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Sustainable Innovative Materials for Interior Architecture Using Biomimicry

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ABSTRACT. *Over the years, man has been on a quest to discover solutions to challenges facing the world. Biomimicry is among the emerging discoveries which offer a lot of potential for solutions to world environmental challenges, especially in the area of sustainability. This paper reviews some ways in which biomimicry has been sustainably applied in interior architecture. A number of plants and animals were identified as models whose natural characteristics have been mimicked and applied to interior spaces. Among the specimens identified is the shark whose skin has been used as biomimetic model for a germ resistant surface material. The samples presented in this paper are sustainable and offer good options for addressing environmental challenges. This paper thus calls for more research to be done with a view to finding other sustainable biomimetic innovations which can be applied to our interior spaces.*

Keywords: Biomimicry, Sustainability, interior space, innovation, application

1. INTRODUCTION

Various challenges abound in the world today which touch different aspects of human and environmental life. From health to transportation, construction to climate change, waste to environmental degradation, the world's problems have been on the increase. Over the years, man has been on a quest to discover solutions to these challenges. Responses to these problems have brought about interesting discoveries in the fields of art and science. Biomimicry is among the emerging discoveries which offer a lot of potential for solutions to world environmental challenges.

According to the Biomimicry Institute, biomimicry is the science and art of emulating nature's best biological ideas to solve human problems. Nature here is an all-inclusive word which includes animals, plants and even microbes. Biomimicry gets its name from two Greek words; bios, meaning life and mimesis meaning to imitate [1]. Meanwhile, the Biomimicry Institute has stated its goal to be creation of products, processes, and policies—new ways of living—that are well-adapted to life on earth.

With biomimicry, exciting solutions are emerging which have the potential to address issues of sustainability. This is because nature has, over millions of years, been able to discover appropriate, long-lasting and workable solutions to the problems that bedevil mankind today. Advocates of biomimicry have argued that the earth has had over 3.85 billion years of evolution to shape the designs of the natural environment in the best way that is suited for the survival of itself and of its inhabitants [2]. Examples of how nature has taken care of problems which man is grappling with today can be seen all around us. For instance, astronomical amounts of energy are expended every year in our buildings just to create conducive indoor temperatures, yet termites are able to build mounds with comfortable interior temperatures and yet zero fossil fuel consumption. It is very obvious therefore that nature indeed has a lot to teach us if only we are willing to learn.

Janine Benyus, who founded the Biomimicry Institute, makes this profound statement: “Nature is imaginative by necessity, and has already solved many of the problems we are grappling with today” [3]. Thus more and more experimental studies are looking into the world of plants and animals all in an effort to bring out designs which can complement nature rather than destroy it.

Biomimicry, though seemingly a recent terminology, has actually been practiced by man for hundreds of years. Some of the greatest minds in history, from whom wonderful innovations were born, received inspiration by observing the systems and creations of nature. An early example of such is Leonardo da Vinci who developed the idea of enabling humans to fly by getting inspiration from birds. Many years later, the Wright brothers also received the same inspiration through the study of birds and were able to draw up plans for developing a human ‘flying machine’. The ideas were eventually brought to fruition with the creation and flying of the first airplane in 1903 [1].

Today’s scientists, designers and architects have also seen the endless inspirational ideas which nature offers. Within the architectural discipline for instance, new innovative ideas have emerged on ways to apply biomimicry to solve problems such as indoor thermal comfort, hygiene, aesthetics, durability, lighting and a host of others. This paper has evaluated some of these biomimetic samples from nature which have found application in interior spaces and which have positive implications towards addressing sustainability in our buildings.

1.1 Problem Statement

With the many challenges facing the world today, especially in the area of environmental degradation and depletion of natural resources, there is a need for man to go back to the study of nature, not just for the purpose of learning about it but rather for the purpose of learning from it [1]. The knowledge which man can obtain from nature is immeasurable and this knowledge can be applied to virtually every area of human and environmental life. Biomimicry emerges as a very good and exciting option open to architects and designers for dealing with sustainability in design of buildings and interior spaces.

Considering the various studies done on biomimicry and the innumerable potentials it offers for interior spaces, there is a need for the findings to be collated and presented in a detailed framework guide for ease of application by architects and designers. That is what this paper has attempted to do.

1.2 Aims and Objectives

The aim of this research paper is to collate examples of sustainable biomimetic samples which are suitable for interior spaces and to present them in a detailed framework so that architects and interior designers can make reference to them when the need arises. The aim will be achieved through a number of objectives which are:

1. To identify natural specimens from nature which have been used as biomimetic models.
2. To identify the unique inspirational characteristics of these specimens which have been adopted to provide solutions for design needs in interior spaces.
3. To consider the sustainable characteristics of each of these specimens.
4. To draw up a tabled framework of the specimens, their characteristics and possible areas of application in buildings and interior spaces.

1.3 METHODOLOGY

The methodology used in this paper is purely qualitative and basically relied on documentary survey. This involved a review of related literature from journal articles, thesis, books and other on-line data sources.

2. LITERATURE REVIEW

2.1 BIOMIMICRY: A GENERAL OVERVIEW

Many inspirational sources are available from which designers get numerous solutions to various challenging problems. One of such sources is nature. A comprehensive study of plants, animals and other living organisms with a view of understanding their workings and methods of addressing environmental challenges has become a current trend which many designers are pursuing. This practice, known as biomimetics, was first introduced by Otto Schmitt in the 1950s [4].

Biomimicry emerges as a great resource within the sphere of design and innovation, for the creation of sustainable projects. With biomimicry, designers are now able to develop projects that are environmentally friendly, resource efficient, cost effective while at the same time able to promote output of workers. Biomimicry also has the potential to impact positively in the areas of education and health.

Biomimicry should however be seen not as a style in itself but as an instrument for design development. El-Zeiny (2012) points to the fact that biomimicry is more than just copying or replicating an organism or system but rather it is a careful scrutiny of the organism or ecosystem in order to obtain its fundamental design principles which are then deliberately applied in emerging technology and designs. He insists that in biomimicry, biology is the central instrument which must be utilized for solving problems and arriving at a purposeful design. The question behind every biomimetric design should be "how would nature do it?" [5].

Various literature studies have pointed to diverse ways in which the process of biomimicry can be applied in design. Among the different options available, two possible approaches stand out. These have been classified by El-Zeiny (2012) and Yurtkuran et al (2013) as the problem-based approach (Top –Down Approach) and the solution-based approach (Bottom-Top Approach).

The problem-based approach proposes that real problems should first be identified in existing or proposed designs and then solutions looked for in nature to solve the problem while the solution-based approach seeks to identify a definite quality or characteristic in an organism or within the ecosystem and then look for how to incorporate that quality into a design in such a way that it responds to a human need. [5]; [4].

Yurtkuran et al have also stated that for the various processes to work, it becomes essential to set up a framework for the application of biomimicry in design. This idea for a framework is supported by Zari (2007) who suggests three elements upon which to base a design according to biomimicry model. These are: organism, behavior and ecosystem. Zari goes further to explain that a design can be designed according to the features and qualities of an organism, the behavior and workings of an organism or the entire ecosystem of an organism and its surroundings. All three elements can be reproduced and used to develop a design [18].

Royall (n.d.) meanwhile, asserts that nature has the potential to serve as a biomimetic instrument in three possible ways: as mentor, as measure and as model. Nature as a mentor essentially means that nature is the teacher and we as its students get to learn from what nature has to teach us. Nature as measure sets nature up as a yardstick for assessing how well our designs stand up according to ecological standards. Nature as model presents nature as a kind of prototype offering us different forms and processes which we attempt to copy [20].

3. SUSTAINABLE BIOMIMETIC EXAMPLES APPLIED TO BUILDINGS AND INTERIOR SPACES

Biomimetic examples in buildings are many and have been used to address various issues such as thermal comfort, hygiene, finishings, lighting and durability among many others. The following examples are ways in which sustainable applications have been developed using bio-mimicry for use in buildings and interior spaces.

3.1 Human Skin - Biomimetic Application: Window Insulation

The skin is known to be the largest organ of the human body (Fig.1). According to Rankouhi (2012), it makes up 15-20% of body weight. Skin plays a number of important functions in the body which include protection, excretion and enabling the experiential sensations of touch and feeling. Another very important function of skin is that of maintaining body heat and regulating fluid. This occurs when there are increases in environmental temperature. The blood vessels (Fig.2) close to the skins surface respond by dilating, leading to increased loss of body heat through convection. The reverse happens when the skin is exposed to cold. There is contraction of the blood vessels as the body tries to maintain its temperature; thus less heat is lost to the environment [6] [17].

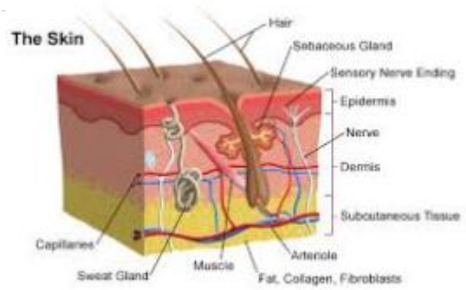


Fig-1: Section through the Human Skin

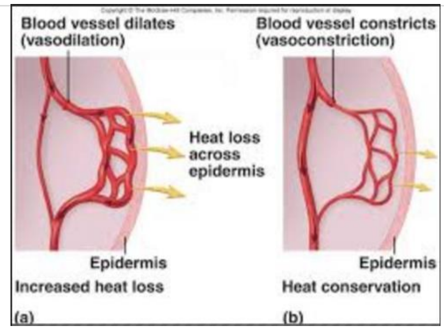


Fig-2: Dilated and Constricted Blood Vessels

A team of researchers at the University of Toronto led by Professor Ben Hatton drew upon the skins' temperature regulatory ability to address the problem of heat loss in buildings through windows. Considering that as much as 40% of energy is lost through windows, the team applied the biological concept explained above to minimize heat loss in winter and to maintain low temperatures in buildings in summer [6].

According to Freeman, their solution involves attaching transparent, malleable sheets of elastomer to normal regular glass window panes. The elastomer sheets, which are made from polydimethylsiloxane (PDMS) have small conduits running along their length. These conduits permit room temperature water to pass through (news.engineering.utoronto.ca) in much the same way that blood vessels transport blood. By so doing, temperatures can be cooled by as much as 7-9 degrees. These sheets can be used effectively at both small and large scales (Fig.3).

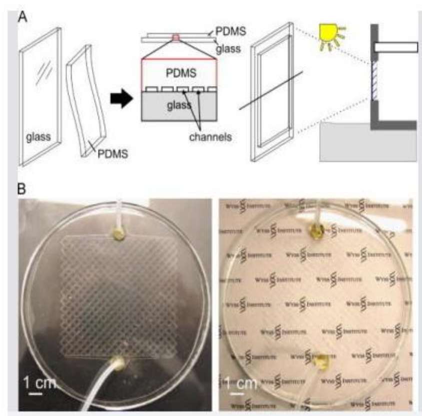


Fig-3: A Schematic of the Composite Window Structure
B. The Artificial Vascular Network Layer

3.2. Shark Skin – Biomimetic Application: Sharklet Surface Texture

Sharks are a well-known marine wildlife with very clean skin. Their skin is made up minute tooth-like features called "dermal denticles or placoid scales [7]. These tiny scales help the shark in a number of ways: they offer protection for the shark from predators, they aid the shark to move sleekly though water with minimal friction and they also prevent marine organisms from attaching themselves to the shark's skin, a phenomenon known as bio-fouling.

By studying the ability of shark skin to avoid bio-fouling, a team of researchers from the University of Florida were inspired to create a material with a structured underlying layer which they called Sharklet AF (Fig.4) the material is potentially similar to the placoids found in shark skin [7]. This synthetic surface material hinders the growth of disease causing microbes. Sharklet technologies have been able to produce these film- based surface protection products to be applied to surfaces which might likely be exposed to germs and bacteria such as in hospitals and public restrooms. Potentials exist for creating workshop mats from these skins whose surface adhesion properties can be enhanced by applying adhesive to the back side of the skins.

The products are free of disinfectants, chemicals and toxins which are harmful to the environment, and rely on the Sharklet pattern alone to inhibit bacterial growth . This makes them a viable and sustainable product.

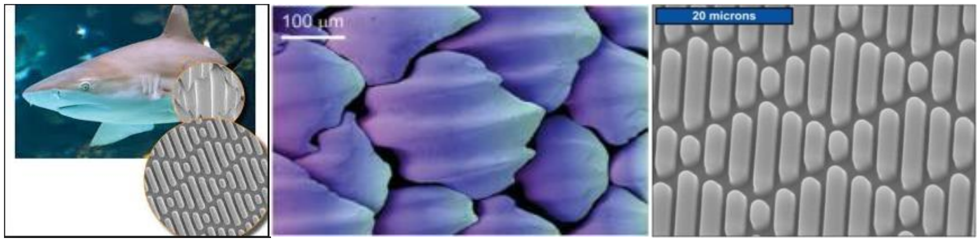


Fig-4 (a) Image of a shark skin showing the details of placoid scales. (b) SEM image of a Sharklet AF pattern that mimics that of a shark skin.

3.3.Gecko Feet – Biomimetic Application: Dry Adhesion Geckskin

The gecko is a wall climbing creature much like a lizard with an amazing ability of gripping surfaces with the skin of its feet (Fig.5) this gives it the unique advantage of clinging to all types of surfaces, both rough and smooth, and also of being able to detach itself at will. Very minute hairs found on the feet of the make this possible. According to Das et al (2015) the foot of a Tokay gecko has about 5000 tiny features (setae of mm2) which enable it to produce 10N adhesive force with approximately 100 mm2 of pad area 42. Das et al (2015) also explain that the strong adhesive force does not impede its movement because of the gecko's ability to curl and flake its toes while attaching and detaching, thus enabling it to move with ease [8].

Drawn from the inspiration of the gecko, scientists have sought to make materials which have dry adhesion qualities much like that of the gecko. The TacTiles introduced by Interface in 2006 is an example of one such product (Fig.6). This glue-free installation system for modular carpets is probably one of the first known biomimetic building products to be introduced into the market [9]. TacTiles have flexible backing systems which hug the floor, creating dimensional stability without glue and enabling the tiles to connect to each other with nothing sticking to the subfloor (interface.com). Hu adds that these products have an advantage of being environmentally friendly and having ease of application when compared to other locally used adhesives used in carpeting [9].

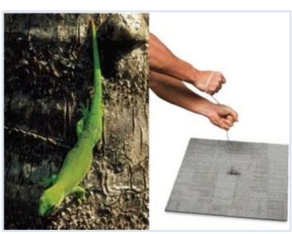


Fig-5: Gecko

Fig-6: materials like the gecko

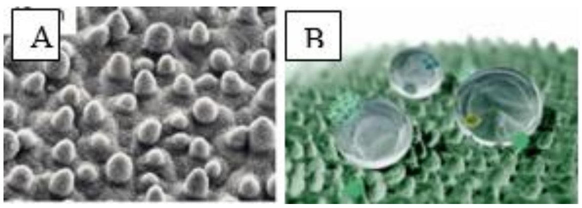
Another product is the synthetic 'geckskin', a new super adhesive based on the mechanics of gecko feet. The Geckskin device produced by scientists and biologist at the University of Massachusetts Amherst has a maximum force of 700

Fig-7: synthetic 'geckskin'

pounds and is able to adhere to very smooth surfaces such as glass [8]. This synthetic skin can easily attach and detach everyday objects such as televisions or computers to walls (Fig.7). It can also be used for medical, industrial, clothing and home appliances, Geckskin is an ideal sustainable product which is reversible, renewable, and biodegradable [11].

3.4. Self-Cleaning and Water Repellant Plant Leaves - Biomimetic Application: Self –cleaning Paints

Certain plants have been known to have water repellent tendencies. One common example is the lotus plant. Both the flower and leaf of the lotus plant have a rough, bumpy exterior which naturally wards off dust and dirt thereby creating a clean surface. The smallest of wind drafts are able to cause a slight change in the angle of the plant which in turn enables dirt to be removed without much effort [1]. Dirt is also carried along with any water droplet that rolls of the leaf (Fig.8, 9).



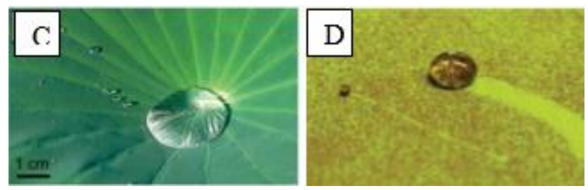


Fig-8: A&B. Clsoe-up of a lotus leaf. The roughness of the leaf surface results from the co-existence of micrometer sized bumps and nanoscale hair-like structures. **Fig-9** C. Water dropletrs rolling on a leaf. Fig. 9. D. Water drop collecting dirt from the surface of a lotus leaf.

This water repellant tendency became the focus of the German company, Ispo, who conducted a research on it and were able to emerge with a paint having similar properties. The paint (Fig.11) employs a micro-structure modeled after the hydrophobic leaves of the lotus plant which minimizes the contact area for water and dirt making it naturally resistant to the growth of mold, mildew and algae [12] (Fig. 10). According to Buczynski, this paint is not only cost effective but is also environmentally friendly thus making it a sustainable product. The idea has led to the development of other building materials such as paints, tiles, textiles and glass which can be used with minimal maintenance and material replacement costs [12].

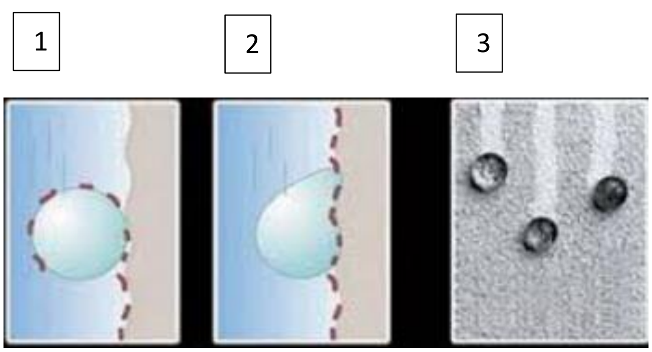


Fig-10:
1. How a raindrop cleans a lotus leaf.
2. The effect of a raindrop on a normal surface
3. The effect of raindrop on a building exterior covered with Lotusan pain

Fig.11: self-cleaning paint

3.5. Squid - Biomimetic Application: Strain Induced Color Changes in Materials

Squids are marine creatures of the cephalopods family (Fig.12). Many cephalopods like squid and cuttlefish are able to quickly blend in with their surroundings by changing color. This process is made possible by chromatophores, cells that contain a sac filled with pigment. When the squid's muscles surrounding a cell contract, the sac is squeezed to appear larger, creating an optical effect that makes the squid look like it is changing color [13].

Figure-12: changing color squid

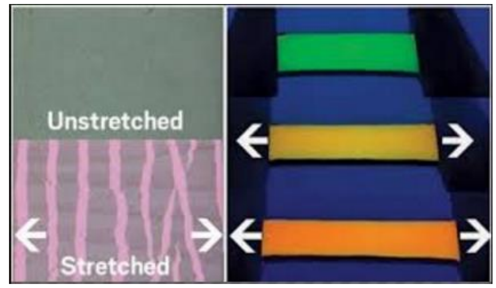


Figure-13: reversibly from transparent to opaque

Drawing inspiration from the squids' ability to change its appearance, researchers have designed polymeric materials that change appearance reversibly in response to mechanically induced folds and deformations [14]. Jacoby goes on to explain the workings of this process by stating that when this material is stretched by 40%, its appearance changes distinctly yet reversibly from transparent to opaque (Figure.13). Thereby the optical changes result from stretch-induced microscopic cracks and folds that trap and scatter light. The material can find possible application as mechanical sensors, optical switches, and color-changing smart windows [14].

3.6. Selaginelia Lepidoplylla- Biomimetic Application: Wooden skin and Marco Wooden Velcro

The Selaginelia Lepidoplylla is an ancient plant which can resurrect after the dry season. The plant can survive decades without water (Fig.14). It is noted for its ability to survive almost complete withering; during dry weather in its native habitat, its stems curl into a tight ball and uncurl only when exposed to moisture [19]. The outer stems of the plant bend into circular rings in a relatively short period of dryness, whereas inner stems curl slowly into spirals due to the hydro-actuated strain gradient along their length.

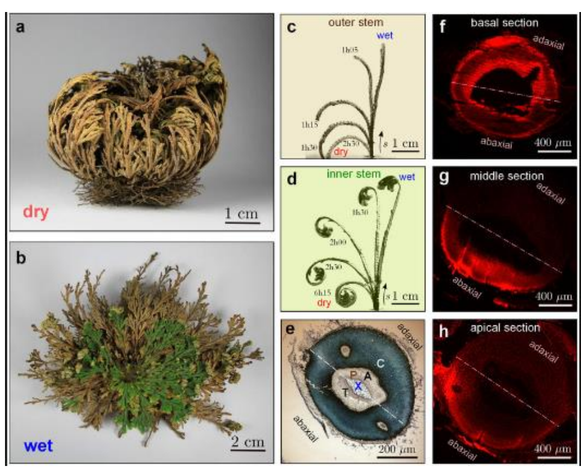


Fig-14: Morphology and composition of the resurrection plant Selaginella lepidophylla.

Inspired by the plant Selaginelia Lepidoplylla, Elaine Ng Yan Ling was able to weave interactive textiles (Wooden Skin and Marco Wooden Velcro) crafted of layers of veneer combined with fabric, dyes and reflective surfaces which react with environmental conditions such as moisture, heat, light intensity or mechanical force to form decorative systems that curl and expand or shrink (the fabricklab.com). The 'macro velcro' tiles are characterized by a large-scale hook-and-loop internal pattern and are cut into a shape that resembles a flower petal; clusters of three form floral sculptures that can be combined for a particularly striking visual effect [10]. They can be applied in interior spaces either on walls or as spatial dividers (Fig.15).

Fig-15: Elaine Ng's Macro Velcro' Tiles

3.7. Termite Mounds- Biomimetic Application: Thermal regulation of interior space

Termites are one of nature's extraordinary engineers. They naturally regulate the internal temperature of their dens by building vertical chimneys to remove heat and gas [15]. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature [16].

A building which has been constructed to operate along these principles is the Eastgate Center in Zimbabwe (Fig.16). This 333,000 square-foot shopping and office complex was constructed with vertical atriums that pull heat up and out [15]. The concrete slabs of the building are kept cool when the night air is pulled in through intake fans. Bonanate explains that though the building doesn't have a conventional air conditioning or heating system, it expends 90 percent less energy to heat and cool by using a ventilation system that cost about one-tenth the price of an air conditioning system in a comparable sized building [15].

Fig-16: Left: Termite Mound, Right: Eastgate Centre- Zimbabwe

3.8. Spider's Web- Biomimetic Application: UV coated Glass Façade

It has been estimated that a large number of birds are killed each year in North America as a result of collisions with glass on man-made structures. This is because of the reflective and transparent nature of glass which cannot be seen by the birds. To prevent this occurrence it became necessary to look for ways to make these transparent glasses visible to birds. To do this, researchers went back to study UV reflective silk strands of some spiders' webs (Fig.17). Birds have the ability to see an ultraviolet spectrum thereby enabling them to avoid flying into the web. From the principles of the web, Ornilux Glass was developed. This glass has a patterned UV coating which mimics the design of a spider web and yet remains transparent to the human eye (Fig.18).

Ornilux is available as double-glazed insulated glass with either a low-E or solar protective coating and can be found in buildings across Canada and the U.S., including The Bronx Zoo's Center for Global Conservation and a renovation in progress at the Great Neck Library [15,21].

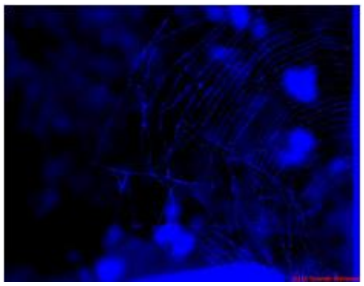


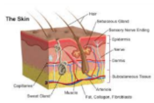
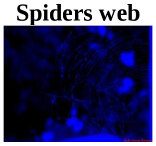
Fig-17: A spider web as seen by a bird, reflecting UV light.

Fig-18: Ornilux Glass

4. Discussion of the findings:

This study has focused primarily on evaluating some ways in which biomimicry can be applied in the field of interior architecture. Though biomimicry is a relatively new term in interior design, sustainable bio-inspired products and materials are on the increase. Biomimicry when used as a problem solving methodology has the potential to address innumerable issues in our buildings and interior spaces. For instance, the samples which have been presented in this paper have shown that biomimicry can be applied to a wide range of areas to address innumerable issues. Indoor thermal control is one such area where unnecessary energy demands for heating and cooling can be significantly reduced by applying the principles of biomimicry. Thus we can say that the principle of biomimicry helps to provide more innovative and smarter designs that are connected to the natural environment The various selected natural models discussed in this paper together with their unique qualities, potential areas of application and measure in which sustainability has been addressed have been categorized in the table below.

Table-1: Summary of Biomimetic Samples, Characteristics, Areas of Application and Possibilities for Sustainability

Nature'sModel	**Unique Quality of Unique**	**Biomimetic Product**	**Characteristic of Product**	**Broad Area of Application**	**Environmental Solutions/ How Sustainability Is Addressed**
Human Skin 	Heat regulation through blood vessel dilation and constriction	Optically clear, flexible elastomer sheets, bonded to regular glass window panes	Water filled channels running through sheets to maintain temperature	Window Insulation	Less energy loss 7-9 degrees additional cooling
Shark skin 	Ability to avoid bio-fouling	Sharklet Surface Material	Hinders the growth of disease causing microbes	For hygiene - To be applied to surfaces exposed to germs and bacteria	Product is free of pollutants such as dis-infectants, chemicals and toxins
Gecko Feet 	Unique ability to grip all surfaces	TacTile	Flexible backing systems which cling to floor, without glue	Adhesive – for carpets	Virtually zero VOC's, 90% lower environmental footprint than traditional carpet adhesives
Gecko Feet 	Unique ability to grip all surfaces	Geckskin	Is able to adhere to very smooth surfaces such as glass	Adhesive – for wall appliances	100% renewable resources natural fibers as well as natural rubber. Reversible, renewable, and biodegradable.
Lotus Plant Leaves and Flowers 	Self - cleaning ability	Wall paints (tiles, textiles, glass, etc.)	The paint is naturally resistant to the growth of mold, mildew and algae	Hygiene, self-cleaning paint	Lotusan- a paint which can reduce environmental impact and is cost effective
Squid 	Color changing ability	Materials with color changing ability	The material changes its appearance distinctly yet reversibly from transparent to opaque	Smart materials: mechanical sensors, optical switches, color-changing smart windows.	Ability of automatically changing color make it cost effective material
Selaginelia Lepidoplylla 	Ability to resurrect after the dry season	Wooden Skin and Marco Wooden Velcro	Ability to curl, expand or shrink after exposure to environmental conditions	Interior Décor – used on walls or as spatial divider	Recyclable and environmental friendly
TermiteMound 	Naturally regulates internal temperature of dens	Eastgate Centre Zimbabwe	Vertical atriums pull heat up and out	Thermal regulation of interior spaces	90% less energy consumption 10% cost of air-conditioning system
Spiders web 	UV reflective silk strands	UV coated glass	Visible to birds yet transparent to human eye	Glass façade - bird strike protection	Low-e coatings providing energy efficiency thereby significantly affecting the overall heating, lighting, and cooling costs of a building.

5. Conclusion and Recommendations

Sustainability has become a major issue which is being discussed globally as the world seeks solutions to the many problems confronting it. For sustainability to be adequately addressed, natural solutions from nature must be sought for. This requires designers and architects to look for ways to include biomimicry in their designs as biomimetics not only provides solutions to many of earth's current challenges but also offers exciting prospects for future design innovations.

This paper has examined a number of natural organisms which have special properties that have found biomimetic applications in buildings and interior spaces. These properties have been applied to address design solutions such as window insulation, indoor thermal control, smart color changing windows, germ resistance and self-cleaning paints among others.

Though biomimicry innovations are as yet quite limited within the field of interior architecture, it is believed that many more options abound which future research is likely to uncover. This paper thus calls for more research to be done with a view to finding other sustainable biomimetic innovations which can be applied to our interior spaces.

REFERENCES

1. Vierra, S. (2016, September 09). Biomimicry: Designing to Model Nature. Retrieved 28/12/2016 from https://www.wbdg.org/resources/biomimicry-designing-model-nature
2. Benyus, J. (2009). Biomimicry - Innovation inspired by nature. New York: Harper Collins.
3. Benyus, J. (1997). Biomimicry-Innovation inspired by nature. New York; harper Collins
4. Yurtkurana, S., Kırlı, G., Taneli, Y. (2013). Learning from Nature: Biomimetic Design in Architectural Education. Social and Behavioral Sciences 89, pp 633 – 639
5. El-Zeiny R.M.A. (2012). Biomimicry as a problem solving methodology in interior architecture Social and Behavioral Sciences 50, pp 502 – 512
6. Freeman, R. (2015, July 30). Geckos, Human Skin and Whale Fins: How Biomimicry Inspires Green Building. Retrieved 31/12/2016 from https://www.poplarnetwork.com/news/geckos-human-skin-and-whale-fins-how-biomimicry-inspires-green-building
7. Genzer, J., & Marmur, A. (2008). Biological and synthetic self-cleaning surfaces. MRS Bulletin, 33.
8. Das, S., Bhowmick, M., Chattopadhyay, S.K., & Basak, S. (2015). Application of biomimicry in textiles. Current Science, 109 (5).
9. Hu, R. (2015). 3 Trends in biomimicry. Retrieved January 3, 2017, from http://www.interiordesign.net/articles/11109-3-trends-in-biomimicry/
10. Hu, R. (2013). Beijing design week 2013 Wuhao presents new work by Mian Wu and climatology by the Fabrick lab (a.k.a. Elaine Ng Yanling). Retrieved 30/12/2016 from http://www.core77.com/posts/25631/Beijing-Design-Week-2013-Wuhao-Presents-New-Work-by-Mian-Wu-n-Climatology-by-the-Fabrick-Lab-aka-Elaine-Ng-Yanling
11. Geckskin. Retrieved 30/12/2016 from https://geckskin.umass.edu/
12. Buczynski, B. (2013, February 02). Eco-friendly House Paint inspired by the self-cleaning lotus flower. Retrieved 03/01/2017 from http://ecosalon.com/eco-friendly-house-paint-self-cleaning-lotus-flower/
13. Treacy, M. (2012, May 3). Color-Changing Squid Inspire Technology that Could finally get Us That Invisibility Cloak. Retrieved 04/01/2017 from http://www.treehugger.com/biomimicry/color-changing-squid-could-inspire-smart-clothing.html
14. Jacoby, M. (2016). Strain- induced color changes in biomimetic materials. Concentrates, 94 (29), pp 9.
15. Bonanate, L. (2015, July 31). Biomimicry: Designs By Nature. Retrieved 28/12/2016 from http://greenhomenyc.org/blog/biomimicry-designs-by-nature/
16. Doan, A. (2012). Building in Zimbabwe Modeled After Termite Mounds. Biomimetic Architecture: Green
17. Rankouhi, A.R. (2012). Naturally Inspired Design Investigation into the Application of Biomimicry in Architectural Design. Master of Architecture, The Pennsylvania State University.
18. Zari, M. P. (2007). Biomimetic Approaches to Architectural Design for Increased Sustainability. Paper presented at the SB07 NZ Sustainable Building Conference, Auckland, New Zealand.
19. Lebkuecher, J., W. Eckmeier (1993). Physiological Benefits of Stem Curling for Resurrection Plants in the Field. Ecology. 74 (4): 1073–1080.
20. Royall, E. (n.d.). Defining Biomimicry: Architectural Applications in Systems and Products
21. Mosaberpanah, M. A., & Khales, S. D. (2013). The Role of Transportation in Sustainable Development. In ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction (pp. 441-448).