Dynamics of Evolutionary Engineering : Revolutionary Biomimicry Applications

** Sandeep Bhattacharjee*

Abstract

The current article is a research article on the concept of evolutionary engineering concept of biomimicry applications. It explores some of the current applications of the natural or biologically inspired processes and designs which have revolutionized the way products and processes have been existing and have been seen so far. It also lays down the basis for numerous possibilities of future applications which are based on similar principles and practices of applications, process and pattern implementation. This research article includes the literature of some eminent discoveries made in the recent past and also connects with real life applications in the present scenario. The relation between the co-existence of biological processes and human adaptability can be visualized from the instances discussed.

Keywords: **Biomimicry, business, design, nature, processes**

I. INTRODUCTION

The domain of biomimicry or biomimetics has provided us with well-known practical applications, such as cats' eyes for the road and Velcro for fastenings [31]. But more modern examples include archetype surgical needles and super strong mini-robots. Evolution in nature's engineering has taken hundreds of millions of years to correct its designs, as compared to modern engineering which in relative terms has only been there for a nano-second. But identifying nature's technicalities is helping us create increasingly better structures and man-made materials.

The present study was conducted on the basis of literature available in various scientific research papers. Section II deals with the literature review of the historical opinions of authors on biomicry and its applications. Section III deals with research objectives, while Section IV states the hypothesis of the study, section V identifies the data collection for the study, section VI includes data analysis on the basis of the requirements of research objectives, and sections VII to IX discuss result findings and conclusion.

II. LITERATURE REVIEW

Rogers [1] elucidated the Beijing National Stadium, conceptualized by Swiss architects Herzog & de Meuron, and is considered as an outstanding instance of the use of biomimmetics in the current architecture. Also known as the Bird's Nest due to its incredibly innovative design, it has already captured the interest of the home and international architecture and related community. The stadium arises magnificently over the landscape in the form of a giant upturned bird's nest. Modern architects and designers are now getting inspired from nature's structural strengths and exquisiteness of natural objects in the skilled use of energy and materials. Todorovic and Kim [2] deliberated that further growth of buildings' energy competence with ability to sustain is inevitably connected to a building's architectural physics study, predominantly essentials of the optimal control of solar heat gains & dynamic control of sunlight. On the basis of the enhanced consideration of such methodologies which actually control comprehensive materials intensity, such as absorption, reflection, and diffusion of solar radiation, there have to be enhanced strategies for systematically controlling division of the daylight ingress from the sun's heat gains. Pertinent active control algorithms and mathematical models, integrated performance prediction of infrastructure/hardware and software and their substantiation need to be further modernized. Their work scrutinizes the most current scientific results, the modern state of art and science, as well as some of the

Manuscript received July 5, 2017; revised July 23, 2017; accepted July 25, 2017. Date of publication August 6, 2017.
* S. Bhattacharjee is with Department of Management-Analytics, Amity University, Kolkata, Bengal, India-700135 (email: sandeepbitmba@gmail.com)
Digital Object Identifier 10.17010/ijcs/2017/v2/i4/117851

ongoing R&D at the periphery of new quantum leaps for creating healthy artistic buildings' day lighting adjustable control's performance forecasting and acceptable justification. Also, another comparative literature review includes the examination of existing biomimicry technologies. Zari [3] discussed distinct approaches to biomimicry design that have been developed. A construct for understanding the various prototypes of biomimicry had been developed and utilized to converse on the distinct merits and demerits inherent in each as a design methodology. It is shown that these varied approaches may be directed to different outcomes in forms of overall sustainability or regenerative potential. El-Zeiny [4] in his paper highlighted that biomimicry is an applied science that exhumes encouragement for innovative solutions to human activity related problems through learning from instinctive natural processes, designs, and systems. The extensive and real time application of biomimicry as a method for design continues to be unfulfilled. Also, the core architecture generally uses biology as a library of shapes, but this cannot be itself pronounced as biomimcry since it requires possession of some biological aspects in itself. He also focused on the requirements of interior architecture having certain aspects and case studies related to its applications. Another review of certain applications indicates that biomimicry is the approach to innovation and continued sustainability and real-time core architecture must pursue these. El Ahmar [5], in his research tried to investigate new methods for feasible design, which result from the evolutionary development of living systems from their material characteristics and from their flexible response to dynamic changes in their environment. This is attained through an effort to co-relate the two emerging sciences; biomimicry and computational design, understanding their potential in developing a more long lasting sustainable architecture. Pawlyn [6], in his interesting work picked up one particularly intriguing phase of that search for a new sense of balance – biomimicry in architecture. He defined biomimicry as copying or simulation of the practical basis of biological forms, processes, and systems which generate practical and sustainable solutions. He insisted that we discover not just its potential but also study detailed case studies in architecture where biomimicry has already had an important influence. Insights of Knippers and Speck [7] for the process of evolving scientific forms of biomimetics can convey real-time insights for the architectural field. A simultaneous investigation of both architectural and biological methodologies will reflect key aspects connecting the convergence of these two fields. This thought was based on a research paper which included a case study of adaptable structures of elastic plant movements. Peter [8] in his paper carefully analyzed current global knowledge in an endeavor to see if and how we can achieve a sustainable future. It concluded on the note that we could progress to a sustainable way of living contained by environmental limits within the next few decades, providing for continuous human development and population growth, at the same time adapting to climate change impacts. Watson [9] in his report recommended points such as (i) acceptance and implementation of biomimicry that can renovate design potential for products and processes, and considerably improve the bottom line. (ii) cynicism is a common but containable obstruction in the design process. People involved in the biomimetic process have faced initial skepticism. (iii) Not all ideas may essentially lead to biomimetic innovation. (iv) Sustainability and attractive design may go simultaneously. The goal of Zhao [10] was to identify pioneering elucidations for mechanical lightweight design by using the relative applications of constitutional bionic approaches. An observation of Giant water lily leaf ribs and cactus stem revealed the best possible framework and advanced performance based structural uniqueness which has been used for the bio-inspired design of Lin MC6000 gantry machining center crossbeam. The bionic model is formed using the mimicking analogous network structure, which possesses superior load-carrying capacity as compared to traditional distribution. Results using numerical simulation Finite Element Method (FEM) indicate 17.36% improved precise firmness of the bionic model.

Aly [11] tried to get a deeper understanding of urban identity. It aimed at understanding the different approaches of reconfiguring and recreating distinctiveness in local urban spaces for the purpose of adapting modern design principles and sustainability while taking care of the local characteristics. The guidelines formulated through this process shall be applied to develop Al Morsi Abul-Abbas Mosque Complex public square situated in Alexandria to portray the prominence of the place's identity. Su, Zhang, and Tao [12] had proposed and designed a new composition of artificial joints with bionic joint capsule to prevail over the criticism of present artificial limbs that had previously ignored many critical functions of essential

lubricant and joint capsule. This new structure included three components: therapeutic lubricant, artificial joints, and artificial joint capsule. The lubricant preserved by the capsule can diminish the erosion of artificial joints and also disallows the wear particles to get mixed with body liquid. Fang [13] discussed a theory of earthworm-like robot having fluidic flexible matrix composite (F2MC) segments as controlling segment. It probed a fresh application of F2MC in the domain of bionics. At first, a basic kinematics prototype of robot with earthworm-like locomotion was created which was analyzed to verify the actuation performance prerequisites for the F2MC segment. It was used to create an innovative analytical model for the F2MC segment to calculate approximately the restricted warp due to internal compression.

III. RESEARCH OBJECTIVES

The research objectives of this study were:
a. To understand the concept of biomimicry.
b. To understand the factors involved in biomimicry.
c. To identify major innovations based on biomimicry.
d.To understand the future possibilities using biomimicry.

IV. HYPOTHESES

The null hypotheses were:
a. H_a: There is no relation between the biological or natural processes with recent innovations in science.
b. H_b : There is no dependency between scientific growth and consumer adaptation.

V. DATA COLLECTION

Data were collected from secondary sources which mainly included scientific notes, journals, and publications available on the internet.

VI. DATA ANALYSIS

A. Natural Principles

❖ Biomimicry is inspired by nature's principles. Thus, it becomes predominantly important to know the basic principles of nature which are the building blocks with sustenance capabilities. During the period of our existence, we as humans have been replicating patterns and forms which originated in nature. Leonardo Da Vinci and Pythagoras are some of the many popular inventors who used inspiration from nature for establishing their theories. Confucius, 500 BC, overwhelmingly noted 'He who is in harmony with nature hits the mark without effort and apprehends the truth without thinking' (fig. 1 and Appendices). Some of the intriguing facts about nature are:

❖ Business Inspired By Nature [14] reveals how the solutions to many of our vital business situations are present all around us in nature.

❖ Nature has been dealing with dynamic change for over 3.8 billion years. So, it's most likely to have engineered more solutions than we might even be capable of thinking.

❖ Thriving species and current ecosystems seen in nature are resilient, where existing beings work together forming special niches within variety in nature.

❖ Kevlar is the strongest man-made material which is prepared at around 1000 centigrade involving complex chemical and energy intensive processes and is still no match for webs made by spiders which are tougher than Kevlar at normal room temperature and are built without pollution.

❖ Waste and pollution is a colossal problem for humans. Observing the nature we become conscious that nature does not generate waste since waste for one part of the ecosystem is actually food for another [15].

B. Relation To Life

These are some of factors related to Biomimicry as seen in fig. 2 and Appendices :

❖ **Human factors**

The human factor mainly comprises of the needs and requirements of individuals living in society. This may range from basic everyday requirements from home usage products to customized technology products at an individual level. At a gross level these may be attributed to social requirements which include providing societal needs ranging from products to be used for facilitation of social needs and requirements.

❖ **Business factors**

Business factors include how brands and multinationals can identify the processes and techniques which are commercially feasible, ensure, profitability, and it is technically feasible to produce these products for consumers and the society. Many of the ideas and creativity remain unexplored as there is no guarantee of profits in the long run.

❖ **Technical factors**

Technical factors may include availability of technology needed to produce products and goods at large and commercial levels. The bigger the corporations are, the swifter the movement that can be seen in adapting technology required to produce superior quality of products and goods. Compatibility may be an issue when hardware and software development are concerned. Many of the leading electronic companies across the world have joint capabilities of creating software and compatible hardware to ensure that better consumer electronics are made for worldwide distribution and consumption. Companies such as Samsung Electronics, Sony Corporation, Xiaomi Electronics, and Apple corporation are prime instances of such ventures.

❖ **Biomicry factors**

Recent developments include copying biological processes from evolutionary patterns of species, nature, and adapting them into unique patterns of processes conducive to human necessities. These patterns have been included even in designing of globally acceptable products for consumers, industries, and so on. These developments include creating harmonious products that are ecologically adaptable and commercially viable. Example of such products are automotive designing, electronic gadgets designing, interior decorations, infrastructure material designing, etc.

VII. APPROACHES TO IMPLEMENTATION

There are two basic approaches for adaptation and implementation of biomimicry (fig. 3 and Appendices)

A. Design to biology

This approach is more inclined towards understanding the requirements of individuals and society, searching and identifying solutions or solution patterns engraved in biological processes. This is also known as "Human needs to biology" approach (also known as " design to biology, " or " problem-driven biomimicry ") [16] as seen in Fig. 4 and Appendices)

B. Biology to design

The other identifiable approach is studying the patterns in biological and natural processes and then creating knowledgebase on successful patterns discovered. Later, these patterns can be replicated to form industrial and commercial designs involving processes and products around consumerism.

Different patterns of functions, aesthetics, and experiences begin to appear once a designer can fully imbibe the unaltered experiences of sun and wind, light and shadow, damp and dry, fragrances and putrid etc. This is regarded as the emerging spot for designing objects, spaces, systems, and experiences that stimulate and assist in creating thoughtful innovative solutions [17].

Biological inspiration is altering several methods we can consider about innovation. Many applications including commercial and theoretical applications are already affecting diverse industries and academic institutions at large. According to Fermanian Business and Economic Institute (Point Loma Nazarene University), the founder of The Da Vinci Index can measure different research and industrial activities enthused by solutions found in nature. (Fermanian Business & Economic Institute, 2013).

VIII. REAL INNOVATIONS

We can see some of the evidences from the recent past: (Fig. 5).

A. Velcro

In 1941, Swiss inventor George de Mestral [18] upon returning to his home after a walk with his dog one day discovered that his pants and the canine's fur were full of cockleburs [19]. He analyzed the burs under a microscope, measuring their natural hook-like shape, which eventually led to the creation of the design of the admired adhesive material, Velcro. Velcro is a two-sided fastener with one side having stiff 'hooks' similar to the burrs and the other side having the soft 'loops' similar to the fabric of his pants. The outcome was VELCRO® brand hook and loop fasteners, coined after the French words of 'velour' and 'crochet'.

B. A Paper House for Wasps

Fine Italian endpapers is like the tissue with which wasps make their nests. Many researchers have praised the architectural concept for its uniqueness and precision [20]. An organization known as Benyus's consultancy, Biomimicry 3.8, assists companies by providing them with scientific literature and assorted data also known as "amoeba through zebra" reports that are actually significant natural design theories that

engineers can utilize in their real time design and implementation. The company known as a public benefit corporation has started to expand its services with not only design research into engineering but also providing for intellectual property development for corporate clients.

C. Shinkansen Bullet Train

The inspiration of creating a bullet train without noise pollution and high velocity was inspired from the concept or theory of a fish eating bird known as kingfisher. Trains can literally cause headaches. Eiji Nakatsu, a bird-watching engineer at the Japanese rail company JR-West, during the 1990s had carefully observed how the kingfisher creates just about a ripple when it darts into water in search of a meal [21]. The bullet train's redesigned nose i.e. a 50-foot-long steel kingfisher beak solved the noise problem, reduced power consumption, and facilitated faster speeds [42].

D. Boats, hospitals don shark skin

The concept of such a design was drawn from sharks staying astonishingly clear of algae and other fellow travelers. The shark has a remarkable and unique skin, which is also known as dentricles. Seen through a microscope, it assists them in reducing drag and manages to shove away microorganisms from sticking to their skins. These patterns were simulated by NASA scientists to create drag-reducing patterns known as riblets [22]. They teamed up with 3M to acclimatize the riblets to a thin film to coat the hull of the sailboat Stars & Stripes, which managed to win an Olympic medal. Similar other applications can assist planes, boats, and windmills by diminishing drag and conserving energy [23]. In recent times, another organization branded as Sharklet Technologies, in Aurora, Colorado, created surface materials for hospitals, restaurant kitchens, public bathrooms, and other places that deter bacteria formation.

E. Harvesting Desert Fog

This concept was replicated from the way the Namibian Beetle lifts its back into the air as fog slides the bumps on its shell, seizes water droplets that run down towards its mouth. “The design of this fog-collecting structure can be reproduced cheaply on a commercial scale and may find application in water-trapping tent and building coverings,” as written by the authors on water collection works. Inventors and designers have taken note of a “Dew Bank Bottle,” created by Pak Kitae of the Seoul National University of Technology, which mimics the beetle's water-collection system [24]. It is based on how the morning dew is condensed on it and transferred to a bottle, which can be consumed using a drinking spout attached to it.

F. Nature's Water Filter

This concept was based on the function of a membrane protein that allows water to pass through the cell walls which is popularly known as aquaporin. It was discovered by Peter Agre of Johns Hopkins around 1990. This process has now been imitated for desalination of seawater for creating fresh consumable water which is considered energy efficient. (Balban, A.T. et al., 2006).

G. Experimental Fish Car

The design of a new car was created imitating boxfish, which was shaped like a two door compact, which is considered to be aerodynamically efficient, reducing consumption of car's energy, and preserving fuel for more mileage. This had nothing to do with its wheels, where the shape of the car had more impact on driving it [25]. This method enabled more superior designs to be created in four wheelers category.

H. Hive Mind Manages the Grid

Bees are more than busy; they are nimble too. Despite their limited brainpower, individuals can sense what job the colony needs to do and set at it instinctively. A problem with complex human infrastructure, such as the electrical grid is that its various parts don't talk to each other. Grid components don't monitor the whole grid. Regen Energy turns a company's uncommunicative power-sucking appliances and machines into a network, which is able to balance loads during pricey peak-power periods when electricity is expensive, or worse, unreliable [26]. The company provides controllers that communicate wirelessly with each other to maximize efficiency keeping every bee in the hive in sync.

I. Fin to the Wind

Turbine designing took a leap forward using the ideas relating to how humpback whales carry themselves far and fast in the vast enormous oceans. This swimming prowess comes from a series of rows of warty ridges,

known as tubercles situated on the front edge of their fins. The process of adding bumps to turbine blades was discovered by Frank Fish which enabled reduction of noise of turbines, enabled higher speeds for changing wind directions, and powering boost by almost 20%. (Fish, F. E., et al., 2011). Currently, these fans are now being created for industrial use by Envira-North Systems and for surfboards by Fluid Earth.

J. Watercube

The watercube design had been used by China during the Beijing Olympics in 2008. This design was created by the formation of soap bubbles on the walls of the gaming facility using rugged plastic, having 0.08 inch thickness, trapping hot air from the sun, and then transferring it to the pools for heating them. This plastic material is said to be resistant to sunlight damage, weather changes, is earthquake resistant, and is also dust resistant [27]. It is also avoids smog created during rainy season. Though some argue that it is a purely physical phenomenon and not a biological phenomenon.

K. Gecko Feet Adhesives

An innovative adhesive has been created using the biological way of how Geckos can scale walls and ceilings using firm grip on their limbs. This magical ability is disguised in the form of microscopic hair on the bottom of their toes, which may be small in size but when combined, they are very effective in creating the grip to hold onto surfaces with ease. According to leading scientists working on this phenomenon, it is estimated that each setae in the tiny toes of a single gecko can tentatively carry 250 pounds. There is also the possibility that the directional change do not leave any residue, or tearing, or no extra pressure on the body of the geckos. This led to the development of Geckskin, with an index sized card, an adhesive which is considered to be strong enough to hold around 700 pounds [18]. This form of gecko tape can possibly be an alternative to modern sutures and staples in hospitals.

L. Spider Web Glass

The concept was developed to prevent accidental situations by using web glasses in glass buildings which can put off birds from crashing onto buildings. The design of the web made by certain spiders contains a silk like rope which reflects ultraviolet rays of the sun, seemingly viewed as obstacles to birds who can change their course of directional flights and avert collision (phy.org, 2012). A new version of glass known as Ornilux glass with a similar web pattern with ultraviolet reflection to prevent birds from collision into buildings was developed by German engineers at Arnold Glass [28].

M. A Very Fishy Wind Farm

Inspiration was taken from the way swarms of fishes take advantage of the distances between different swarms for forward movement in water. The discovery of the movement led to the formation of wind turbines by Caltech Field Laboratory for Optimized Wind Energy Flow (FLOWE), in which the turbines are located in such a way that they can take advantage of the air flow amongst them [29]. This also solved problems of efficiency in power management and conserves more energy than traditional wind turbines.

N. Candy-Coated Vaccines

Medicine and vaccine refrigeration are considered to be essential life savers. Normal refrigeration consumes lot of power and energy. An alternative method was discovered from natures' own evolutionary process identifying Tardigrades (millimeters long cousins of Arthropods which take almost 120 years to dry out. This phenomenon has been applied by a company known as Biomatrica, a San Diego based company) for protection of live vaccines during transportation or treatment. They have formally developed "shrink-wraps" and adapted a process known as anhydrobiosis for re-usage and reanimation in water. Another company known as Nova Laboratories, based in Leicester, England has developed a similar technology for securing vaccines in a glassy film made of sugars [30]. This coating helps in keeping the virus active for almost 6 months at temperatures upto 113 degrees Fahrenheit for vaccination in mostly tropical countries.

O. Firefly Lightbulbs

The concept of an improved Light Emitting Diode (LED) with 55% more brightness was inspired from the fireflies' way of lightning their bellies using Photuris light, whose radiance is further amplified due to their anatomy which is sharp with jagged scales, as per a research conducted by scientists from Belgium, France, and Canada [43].

P. SEA SHELLS' ARMOUR PLATING

Armor systems for airplanes and automobile panels have been developed in recent times by adapting the process of protection used by sea snails that have a nano structured armor system that is lightweight but strong enough to resist ocean particles. Nacre was developed using two relatively weaker materials (95% calcium carbonate), and 5% flexible biopolymer [32]. These materials were structured in brick and mortar shape i.e. like coins piled over one another, and the weaker nacre building blocks were replaced by stronger sets which led to the newer version of armor plates for applications such as automobile panels or plane wings [33].

Q. Termite mounds

In extreme hot climates, preserving room temperatures at normal levels may be a concurrent problem. The solution to such a problem was discovered by observing how termite mounds whose inner temperature remains around 87°F (30.5°C) in a 24 hrs duration are formed. The process was adapted in Eastgate complex, Harare, Zimbabwe which has a 3,24,000 square-foot commercial office and shopping complex, two nine-storey office buildings, and a glazed atrium. A passive cooling structure with especially designed hooded windows, thick variable walls, and light colored paints were used to reduce heat absorption [34].

R. Lotus leaf

The hydrophobic properties of lotus leaf to repel water from its surface was used to create exterior coating by a German company, Sto AG. The inspiration was drawn from observations made by Professor Wilhem Barthlott from the University of Bonn in Germany who created the surface after searching for environmentally benign alternatives for toxic cleaning detergents which are harmful for users as well as for the surfaces on which these are used [35].

S. Neural Networks based algorithms

Neural networks refers to different models used in modern computing that derive inspiration from the neuronal connections found in the human brain. Computer scientists have created such networks by creating separate individual processing units which perform different operations mimicking the action of neurons. Such a network is created by connections between these input processing units, similar to the way neurons are connected inside the human brain. Using such model of computing, scientists have been able to replicate the most suitable, flexible, and adaptable programs which can be connected in different ways to perform vital functions. Many such applications of neural networks are more of experimental nature which can learn from historical results and perform tasks that adapt and predict more errorless results such as identifying symptoms and diagnosing different types of cancer and other diseases [36].

T. Digital security - ants swarm to protect computers

As seen in different security gadgets and devices, there are computer based digital ants which move around different networks or computer networks, replicating and identifying different potential threats which may hack, or compromise security systems. On detection of such threats, it forms ants like chains and moves or converges towards such potential areas of threats, which are detected by human users who may then put more investigative thoughts into such intrusions.

U. Genetic Quantum Algorithm - (GQA)

Han & Kim [38] discussed the use of the qubit (the quantum analogue of the classical bit) as the fundamental unit of representation. These qubit registers are utilized to symbolize a linear superposition of different states that may exist in the chromosome. It provides suggestive merits over traditional computation using parallelism (all individuals are processed together or parallel processing), and identifies the requirement for using quantum gates for activating the evaluation function. This algorithm has also been discussed in the purview of solving the 0-1 knapsack problem, a type of NP-Complete problem.

V. Robotics

Robots are often being designed according to biological systems [39]. These are based on those living things that undergo a given selection process tested as successfully active for thousands or more number of years and is still enduring, specifically, evolution. Natural selection is more implicitly directed for more efficient creatures i.e. survival of the fittest, thereby providing nature a brilliant source of ideas to create robots that can perform different types of specialized activities efficiently and effectively.

W) Quantum Genetic Algorithm (QGA)

Rylander [40], specifically talked about notions of the quantum Turing machine, superposition, and entanglement. Again, this quantum technique is sought after to influence the effectivity of quantum computing to be used in evolutionary search. Qubit registers can be used to symbolize individuals in a given population. A typical problem known as travelling salesman and many other algorithms with their extensions have also been resolved by reducing errors in quantum computing.

IX. FINDINGS AND CONCLUSION

The above discussion strongly indicates a relationship between the biological or natural processes with recent innovations in science, rejecting our null hypothesis (H_a). Also, there exists a dependency between scientific growth and consumer adaptation, affirming the acceptance of the alternate hypothesis H_b.

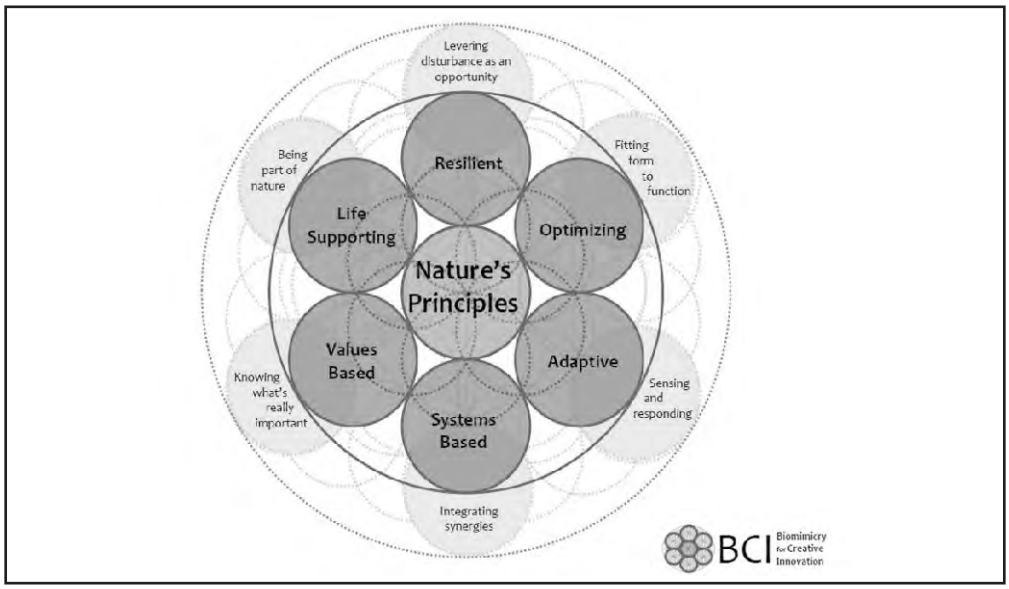
X. FUTURE WORK AND SOCIAL RELEVANCE

Therefore, we can expect more future research work on the aforementioned proposal of deeper research on biomicry applications. This shall have more relevance in terms of academic research and more meaningful for future expectations of the society and consumers from businesses and corporate engaged in creating high quality customized products.

APPENDIX I.

NATURE'S PRINCIPLES

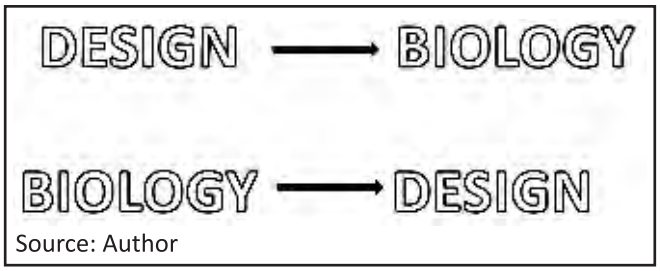
Fig. 1. Nature's Principles



Source: https://thenatureofbusinessdotorg.files.wordpress.com/2012/06/1-business-nature1.jpg [15]

APPENDIX II.

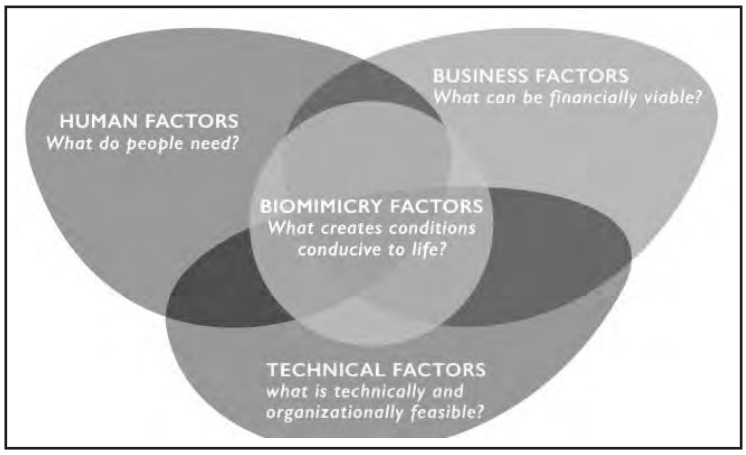
Fig. 2. Approaches to Biomimicry implementation



Source: Author

APPENDIX III.
RELATION TO LIFE

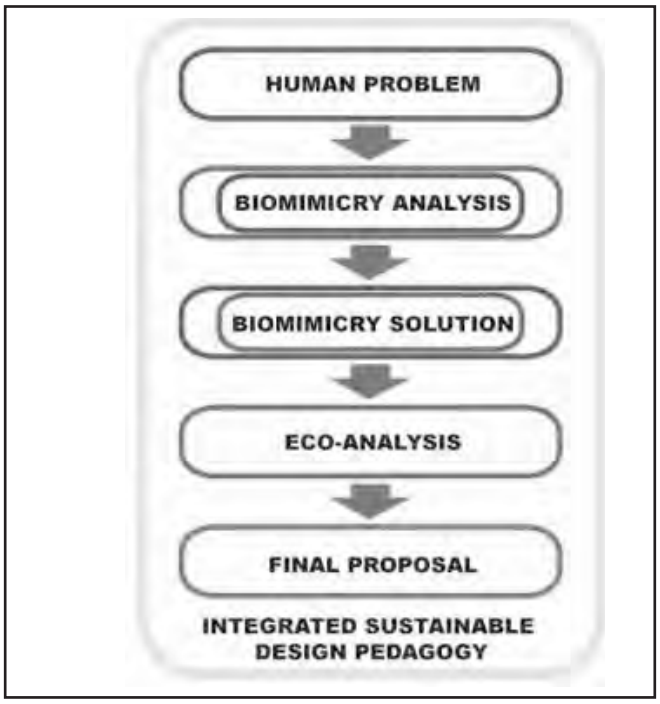
Fig. 3. Relation to Life



Source: https://www.linkedin.com/pulse/why-integrating-biomimicry-packaging-development-paulo-correia[41]

APPENDIX IV.
BIOLOGY TO DESIGN

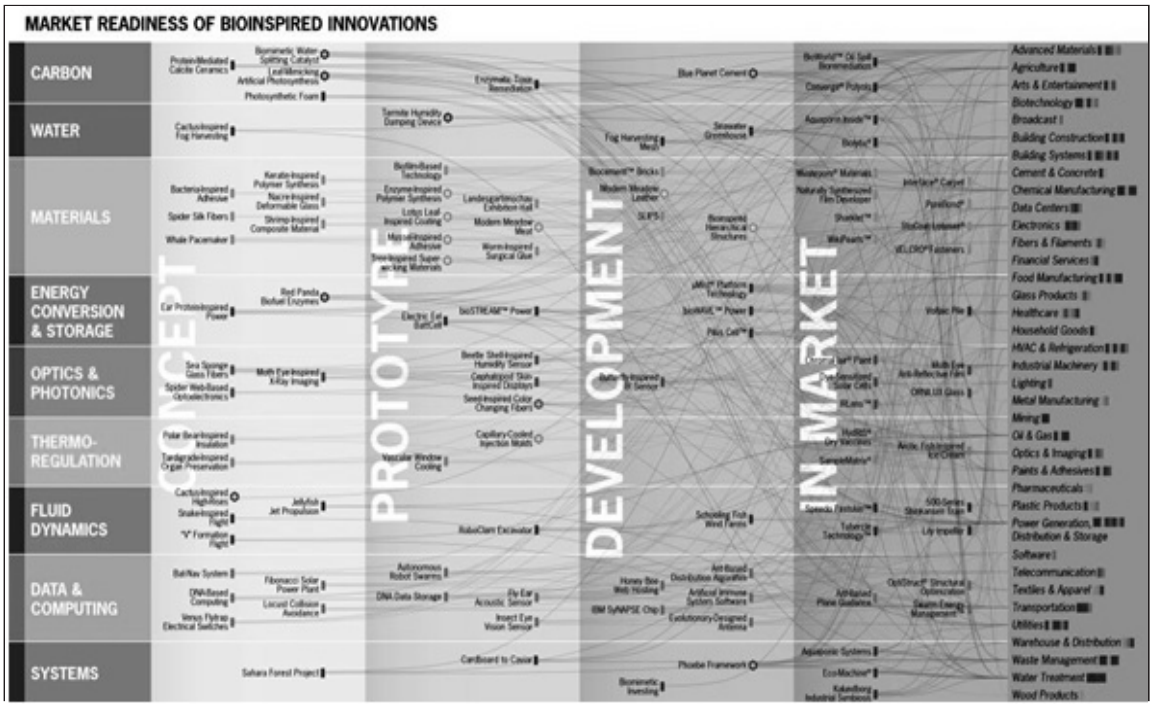
Fig. 4. "Biology to human needs" approach (also known as "biology to design," or "solution-driven biomimicry")



Source: Montana-Hoyos and Saiki, 2008.

APPENDIX V.
READINESS OF MARKETS TO INNOVATIONS IN BIOMIMICRY

Fig. 5. Market readiness biomimicry innovations



Source: https://biomimicry.org/nature-business/
From "Nature and business: Developing a sustainable society together," by The Biomimicry Institute, 2015. Copyright 2017 by The Biomimicry Institute.

REFERENCES

[1] A. Rogers, B. Yoon and C. Malek, "Beijing Olympic Stadium 2008 as Biomimicry of a Bird's Nest," *Architectural Structures*, *ARCH 251*, 2008.

[2] M. S. Todorovic and J. T. Kim, "Beyond the Sci. and art of the healthy buildings day lighting dynamic control's performance prediction and validation," *Energy and Buildings*, vol. 46, pp. 159–166, 2012.

[3] M. P. Zari, "Biomimetic Approaches to Architectural Design for Increased Sustainability," *Proc. SB07 NZ Sustainable Building Conf.*, Auckland, 2007.

[4] R. M. A. El-Zeiny, "Biomimicry as a Problem Solving Methodology in Interior Architecture," *Procedia - Social and Behavioral Sci.s*, vol. 50, pp. 502-512, 2012. doi: https://doi.org/10.1016/j.sbspro.2012.08.054

[5] S. A. S. El Ahmar, "A thesis on Biomimicry as a Tool for Sustainable Architectural Design towards Morphogenetic Architecture," Graduate School Faculty of Eng., Alexandria University, 2011.

[6] M. Pawlyn, Biomimicry in Architecture, 2011, RIBA publishing.

[7] J. Knippers and T. Speck, "Design and construction principles in nature and architecture," *Bioinspiration & Biomimetics*, vol. 7, no. 1, doi: https://doi.org/10.1088/1748-3182/7/1/015002, 2012.

[8] H. Peter, "Entering the ecological age: the engineers role," The Inst. of Civil engineers Brunel lecture series, UK, 2008.

[9] S. Watson, *A case study on Focusing on Quality While Moving to Sustainability: Interfaceflor*, Terrypin bright Green.

[10] L. Zhao, J. Ma, W. Chen, and H. Guo, "Lightweight Design and Verification of Gantry Machining Center Crossbeam Based on Structural Bionics," *J. of Bionic Eng.*, vol. 8, no. 2, pp. 201–206, 2011.

[11] S. S. A. Aly, "Modernization and regionalism: Approaches for sustainable revival of local urban identity," in *2011 Int. Conf. on Green Buildings and Sustainable Cities*, *Procedia Eng.*, vol. 21, pp. 503-512, 2011. doi: https://doi.org/10.1016/j.proeng.2011.11.2044

[12] S. H. Su, J. H. Zhang, and D. H. Tao, "Bionic Lubrication System of Artificial Joints: System Design

and Mechanics Simulation," in *Proc. World Tribology Congr. III, Vol. 2*, Paper No. WTC2005-64211, Washington, D.C., USA, 2005, 697-698.
[13] H. Fang, S. Li, K. W. Wang, and J. Xu, "Locomotion Gait Design of an Earthworm-Like Robot Based on Multi-Segment Fluidic Flexible Matrix Composite Structures," in ASME 2013 Conf. on Smart Materials, Adaptive Structures and Intelligent Syst., Paper No. SMASIS2013-3027, Snowbird, Utah, USA, 2013. doi: 10.1115/SMASIS2013-3027
[14] The da Vinci Index & Biomimicry. [Online] Available: http://www.pointloma.edu/experience/academics/centers-institutes/fermanian-bus.-economic-institute/forecasting-and-expert-commentary/da-vinci-index-b. Accessed on December 26, 2013.
[15] Biomimicry for creative innovation. [Online] Available: https://thenatureofbusinessdotorg.files.wordpress.com/2012/06/1-business-nature1.jpg
[16] C. A. M. Hoyos and T. Saiki, "A Proposal for Biomimicry as Basis for an Integrative Pedagogy for Sustainable ID," Paper presented in the Nat. Edu. Symp., Ind. Designers Soc. of America, Arizona, USA, September, 2008.
[17] Biology to Design [Online] Available: https://biologytodesign.wordpress.com/
[18] G. de Mestral, "George de Mestral Biography.com. [Online] Available https://www.biography.com/people/george-de-mestral-9271201
[19] C. F. Jones, *Mistakes that Worked: 40 Familiar Inventions & How They Came to Be*, Delacorte Books for Young Readers, 2015.
[20] A. K. Goel, D. A. McAdams, and R. B. Stone, *Biologically inspired design*, Springer, 2015.
[21] E. Snell-Rood, "Bring biologists into biomimetics: engineers, chemists and others taking inspiration from biological Syst. for human applications must team up with biologists," *Nature*, 529(7586), 2016, pp. 277-279.
[22] G. D. Bixler and B. Bhushan, "Biofouling: Lessons from nature," Phil. Trans. R. Soc. A, vol. 370, pp. 2381-2417, 2012, 1967. doi: 10.1098/rsta.2011.0502
[23] NASA riblets for stars & stripes.[Online] Available: http://www.nasa.gov/centers/langley/news/factsheets/Riblets.html
[24] A. R. Parker and C. R. Lawrence, "Water capture by a desert beetle," Nature, vol. 414, no. 6859, pp. 33-34, 2001. doi: 10.1038/35102108
[25] M. Ramirez, "Insights into ecodesign practices amongst the world's largest carmakers," Communication présentée au 16th ERSCP Eur. Roundtable for sustainable Consumption and Prod., Istanbul, 2012.
[26] Hedges, W. P., U.S. Patent 4 247 786, 1981.
[27] T. Button, "Biomimicry: A source for architectural innovation in existing buildings," Rochester Inst. of Technol., 2016.
[28] N. Owano, *Birds can see web-inspired Ornilux glass*. [Online] Available: https://phys.org/news/2012-08-birds-web-inspired-ornilux-glass.html
[29] Y. Bazilevs, A. Korobenko, X. Deng, and J. Yan, "Novel structural modeling and mesh moving techn. for advanced fluid–structure interaction simulation of wind turbines," *Int. J. for Numerical Methods in Eng.*, vol. 102, no. 3-4, pp. 766-783, 2015. doi: 10.1002/nme.4738
[30] H. C. Lee and F. Tirnady, *Blood evidence: How DNA is revolutionizing the way we solve crimes*, NY: Basic Books, 2003.
[31] R. Bogue, "Recent innovations in adhesive technol.," *Assembly Automation*, vol. 35, no. 3, pp. 201-205, 2015. doi: https://doi.org/10.1108/AA-10-2014-81
[32] H. D. Espinosa, J. E. Rim, F. Barthelat, and M. J. Buehler, "Merger of structure and material in nacre and bone–Perspectives on de novo biomimetic materials," *Progress in Materials Sci.*, vol. 54, no. 8, pp. 1059-1100, 2009. doi: https://doi.org/10.1016/j.pmatsci.2009.05.001
[33] "Nature gives a lesson in armor design," Eve Downing, Inst. for Soldier Nanotechnologies , 2005 [Online] Available: http://news.mit.edu/2005/seashells.
[34] J. Goss, *Biomimicry: Looking to nature for design solutions,* Washington, DC: Corcoran College of Art + Design, 2009.
[35] A. Solga, Z. Cerman, B. F. Striffler, M. Spaeth, and W. Barthlott, "The dream of staying clean: Lotus and biomimetic surfaces," *Bioinspiration & biomimetics*, vol. 2, no. 4, S126, 2007. doi: 10.1088/1748-3182/2/4/S02
[36] S. Robin, "5 Examples of Biomimetic Technol.." [Online] Available: https://www.lifewire.com/examples-of-biomimetic-technol.-2495572
[37] J. Heimbuch, "New biomimicry in digital security - Ants swarm to protect comput.," TreeHugger, 2009. [Online] Available: https://www.treehugger.com/clean-technol./new-biomimicry-in-digital-security-ants-swarm-to-protect-computers.html
[38] K. Han and J. Kim,"Genetic quantum algorithm and its application to combinatorial optimization problem," in Evol. Computation. Proc. of the 2000 Congr. on July

16-19, vol. 2, IEEE, pp. 1354-1360. doi: 10.1109/CEC.2000.870809
[39] R. C Arkin, *Behavior-based robotics*, The MIT Press,1998.
[40] B. Rylander, T. Soule, J. Foster, and J. Alves-Foss, Quantum evol. programming. In Proc. of the 3rd Annu. Conf. on Genetic and
Evol. Computation (pp. 1005-1011). Morgan Kaufmann Publishers Inc., July, 2001.
[41] P. Correia, "Why integrating biomimicry in a packaging develop. structure?," [Online] Available: https://www.linkedin.com/pulse/why-integrating-biomimicry-packaging-development-paulo-correia
[42] Example of biomimicry design. [Online] Available: https://sites.psu.edu/fkm5030biomimicrydesign/2015/04/11/shinkansen-bullet-train/
[43] E. Widder, Bioluminescence. In Adaptive mechanisms in the ecology of vision, Springer, Netherlands, 1999, pp. 555-581.

About the Author

Sandeep Bhattacharjee is Assistant Professor, Management and Applied Analytics at Amity University, Kolkata, India. He was previously working as Assistant Professor of Marketing with Usha Martin Education & Solutions group. He has more than nine years of experience with more than eight years in academics & has a year of corporate experience. He qualified for NET(UGC) in Management in 2012. His previous experience includes working at Indian Institute of Management, Calcutta as a teaching associate for a year & half, in the domain of neural networks, data mining, and corporate social responsibility. His research areas include applied data -mining in marketing and other social areas of development. He also conducts training on SPSS, R studio, and console based computational and statistical modeling for academics.