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Biomimetics as an Approach to Sustainability of Architectural Designs

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Abstract

The universe around us stands as a proof of the greatness of God. Everything around us, small or huge, tiny or great, all confirms the fact that this universe has a creator who initiated it and keeps running and maintaining it. No one can ignore such a fact. All aspects of beauty and perfection have been created by Allah. Despite the vast technological and scientific development that humanity witnesses these days, we still discover new indications of God's creativity and miraculous formations every day. This was a source of inspiration for architectural designers that made them come up with new inventions and creations that help regeneration and natural environmental sustainability. Many architects try to copy nature in their designs as they believe that the biomimetic approach is considered the design approach that best preserves the environment and sustains buildings. The absence of a clear definition of different approaches of biomimetic designs of various architectural works is one of the stumbling blocks that face many developers of architectural trends and architectural designers in particular. The research problem is summarized by highlighting various biomimetic approaches of architectural designs through reviewing all previous theories and researches and also studying biomimetic technologies that lead to different results as an introduction to sustainability.

Keywords

Bio mimicry; Sustainability; Bio mimetic design; Built environment; Natural environment

1. Introduction

The approach of copying nature in architectural design which includes an understanding of environmental systems might be the tool to create an environmental building that could go further more than just simply being a preserver of the natural environment, but a way of environment regeneration as the building is a vital component in complementing with natural ecological systems.

"From my designer's perspective, I ask: Why can't I design a building like a tee/ a building that makes oxygen, fixes nitrogen, sequesters carbon, distils water, builds soil, accrues solar energy as fuel, makes complex sugars and food, creates microclimates, changes colors with the seasons and self-replicates. This is using nature as a model and a mentor, not as an inconvenience. It's a delightful prospect . . . " (McHarg, 1965).

Although different forms of bio mimetic designs or designs inspired from alive elements have been the subject of discussion and interest of researchers and professionals in the field of sustained architect, yet practical application of such a trend in architectural design has not been materialized as a common concept. This is obvious from the rarity of built case studies. Examples of successful designs that copy nature which went beyond the stage

of concept and development are mainly limited to products and materials and do not concern the building gas a whole or a building system but tend to copy nature from one aspect of a certain organism. Vincent et al and Vogel studied many historic and contemporary examples. An international research organization interested in biomimecry defined several obstacles that hinder the utilization of this method. The absence of a clear defined approach of bio mimetic designs is one of the barriers that architectural designers have to tackle.
By reviewing and comparing published materials and by studying current technologies of bio mimetic work it was found that bio mimetic design approaches do exist. Each of such approaches has its positive as well as negative points. Different approaches have different results as far as sustainability is concerned. While some designers and scientists use the method of copying nature as a method to increase the sustainability of what they design yet bio mimetic design method could also be used, in some cases, as a source of new innovations. Reap et al indicated that bio mimetic design approach does not necessarily mean coming up with a product or a material that outlasts traditional product or material if the analysis is done from a life cycle perspective (Waddington & Whyte, 1968).

2. Terms and General Concepts

2.1. Bio Mimicry

Bio mimicry is copying of models, system and nature elements for the purpose of solving complicated human problems. Biomineralized structures have been used inspired from nature. From studying the morphology of living organisms many applications have been developed through multidisciplinary cooperation among biologists, chemists, bioengineers and metallurgists for solving human problems and creating balance between natural environment and manmade build environment (Zari & Storey, 2007).

2.2. Bio Mimetic Design

It is the creation of balance and attraction between natural environment and the built mass within a natural harmony either in the shape of the building, building material or the building colors, as if they are all melodies within the same symphony, the earth with its sky, topography, mountains, trees and its living organisms. We are all invited to look and examine such aspects deeply and try to live through it. Nature is a proof of being creative. A singly idea may give numerous solutions and forms. From the idea of forming a tree, a birth a human all types of tress, birds and people where there is no identical pair despite that they all follow the same plan and system.
With the same concept of nature and its method to present solutions, the designer extracts numerous designs from a certain idea. The designer does not neglect the role of nature in enriching his creative ideas. Nature to such a designer is and open display or show in all times and places. This could be fulfilled through:
-Minimizing internal partitions which might obstruct the flow of air and light through the whole building.
-Creating harmony between the building and external environment e.g. emphasizing roof surfaces and domes.
-Giving logical ratios for internal and external openings dimensions all over the building.
-Avoiding mixing of varied materials and maximizing the utilization of natural materials which express its function in the building.
From here we can interpret the building as being a part of the natural environment through its inspired idea out from natural elements. The following is an example of that:

2.2.1. Spiral Shape

Main Characteristics

Continued on next page

Table 1 continued

A	Indirect and goes around itself in a repeated manner and can infinitely fill all two dimensional space.
B	It is a bend that starts from the point of origin and gradually diminishes to larger bends as if trying to get away of this point.
C	Spiral growth occurs by enlarging longer outer surfaces that turns around internal shorter surfaces and covers it. Difference in growth speed creates spiral growth.
D	Spirals are a doubling image, i.e. each image reflects another.

2.2.2. Spiral Form in Living Organisms: Figure. 1

Figure 1. Spiral form in living organisms starting from ram horns to human palm print Source: (Waddington & Whyte, 1968)

Snails grow by enlarging the outer surfaces faster away from rotation axis. Difference in growing speed creates the form of spire without using any other method (Feuerstein, 2002).

2.2.3. Utilizing the Spiral Idea of Seashells in Building Spiral stairs: Figure. 2.

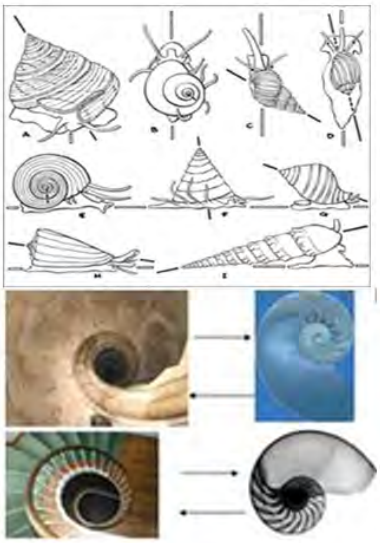

Figure 2. Showing the utilization of spire idea of seashells in making spiral stair case. Source: (Waddington & Whyte, 1968).

2.3. The Natural Environment

The definition of scientific concept of environment was first used by scientists working in the field of biology and physics. Some see that environment has two concepts each complements the other. The first is ”biological environment” which relates not only to man life and his reproduction and genetics, but also the relationship between man and other living organisms, (fauna and flora) which exist together. The second is ”physical environment” and this includes water resources, earth and air whether pure or polluted and other natural characteristics of the medium. Some others see that environment means the medium that the living organism lives in. It forms the total conditions and elements that keep the organism alive. Another trend concentrates on man as one of the active components of environment, so they go to define environment as being all the components of the medium with which man is reacting affecting or being affected by. Or it is the framework where man lives and from which he gets all that supports his life whether it is food, clothing, shelter or medicine, and in the same time exercises relationship with fellow man. It seems that it is closer to a scientific fact to state that environment is the group of physical elements, nature, and social, cultural and economic factors that harmoniously exist side by side in a unique balance affecting the life of man and other living organisms in direct or indirect way. This definition shows that environment is a complex term: as there is the natural environment with its components placed by God, including water, air, soil, sun rays and also what lives on such elements and components i.e. man together with fauna and flora. And there is the built environment which includes all that results from man’s interference and dealings with natural environmental components such as towns, factories, human and social relations that run such establishments (Biomimicry Guild, 2007).

In general environment refers to all surroundings of an object. This object might be a human, an animal or a computer program. In the present time scientists agree that the concept of environment includes all conditions and external factors where living organisms exist and affect in its operations. Environment for humans is: ”The framework where he lives and hosts soil, water and air and any inanimate or any living organism that is included in each of these three elements. It also includes what wraps this framework of different manifestations such as weather, climate, winds, rains gravity, magnetic field . . . etc., and also the mutual relations between these elements.

2.4. Built Environment

It is the collection of creations, achievements and changes performed by man to change the natural environment, i.e. changing the basic conditions and reforming it to suit his needs.

Included in such changes, not only by building (architect, houses . . . etc.) but also include agricultural products and so on. Built environment, e.g. buildings and infra structures from urban areas to rural or natural places that crosses (such as highways, railways, etc.) in desert and through mountain ranges.

2.5. Sustainability

The concept of sustainability goes back to the beginning of the seventies of last century. That is when numerous nomenclatures for increased sustainability design such as green design, environmental design and ecological design started to appear. All such names were mainly aiming to emphasize that, when designing any building, a considerable consideration should be given to the effect of this building on the natural environment.

The word sustainability comes from Latin which means (to hold up) support from below. Society holds from below by its dwellers, nowadays and in the future, according to Greek concept. The site has certain physical, cultural, and spiritual characteristics to deal with sustainability, which means sustainability of reaction between society and ecological system (McHarg, 1965).

Sustainability means integration of ecological systems with human behavior patterns to give sustainability and uniqueness of making up the place. Sustainability might indicate that various natural resources are being utilized in a way that does not deplete them or reduces their renewable value for coming generations by protecting stored consumable natural resources like cooling, water and living organisms.

Sustainability includes self-relying development operations and depends on potentials generated from within. It uses resources in a way that does not deplete them. It represents rational investment of natural resources. This puts sustainability in its right position and secures maximization of its returns.
The main aim of sustainability depends on ecology, which is the science that studies the relationship between living organisms and the environment and social cultural effects. Achieving sustainability requires minimization of resources consumption.
Environmental researcher David W. Orr has classified sustainability into two groups: environmental sustainability and Technological sustainability. Although both have the same aim, yet the way to fulfill such targets may differ.
Environmental sustainability means maintaining and protecting natural assets, which include environmental systems and its services together with waste treatment, regulating climate, producing nutrition, forming soil and consuming resources at a minimum level. Technological sustainability deals with the technologies that achieve sustainability by of the methods of modulating resources to useful products together with combining sciences and designs from human perspective with innovations and creations of designers to come up with futuristic designs (Graham, 2003).

3. The Approach of Bio Mimicry

The bio mimetic approach as a design procedure could be categorized into two procedures: A design inspired by looking at nature trying to define specification, behavior or function in an organism or ecological system and then translate that into architectural designs influenced by nature. The other approach is nature's effect on a design which means that if there is a problem we examine and measure the way nature went through to get it solved. This could be shown in Figure. 3.below

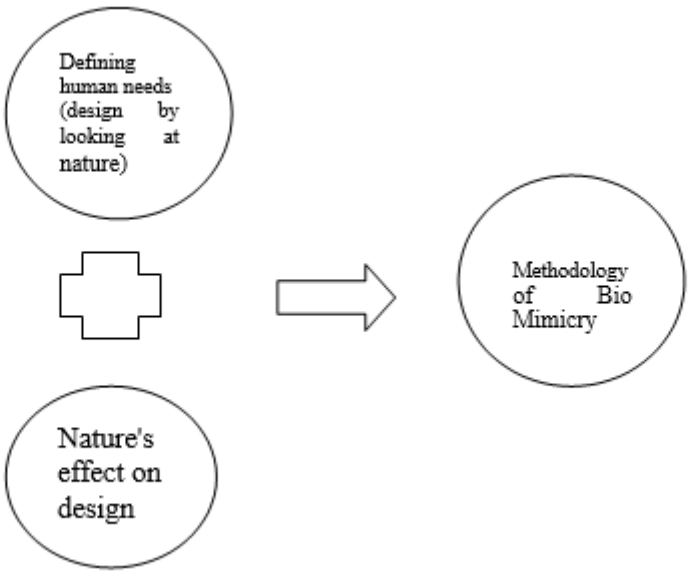

Figure 3. a diagram shows bio mimetic approach categorized in two categories: design by looking at nature and nature influence on design. Source: the writer.

3.1. Design by Looking at Nature

The approach of designers looking for solutions with the world of living organisms requires information about the way nature solved certain problems. Biologists can help in this area. This approach leads designers to identify prime aims of the design and its parameters.
An example of this approach is the prototype bionic car of Daimler Chrysler. The aim here was to reach a large

volume with a small wheel base. The design was inspired by the shape of boxfish (ostracion meleagris). This fish looks like a box but in the same time it is still aerodynamic. The chassis and structure of the car is a typical case of bio mimetic. It was designed using modelling computer software method and based on the way trees grow by making as little as possible of stress concentration. The resulting design gave a structure that looked very similar to a skeleton where material was added exactly where it needed most.

No enough studies have been directed to the implications of architectural design and bio mimetic trends with the identification of humans to design problems which are the basis of the approach to solve certain problem and the way buildings are related to each other, also the relation between buildings and ecological systems. This approach does not necessarily eliminate the underlined causes of destroying environment or damaging it (Faludi, 2005).

Figure. 4. shows a car designed by using the concept of copying nature. It is more efficient and the aerodynamic shape taken from the boxfish makes it more economic in fuel consumption. There is also high efficiency in using materials as mimicking tree growth patterns led to using minimum amount of materials in the car structure. Although the car itself is not a new trend in transport but simple improvements were made possible over current technologies without restudying the idea of the car itself as a means of transportation.

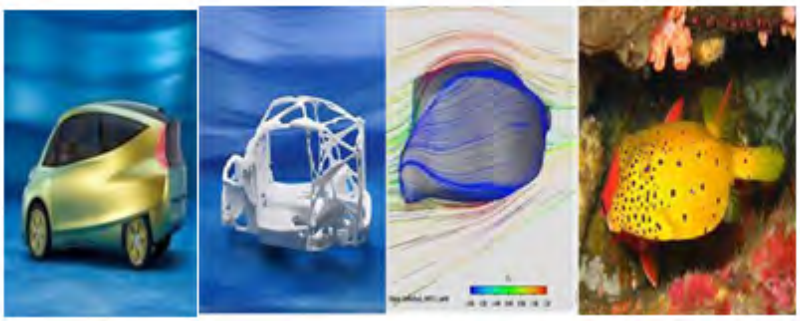

Figure 4. Daimler Crysler car design inspired by the shape of a fish and the way trees grow.
Source: (Kibert, 2006)

Designers can look for the possibility to reach solutions to design problems through the bio mimic approach without going so deeply in understanding the scientific aspects and even without cooperating with biologists or environmentalists if they can take the trouble to watch and examine living organisms and ecological systems and go through available biological researches.

With the limitations of scientific understanding the translation of biological knowledge to a man-made design is likely to remain superficial. For example it is easy to copy mechanical aspects of creatures, yet it is still rather difficult to copy other sides such chemical reactions without suitable collaboration with scientists. Despite such drawbacks, this approach could very well be the way to convert existing built environment from unsustainable environment into a more efficient environment. Pioneer thinkers like William Reed and Ray Cole reckon that a shift from a built environment that ultimately is degenerating ecological systems to a built environment that regenerates capacity for ecosystems to thrive and restore local environments. This will not be a gradual process but will require a fundamental rethinking of the way architectural design is dealt with (Faludi, 2005).

3.2. Influence of Biology on Design

Biological knowledge acquired by human designer, and backed up by familiarity with ecological research i.e. designer's knowledge is the way to reach the required design rather than the determination to solve a certain design problem. The example given in this case is the scientific analysis of the lotus flower emerging clean from dirty swampy waters. This analysis led to many innovative designs. This was detailed by Baumeister (2007), including Sto's Lotusan paint which enables buildings to be self-cleaning. Figure. 5.

Figure 5. Human designer copying nature using the idea of the Lotus flower cleaning itself despite being in a swamp. Source: (Feuerstein, 2002).

Hawken (2007) points out that humans as a species of man, has been on earth long before the oldest living forest and since then humans are learning to adapt to their environment. The similarity between solutions that are designed by humans and the adaptability shown by other species is not all that great despite the fact that such organisms (species) live in the same environment with the same available resources. The advantage of this approach is that biology influences humans in ways that could be considered different from predetermined design problem, resulting in previously unthought-of technologies or systems or even approaches to design solutions. Possibilities of a true change in human designs and what is concentrated on as a solution to a problem exists with such an approach to bio mimetic design.

From the designer's perspective this approach has the disadvantage that biological studies must be extensively carried out followed by recognizing the relevance of the design workout. Ecologists and biologists should be able to identify the potential of their study in creating innovative application.

4. Application of Bio Mimicry on Different Architectural Work

As far as the previously mentioned two approaches, it is possible to apply three different level of mimicry in the design. Those three levels are form, process and ecological system. When looking at a living organism, the aspects that could be copied are the form and the design process. In ecological system, it should be searched looking for aspects that could be copied.

In this paper a framework is suggested to understand the application of bio mimicry in architectural design where the different levels are recognized. There is also an attempt to show the way of using bio mimicry as a method for increasing the ability to regenerate environment. Deciding about the developed type of bio mimicry, this framework paves the way for designers who like to use bio mimicry as a method for improving environmental sustainability. It also allows them to identify the efficiency of the approach they are about to head for. The framework that is described here could be applied in both approaches i.e. design looking at nature and the influence of nature on design.

By going through available bio mimic technologies, three different levels of mimicry could be recognized. These three levels are: the organism, behavior and the ecological system. The level of the organism points at a certain organism such as a plan or an animal. The mimicry could by for the whole organism or just a part of. The second level is copying the behavior and this could include a translation of one side or more of the organism's behavior towards the ecological system around it. The third level is about mimicking the whole ecological system and the main mutual principals that provide successful functioning (Zari & Storey, 2007).

Within these levels five other dimensions mimicry could be seen, so a bio mimetic design could, for example, be a matter of copying the (form), i.e. the design looks like the mimicked organism or it could be made out of a similar (material). The imitation could be of the way it is made, this is the (function) or how it works (process), or may be what it is able to do (function). Achieving the aim function of a building means that the building is having a successful function suitable for the environment and the ecological system. So it enjoys the environmental balance through sustainability and the main building function which helps to reduce material consumption and adaptation

with external environment.

Figure. 6. below shows the methodological framework followed in bio mimicry of architectural design.

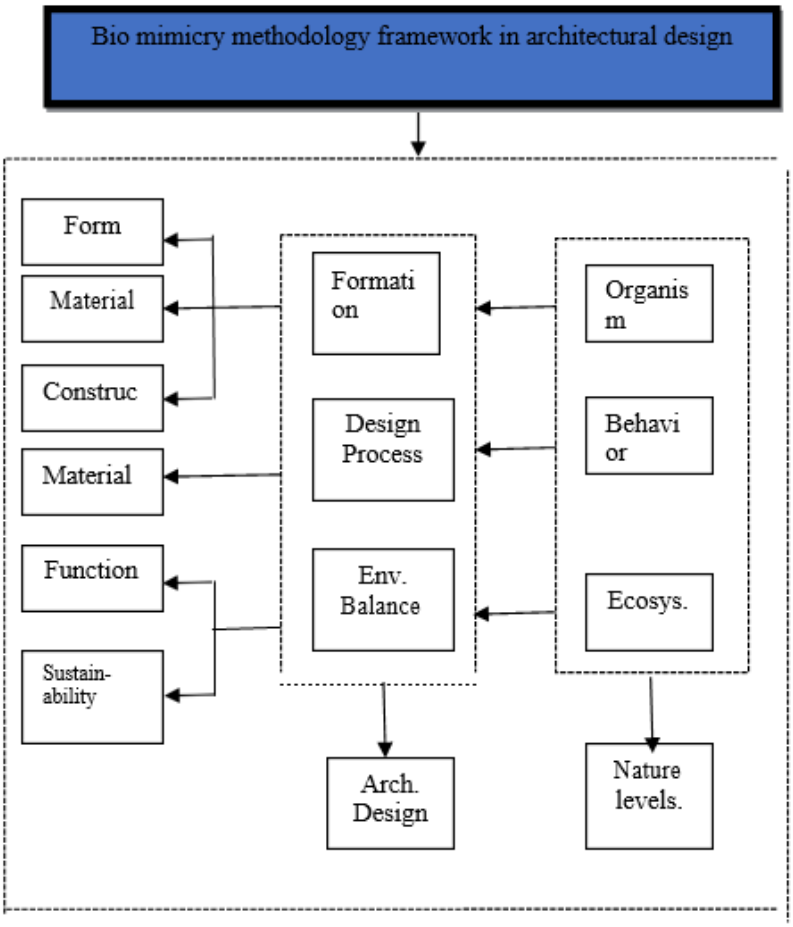

Figure 6. Shows the bio mimic methodology framework in architectural design.
Source: the writer

The paper discusses the three level of architectural design through the form. Design process and the environmental balance with comparative analytical examples.

4.1. First Level: The Level of Organism Bio Mimetic in Architectural Form

Example: the Project of East Gate Building in Harare, Zimbabwe (Elkholy, 2001).

Figure 7. To show the extent that designer applied mimicry of termite mounds

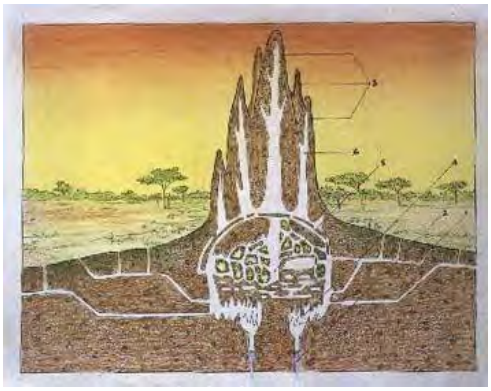

Figure 8. To show a termite colony and the ventilation idea from inside to outside and discarding refuses underneath

Table 2. Bio mimetic of architectural form at organism level Source: collated by the writer

Bio mimetic methodology framework in architectural design	
Organism level	
Project description: It is possible to copy the relation between organisms or species in a similar way. It is possible to show the bio mimicry of process and function at the behavior level by the East Gate Building in Harare, Zimbabwe. The building is partially based on negative ventilation technology and heat regulation that could be seen in ant hills to create fixed heat inside. Water is extracted and purified from drainage under the building. This is a mimicry of what is done by some types of termites near ground water as a cooling mechanism by evaporation.	Figure 7 Figure 8
Bio mimetic methodology framework in architectural design (continued)	
Form	The building looks like a termite mound
Material	The building is constructed using a material similar to that used to build termite mound, a material inspired by nature and mimics conical structure or skin.
Construction	The building is constructed in the same way termites use, i.e. building gin stages.

Continued on next page

Table 2 continued

Analysis	Mimicking on behavior level requires making some decisions about the suitability of mimicry to the human contest. Not all organisms have the kind of behavior that is suitable to mimic by humans. There is always the risk that a consumption pattern could be interpreted on bases of other species behavior. For example copying of behavior of a building to termites could be suitable to create a building with a comfortable temperature that is negatively controlled. Mimicking the social structure of termite colonies does not coincide with the evaluation of international human rights. It could be more suitable to use behavior mimicry for a certain building in a way to increase sustainability and capacity for environmental regeneration rather than applying mimicry in social and economic fields without careful studies. It might be better mimicking full system rather than mimicking individual organisms in this matter

4.2. Second Level: Level of Behavior Level in Architectural Design Process

Example: The Project of Tsui house Residence for Florence & William Tsui (Elkholy, 2001).

Figure 9.

Figure 10.

Figure 11.

Figure 12.

Table 3. Bio mimetic of architectural form at behavior level Source: collated by the writer

Bio mimetic methodology framework in architectural design
Behavior level of mimicry in architectural design

Continued on next page

Table 3 continued

Project Description: Basically the building is a reinforced concrete structure constructed on a chain of perforated drain pipes that dissipate the building water and water resulting from cases of flash floods, water is pushed directly outwards through large drain pipes of the house partially buried in the soil at about 1.50 m underground. Walls are made out of insulating materials that have been recycled and added to cement blocks. The resultant product is called Restra block. Such walls are impervious to water, fire and termites. They also reduce noise. From the economic point of view, they are less expensive (by about 10 %) of the cost of traditional structure. Upper structure consists of a chain of arches in the shape of a parabola connected together with timber posts tied and covered with a spray of cement connected to a system of blocks. This leads to the formation of a united, continuous structure. Walls are at an angle of 4° towards the inside which creates compression towards the center of gravity of the structure. Resulting side forces also help against earthquakes. Side walls are designed in the form of curves and arches so winds accelerate around surfaces. External surfaces also have depressions which enhance aerodynamic efficiency by reducing air friction with surfaces. Materials used in this building are timber, plywood, concrete (cement blocks+ insulating materials) and structure adhesives, gypsum, water resistance acrylic, fiberglass and steel wires.	Figure 9, Figure 10, Figure 11, Figure 12 Tilted walls towards the inside with a 4° angle forming structural compression toward center of gravity also generated side forces help to resist earthquakes
Function	The designer was inspired by an organism which is the water spider with its elliptical form which withstands natural disasters.
Analysis	The main project idea is inspired by the morphology of one of the most widespread organisms in nature, the water spider with its elliptical shape. The designer followed the same principle natural structure

4.3. Third Level: The Level of Mimicry of Ecological Systems with Balance Between Building and Nature.

Example: ”Venterra Project” Greg & Diane Kaumann Residence (Elkholy, 2001).

Table 4. showing mimicry of ecological system in balancing the building with nature. Source: collated by the writer.

Bio mimetic methodology framework in architectural design
Ecological system level of mimicry in architectural design

Continued on next page

Table 4 continued

Project Description: It is a project of designing a residence in USA. A large part of the residence is buried under ground with a corrugated roof above the ground floor, made out of golden colored bright metal. The roof corrugations help in dispelling the strength of hurricane winds and in the same time providing a multi drainage system as it forms a funnel shape to collect rain water in outdoor and indoor reservoirs for recycling water. The roof also forms a chain of a random system that has random minor bumps which alleviate the strength of hurricane winds and allow those winds to pass at the top of the house with least effect. The plan of the house is in the form of a horseshoe. This shape allows for maximum exposure to sun rays over the year. It is the only design that provides that. The shape also forms a wind barrier for north west and south west winds which are considered as the main source of hurricanes. The house has three car garages. It also has an upper work area and a tunnel from the house to the garage, partially buried under ground.	Figure 13, Figure 14, Figure 15, Figure 16 Venterra, Greg & Diane Kaumann Residence, the designer was inspired by the ecological system to solve ventilation and heating problems creating balance and functional sustainability inside the house to meet dwellers' needs.
Function	The designer was inspired by system function through form treatment in the building.
Sustainability	The building is designed in a way that makes it meet requirement of its dwellers and withstanding weather and function conditions with minimum cost and effort
Analysis	The construction of the house utilizes Styrofoam as an insulating material and corrugated steel plates. Walls and floors have a network of hot water pipes that warms the place. The pipes go through the fireplace in living area helping to heat the water. The designer was inspired by the ecological system to solve the ventilation and heating problems inside the house to create balance and functional sustainability to meet requirements of the house users.

After studying and understanding analytical examples of architectural works designed on basis of bio mimicry and the development of living organisms across millions of years, where such organisms survived on earth because they possess survival mechanisms and continually developed across the years. This is a wealth of knowledge and examples for humans to inspire them to come up with problem solutions copying what such organisms did to handle aspects such as energy and resources. It was also possible to understand the consequences of negative environmental impact of human activities on ecological system of the globe (Doughty & Hammond, 2004).

Figure 13.

Figure 14.

Figure 15.

Figure 16.

5. Results and Recommendations

1. To make nature the right course to go through for constructing an environmentally reactive and balanced building, there is a methodological framework that is followed through three level of nature, organism, behavior and ecological system, as formation has dimensions which are: form, material and construction. Design process has method of operation while environmental balance, without function and sustainability it is difficult to reduce revenues consumption and adaptation with external environment.

2. The main advantage of bio mimic design is that it would have an overall positive effect on environmental performance. It would also be applicable on a groups of spatial and time ranges and this is considered to be a good start point for a building design that is actually sustainable and regenerative of a certain place.

3. The research emphasizes that bio mimetic designs can withstand natural conditions such as heavy rain, hurricanes, floods, fires, earthquakes and soil compression.

Studies showed that when designing a sustained building, nature must be looked at as a source of inspiration and mimicry providing the designer with the course of work leading to the ideal situation which means that buildings should multiply their systems, treating their wastes, generating their energy and reaching comprehensive aesthetic formations over time. This means that the designer can take natural or previous forms or copy them allowing nature to show itself in the design and come out to the surface through appearing in its different forms such as the form of flowers and birds and the touch of materials or even the characteristic that accompany natural light and ventilation and reflects into buildings.

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