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# RESILIENT MATERIALS AND STRUCTURES EMULATING NATURAL ORGANISMS

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## **Abstract**

Materials always reflect the physical effects of a space; they are skins of spaces both internal and external. Materials are not only used for gaining visual characteristics of a space but also to create healthy environments, which means air quality, lighting quality, or ergonomics of a spaces. Structures that create these spaces are important elements of defining tangible skins of spaces such as wall, floor and roof coverings. On the other hand, they have a high impact on energy consumption, carbon footprint and indoor air quality due to production and usage processes. Thus, a need for producing resilient materials and structures has developed. However, emulating such materials and structures need a sustainable approach such as biomimicry. Biomimicry is a new field of science that embraces strategies, ideas and solutions from living or nonliving organisms of nature, and aims to use them to solve challenges in human life, manage them successfully, and create sustainable environments. Since the existing condition of the earth is not healthy in terms of carbon footprint, energy consumption, and environmental pollution; then it means there is a necessity for flexible materials and structures to minimise, perhaps prevent, these negative impacts. Nowadays, architects research to develop materials that are more flexible, self-healing, growing, and decomposing just like organisms in nature [1]. Besides, engineers and architects are working on structures inspired by nature that could make buildings more resilient and durable. As it is known that the construction industry is one of the largest fields that has a negative impact on earth, therefore it must be reduced to create better sustainable environments for future generations.

This paper analyses some of the most important resilient materials and structures derived from nature and evaluates their physical effects on architecture, indoor environment and structural behaviour of buildings. It also emphasises and describes how principles of biomimicry have led the way on emulation of these materials and structures. Additionally, the paper draws attention to importance of how nature's genius can help to save the earth.

**Key Words:** *resilient; nature; biomimicry; structure; physical effect.*

## **1. Introduction**

Spaces may leave either a positive or negative impression on users when they are constructed with various materials. This not only affects the psychological behaviors of users but also the environmental conditions both inside and outside. When it is mentioned as inside, it means the indoor air quality of a space and when it is outside, it means the environmental pollution including carbon footprint, air pollution, etc. Walls, floors and ceilings –including surfaces of furnishings- are tangible skins of a space. They are supposed to be designed as healthy architectural elements. However, large group of materials that are to be used when designing these spaces, are not completely harmless. These materials are either less harmful or more chemically produced; either ways are bad. William McDonough writes “*Less is not good*” in his book *Cradle to Cradle*, to clarify that producing materials that are less harmful or less chemical are not helping earth to heal [2]. He emphasizes the importance of producing materials with zero waste or become raw materials for other goods at the end of their life cycle. This is the fact that the construction industry should seriously consider this issue when producing materials.

As architecture is defined as the widespread profession which focuses on designing built environments; it rather stands for the material and structure that define space and enable interaction [3]. Structures are other important elements of architecture. They are materials in big sizes which bear the load and create a shell to enclose spaces in different shapes and forms. Nature is full of ideas that help to find ways for designing resilient structures. Resilient structures are structures that can response to weather, loads or forms of shells which need to change in size or height.

Before starting to design resilient materials and structures, it is important to consider sustainable and eco effective approaches. Although there are some design approaches that are used by architects, the most effective one is biomimicry, which is applied for emerging ideas from nature into designing eco-effective and sustainable products. It is also used to get inspirational ideas from nature to solve human challenges, not only in architecture but also in different fields, such as medicine, business, technology, etc.

#### *1.1. Biomimetic approach in designing resilient products*

Biomimicry, known as the design tool for ecologically efficient and sustainable designs, is also taken as the most effective approach in design. It is a fresh field of science that helps to understand organisms and learn their functions and then combine these useful functions to solve human's challenges. The main aim of biomimicry is to help designers comprehend that there are better solutions in nature which have evolved in millions of years. Biomimicry teaches them how to integrate those sustainable solutions in to their designs. It is also a multi-disciplinary science involving many fields, such as architecture, engineering, biology, business, education, etc.

There are principles of nature which designers should follow while thinking, designing and applying their designs:

- Nature runs on sunlight
- Nature uses only the energy it needs,
- Nature fits form to function
- Nature recycles everything,
- Nature rewards cooperation,
- Nature banks on diversity,
- Nature demands local experience,
- Nature curbs excesses from within,
- Nature taps the power of limits [4].

Natural processes build upon unique geometry and material properties [5]. These are two basic criteria that make shapes and materials resilient in nature. Resilient materials are ones that can resist inconvenient conditions in nature. Furthermore, some of these materials can resist man made world. Here biomimicry, in collaboration with biology, can be used as design approach firstly to discover these organisms and their abilities then apply them in to designs. There are two approaches that can be used in design; *looking to biology and biology influencing design* [6]. Both approaches are fundamentals of biomimetic design; in the first one designer looks to nature for ideas and in the second one, designer reveals a challenge and tries to find its solution in the nature. Although they look the same, the procedure differs from each other.

When pondering over a good and sustainable design, it is important to create a design that lasts, a material that recycles in to something else when it is done, a structure that can reshape for another use, a building that can function just like a tree. These ideas are not too far. During application of such ideas from nature, designers should learn to work with biologists, include biological paradigm in to architectural design process. Taking ideas from nature has a deep meaning because organisms in nature have evolved during their life cycles; encountered with many conditions and they know how to resist against those conditions.

#### *1.2. Examples of resilient materials*

Traditional materials require and include high embodied energy, and they also depend on natural resources which are limited. Production techniques and systems require reform. Most of global carbon dioxide emissions are directly related to construction industry [7]. Production process is as important as the production of resilient materials. However, there are materials which are designed with inspirations from nature. But, these materials are not enough to decrease the negative impacts on earth; carbon levels, environmental pollution, air pollution,

etc. On the other hand, there are good developments that take place in different parts of the world. For example, one of the most commonly used material is brick, and its production process is very harmful; %70 of brick production is made in Far East. Some young researchers developed a brick called “*biobrick*” which requires no embodied energy that results no CO<sub>2</sub> emissions and can be made on site [Fig.1] [7-8].



Fig. 1. Biobrick after manufacturing, [7].

Biobrick is produced with the help of bacteria called *sporosarcina pasteurii* [Fig.2]. This organism helps sand to melt into the particles which the process ends with a tough and durable solid shape. The result is fascinating. This brick is stronger and more durable in comparison to traditional brick which are used today and it is produced with zero carbon emission. Thus, producing a material with no waste, zero carbon emission, etc. is as important as producing a sustainable and resilient material.

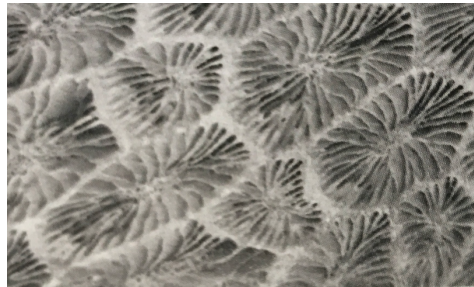


Fig. 2. Bacterially cemented aggregate, [8].

The process is a combination of microorganisms with sand which results as calcium chloride and urea to start the microbial-induced calcite precipitation (MICP). This is where bacteria start to stick grains and sand together to form stone [8]. Although this process works slowly, producing such brick requires a week due to its natural process, it is very promising and is under production and development. This material, beside its zero waste and no carbon emission, has some other advantages; such as product adaptation, ability to cast on site and increased insulation [7-8].

Achieving the required material with series of successful engineering process and appropriate combination of ingredients with a good selection of organism ends up with materials like biobricks. Natural materials have impressive criteria and privileges. However, nature and technology work for different constraints [9]. Therefore, nature must be studied in terms of its processes and materials to identify what it can offer for useful and sustainable solutions.

### 1.3. Examples of resilient structures

How does nature build resilient structures? It has many different processes ending up with structures that have high resistance against loads. There are plenty of examples in nature that can be taken as inspirational ideas to build flexible and more durable structures; for example, bamboo a renewable and fast growing (*Bambusa balcoa*) reed that can grow up to 25 m high and resists lateral loads of tsunami effectively and efficiently [10-11]. Bamboo, due to its geometric proportions and natural structural properties, has become an inspiration for the design of China World Trade Center 3B, the second tallest building in Beijing. It is made of culm or stem that contains nodes and internodes which mark the location of new growth. In every new growth, the diameter of the stem changes where internodes become hollow. This hollow creates an inner cavity that culm walls surround it. The maximum bending resistance occur at the point where material in the culm is located at the very end of the point from the neutral axis of the stem [11]. This load bearing process and bending resistance of the bamboo were ideal for designing a resilient structure for a tall building that could resist multidirectional loads. Architects of SOM, an architectural firm, have studied the geometrical proportions of bamboo and applied them to the structure of China World Trade Center 3B [Fig.3].

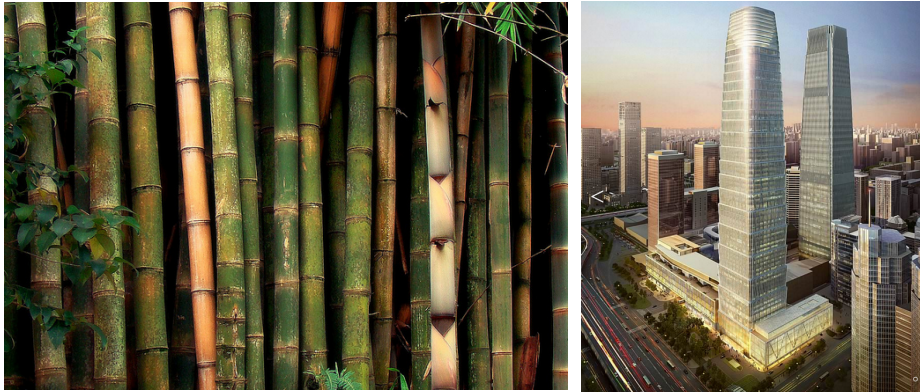


Fig. 3. (a) Bamboo [12]; (b) China World Trade Center 3B [13].

The structure of tower works just like the bamboo stem or culm; building is divided in to multiple segments in vertical direction. The bottom of the tower is shorter than the rest, due to the maximum demand for lateral loads at the bottom [11].

Following up the biomimetic approach, in the structural design of this tower, results with more flexible and resistant structure. However, the manufacturing of this structure does not have any sustainable implementation technique. When one talks about the biomimetic design, he/she should not only mention the application of organism's functions in to a design, but also emphasize the importance of construction or manufacturing process of a design. Both processes, design and manufacturing, are as important as each other in terms of their sustainability and resiliency. Everything that functions in nature has a relation with its surroundings; but when they are on their own, they do not function with full capacity. If nature is researched profoundly, it can be easily seen that every organism has reasons for being what they are.

Even though bamboo's structural system has inspired architects and engineers of World Trade Center 3B, it is an ancient but modern material that is used widespread, especially in Southeast Asia. It is a kind of grass that differs in types and sizes. One of the most remarkable examples of bamboo structure is ZERI (Zero Emission Research Initiative) Pavilion which was designed by Simon Vézec for EXPO 2000 in Hannover, Germany (Fig.4.) [14]. This example shows how natural materials can be used for sustainable and resilient structures in architecture. Bamboo structures have ability to fix carbon dioxide almost %40 more than wood and they are very resistant against loads in certain dimensions. If financially supported, such structures can be used for social housing for needy families [15]. The result would be enormous in terms of housing the needy, minimizing carbon foot print and preventing pollution of unrennewable resources; water, air and soil.



Fig. 4. ZERI Pavilion, Hannover, Germany [15].

## 2. Natural functions and processes as prototypes

Nature is full of resilient structures and processes; such as bamboos, trees, bones, shells, horns and eggs, are load bearing or protective structures. They are enhanced by nature to give maximum strength during minimization of energy and materials that are used to create them [16]. When architects work with nature as a model, the separation between material, structure and surface is no longer valid. This is important for biomimetic approach in architecture.

Nowadays, using smart materials which react to changing weather conditions, is very common in construction industry; easy to clean and self-cleaning surfaces are some of them [17]. Such materials are adapted to different industries like glass and coating industries of construction materials. There are self-healing, self-repair, anti-reflectivity, switchable, transparency, etc. properties that require nano-structural production. These processes are already under development but still there is a need for resilient production of such materials inspired by nature.

### 2.1. Structures

Biological structures which are developed through the evolution, are analyzed by biologists. Obtaining this information from nature requires collaboration with biologists. This evolutionary development is a process that makes organisms multifunctionally adapted and optimized. Transferring these information and processes correctly and adequately in to design is the most important part of the biomimetic process [18]. There are some organisms that are important in terms of their structural features.

One of the most resilient structural materials in nature is the spider web. It is known as the strongest material ever. Man-made materials did not surpass the toughness and strength of the spider web yet. It is waterproof and very elastic (Fig.5). It is also coated with antiseptic agents; therefore, Ancient Geeks used them to cover wounds [16]. But there are more than that about spider webs. Darwin's bark spider absorbs massive kinetic energy before it collapses due to any attack by bigger predators. What makes the spider web resilient is that its material consists of complex mixture of strength and flexibility [19]. Consequently, until another material is discovered, it is the most suitable material to develop high performance biomimetic fibers that can be used to establish strongest and lightest structural systems in architecture [20]. The content and functional criteria of this material can be used to establish lightweight and tensile structures that could be easy to carry but impossible to collapse,

There are many types of structural systems in nature that work in collaboration with their surroundings; *entada gigas* (monkey ladder- sea beans) is one of them (Fig.6). This organism is a flowering liana from pea family. It grows almost 15 cm wide and 2 meters high and contains seed that make it buoyant, so it can reach to other lands by collaborating with seas to grow and spread [21].

The functional criteria of this plant can be used to develop earthquake resistant long span structures which architects need to use in their designs for covering the whole with a single roof on top without any colonnade.



Fig. 5. Spider web [20].



Fig. 6. (a) Entada gigas-monkey-ledder, (b) Seeds of entada gigas [21, 22].

There are many types of organisms that can be analyzed for resilient structural designs. The most important step in designing structures that emulate natural organisms is to make a profound research about these organisms and follow up the biomimetic principles.

## 2.2. Materials

Construction industry uses the greatest amount of embodied energy in the production process of materials [17]. Designers should look at nature to get ideas to design materials that decrease the usage of embodied energy. There are materials in nature that can inspire construction industry to produce resilient materials and manufacturing processes. Production processes of these kind of materials are also vital.

There are self-healing organisms like lizards that can restructure their tails or autotomize after releasing, which is a defense mechanism that lizard uses to distract its predator [Fig.7] [23]. This restructuring of tail process, can be used for developing self-healing or self-repairing materials, like paints and plasters. These materials could be self-healing after a damage or breakage, which could result as increase in the lifespan of the material and decrease in the production frequency.



Fig. 7. Lizard while autotomizing its tail [23].

Another natural material that can be studied for resilient material design is the polar bear fur. Polar bear's fur is very effective in terms of balancing bear's thermal comfort. There is highly reflective cylinder inside the follicles and their bases in the dark layer of the skin that fulfill the demands for absorption of energy, producing minimal waste by using conduction, convection and radiation, and free direction of sunlight [Fig.8] [14]. Due to the reflection of ambient light from the dark skin, the fur looks white even it is transparent. The process of insulating polar bear's body can be used to create transparent insulation materials.

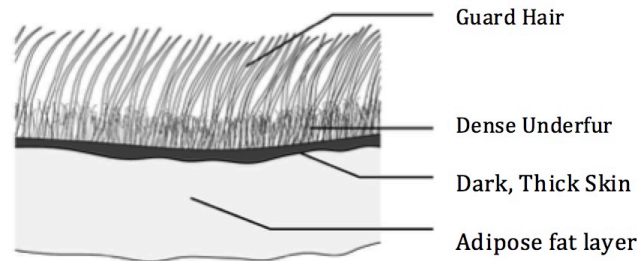


Fig. 8. Polar bear's fur [24].

Construction industry can use two main principles of this system: first, using evolution of inventive transparent insulation materials that absorb direct, scattered and diffused sunlight, and basically transform them into heat radiation with longer wavelength for warmth and balancing heat, and secondly, systems in nature are always complete, they are never individuals or closed elements [14]. Consequently, as many organisms studied, it is much better to start a careful analysis and abstraction of biological processes, materials and structures and apply them in to architecture.

## Conclusion

If buildings become uninhabited due to earthquakes, or other devastating disasters, low carbon emission materials or other green building designing criteria do not matter at all. Therefore, construction industry should establish a research center where all organisms mentioned above can be studied and prototypes can be developed to lead the construction material firms on producing resilient structures and materials. Thus, negative impact of construction industry on earth can be minimized. On the other hand, implementation of these systems requires significant adaptation. But using common engineering knowledge may not guarantee successful solutions. Hereby, new technology systems must be developed, then resilient structures and materials emulating nature can be developed easily and effectively.

As Aristotle says "Nature does nothing uselessly", designers must follow the rules of biomimetic approach to gain the ability to think like nature and act like nature which will result with nothing useless.

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