed by Foster and Partners which employed a radial plan with the outer enclosure that integrates wall and roof into a "continuous triangulated skin" to allow for column free space, ventilation and daylighting. The particular form also greatly helps deal with wind deflection on this towering building. The engineering of this building greatly resembles the structure of sea sponges also known as Venus Flower Baskets (The Biomimicry Institute, 2010; Swiss Re building). Akadiri, P.O et.al (2012) mentions about Acoustic comfort that can be enhanced by Proper selection of windows, wall insulation and wall framing, and materials are essential to reducing noise from outside. Some sound insulating materials, such as acoustic ceiling tiles and straw-bale construction, can offer the advantages of recycling and using natural materialsRai, S. N., & Manglik, A. (2012) explains flexibility and evolution in Design that is inspired by coral reefs which grow dynamically over a period. However, the carbon neutral utopian village is formed by using liquids taking the shape of corals that can grow for more than thousand families.

ACS News Service Weekly Press Pac -June 13, 2018 reports Jalabos which is a place that has Galapagos shark skin like surfaces where bacteria find difficult to attach. These surfaces are very important in a hospital environment because of their ability to prevent bacteria growing. this coating designed to mimic a shark's skin, and it reduces the ability of bacteria to adhere to surfaces, thereby helps reduce the use of chemicals.

APPLICATION OF BIOMIMICKING IN VEHICULAR DESIGNS

Prasanth et al discusses a solution to the problems in the automobile production sector due to shortage of non-renewable sources like fossil fuel and oil-based fuels that harm the environment. To the above problem, new interests are emerging to review these biomass sources and bio based as the viable options of sustainability. Specifically, biobased fuels are capable of fuelling today's engine and yield positive environmental impact. Also, it is beneficial to switch from oil to bio-sourced products such as bio-polymers, bioplastics, and bio-composites to manufacture cars. Sundaram T (2023) emphasises the importance of bioengineering that cannot be overemphasized especially regarding some biofuels such as biodiesel and ethanol. Algae-based biofuels provide an environmentally friendly alternative to petroleum-based fuels while reducing greenhouse emission of gases.

The macro-structural design solutions in this section include the biomimetic implications on the overall structure of the vehicle. It also discusses biomimetic components in automobile sub-systems such as wheel assembly, powertrain, steering, and air conditioning. *Wijegunawardana, Isira & de Mel, W.R.. (2021).* Several automobile producers have used animal appearances for their models and have also used the mimicked animal name as the model name

Plastics contain many useful features for automobile purposes such as low weight, bendability, or a lot of positive features. Plastics have several favourable characteristics which are suitable for making car parts as they help reduce car's overall weights leading to enhanced fuel economy. *Vieyra H* et al. analyses that such high performance, non-natural resources as for instance high-performance class of engineering plastics. These innovative engineering plastics compared with conventional ones are usually considered cheaper. Various types of plastics have been introduced by automotive manufacturers all over the world in a bid for sustainability that included bioplastics and bio-based plastics such as natural fibre composites and engineered composite plastics. In this case, sustainability is about moving from non-sustainable plastics obtained from fossil fuels such as carbon dioxide and oil to sustainable alternatives from renewable raw materials. It is a shift that creates an opportunity for the use of quality plastics, recycled plastics, bio-based plastic, and biodegradable plastic; thus, integrating sustainable approach within the design development process of mobility cycle. The paper suggests that the switch towards eco-friendly electric cars involves changing fuels for plastics and other petroleum derivatives.

Samir, A (2022) presents the application biodegradable polymers, treatment, composites, blending and modeling are studied. Environmental fate and assessment of biodegradable polymers are discussed in detail. The use of biocompatible materials for auto parts especially interior items. Instead of having the conventional plastic products manufactured from chemical substances which have a negative impact on the environment during production as well as post-use, biologic plastics sourced from natural materials would offer an alternative.

Biometric Sensors and Safety Systems are explained in Arakawa T (2021) . Bioengineering is now involved in the installation of biometric sensors onto vehicles that will measure vital signs and a driver's level of awareness all day long. These can warn about sleepy/distracted driver and add preventive safety measures. Vargas J, elaborates about bioengineering that is used in the design of autonomous vehicles, as this system takes its cue from human perception and action. With advanced sensors, these vehicles can negotiate complicated spaces, engage people along waysides, and adapt quickly to changing traffic scenes.

Bittencourt DMC(2022) discusses the advances in synthetic biology have enabled the design and production of spidroins with the aim of biomimicking the structure-property-function relationships of spider silks. Bioengineers pursue the recreation of naturally occurring textiles and fibres such as spider silk whose light but tough qualities are well-known. Consequently, these materials can be employed in creating cars which will lower the fuel usage and emission production.

Modern bioengineering has made significant impacts in the mobility and transport sector. There is nature-based innovation in vehicle design, clean environment energy sources to make vehicles safe with latest technologies and eco-friendly materials. Life science intersecting with engineering now is bringing us into the future of safe, clean, and efficient transport. There is a potential for the continued relevance of biomimicry applications in the future.

REFERENCES:

[1] Shahda, Merhan & Elmokadem, Ashraf & elhafeez, Prof. (2014). Biomimicry Levels as an Approach to the Architectural Sustainability.
[2] Zuhri S (2020) Sustainability Architecture Strategy in Sports Building Design. J Archit Eng Tech 9: 232. DOI: 10.4172/2168-9717.1000232
[3] Kasi, Krishna, "Biomimicry: Integration of Dynamic Thermal Regulation in Human Habitation" (2011) Electronic Theses and Dissertations. 323.
[4] National Stadium. (n.d.). Design concept. Retrieved August 21st, 2011, from http://www.n-s.cn/en/generalinfo/

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 10, October-2023

designconcept/index.shtml

[5] Akadiri, P.O.; Chinyio, E.A.; Olomolaiye, P.O. Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector. *Buildings* 2012, *2*, 126-152. https://doi.org/10.3390/buildings2020126

[6] Rai, S. N., & Manglik, A. (2012). An analytical solution of Boussinesq equation to predict water table fluctuations due to time varying recharge and withdrawal from multiple basins, wells, and leakage sites. Water resources management, 26, 243-252.

[7] ACS News Service Weekly Press Pac -June 13, 2018

[8] S.M. Prasanth, P. Senthil Kumar, S. Harish, M. Rishikesh, Sonil Nanda, Dai-Viet N. Vo, Application of biomass derived products in mid-size automotive industries: A review, Chemosphere, Volume 280, 2021, 130723, ISSN 0045-6535.

[9] *Wijegunawardana, Isira & de Mel, W.R.. (2021). Biomimetic Designs for Automobile Engineering: A Review. International Journal of Automotive and Mechanical Engineering. 18. 9029-9041. 10.15282/ijame.18.3.2021.15.0692*.

[10] Vieyra H, Molina-Romero JM, Calderón-Nájera jdd, Santana-Díaz A. Engineering, Recyclable, and Biodegradable Plastics in the Automotive Industry: A Review. Polymers. 2022;14(16):3412. Https://doi.org/10.3390/polym14163412

[11] Samir, A., Ashour, F.H., Hakim, A.A.A. *et al.* Recent advances in biodegradable polymers for sustainable applications. *npj Mater Degrad* **6**, 68 (2022). https://doi.org/10.1038/s41529-022-00277-7

[12] Sundaram T, Rajendran S, Gnanasekaran L, Rachmadona N, Jiang JJ, Khoo KS, Show PL. Bioengineering strategies of microalgae biomass for biofuel production: recent advancement and insight. Bioengineered. 2023 Dec;14(1):2252228. doi: 10.1080/21655979.2023.2252228. PMID: 37661811; PMCID: PMC10478748.

[13] Arakawa T. A Review of Heartbeat Detection Systems for Automotive Applications. *Sensors*. 2021; 21(18):6112. https://doi.org/10.3390/s21186112

[14] Vargas J, Alsweiss S, Toker O, Razdan R, Santos J. An Overview of Autonomous Vehicles Sensors and Their Vulnerability to Weather Conditions. *Sensors*. 2021; 21(16):5397.

[15] Bittencourt DMC, Oliveira P, Michalczechen-Lacerda VA, Rosinha GMS, Jones JA, Rech EL. Bioengineering of spider silks for the production of biomedical materials. Front Bioeng Biotechnol. 2022 Aug 9;10:958486. doi: 10.3389/fbioe.2022.958486. PMID: 36017345; PMCID: PMC9397580.

