The Role of Biomimicry in Producing Sustainable Architecture

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Abstract

Architects and urban planners of the 21st century face an ecological design challenge to develop optimal processes for design, construction and planning. This includes developing holistic design approaches to build man-made environments with less materials and energy resources while producing fewer waste without restricting new innovations.

Biomimicry, or in other words taking the natural environment as a main source of inspiration for human activities, provides great potentials for the creation of sustainable, long-lasting, and cost-effective solutions to these challenges. Biomimicry can enhance ecological sustainability in architecture to transfer the society to a new sustainable way of living within environmental limits over the next few decades, whilst adapting to the challenges of climate change.

However there is a lack of knowledge concerning the natural environment and its potential in developing a new sustainable built environment via biomimicry. It is hypothesized that by mimicking natural organisms, we can produce more sustainable cities. These may include creating new design concepts, building materials, interiors and structures.

This paper is based on the premise that biomimetic can not only change the traditional architectural and urban design processes but can afford a new holistic sustainable architecture and urbanism to make the built environment work as a part of the outer natural ecosystems, rather than an isolated entity in it.

The research adopted a descriptive, analytical method to find out how Nature affects architecture and building structures. It concludes that there is a great scope for adopting bio-mimicry to enhance sustainable architecture.

Keywords: biomimicry, structure, architecture, sustainable design.

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Introduction

Sustainability requires multiple themes that go beyond reducing consumption and recycling materials, but rather a new direction to reshape people's way of life, values, and daily behavior to produce a sustainable society (Stegall, 2006). Therefore, several researchers, such as David Orr have sought to put forward the idea that environmental sustainability can be achieved when an individual's values are associated with the vocabulary of Nature, enabling them to live in harmony with the natural environment. After we understand the language of Nature and realize that its principles are a means of achieving sustainability to solve the environmental problems resulting from the built environment, such a new approach can be invented. Some, therefore, advocate and encourage the production of sustainable environmental communities (Kibert & Guy, 2002), leading us to a sustainable ecological age. A new kind of philosophy has emerged from sustainable design and the shift from the use of the principles of Nature to the transformation of the structure of the economy. Through these, the society is encouraged to work with the broader general framework of the environment towards a more sustainable environmental framework to achieve a comprehensive and integrated framework of sustainability. Therefore, a new definition of sustainability has emerged as "a design philosophy that links the natural processes of the earth and the way ecosystems are self-modifying for the entire ecosystem being the starting point" (Mclennan, 2004). It defines that environmental sustainability is the ability of the entire system to remain healthy continuously (Eisenberg, 2002).

Biomimicry

Many terms refer to the process of learning from Nature. The term' 'Bionic' is associated with Jack E. Steel (1958) who studied living organisms or their parts after considering their mechanical systems that are interconnected and work in an integrated and homogeneous manner. He proposed to use them in designs; his idea was to understand the natural ecosystem and transform it into an applicable technical system of architecture. He proposed to trace their origins to serve as the basis for the development of later designs. Marshal & Lozeva (2009) also linked the word Biomimetic as a method to know the mysteries and foundations of biological sciences based on the theories and techniques of the physical sciences.

The term "bio mimicry" was associated with the researcher Janine Benyus in the 1990s and became the broader term for the principle of learning and quoting Nature and its systems. The idea is based on the fact that the evolution of life over millions of years has enabled natural systems to become efficient and sustainable by maintaining what is good, evolvable, resistant, and viable. The idea of Bio-inspired design, which was developed by Benyus in 1997, emphasized the need for better analysis and use of Nature for the benefit of human beings. It proposes to apply the principle that Nature can be the inspiration for designs (Marshal & Lozeva, 2009) by mimicking biological systems to develop architectural and technical solutions to solve and address human problems (Helms, et. al., 2009).

Thus, the vast base became an environmental awareness movement for the production of sustainable designs, which explains its name's association with the Greek word 'Bios', which means life and the word 'Mimics', which means 'to imitate'. Thus architecture can imitate the principles of normal life systems and that ecological designs are an attempt to translate ecosystems into designs.

Biomimicry has two main approaches: top- down and bottom-up (Fig.1). "In the top-down approach, designers will consider Nature as a source for solutions, to resolve human problems–as organisms that have solved similar issues. In the bottom-up approach, designers will adapt a process that depends on getting knowledge of relevant biological solutions rather than determine specific design problems" (El-Ahmar,2011).

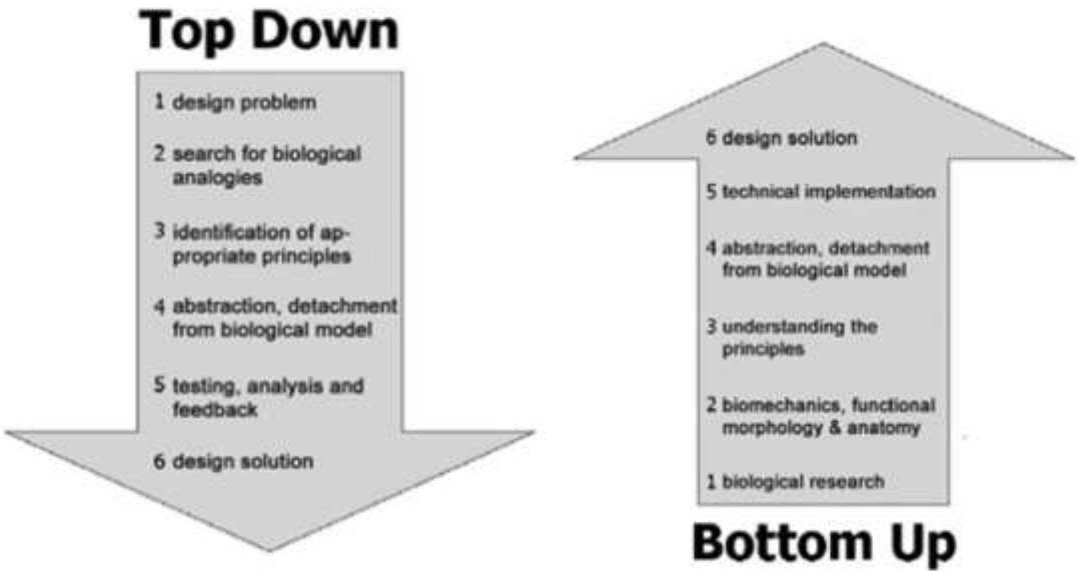


Fig.1: Top-down design and bottom-up approaches
Source: Jean Knippers, 2009

Biomimicry as a Design Theory

Biomimicry can be a theory of design by mimicking natural processes to create sustainable and creative designs, bearing in mind that Nature is the model, guide, and criterion for this design or solution. Thus, we need to study Nature, and natural forms and processes within the ecosystem through biomimicry to extract what can be learned from or quoted to solve humanity's problems and then apply them by emulating them in creating sustainable designs. Therefore, it is a creative process that encourages the transfer of ideas, processes and strategies in living systems to reach the goal of achieving sustainable development. The adoption of Nature as an inspiration provides a method of learning and evaluation with high efficiency and great credibility to find innovative design solutions, but it needs greater clarification through ecological architectural designs (Marshal & Lozeva, 2009).

Thus, the subject of biomimicry can be directly included in the design processes by imitating the nature of relationships and strategies for environmental aspects within living systems, such as their behavior and their pattern or system in Nature. With the help of a system that translates Nature through simulations, or through indirect methods or by quoting the foundations and nature of the relationships, we may understand the principles of the relationship within living systems, and how Nature behaves, and then use them to produce architecture.

Within this context, this research aims to explore the possibilities of employing biomimicry as a design approach to produce sustainable architecture.

Research Method: A Documentary Survey

There are many studies that have dealt with biomimicry. Some of them have been summarized in Table.1. This research examined some of them to analyze how these studies have dealt with biomimicry according to the:

- Directions of research.
- Aspects covered.

Table 1: Analysis of studies that have dealt with biomimicry.
Source: Author

Study	Title	The issue of biomimicry discussed	The applied Level of biomimicry to the building	The direction of research regarding biomimicry
El-Zeiny R. M. A 2012	Biomimicry as a Problem Solving Methodology in Interior Architecture	Nature as a main source for interior design	Interior design	Adding biology as an additional issue in interior design
Rajshekhar Rao 2014	Biomimicry in Architecture	How biomimicry can offer solutions for sustainable buildings	Design approaches and levels	Increasing resource efficiency for built environment
Arosha Uppala Gamage 2015	Exploring a Biomimicry Approach to Enhance Ecological Sustainability in Architecture	How eco practitioners perceive biomimicry as a design approach in architectural eco design practice.	Design approach	use of indirectly mimicking and directly mimicking for architectural eco design projects
Dr.Gehan.A.N.Radwana & Arch. Nouran Osamab 2016	Biomimicry, an approach, for energy efficent building skin design	How Nature can be used through biomimicry to design the skin	Building the outer skin	Reducing energy consumption by mimicking nature
Hawaa Ismail Hawsawi 2016	Nature Inspired Interior Design Principles in the Hot Arid Climate of Saudi Arabia	How Nature can be used through biomimicry to interior design	Interior in hot dry areas	Providing thermal comfort impacts of biomimicry and natural strategies applicable to enhance interior environments of buildings.
DEENA EL-MAHDY & HISHAM S. GABR 2017	BEHAVIOR OF NATURAL ORGANISMS AS A MIMICKING TOOL IN ARCHITECTURE	explaing how organism behave when producing its materials to mimic its behavior in construction.	Orgasm structure	using natural organisms to produce physical components for architectural product design
Natasha Chayaamor-Heil, Nazila Hannachi-Belkadi 2020	Towards a Platform of Investigative Tools for Biomimicry as a New Approach for Energy-Efficient Building Design	using biomimetic strategies with better accessible facility in sustainable buildings	Design approach	reducing energy consumption by applying biomimetic strategies on efficient-energy building design

Michael Yacubov 2020	Biomimicry in Structural and Architectural Design	Biomimicry as integral tool in for designing construction system	structure	Making a-new way for building construction in the 21st century
Louis Vitalis , Natasha Chayaamor-Heil 2022	Forcing biological sciences into architectural design: On conceptual confusions in the field of biomimetic architecture	The relationship between biomimicry, science and architecture	New design approach in buildings	Combing biology as a science and architecture in design approach

Above analysis shows that there is an absence of a comprehensive cognitive view in determining the impact of biomimicry in architecture including buildings skin, structure and the capability for providing thermal comfort , which can be adopted in different types and forms in the modern contemporary architecture. Besides, there is also an absence of biomimicry levels that can be covered. From here, the research question was formed as follows. Is it possible to determine the aspects and direction that can be inspired from Nature through biomimicry to solve human needs, particularly in buildings?

The research problem has been identified as "a cognitive deficiency in determining how Nature can be a main source of solving difficulties in modern architecture through biomimicry in a successful way that have been developed through hundreds of years".

Findings

The impact of Biomimicry on Structural Design

There is a great difference between the first attempts to simulate natural systems and forms through processes, and systems before and after the industrial revolution and the possibility of simulation (Zazzera, 2020). Geometry is related to the sizes of natural forms. Processes are related to actions or relationships between or within organisms or in Nature. Systems are complex, interrelated and integrated into several parts.

The biomimicry principle has also been used and entered into an important area: that is the structural design of buildings through understanding of the composition of natural forms, how forces within natural structures are transmitted, and how they resist external influences efficiently. Studies of mathematics and natural forms have shown that there is a great potential for linking structural design to the fact that the basic principles of mathematics are rooted in Nature (Groome, 2017). In mathematics, we find fractals that can be multiplied by a related series of multipliers up or down, and it's very similar to the creatures in the organism's body and its different tissues (Mathigon, 2020).

Many applications of fractals can be found in Nature. Therefore, through mathematics, the best way to shape the performance of natural shapes and objects is to understand, phenomena such as the bird's wing feather and components, the ability of large trees to bend to strong winds, and the way to stabilize them with soil through the network of underground roots. These natural formations can, after study and analysis, inspire architectural and construction designers to create structures that did not exist before. Therefore, trees, skeletons, and spider web tissues can base the development of the use of Fractal Geometry for designing and implementing structures that are more efficient in the distribution of loads and reduce the economic costs. These will reduce the amount of material used in terms of quantity and size and thus reduce the loads of buildings and weights to a minimum and more sustainable levels.

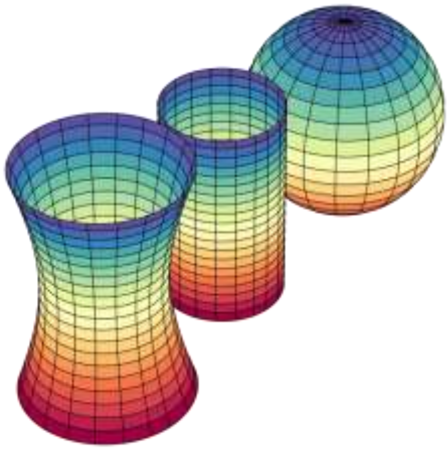


Fig.2: Gaussian Curvature
Gaussian+Curvature&source=lnms&tbm=isch&sa=X&ved=2ahUKEwii5

Gaussian Curvature is another important principle related to geometric surfaces that determine their true properties and strength. Thus, these surfaces can bend in one direction to provide resistance and stiffness in the other direction (Bhatia, 2014). It is an *intrinsic* measure of curvature (Fig. 2), depending only on distances that are measured on the surface, not on the way it is isometrically embedded in shape (wikipedia.org/wiki/Gaussian_curvature).

Fibonacci sequence is a set of numbers that have been studied by mathematicians and other specialists for the possibility of their application in uses and designs (Fig. 3). In mathematics, the Fibonacci numbers commonly denoted Fn, form a sequence, called the Fibonacci sequence, such that each number is the sum of the two preceding ones, starting from 0 and 1 (wikipedia.org/wiki/Fibonacci_number).

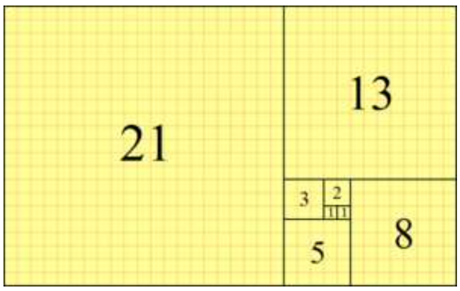


Fig.3: Fibonacci numbers
Fibonacci+numbers&tbm=isch&source=iu&ictx=1&fir=H9RnvwLNgC77iM%252CCLV60y
60y

They can be found in the geometric structures of organisms such as the Nautilus Sea Shell and the sunflower flower as well as observed in cyclones (Som, 2011) as they have been used in building structures such as the Christ the Light Cathedral in Oakland/California. There, the structure has been designed by drawing inspirations from this series and with several dimensions. It is evident in the two interconnected spheres that represent the engineering principle of the building and the multiple spherical shapes and variable diameters of the building's internal and external walls as well as the volumes of its internal spaces and the building's main gates (Fig. 4) (Som, 2011).

Fig.4: Christ the Light Cathedral in Oakland - California
Source: https://evergreene.com/projects/cathedral-of-christ-the-light/

This principle has also been applied in the design and implementation of the structure of skyscrapers for its ability to simulate and process complex structural designs. Architects used this principle to design the "Salesforce tower" in San Francisco/California, where the Grid was used for the construction of structure according to the Fibonacci sequence and through a specific scale that was mainly focused on a certain point from which the spiral parts are released (Fig. 5).

Fig. 5: Salesforce tower in San Fransisco
Source:https://www.inc.com/salvador-rodriguez/salesforce-tower-diversity.htm

This architectural construction system was designed to resist the earthquakes in that area, as most of the spiral shapes were concentrated in the corners to resist the horizontal forces in the structure of the building, while the open areas were projected at the top because they are exposed to the least amount of this type of powers. In collaboration with the construction designers, the architects tried to reduce the surface area of the building exposed to the wind, and the design was, therefore, a model of Biomimicry through the formation of architecture with a distinctive and unique construction design using minimal construction materials.

Another example is the Bamboo plant, resisting the lateral strong winds because of the nature of the plant's structural composition, the nature of its tissues, and the proportion of its geometric shape. Furthermore, the nodes along with the bamboo, which is unevenly spread, are more rounded at the base and at the top of the plant, but they are more spaced in the middle, thus preventing buckling of the thin plant cover when exposed to gravity or the lateral forces of the wind. The relationship between the thickness of the outer layer of the plant and its diameter also provides an additional force against buckling. The relationship between the diameter of the plant and its height also represents the same geometric ratios (Cantilever), but it works vertically instead of horizontally. This has helped the architects to present a project idea for a building for the Chinese World Trade Center competition in Beijing (Fig. 6), represented by a high-rise building. The building can, through Natural Steams, provide strength to the building structure and at the same time respond well to the horizontal forces of the wind. These qualities provide the optimum use of materials when a building or structure is exposed to precipitation (bending). This is what was applied in the designs of the aforementioned tower (Michael,2020).

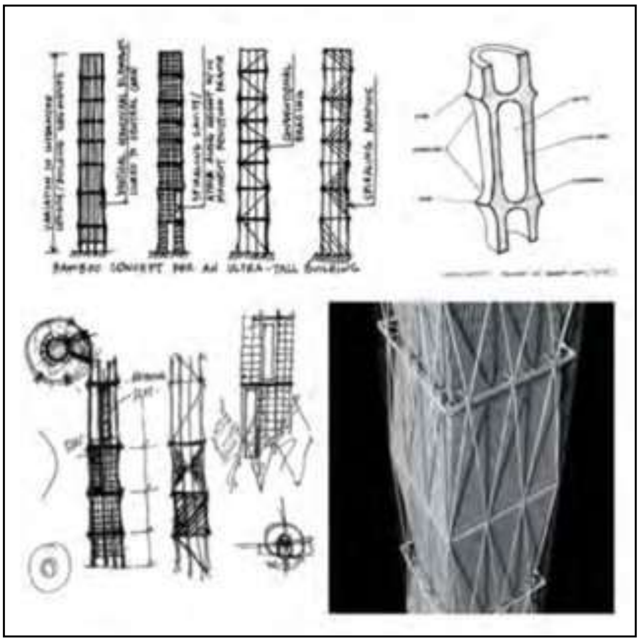


Fig.6: The Chinese world trade center and bamboo plant concepts
Source: https://www.researchgate.net/figure/China-World-Trade-Center-18_fig1_318018203

CD/ITKE Research Pavilion 2014-15 / ICD/ITKE University of Stuttgart

Spiders produce different types of silk with different characteristics in terms of strength, extensibility, and behavior. Thus, architects of this project tried to draw inspiration from Nature and learn some smart and effective solutions from this process. Spider silk is an engineering miracle because it's one of the most powerful materials compared to its size. The secret of the strength of silk lies in the atoms of its fibers and the composition of its molecules, which determines the nature of the structure, which gives flexibility to silk and makes it resistant to tearing at the same time. Silk fibers are five times stronger than steel and twice more flexible than nylon. Water spiders spend most of their life underwater, to build air bubbles in order to stay alive. Spiders attempt to build a horizontal flat web under which the air bubbles are placed. Another step, to reinforce these air bubbles is by placing a hierarchical arrangement fabric of fibers inside (Fig. 7). They make a stable structure capable of withstanding the outer and internal stresses, including different water currents, to provide a safe and stable environment for the spider. This natural production process illustrates how adaptive manufacturing strategies can be used to create effective fiber-supported structures.

The process of building the network (Agyroneda Aquatica) proved to be particularly important for the possibility of benefiting from it architecturally and structurally, where the concept of learning from Nature depends on the study of the biological construction processes of fiber-reinforced structures. These processes can be considered to be relevant to the applications in architecture, as they are a natural technique that does not require complex casting templates and can adapt to the diverse requirements of individual construction.

Thus, the web-building process of water spiders was examined, analyzed, extracted, and transferred to a technological manufacturing process. This was done in the ICD/ITKE Research Pavilion 2014-15 project. At the beginning of design and construction, the exterior cover was designed and the key fiber packets were located through the method of finding the computational model, which connects manufacturing determinants through structural simulation. Then a design method based on the computational factors was developed, and through numerical determinants in the geometry of the shape's surface, a robot path is generated to install fibers simultaneously in many directions and with different performance fiber densities. (http://www.achimmenges.net/?p=5814).

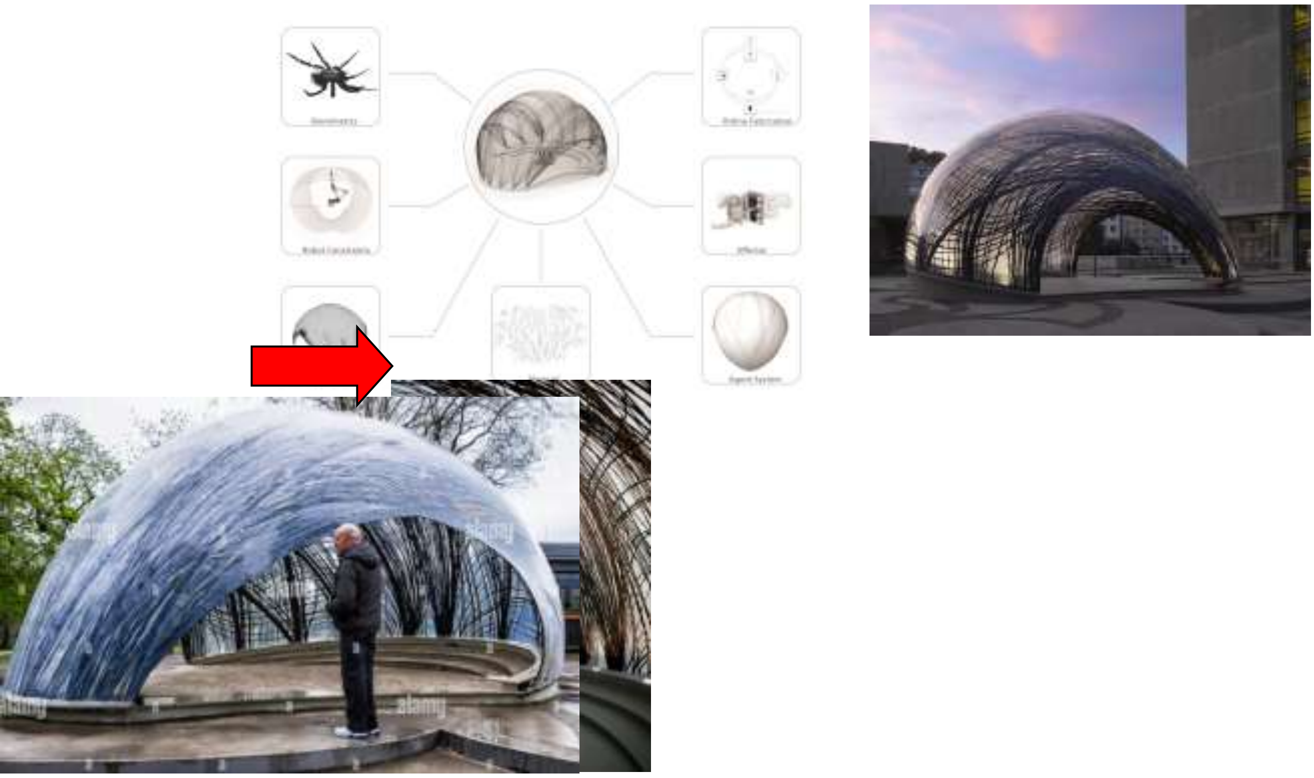


Fig.7: ICD/ITKE Research Pavilion 2014-15 University of Stuttgart
Source:https://www.archdaily.com/770516/icd-itke-research-pavilion-2014-15-icd-itke-university-of-stuttgart

The Role of Biomimicry in Architecture

Biomimicry is an applicable concept, to provide sustainable solutions to solve human problems, by learning from Nature. It does this through mimicking the strategies used by living species in Nature. The goal is to create sustainable products and processes to solve design challenges including architecture.

The traditional architectural design process is often described as a linear process. It moves from one step to the next ones in a logical order (HMH Architects, 2017). These contrast biomimetic design processes (Fig. 8). Thus, biomimetic design approach will become more flexible than the traditional one for it allows designers to move back and forth between stages to implement new biomimetic design solutions (Cohen & Reich, 2016).

Zari (2010) referred to biomimetic architecture design in two major methods: The first is design looking to biology and the second is biology influencing design. The first one starts with identifying the design problem and then looking for biological systems to solve this problem. The second one starts with identifying the general biological characteristics to search and find the proper sustainable way to implement it in architectural and structural designs (Zari, 2010).

Fig. 8: Biomimetic design process
Source: https://www.colorado.edu/envd/sites/default/files/attached-files/brodrick_final_thesis_2020.pdf

Other biomimetic design strategies exist to inspire architects about the process of biomimetic design like Hastrich's Biomimicry Spiral Design strategy (Fig. 9**)** that shows the impact of biomimicry on architectural design.

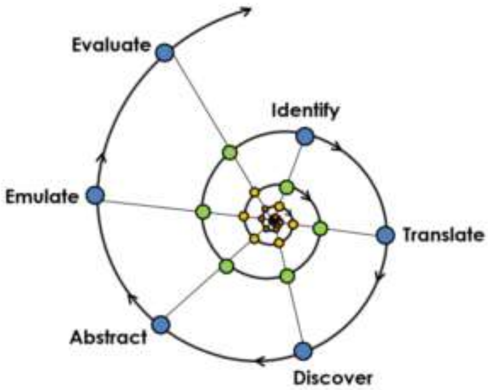


Fig. 9: Carl Hastrich Spiral Design
Source: https://www.google.com/search?q=Carl+Hastrich%E2%80%99s+Design+spiral&sxsrf uploads/2017/10/Design.Spiral-Diagram_10.17.pdf)

Nature provides a variety of different types of systems and models for humanity that can be imitated and exploited to design buildings and projects in harmony with Nature and its systems. Thereby, we can reduce their damage to the environment and make them more sustainable. Architectural and structural studies have shown that the composition and structure of organisms, their functions, the relationships between their parts, their relationship to their external environment, on the one hand, and their possible connection to architectural designs, on the other hand can be taken advantage of (Yeang, 2010). These ideas comply with David

Orn, who emphasizes that "sustainability depends on the identical reproduction of the structures and functions of natural systems." Thus, by studying the forms and functions of natural organisms and the nature of the relationship between them and their natural environment, and their compatibility and complementarity with their environment, we can come up with methods to translate and transfer these qualities and relationships to the built environment that exists within their natural environments. Despite the high stability of natural systems, climate change and environmental disturbances have helped to reduce and alter this stability and have exposed it to vibration and unbalanced change. This has led to greater difficulty in understanding the stable and unstable state of the natural environment, which requires a greater flexibility in understanding this situation because understanding environmental integration can contribute to the improvement of many levels of architectural designs that include the life cycle of the building, design, construction, operation and maintenance (Yeang and Woo, 2010).

The Impact of Biomimicry on Building Envelopes

Building skins can be defined as the boundary through which the buildings interact with the environment (Mazzoleni,2013). It consists of different layers that react to the outer conditions like light, air and heat to maintain the best internal conditions, according to the building functions. Other researchers call it the building shell and fabric that is capable of enclosing the building to become the border between the building interior and the outer environment (Hoeven,2012). Building envelope represents the building identity. Its elevations consist the windows and doors. To analogue building skin and biomimicry, we can find the main similarities and the driving forces that affect Nature and the architectural design process (Mazzoleni,2013). The thin building skin is an outer membrane that covers the structure of the building to protect and hide the inner organs (mechanical and electrical) to define the interior spaces. The building skin is similar to the natural skin because it consists of many layers that react to the outer conditions. It is capable of maintaining the internal conditions while being responsive to its function. It is capable in dealing with both the internal and external forces. It filters what is allowed to come in and go out (Yowell,2011).

Environmental Building Envelopes

The East Gate Shopping Center in Harare

Use was made of termites, where the architect, Mike Pearce, who designed an administrative and commercial building in Zimbabwe took advantage of research on termite house specifications and how its temperature and humidity are constant throughout the year, regardless of extreme external climate conditions. This process is done through the work of termites, a different set of openings and ventilation tunnels in their home to obtain stability in temperature and humidity. Thus, the designer tried to imitate the Termite Mound when designing the East Gate building shopping center in Harare, which made it a sustainable building that consumes a small amount of energy for heating and cooling, especially since the building is large and was implemented in hot weather (Fig. 10), where the building consumes less energy by 10% compared with a similar building.

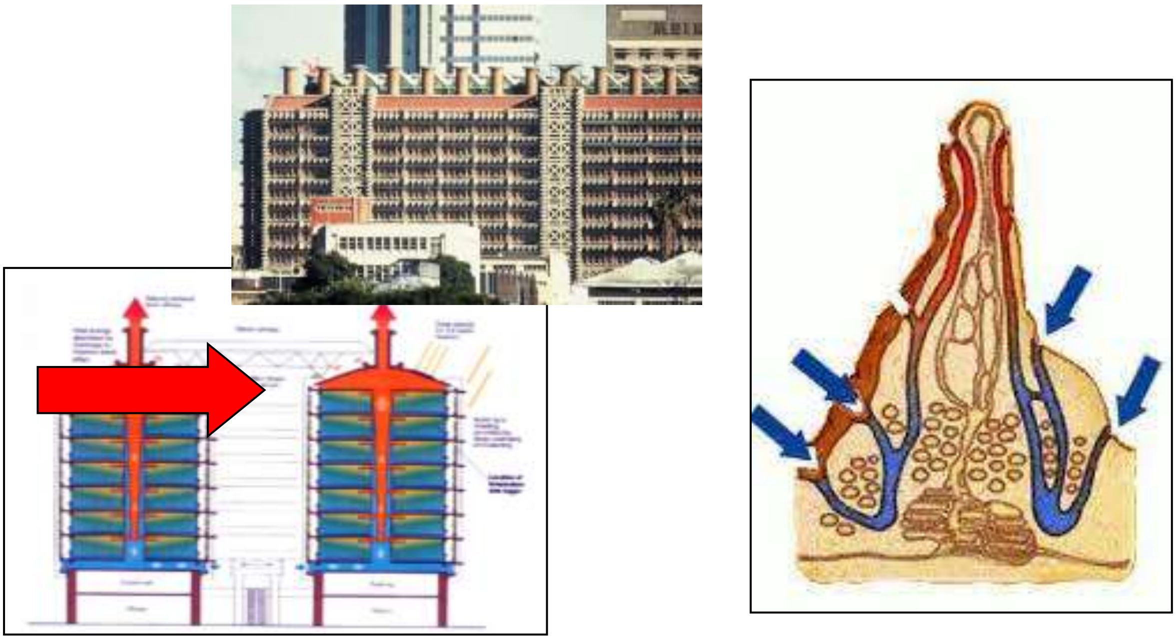
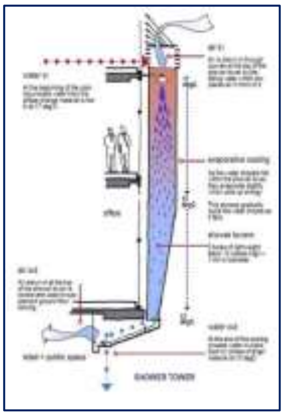


Fig. 10: The East Gate shopping Center in Harare
Source: http://cargocollective.com/harare/Eastgate-Centre-Harare

Council House 2 Melbourne Biomimicry

Biomimicry has a great influence in designing this building, because the architect used a useful passive cooling system that has been previously used in the Eastgate Centre in Harare. The system of passive cooling, heating and ventilation was designed according to the termite strategies used in their mound (Fig. 11).

Fig.11: Council House 2 Melbourne biomimicry
Source:



https://www.google.com/search?q=council+house+2+melbourne+biomimicry

The Impact Biomimicry on Architectural Design Concepts

Aloe Vera plant

The Aloe Vera plant is a species of plants found in the desert areas with a harsh climate in terms of high temperature, low rainfall, and limited water availability. Spines fully cover the plant and serve it in more ways than the obvious, which is to protect it from being a source of food for animals and also help to direct fallen or concentrated water to its base for irrigation or storage. However, the most important function of these thorns is to provide shades for the plant as a means of protection from the sun's rays, thus keeping its temperature as low as possible and preventing the evaporation of the little water that the plant was able to collect. This principle was used for the design of the (MMAA) building in Qatar (Fig. 12), which was implemented in a harsh environment in which the rainfall does not exceed 3.2 inches annually, where the sun filters were spread on the facade of the building similar to the spread of Spines on the cactus plant.

These filters of sunlight penetrate the building due to the oscillation and automatic movement of these filters up and down depending on the amount of sunlight that is to be blocked or entered into the building and according to the required internal temperature. Thus, by simulating Nature, a sustainable building was designed that uses small amounts of energy for cooling purposes and has a good aesthetic quality (Michael,2014).

Fig. 12: MMAA building in Qatar
Source: https://revistia.org/files/articles/ejnm_v3_i2_20/Yetkin.pdf

Namibian Beetle and the Water Collection

One of the most important insects in Namibia deserves to be studied and used for design. This insect lives in arid areas where rain rarely falls, but the area is characterized by fog. Especially in times of dawn, the insect uses the fog through the formation of its body, whereby its outer shell extracts the water necessary for life with the help of protruding areas of the shell that work on (Water-Repelling). These act as channels for collecting condensed water on the insect’s cortex. During the day, because of the black color of the insect, a large amount of thermal energy is absorbed into the insect's shell. It comes out at night and climbs into high areas, and because the temperature of the insect’s shell is higher than the temperature of the surrounding air, it will be a reservoir for collecting the humidity in the atmosphere, so that dew droplets will be collected on the surface of the insect's body, and the droplets will direct the water gathered through channels on its surface towards the insect’s mouth. Several architects have benefited from the design of the Hydrological Center building for the University of Namibia. The architect Matthew Parks has mimicked what the insect is doing by creating a system that collects water in the atmosphere in the form of fog transforming it into water that can be used in the building (Fig. 13). It uses a system consisting of a group of Pods located behind long, thin arched nets (Mesh) that are used to collect water from the air and directed towards the ocean to capture and collect as much moisture as possible. The moisture on the clamps is condensed and then the condensed water is collected in channels below and stored in underground tanks to keep it from evaporating and lowering its temperature. The insect has thus been utilized and its way of life emulated to create a sustainable building in a harsh environment to improve the quality of life of its residents and users in particular (Michael,2014).

Fig. 13 Hydrological Center building for the University of Namibia
Source:https://www.researchgate.net/figure/Hydrological-Centre-for-University-of-Namibia_fig1_328132089

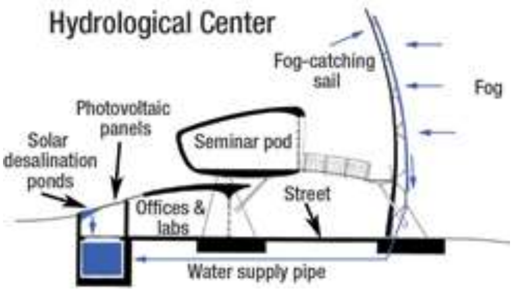


Table 2: The impact of biomimicry on building structure
Source: Author

Building name	Building image	inspiration	Design concept	Part of the building with biomimicry affect	Level of biomimicry

East Gate shopping center in Harare		Termite mound	Natural ventilation to obtain thermal comfort	Exterior/Building skin	Behavior level
Council House 2 Melbourne		planet's ecology	Passive cooling to obtain thermal comfort	Exterior and building service systems/Building skin	Ecosystem level
(MMAA) building in Qatar		Aloe vera plant ecology spread of (Spines) on the cactus plant	Passive shading and natural cooling methods	Exterior/Building skin and visual inspiration	Ecosystem level
Hydrological Center building for the University of Namibia		Namibian beetle and water collection	Collecting water from the fog like Namibian beetles	Exterior and building systems/Building design concept	Ecosystem level

Table 3: The impact of biomimicry on the exterior and interior of building
Source: Author

Building name	**Building image**	**Inspiration**	**Design concept**	**Problem solved**	**Levell of biomimicry**
Christ the Light Cathedral in Oakland/California		Structure	Fibonacci numbers found in Nautilus Sea Shell and the sunflower flower	Building structure	Orgasm level
Sales force tower" in San Francisco/California		Structure	Fibonacci sequence	construction system was designed to resist the earthquakes	Behavior Level
Chinese world trade center		Structure	bamboo plant concepts	Strong structure capable to resist lateral forces like wind	Behavior Level
ICD/ITKE Research Pavilion		Structure	Spider silk	numerical determinants in the geometry of the shape's surface	Behavior level

Conclusions

All the selected projects analyzed have used biomimicry as an approach to be inspired by Nature. The inspiration in architecture and structure is in a limited level as mentioned in the Table 4. These show that Nature can be the model for: building structure, and can inspire buildings designs. It can affect in buildings form, visual aspects, services, cooling methods and the building skin. In addition, biomimicry can affect the buildings in their ecosystem level, behavior level, orgasm level and structure (Fig.14) at the same time. Thus, the research finds that architecture can be upgraded to a high level of sustainability by mimicking Nature combining these different biomimicry aspects in the future. It can even be applied to building interiors to generate a holistic design concepts.

Table 4: Sumary of the projects
Aspects of biomimicry not applied
Source: Author

Project	**Level of biomimicry**				**Biomimicry affecting architecture**			Biomimicry affecting structure
	Orgasm level	Behavior level	Visual level	Ecosystem Level	Walls Outer skin	Building services	interiors	
Christ the Light Cathedral in Oakland/California	★							★
Sales Force Tower" in San Francisco/California		★						★
Chinese World Trade Center		★						★
ICD/ITKE Research Pavilion		★						★
East Gate Shopping Center in Harare		★		★	★	★		
Council House 2 Melbourne				★	★	★		
(MMAA) Building in Qatar	★		★	★	★			
Hydrological Center Building for the University of Namibia				★		★		

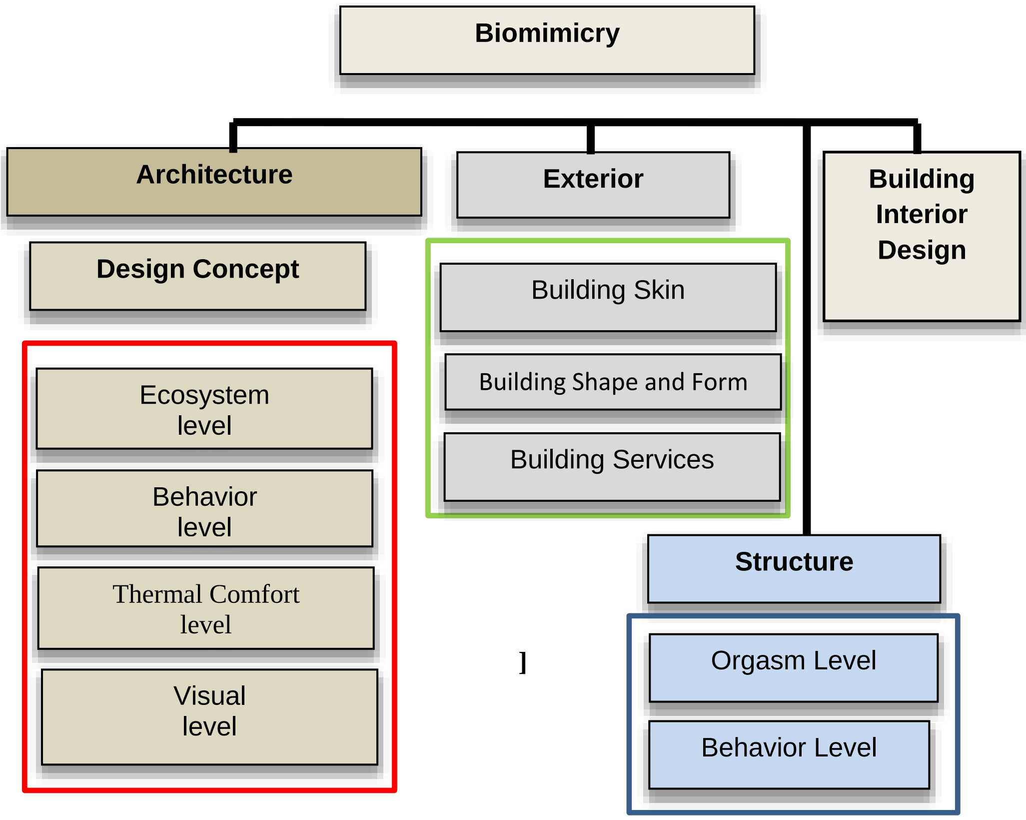


Fig. 14: The impact of Biomimicry proposed on architecture and structure to generate a new holistic sustainable architecture
Source: author

This paper thus concludes the following.

1. Understanding Nature and its principles through bio-mimicry help to find new and sustainable applicable solutions to the problems facing humanity in various areas, including architectural, structural and urban design aspects.
2. The study of organisms in Nature through bio-mimicry enables access to new ideas and principles of sustainability that can be used to solve the problems of a diseased energy-consuming built environment, thereby helping to reduce the load and damage to the natural environment resulting from the built environment.
3. Through the holistic application of biomimicry principles, an environmentally sustainable architecture and construction designs and urban areas can be produced in environments with extreme and harsh climates similar to the ability of living organisms in these environments.
4. By applying these ideas and principles, it is possible to produce a holistic aesthetically sustainable built environment and urban areas compatible with their natural environments.

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