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Promoting biomimetic materials for a sustainable construction industry

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This article reviews current knowledge of biomimicry and its potential in the sustainability of the South Africa construction industry through materials selection. Biomimicry is the applied science that derives inspiration for solutions to human problems through the study of nature's designs, processes, and systems. The article evaluates, promotes and encourages the use of biomimetic materials in the South Africa construction industry. An extant literature review was conducted on biomimetic materials, applications and their roles in the achievement of sustainability in the South African construction industry. The study shows that there is a misconception of bioprospected and biopirated materials as biomimetic materials, also, the study found that there are already existing materials that were designed based on biomimicry principles. The paper offers a new approach and strategy to achieving a sustainable construction industry in the South African construction industry through the use and incorporation of biomimetic materials into construction activities. Hence, it is envisaged that new ideas and innovations will be proffered which requires an interdisciplinary collaboration between biologists and other stakeholders in the industry. This study challenges all stakeholders in the South African construction industry on the adoption of biomimicry in their construction practices.

1. Introduction

In the progress towards rapid urbanisation and global economic development, [1] of which the construction industry remains a major driver, statistics has shown that the **industry** contributes heavily towards a gradual but accelerating decline in the world's environment. This is especially true in the construction industry, where forest and vegetation are replaced by the impervious concrete surfaces of roads and buildings.[1] Construction activities have been accused of causing broader problems affecting the environment, including global warming, climate change, land pollution, water pollution, air pollution, loss of diversity, desertification, deforestation and consumption of valuable resources such as fossil fuels, minerals and gravels.[2] It consumes enormous natural resources and energy, produces a large amount of waste and contributes significant amounts of toxic air emissions.[3, 4, 5] Statistics has further shown that the social and environmental impacts of the construction industry is enormous,[6] thereby contributing heavily towards unsustainable development. Globally, the construction industry consumes 40% of total energy produced, 40% of all raw materials and 25% of all timber, and accounts for 16% of total water consumption and 40% of natural resources extracted in industrialized countries.[7, 8] Overall, the construction industry has a significant impact on the environment and society and is a major sector involved tasked with the responsibility to achieving sustainability.[9] However, in South Africa, the shift of the construction industry from the traditional paradigm towards sustainable development in tandem with the global sustainability goals is constrained. One of the constraints identified is the unsustainable construction technologies and practices adopted by the stakeholders, practitioners and policymakers in the industry. This is partly due to the historical development and evolvement of the country from the previous disadvantaged political background.

Humans have since the dawn of time, turned to nature to find food and shelter. As humans' civilization has progressed, nature's roles have grown to be more complex and intricate, becoming a source of inspiration, innovations, and useful ideas.[10] With the onward march of science and technology and the continuing quest for improvement, there is a growing curiosity about the world around us and how best to make things work. By observation, scientists and innovators around the world have gathered invaluable information about how ecosystems function, exploiting resources both efficiently and sustainably. For instance, a more in-depth study of nature reveals robust systems whose performance is as close to perfection as it can be, as nature presents an endless source of inspiration for scientists and engineers from different fields of interest. By responding to its need and finding solutions that work, nature has evolved, as each organism is unique and fully adapted to its own environment.[11] Nature, based on her 3.8 billion years of evolution has however been the supreme role model of efficiency, sustainability, resource utilisation, value creation, propagation, longevity, and collaboration.[12] It is a pointer to the fact that "doing it nature's way" is the gateway to sustainability. This new methodology and thinking pattern will offer sustainable solutions to human problems by using nature as mentor and inspiration, mimicking the functional basis, processes, and systems of the biota (flora and fauna). It was this understanding that led to the term Biomimicry, a new science that studies nature's models and then emulates their forms, process, systems and strategies to solve human problems in a sustainable manner. Biomimicry (also known as biomimetics) is a term coined in 1997 by Janine M. Benyus, an American Biologist, to describe this new field of science. This term was popularized in her book titled "Biomimicry: Innovation Inspired by Nature".

Nature is a rich source of knowledge, and present-day human life has undoubtedly progressed because of our ability to be inspired by nature, and to then innovate solutions to our problems through biomimicry.[13] The field of biomimicry has attracted worldwide interest in the areas of architecture, construction, and engineering, amongst others. This is due to both the fact that it is an inspirational source of possible new innovation and because of the potential it offers to create a more sustainable built environment.[11] While biomimicry can be used specifically as a method of increasing the sustainability of what have created,[14] biomimicry can as well be used in birthing novel inventions and innovations.[15] So far, the application of biomimicry has led to several innovation breakthroughs that are sustainable, few cases of which will be examined in this paper. Therefore, this paper reviews extant knowledge of biomimicry and its potential in the sustainability of the South Africa construction industry through the use of existing literatures. This paper evaluates, promote and encourage the use of biomimetic materials for the sustainability of the South Africa construction industry.

2. Biomimicry: an overview

"We must draw our standards from the natural world. We must honor with the humility of the wise the bounds of that natural world and the mystery which lies beyond them, admitting that there is something in the order of being which evidently exceeds all our competence."
– Vaclav Havel, Former President of the Czech Republic

Mimicking or emulating nature in human endeavours is not a new practice, it is however believed that biomimicry feel it has something novel and important to contribute to the modern world because it encourages an implicitly sustainable approach to industrial innovation.[16] Early humans observed nature and natural phenomena and replicated/ adapted them to their advantage in numerous ways such as shelter and shelter architectures; weapons and defense, including armor, sensors, and alarm systems; and processes related to synthesis and manufacturing.[17] There are also historical records of the practical application of biomimicry before the term was coined and popularised. The following are few historic records of iconic biomimicry/biomimetic applications and innovations:

i. The stable wing designed by Ignaz and Igo Etrich in 1904 was derived from the large (15 cm span) winged seed of Alsomitra macrocarpa, a liana which grows on islands in the Pacific.[18, 19] The seed with its outgrowths functions as a flying wing and can glide for significant distances.
ii. Velcro; an invention derived from the action of the hooked seeds of the burdock plant which caught in the coat of George de Mestral's dog when they were out on a walk.[19, 20] The first use he wanted to put the concept to was a novel type of a zip fastener. While Velcro mimics how burs of a certain plants attach to animal fur, the product itself is made from petrochemicals and is not typically recycled or recyclable, nor does it take into account any of the principles of nature.[21]
iii. Jeronimidis analysed the main toughening mechanism of wood in tension and decided it was due to the orientation of cellulose in the walls of the wood cells, which is commonly at 158 to the long axis of the cells in softwoods. He made assemblages of tubes with various orientations of glass fibre in a resin matrix and showed that this indeed produces the toughest material.[19, 22] In another series of tests, Jeronimidis showed that this structure is weight-for-weight, about five times tougher than anything else in impact (Chaplin et al., 1983; Vincent et al., 2006).[19, 23]
iv. Clement Ader designed and built several steam-powered aircraft (Eole) using the wing design of a bat. He attained a flight of 300 meters, but could not gain control with such a compliant wing.[18, 19]

Biomimicry is an applied science that derives inspiration for solutions to human problems through the study of natural designs, processes, and systems.[24] Also defined as the science of solving problems by emulating natural methods through forms, structures, mechanisms and technologies of natural elements.[25] It is an innovation method that seeks sustainable solutions by emulating nature's time-tested patterns and strategies, such as a solar cell inspired by a leaf. It ushers in an era that is not based on what we can extract from nature, but on what we can learn from her,[26] because it the field belongs to a professional field of innovation studies.

Biomimicry is the conscious emulation of life's genius. The word "conscious" refers to intent- it is not enough to design something without nature's help and then in retrospect say, "this reminds me of something in the natural world". Biomimicry implies conscious forethought, an active seeking of nature's advice before something is designed.[26] Seeking nature's blueprints and recipes is only part of the process; the intent should be to create products, processes, and policies that fit seamlessly within the larger natural system, that embody life's principles. Benyus further informed that the word "emulation" is also carefully chosen in the process of learning from nature because it is more nuanced than mere copying or slavish imitation.[26] Hence, biomimics may study a spider to learn about sensing, fiber manufacture, adhesion, or tensegrity, but not actually recreating the spider. What is being emulated are the design principles and living lessons of the spider. That is, how a spider meets its needs while helping to enhance its habitat is as important to a biomimic as how it spins its silk.[26] Biomimicry is now on the forefront of scientific and technological research, because it brings about novel insights for the synthesis of biologically-compatible, environmentally-friendly and energetically-efficient materials.[27]

2.1 Biomimicry levels and approaches

Biomimicry delivers on triadic levels (form, process and ecosystem) of increasing requirements in other to achieve solutions, designs and innovations that awe in terms sustainable performance.[28, 29] These levels are foundational and fundamental in other to maximise the sustainable benefits Biomimicry offers. They serve as inspiration eyes through which Biomimicry is perceived and subsequently applied to proffer sustainable solutions to human challenges. As posited by Benyus,[26] this triad of natural forms, natural processes and natural ecosystems are levels through which Biomimicry delivers its supreme objective of achieving sustainability wherever it is applied. However, El-Zeiny refers to another levels of classification that are biologically inclined and this has it application in three levels of application such as:

- imitation of organism's features (shape, color, transparency, structure, behavior, motion, modularity);
- imitation of organism-community relationship (survival techniques, group management, communication, sensing and interaction); and
- imitation of organism environment relationship (adaptation, response to climate, source management, waste management).[11]

There are different views to how biomimicry should be applied, as described by Volstad and Boks.[30] These views are divided between reductive/shallow and holistic/deep view. The first refers to the replication of an individual nature process to an industrial level; whilst the second approach aspires to replicate a whole system of products and processes that are interrelated. This approach supports a level of applicability both on individual or at the scale global. Examples of applications for the reductive view include recreating the properties of materials in a laboratory, development of materials, products and systems from nature or creating products with shapes and forms from nature.[11, 30, 31]

Some examples of the replication of nature's biological features are widely spread on multiple sources of information. For instance, Pawlyn indicates two of them, which include: 1) the biomimetic car made by Daimler Chrysler which is shaped in an aerodynamic form, thus reducing the friction and increasing efficiency; and 2) the swimsuit based on shark's skin surface; to provide faster velocities for swimmers.[32]

2.2 Biomimetic misconceptions

There have been great concerns about the growing misconceptions about biomimicry. One of the most important ways to understand this meme is to understand what it is not.[26] Many believed their use of plants to repel mosquitoes and rodents make them practitioners of biomimicry. But, this is nothing close to the practice of biomimicry, which are mere activities found to be contributing to the depletion and resultant extinction of the biota; a clear departure from what biomimicry stands for. In other to clear the confusion, it is important to understand the terms bio-utilisation, bio-assisted technologies, biopiracy, and bioprospecting stands for with respect to biomimicry/biomimetics.

2.2.1 Bioprospecting

Bioprospecting was first defined by Reid et al. and amplified by Shiva as the exploration of biodiversity for commercially valuable genetic resources and biochemical.[33, 34] It is the search and use of biological resources (biona) and accompanying indigenous knowledge essentially for commercial exploitation. Shiva further describes it as a term that was created in response to the problematic relationship between global commercial interests; the biological resources and indigenous knowledge of local communities; and to the epidemic of biopiracy, the patenting of indigenous knowledge related to biodiversity.[34] However, one of the major effects of bioprospecting according to Sandhu is the imbalance in the ecosystem due to excessive exploitation of material resources.[35] This is believed to have resulted in the gradual disappearance of the tropical rainforest of the world that contains more than 50% of medicinal plants. Other effects of bioprospecting among many others are deforestation that increase greenhouse gasses (GHGs) in the atmosphere, climate change, flooding, soil erosion and loss of habitat for millions of species.

2.2.2 Biopiracy

Biopiracy, on the other hand, is a word coined by the North American advocacy group, Action Group on Erosion, Technology and Concentration (ETC Group) - formerly known as Rural Advancement Foundation International; to refer to the uncompensated commercial use of biological resources or associated traditional knowledge from developing countries, as well as the patenting by corporations of claimed inventions based on such resources or knowledge.[36] Biopiracy also refers to the privatization of genetic resources; whether derived from plants, animals, microorganisms or humans -or related knowledge.[37] It is the illegal appropriation or exploitation of genetic, biochemical and ecosystem resources by individuals, organisations and multinational companies without authorisation from the concerned geographical area/community and compensation to them. Social, economic and environmental harm are the potentials of biopiracy if not checked or banned as suggested by Dutfield.[38]

2.2.3 Bio-utilisation and bio-assisted technologies

Bio-utilisation, on the other hand, entails harvesting a product or producer, such as cutting wood for floors or wild-crafting medicinal plants. It is also distinctly different from bio-assisted technologies, which involve domesticating an organism to accomplish a function; for instance, bacterial purification of water or cows bred to produce milk. Whilst, instead of harvesting or domesticating, biomimicry consult organisms; they are inspired by an idea, be it a physical blueprint, a process step in a chemical reaction, or an ecosystem principle such as nutrient cycling.[26]

Therefore, biomimicry is the art of studying a leaf to invent a better solar cell, or a coral reef to make a more resilient company.[26] For instance, it is process of studying the functional basis, processes and systems of lotus leaf, the bumpy surface structure of which is such that dirt particles cannot stick but are rolled off by raindrops, to invent a self-cleaning external paint or surface. It further includes the idea of designing buildings that imitate the structure of termite mounds in order to cool themselves; fabric that can be stuck to furniture and peeled off when in needs of replacement; the adhering mechanism being inspired by geckos, whose foot pads adhere to surfaces without glue, using small doses of static electricity.[39] This trusted sources of inspiration arrives just as our species are counting the casualties of our industrial crash.[26] It is, therefore, noteworthy that while bioprospecting and biopiracy threaten the existence of the natural environment through continuous exploration and exploitation, biomimicry captures our imagination because of its promise, because it is at once pragmatic and culturally transformative. At its most practical, as expanded by Benyus, biomimicry is a way of seeking sustainable solutions by borrowing life's blueprints, chemical recipes, and ecosystem strategies.[26] At its most transformative, it brings us into right relation with the rest of the natural world, as students learning to be a welcome species on this planet.

2.3 Biomimetic innovations/applications in the construction industry

"Nature, imaginative by necessity, has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. They have found what works, what is appropriate and most important, what lasts here on Earth."

–Janine M. Benyus, Innovation Consultant, and Co-Founder Biomimicry 3.8

Biomimetic approaches have considerable potential in the development of new high-performance materials with low environmental impact. Biomimicry innovation methods can help construction professionals and it associated partners to create products and processes that are sustainable, high-performance, save energy, reduce materials cost, and redefine and eliminate waste and subsequent environmental degradation.[40] Already, biomimetic approaches have provided an inspiration for evolving new techniques/processes to many engineering problems. Several examples of biomimetic innovations have been identified with varied applications in the construction industry. Such applications span the field of engineering, design, architecture, construction, aviation, medical sciences, agriculture and transportation amongst others. AskNature (www.asknature.org), an initiative of the Biomimicry Institute, created with the goal of making the act of asking nature's advice a normal part of everyday inventing. Since its launch in 2008, AskNature has now grown to be the world's most comprehensive catalog of nature's solutions to human design challenges.[41] This online library/database features free information on more than 1,800 nature-inspired technological innovations, ideas and its corresponding applications. Table 1.0 below presents few existing biomimetic innovations, applications, natural source and their corresponding biomimetic features. However, few of the products that have a high significant usage value will be further discussed. This is in line with the paper objective, which is aimed to promote and encourage the use of biomimetic materials in the South Africa construction industry. But, all materials presented are thus encourage to be used for construction of infrastructure in the South Africa construction industry in order to mitigate against the environmental impact of construction activities. Furthermore, Bogatyrev and Bogatyreva informed that the application of biomimicry in the process of creating an eco-friendly product are expected to have properties that should be adaptable in short term innovation, recyclable, manageable, easily maintained and self-repairing; although some characteristics could have limited functionality but reliable.[42]

S/n	Product	Natural source of inspiration	Biomimetic features	Area of application
1	Concrete alternative	Abalone Shell	Biomineralisation process that stores carbon & creates durable, crack-resistant material	Construction works
2	Entropy carpet	Riverbed stones and fallen leaves	Organized chaos of mismatched patterns, randomness, and disorder	Floor finishes for building's interior
3	Purebond *Formaldehyde-free Plywood Resin*	Bivalve Shellfish	Waterproof adhesion method used by shellfish to attach to stationary surfaces in the ocean	Construction works, wood fabrication etc.
4	gecko tape	Gecko	Plastic microfibers with electro-dynamic adhesiveness that resemble hairs on gecko paw	Construction works fabrication etc.
5	Synthetic gecko *Adhesive Material*	Gecko	Adhesiveness from gecko paws that enables unique climbing ability	Construction works, fabrication etc.
6	Ice axe	Woodpecker	Chiseling ability, structural strength, light-weight construction, balance, percussion efficacy	Construction works, fabrication etc.
7	Multi-plug electric socket	Crustacean Exoskeleton	Lateral distribution of sockets with central energy source based on underbelly articulation	Construction works, fabrication etc.
8	Natural intelligence *Iridescent Drapery Fabric*	Butterfly	Color created through underlying structures that reflect light in certain ways: Color that is based on perception, not pigment	Exterior and interior finishes
9	Biodegradable plastic	Plants	Imitate process of carbon sequestration by turning carbon dioxide into carbon-based polymers for plastics	Construction works, fabrication etc.
10	Safety road reflectors	Cats' Eyes	Reflector cells that reflect even small amounts of light	Construction works, signage etc.
11	Automobile anti-collision safety sensors	African Locust	Anti-collision sensors activated during swarms	Automobiles, building safety systems etc.
12	Submarine and aircraft skin	Dolphin Skin	Resilient skin structure that reduces turbulence, drag, and friction, permitting great speed at low sound levels	Construction works, fabrication etc.
13	Teatro del aqua	Namibian Desert Beetle	Method of water capture used to design desalination facility	Construction works, agriculture etc.
14	Hydrological center at University of Namibia	Namibian Desert Beetle	Ability to capture water from fog without use of pumps or large amounts of energy	Built environment, agriculture etc.
15	Lotusan paint	Lotus Leaf	Micro-textured surface that allows for self-cleaning	Finishes and coats

Table 1. Existing biomimetic materials and their areas of application [10]

A fundamental biological principle in the design of the materials and processes is that of minimizing the use of materials in non-critical areas, which can thus reduce weight, cost and reduction of building construction activities on the environment. For instance, in a country such as South Africa where infrastructure and other basic services delivery is one of the deciding factors for socio-economical upliftment of its people and the economic and social development; the production process, use of resources and means of efficient disposal of waste is a must, which thus create a huge opportunity for the uptake of biomimetic materials. The next section of the article discusses some biomimetic materials that are encouraged to be better utilized in the promotion of sustainability in the South Africa construction industry.

2.3.1 Self-cleaning paint and roof

Lotus plants (*Nelumbo nucifera*) live in typically muddy aqueous habitats, yet stay dirt-free without using detergents. This is accomplished through the micro-topography of their leaf surfaces, making the plant extremely water-repellant (superhydrophobic). Dirt particles on the leaf's surface stick to water droplets on the leaf and when the water droplets roll off, the attached dirt particles are removed with them, thus cleaning the leaf without using detergent.[43] This phenomenon is popularly known as the 'self-cleaning effect'. The self-cleaning property is highly important for water plants. This natural phenomenon occurring in lotus leaf led to the finding of a new self-cleaning paint. Surface finishes inspired by the self-cleaning mechanism of lotus plants and other organisms, including many large-winged insects; have been applied in *i.e.* self-cleaning paint (Lotusan®) and clay roof (Erlus Lotus® clay roof), reducing the need for chemical detergents and costly labour [44] for maintenance and cleaning purposes. The paint surface takes the shape of densely packed ridges or bumps, just like the bumps found on lotus leaves, preventing water drops from spreading out, instead, the drops roll off the surface taking the dirt with them. [11] Zari informed that the application of this paint will enable buildings or the surfaces they are applied to be self-cleaning.[14]

Typical manufacturing surfaces which feature a "Lotus-Effect®" are technically challenging and still poses certain problems. To date there are only a few low-cost processes which can produce the surface structures on a large scale. One example according to Ramaratnam et al. is the application of "Lotus-Effect®" structures in house paints.[45] Here, the required surface structures are created from hydrophobic polymers early on at the construction stage or post-construction stage by means of moulding, etching or applying a powder made from hydrophobic polymers or from nanoparticles such as silicon dioxide. A further possibility is the subsequent hydrophobisation of a previously manufactured surface that has the required structures.[45] The use of this biomimetic materials is thus encouraged for use in low-income housing construction in South Africa as this will considerable reduce the plight of the low-income earners in having to repaint their houses during the usage life of the building.

2.3.2 Sustainable carpet and floor finish

The carpet company, Interface, has worked together with the Biomimicry Institute to manufacture sustainable closed-loop products. Inspired by the organized chaos of a blanket of fallen leaves and a bed of river stones, David Oakey and his team working for Interface FLOR discovered that none of nature's examples had exactly the same color makeup and contents, yet collectively they each created a complex and cohesive pattern.[11] El-Zeiny further reported that it is chaos because no two stones, no two leaves, no two sticks look alike, yet there is a pleasant orderliness in the chaos, said Interface Inc. Chairman, Ray Anderson.[11] With the discovery, "Interface" now design totally random tiles, each slightly different in pattern and color. This increases the flexibility, makes installation faster, repair easier, and reduces waste. Further, Interface designed a carpet tile installation system that uses small adhesive squares to connect carpet. By this, the company omitted the need for glue and made the installation process easier and faster, resulting in 90% lower environmental footprint.[44] This carpet offers a sustainable option of material selection by architects and interior designers for specification of floor finish for different kind of buildings. The adaptation of this materials for building construction in South Africa is more than necessary as the adoption of this biomimetic material will afford home owners the flexibility of maintenance in their building and for ease of replacement of damaged parts with minimum environmental impact from synthetic materials. Since building floors are never left uncovered, the adaptation of this material will revolutionized the South Africa construction industry and considerably reduces the environment footprint of the industry.

3. Lessons learnt

"Those who are inspired by a model other than Nature, a mistress above all masters, are laboring in vain." –Leonardo Da Vinci

This study has found that nature is a rich source of knowledge, and present-day human life has undoubtedly progressed because of our ability to be inspired by nature, and to then innovate solutions to our problems through biomimicry.[13] Also, the study revealed that biomimetic materials and products, created according to deep biomimicry, must be a part of a larger economy aimed at restoring and preserving the earth rather than depleting it as indicated by Ásgeirsdóttir.[44] Hence, the viewpoint of biomimicry on the importance of creating sustainable solutions is very much intertwined with biodiversity conservation. Rao also affirmed that under this new order of sustainability, buildings, outdoor art and other manmade structures would function like trees, meadows, flora and fauna, capturing, cleaning and storing rainwater; converting sunlight to energy and carbon dioxide to oxygen; protecting soil from erosion; disseminating seedlings; and eliminating waste.[46] Biomimetic materials are sustainable, perform well, save energy, cut material costs, redefine and eliminate "waste", discourages the depletion of the natural habitat thereby systematically and indirectly reducing the amount of toxic air emissions. As suggested by Peat, the use of materials and products with sustainable credentials could potentially improve resource productivity and aid sustainable development.[47] Also, for the construction design team and other innovators of all stripes, the answer to the question "What would nature do here?" is a revelation according to Benyus.[26] Benyus further emphasized that there is not one new idea, but millions, ideas evolved in context, tested over eons, and proven to be safe for this generation and the next.[26]

4. Conclusion and recommendations

This paper reviews current knowledge of biomimicry and its potential in the sustainability of the South Africa construction industry through the encouragement of the use of biomimetic materials. Hence, the study evaluates and promoted the use of biomimetic materials in the South Africa construction industry. For an industry known globally as a major consumer of energy and natural resources and producer of significant amount of waste, the use of these materials, components and products known to have sustainable credentials will make the government's sustainability agenda a reality. Thus, the study found that there are numerous already existing biomimetic materials that can be further explored and study for a wider adaptability in the entire South Africa construction sector. Some of these materials include: concrete alternatives, paint and concrete roof tiles alternative and floor covering alternatives. The implications arising from the study are thus diverse. First, it is envisaged that the use of the explored biomimicry materials will significantly reduce the carbon footprint of the construction industry. Secondly, the investment into these products by the government and other agencies supporting eco-friendliness of the industry would make the South Africa government's accession into numerous climate change and environmental protection protocol to be realized. Lastly, the use of the materials will to a larger extent reduce the life cycle cost of building in relation to the maintenance of the building. Therefore, it is recommended that the key players and stakeholders in the industry should embrace and incorporate biomimetic materials and processes into their construction activities which will directly minimize environmental pollution and depletion of the natural resources. Likewise, the collaboration and cooperation of biologists, designers, researchers and other stakeholders in the industry is suggested for the creation of new ideas and innovation that are biomimetic-based. Such collaboration is believed will lead to the innovation and development of green materials. This is believed will fast-track and aid the sustainability of the industry. It is also recommended that the government should plan and enforce a systematic withdrawal of unsustainable construction materials in circulation that already have sustainable alternatives. Thus, using the new materials developed, it is possible to construct structures, which will be 'green' and 'sustainable', requiring optimum resources and energy.

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