***EQA** – Environmental quality / Qualité de l’Environnement / Qualità ambientale,* **29 (2018) 1-28**

BIOMIMETIC ARCHITECTURE: CREATING A PASSIVE DEFENSE SYSTEM IN BUILDING SKIN TO SOLVE ZERO CARBON CONSTRUCTION DILEMMA

Abeer Samy Yousef Mohamed

Department of Architecture Engineering, Faculty of Engineering, Tanta University, Egypt
Corresponding author Email: drabeersamy@hotmail.com

Abstract

The entire world is confronting a genuine risk and a continuous issue that has just begun decades prior, however yet is still expanding, this issue is the “Global warming” happened from Greenhouse Gases (GHG) - particularly by Carbon Dioxide (CO_2) emission, which is related with the ascent in Earth's temperature that accompanies a rundown of hurtful results. Therefore, architects should bring innovative solutions for energy efficient buildings, and the best tutor to learn from how to design such buildings is our great mentor Nature, through the innovative approach of biomimetic. Which is a new way of viewing and valuing nature that contributes in making the built environment similar to living organisms in many ways hence sustaining it. Building skin as subcategory of biomimetic that frames the whole outside of the building, as the first line of defense for the building against external influences that will interact with all environmental aspects like living organisms. The main aim of this paper is to investigate how energy consumption could be reduced through this innovative building skin, by applying biomimetic architecture approaches in design processes. In order to create a Passive Defense System in building skin to solve Zero Carbon Construction Dilemma, regarding this new vision the study will introduce: (i) framework for the Integration of biomimetic and Sustainable architecture, (ii) new design processes phase through biomimetic vision, (iii) building skin design criteria through biomimetic. That will be a road map and guide line for architects to facilitate the process of compatible environmental design with zero carbon emissions.

Keywords: *global warming, GHG, biomimetic architecture, building skin*

Introduction

The Earth is confronting today genuine climatic changes caused by the human obstruction in its ecosystem, which was never appeared to be conceivable that people were able to change the essential physical and concoction properties of this whole huge planet. Right now, in the 21st century everywhere throughout the globe, an enormous amount of primary energy is wasted due to the inefficient design of buildings which not compatible with its own environment. In addition, the running of the machines and equipment used to convert energy into required services,

DOI: 10.6092/issn.2281-4485/7855

or change it from phase to another. According to McDonough and Braungart (1998) question: ―From my designer's perspective, I ask: Why can't I design a building like a tree? A building that makes oxygen, fixes nitrogen, sequesters carbon, distills 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". Regarding to the previous vision and climatic changes there causes and consequences architects have an essential role in protecting their environment. Therefore, a number of design approaches and solutions have been researched and applied in order to overcome energy problems. One of those approaches is "Biomimetic" which is defined as "the applied science that derives inspiration for solutions to human problems through the study of natural designs, systems, and process" (Benyus, 1998). Building skin is one of the key considerations in designing energy-efficient buildings. That is because of its capability of improving the building's performance in natural ventilation, managing heating transfer, redirecting and filtering daylight and enhancing occupant well-being among several other functions. Therefore, it could play an important role in reducing the energy consumed in cooling loads. The paper will discuss the principals of biomimetic as an approach for sustainable and efficient design, to create a passive defense system in building skin, that helps to solve zero carbon construction dilemma. Therefore, the aim of this study is to provide guidelines for applying biomimetic principals on building skin, design concepts, criteria, building technologies, efficient use of materials and process for efficient energy management. That is to reach a small detail, which would add to architecture to help to decrease one of the causes of global warming, by decreasing energy consumption.

Problem definition

Greenhouse gases affect negatively on the environment, climate, continuing to need high maintenance and buildings' energy demanding will not lead to a promising future. Therefore, energy consumption is a growing global concern, since buildings contribute significantly to energy usage. Further steps relating to efficient buildings have to be applied in order to reduce energy consumption in buildings. By seeking solutions, architects are returning to basic passive design principles while also utilizing sophisticated high-tech systems. Therefore, qualities of life are becoming the focus while designing of the built environment. This inspiration found in nature that could be introduced into the artificial, cultural, or social, environment to maintain the quality of life and biodiversity. One of the specific area needs further investigation is the building skin, because it determines so much of the efficiency of a structure. By proper management, building skin can significantly minimize a building's energy demand. In addition, skin system can waste tremendous amounts of energy, if not properly designed. This design will greatly affect the amount of energy required for lighting, mechanical systems, and maintenance. Regarding this point of view, this paper introduces a new approach through biomimetic architecture especially in building skin as a passive defense system to solve zero carbon construction dilemma that mimics nature and integrates it with our local conventional building structures.

Research hypothesis

Inspiring architecture from nature will help to find ways for safeguarding the biodiversity of the environment from being destroyed. Thus, biomimetic principals could provide guidelines for improving the energy efficiency of buildings through applying those principals especially on building skin. As the skin furls our body, the building envelope furls the building; therefore, building skin should do the same performance especially in thermos regulating the building, which decreases the energy consumed in buildings. Regarding this vision, by mimicking the human skin using new techniques and smart materials that act on its own, then building's skin that thermos-regulate the building naturally without mechanical interference thus decreasing the energy consumed to reach a proper thermal comfort. A passive defense system could be created through building skin as a simulating from nature, which will reduce the environmental negatives to create a positive environment. Bio-inspired regenerative architecture can develop the design of mutual relation between the building and natural environment.

Research methodology

According to research objectives, research methodology has been carried out in four phases:

- The first phase, a literature review about global warming and its negative effects on architecture, biomimetic approaches and biomimetic architecture in building skin through the study of existing literature.
- The second phase, a theoretical study that will introduce Principles of Biomimetic Architecture that will be the base for analytical study.
- The third phase, an analytical study for international case studies will be presented and analyzed in terms of usage of biomimetic, and the impact they had on reducing the buildings energy consumption, through building skin.
- Finally, guidelines for creating passive defense system in building skin to solve zero carbon construction dilemma to be efficient and regulate energy.

Global warming

Climatic changes and global warming

Climatic changes and global warming refer to an increase in average global temperatures. Natural events and human activities are believed to be contributing to this increase, which is caused primarily by increases in "greenhouse" gases such as Carbon Dioxide (CO_2). A warming planet thus leads to a change in climate, which can affect weather in various ways, as discussed further below.

The main indicators of climatic changes

As explained by the US agency, the National Oceanic and Atmospheric Admini-

DOI: 10.6092/issn.2281-4485/7855

stration (NOAA), there are 7 indicators that would be expected to increase in a warming world (and they are), and 3 indicators would be expected to decrease (and they are) (Nessim, 2016) (Fig. 1).

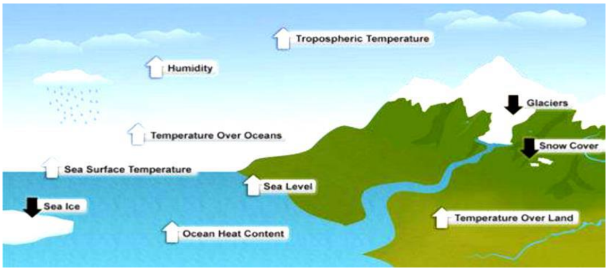


Figure 1
Ten indicators for a warming world, which confirmed that the past decade warmest on record according to scientists in 48 countries, (Source: Nessim, 2016)

Greenhouse effect

The term greenhouse is used in conjunction with the phenomenon known as the greenhouse effect (Nessim, 2016) (Fig. 2):

- sun’s energy that drives the earth‘s climate and atmosphere, and warms the earth’s surface;
- in turn, the earth radiates energy once again into space;
- some atmospheric gases (water vapor, carbon dioxide) and different gasses trap a portion of the active energy, retaining heat somewhat like the glass panels of a greenhouse;
- therefore, these gases are known as greenhouse gases;
- the greenhouse effect is the rise in temperature on Earth as certain gases in the atmosphere trap energy.

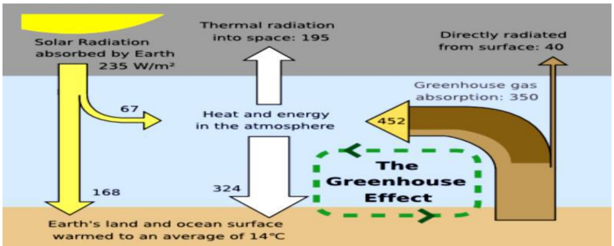


Figure 2
Greenhouse effect in W/m^2, (Source: Nessim, 2016)

Greenhouse Gases are six main gases plus water vapor that considered a greenhouse gas, these gases are:

- carbon dioxide (CO$_{2)}$;
- methane (CH$_4$) which is 20 times as potent a greenhouse gas as carbon dioxide;
- nitrous oxide (N$_2$O);
- three fluorinated industrial gases: hydro fluorocarbons (HFCs), perfluoro-carbons (PFCs) and sulfur hexafluoride (SF6).

All these types of greenhouse gases got major consequences on raising the temperature of the Earth. The importance of analyzing the electrical consumption and energy resources is that non-renewable energies derived from fossil fuel emit tons of CO$_2$, which is the main gas of greenhouse gases, hence contributing to raising the Earth temperature.

Climate change and the built environment

Climatic changes, and related impacts on the built environment, are expected to increase in intensity in the future, suggesting that a re-evaluation of the built environment is necessary (IPCC, 2007). Established responses to climate change in the built environment broadly fall into two categories (Zari, 2010):

- the first: is mitigating the causes of climate change by reducing GHG emissions;
- the second: is adapting the existing and future built environment to predicted climate change impacts.

Many technologies and established design techniques have been assisted to mitigate the causes of climatic changes, such as: passive solar design, new techniques or technologies that are able to contribute to mitigation and adaptation to climatic changes with significant other economic, social and environmental benefits can be revealed by a careful study of how certain organisms and the ecosystems they create (Table 1).

Table 1. *Climate changes direct impacts on the built environment (Source: Zari, 2010).*

Potential direct climatic changes impacts	Consequences of the built environment
Changes in temperatures (likely to increase in most areas)	Increased overheating and air conditioning load Decreased winter space heating Decreased water heating energy Intensified urban heat island effect
Increased intense weather events	Damage to buildings and infrastructure
Changes in precipitation patterns	Damage to foundations, underground pipes/cables, etc. Increased inland flooding Damage to façades and internal structure due to rain penetration Increased subsidence (clay soils) Increased erosion, landslips, rock falls Changes in aqwuifers and urban water supply and quality Increased pressure on urban drianage systems Increased stormwater run-off and leaching of pollutans into waterways or aquifers
Thermal expansion of oceans and changes in the cryosphere (ice systems), such as retreating snow lines and ice packs, and melting glaciers	Increased coastal flooding Increased erosion Cnages in sedimentation patterns Changes in water tables and possible infiltration of aquifers Relocation from coastal areas Loss of inter-tidal areas acting as buffer zones
Changes in wind patterns and intensities	Changes in wind loading on buildings
Increased air pollution	Increased ventilation needed Damage to building façades

Approaches to biomimetic (fundamentals concepts – an overview)

For the term "bionic", there is diverging information available about its creation (also known as "biomimetic", "biomimicry", "bio-inspiration", "biognosis", "biologically inspired design") and similar words and phrases implying reproduction, adaptation, or derivation from biology. Consistent is that it was

DOI: 10.6092/issn.2281-4485/7855

introduced by Steele around 1960 Jack E. Steele (was an American medical doctor and retired US Air Force colonel, most widely known for coining the word bionics). The term possibly originates from the Greek word "βίον" (bíon), meaning (unit of life) and the suffix "ic", meaning (like or in the manner of, hence it may be translated as like life) (Gruber, 2008; Abermann, 2011). According to that, all these terms aim to denote it as a study that makes practical use of mechanisms and functions as present in biology or nature in engineering, design, chemistry, electronics, and so on. Also it is defined as "the study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones" (Harkness, 2001; Abermann, 2011).

Bionics

The explanations of the term "bionics" mean (biology + technics) which describe the process of "copying, imitating, and learning from biology" was conceived by Jack Steele in as early as 1960 prior to the infamous bionics symposium, (Iouguina, 2012).

Biomimicry and biomimetic

The terms Biomimicry and Biomimetic originates from the Greek words bio - meaning life, and mimesis - meaning to imitate. As mentioned in Benyus' words: "Biomimicry is the conscious emulation of life's genius" (Benyus, 1997). Biomimetic is the technical term usually used in biology, biochemistry and pharmaceuticals, also is commonly used by material scientists in their quest to find properties in living organisms and natural systems that can be analyzed in order to recreate those properties for industrial, medical, and biological products (Mueller, 2008). It represents the studies, imitation of nature‘s methods, mechanisms and processes (Bar-Cohen, 2006). From this vision, nature will be a source of inspiration for the everyday design. Therefore, the real benefit of using biomimetic is that it brings in a completely different set of tools and ideas you would not otherwise have (Mueller, 2008). Therefore, biomimicry and biomimetic implications are the examination of nature, their models, systems frameworks, procedures and components that can give answers to human issues. Albeit different types of biomimicry or bio-inspired design are discussed and examined by scientists, researchers and professionals in the field of sustainable architecture (Reed, 2006; Berkebile, 2007), the boundless and viable use of biomimicry as an architectural design method and technique remains generally undiscovered, as demonstrated by the modest number of built case studies (Faludi, 2005). Although, in the same field there are two other terms that need clarification, (Redolfi and Shiva, 2015): "bio-utilization". This refers to the direct use of nature for beneficial purposes, such as incorporating planting in and around buildings to produce evaporative cooling. "Biophilia": this was popularized by the biologist Edward O. Wilson (is an American biologist, researcher, theorist, naturalist and author. His biological specialty is myrmecology, the study of ants, on which he has been called the world's leading expert), which point to a hypothesis that there is an instinctive bond between human beings and other living organisms (Wilson, 1984,1994). From an architectural perspective, there is an important distinction has to be made between "biomimetic" and "biomorphism". The Biomorphism approach is "using nature as a source for unconventional forms and for symbolic association", and this was the modern architect's frequent approach. According to this approach, there are some examples of how this has produced majestic works of architecture such as Eero Saarinen's TWA terminal (Fig. 3). The reason that it is necessary to make a distinction is that we require a functional revolution, if we really want to bring about transformations; it is supposed that it will be biomimetic rather than biomorphism, which will deliver the solutions needed.

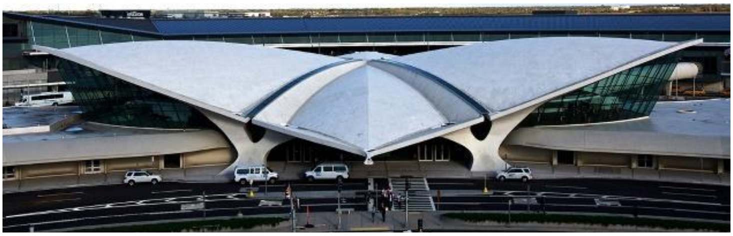


Figure 3
Eero Saarinen's TWA terminal.
(Source: Pawlyn, 2011)

Historical Background. The Greek philosophers in 500 B.C have realized and discover natural organisms as models for a harmonious balance and proportion between the parts of a design that is synonymous to the classical ideal of beauty, so it was the beginning of biomimicry to appear where. After many centuries, in 1482 Leonardo Da Vinci considered it essential to observe the anatomy and flying techniques of birds as an inspiration to create a flying machine as an early example of biomimicry (Fig.4a) (Steadman, 2008). Although his machine was never completed, the mere principle of being inspired by nature introduces da Vinci as a biomimicry pioneer along with the Wright Brothers, who derived their inspiration from flying pigeons to construct the first airplane. It helped in the development of their first prototype to an airplane in 1948. In1958, Jack E. Steele introduced the term "Bionics" and he defined it as the science of natural systems or their analogues. Sir Joseph Paxton (was an English gardener, architect and Member of Parliament, best known for designing the Crystal Palace, and for cultivating the Cavendish banana, the most consumed banana in the Western world). He was inspired by the leaves of the water lily, which appeared in his design of the crystal palace by designed a greenhouse at Chatsworth in England, with a structure based on the study of the giant Amazonian laves of water lily (Fig.4b and 4c). For the term "Biomimicry", first appeared was in 1982. Yet, it's genuine transformation in 1997, when Janine Benyus (scientist and author) has advanced the term more in her progressive book; "Biomimicry: Innovation inspired by Nature". In her treatise, as Benyus had described, "a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g. a solar

DOI: 10.6092/issn.2281-4485/7855

cell inspired by a leaf" (Benyus, 1997). The similar term, "biomimetic" was coined by Schmitt (1969), one of the early giants in biomedical engineering in his article "Some interesting and useful Biomimetic Transforms". Schmitt (1969) argued that nature provides useful models that can be used in science and engineering to solve human problems. According to previous, Biomimetic is the replication of the functionality of a biological structure by approximately reproducing an essential feature of that structure, (Lakhtakia and Martin-Palma, 2013).

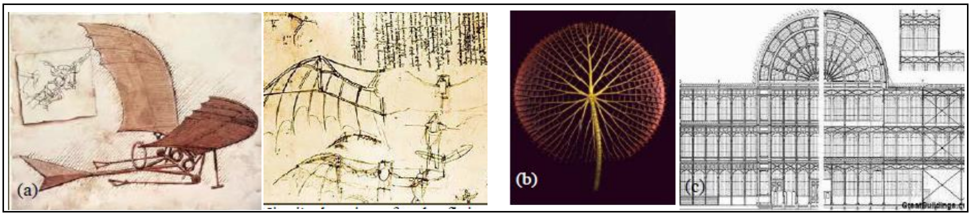


Figure 4. (a) *Leonardo Da Vinci's drawings for the flying machine; one of earliest Biomimetic designs in the 13th century* - (b) *Water lilly* – (c) *Crystal palace. The secret was in the rigidity provided by the radiating ribs connecting with flexible cross-ribs. Constant experimentation over several of years drove him to devise his glasshouse design that inspired the crystal palace.*

According to the previous background, architects should have an obligation towards upcoming generations to a paradigm shift their way of thinking in design towards not only enhancing identity, functionality and aesthetic values, but also towards the interpreting sustainable strategies and methodologies in integration with nature.

Nature-inspired design strategies. Nature-inspired design strategies are new ways of viewing and valuing nature. They are design strategies that base a significant proportion of their theory on "learning from nature" and regard nature as the paradigm of sustainability (Ingrid et al., 2010). Regarding to that, the main concepts are to benefit from nature as apart, to conserve the environment and to have zero carbon building.

The philosophy behind biomimetic. Biomimetic described as a tool that increases the sustainability of human-designed products, materials and the built environment (Mazzoleni, 2013). Biomimetic is a new scientific field that studies nature's unique ideas and their best practice, and after that imitates these outlines and procedures to solve human issues (Rao, 2014). A new ideology joins biology and architecture keeping in mind the end goal to accomplish finish solidarity the building and nature. Regarding that, a biomimetic approach based on studying the living organisms - their structures, functions, processes, interactions and relationships among them and their surroundings, in order to learn from their strategies, methods and principles and emulate them to optimize the environmental performance and attitude of the designs.

Importance of biomimetic research. Biomimetic is considered one of the most important design tools that flourished with the dawn of the twenty-first century to evolve revolutionary sustainable design solutions. This is consistent with global attention for the importance of new vision toward zero carbon buildings & structures. Therefore, biomimetic is a unique and creative approach to innovation that helps to invent sustainable solutions to human challenges by emulating nature and tested patterns and strategies.

A. Paradigm shift the way of nature design principles. God created nature to be our mentor for survival on earth, not merely a source of extracted goods. Therefore, our way of thinking has to be shifted, by seeing nature as a model, a measure and a mentor will introduce an era based not on what we can extract from the natural world, but on what we can learn from it (Benyus, 1997). Therefore, nature's unique characteristics and principals could be applied and help develop architecture. One of the impressive biological processes is the ability of adaptation found in natural organisms. Flora and fauna offer numerous examples of adaptation methods to hot climate by means of physical characteristics, behavioral reactions.

According to Benyus vision, ten principles could identify as underlying nature‘s rules for sustaining ecosystems, which are (Minsolmaz, 2015):
- use waste as a resource,
- diversify and cooperate to fully use the habitat,
- gather and use energy efficiently,
- optimize rather than maximize,
- use material sparingly,
- don‘t foul nests,
- don‘t draw down resources,
- remain in balance with the biosphere,
- run on information and shop locally.

Therefore, if interior spaces, buildings and cities have designed in accordance with these principles, as Benyus suggests, we would be well on the way to living within the ecological limits of nature, and thus achieving our goal of sustainability (Minsolmaz, 2015). In addition, nature solves the following aspects (Giurea, 2016):
- the economy of constructive materials,
- original structures,
- perfectly adapted to their environment
- aesthetic quality.

So, nature‘s principles provide verified information through the natural selection process.

B. The way of thinking about nature (Wasfi, 2014):

B.1 Nature as model: studies nature‘s perfect models and strategies then imitates or takes inspiration from their designs criteria and processes to solve human problems of humanity in a sustainable manner.

B.2 Nature as measure: utilizing nature's 3.8 billion years of advancement, quality control and ecological guidelines to determine the sustainability of innovations.

Nature has officially realized what works sustainably; Nature has realized what works and what keeps going (according to nature's life principals). Biomimetic utilizes an ecological standard to judge "rightness" of our innovative creations.

B.3 Nature as mentor: finally, relationship with nature would change by Biomimetic from seeing nature as a source of raw materials, to a source of ideas for problem-solving, a mentor that has the wisdom and knowledge for survival and living sustainably (Anous, 2015). A new way of seeing and valuing nature as a resource that we can learn from and that we should preserve instead of uncontrollably extracting its resources valuing nature.

Biomimetic presents an era of ecological creation not in light of what we can extract from the natural world; however, what we can gain from it.

Applying biomimetic in the design process: biomimicry design spiral

The Biomimicry Institute created a design spiral methodology as shown in (Fig. 5) to help people learn and practice Biomimicry (Rossin, 2010). Biomimicry design spiral usually used by architects as a tool to guide through the reiterative process of design. Innovative architects explore the true functions they want their design to accomplish, and then search for what organisms in nature depend on those functions for survival.

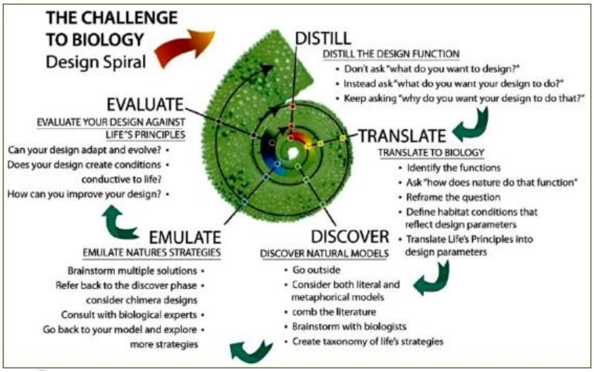


Figure 5
Design spiral by the biomimicry institute.
(Source: Rossin, 2010)

Biomimetic architecture design methodology/ approaches

Biomimetic as described before is mimicking life, so it is necessary to identify what exactly it is in life could mimicked. Commonly for life mimicking, there are three existing levels (Miles and Michael, 2009):

- mimicking of natural form;
- natural process (or how things operate);
- mimicking of natural systems (like eco-systems).

Some of these levels used in certain design fields exclusively, but in terms of architecture; all three could be used either on their own or in combination (Miles and Michael, 2009). Biomimetic use Life's Principles as an overarching, scoping and general evaluation tool. We need to know how the biomimetic methodology works,

to realize how one applies this practically to the design process. Therefore, for biomimetic approaches as a design process commonly introduce through three categories:
- Design approach: problem-based approach (Design to biology);
- Indirect approach: solution-based approach (Biology to design);
- Stochastic approach.

Direct approach: problem – based approach (Design to biology) (Fig. 6).

This approach has different naming “Design looking to biology”, “Top-down approach”, “Problem driven biologically inspired design”, “Challenge to biology”, all is mainly based on an existing design problem looks to nature for solutions/inspiration (Zari, 2009). By characterizing a human need or design issue and looking to the ways that different organisms or ecosystems solve, this named here design looking to biology. From analyzing the pattern of problem-driven biologically inspired design process follows a progression of steps which in practice, is non-linear and dynamic in the sense that output from later stages frequently influences previous stages, providing iterative feedback and refinement loops (Helms et al., 2009).

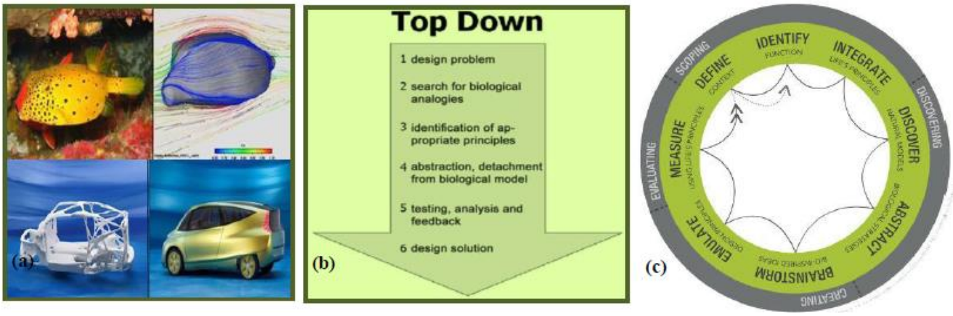


Figure 6. (a) *Daimler Crysler bionic car inspired by the boxfish and tree growth patterns (Source: Zari, 2009)* – (b) *Top-Down design approach (Source: El Ahmar, 2011)* – (c) *Problem-based approach (Source: https://biomimicry.net/the-buzz/resources/designlens-biomimicry-thinking/)*

In addition, this approach has been defined through 6 definite steps, which are very similar to those defined by the Biomimicry Institute, (Helms et al., 2009):
- Step 1: problem definition
- Step 2: reframe the problem
- Step 3: biological solution search
- Step 4: define the biological solution
- Step 5: principle extraction
- Step 6: principle application

Indirect approach: solution-based approach (Biology to design)

The “top-down approach‟, also known as ―biology influencing design‖ is mainly based on inspiration from nature applied to an existing area of interest (Zari, 2009),

DOI: 10.6092/issn.2281-4485/7855

by identifying a certain characteristic, behaviour or functions in an organism or ecosystem then translating that into human designs, which known as biology influencing the design (Fig. 7). In this manner, the collaborative design process is at first dependent& concentrating on individuals that knowing about important natural or biological research as opposed to on decided human outline issues (Zari, 2009). This approach mirrors the potential for genuine moves in the way people outline and what is centered around as an answer for an issue within comparative thinking through the environment, exists with such a way to deal with biomimetic design (El Ahmar, 2011).

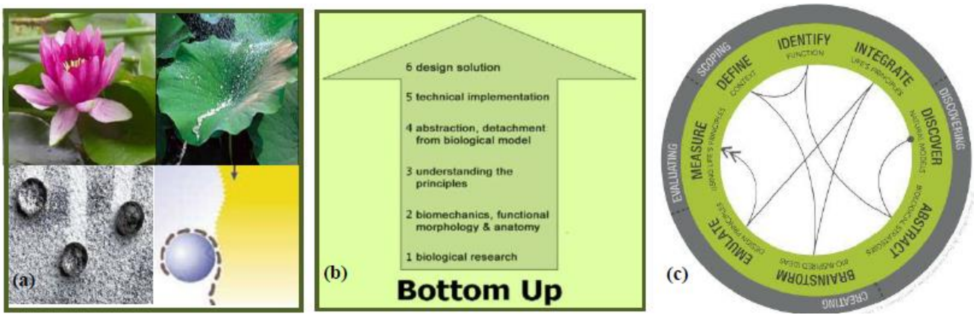


Figure 7. (a) *The lotus effect; a self-cleaning method in nature. Mimicked into self-cleaning paint (Source: Zari, 2009)* – (b) *Bottom-Up Design Approach, (Source: El Ahmar, 2011)* – (c) *solution based (Source: https://biomimicry.net/the-buzz/resources/ designlens-biomimicry-thinking/).*

In addition, this approach has been also defined through 7 definite steps, which are very similar to those defined by the Biomimicry Institute (Helms et al.. 2009):

- Step 1: biological solution identification, here designers start with a particular biological solution in mind.
- Step 2: define the biological solution.
- Step 3: principle extraction.
- Step 4: reframe the solution, In this case reframing forces designers to think in terms of how humans might view the usefulness of the biological function being achieved.
- Step 5: problem search, whereas search in the biological domain includes search through some finite space of documented biological solutions, problem search may include defining entirely new problems. This is much different from the solution search step in the problem-driven process.
- Step 6: problem definition.
- Step 7: principle application.

Stochastic approach

This approach performed by using large databases, through gathering many different phenomena from nature as possible, to collect the desired information. The European Space Agency (ESA) uses a "biomimetic database" to look for

suitable role models from nature, through ordering them as follows (Abermann, 2011):
- Structures and materials
- Mechanisms and processes
- Behaviour and control
- Sensors and communication
- Generative biomimicry.

In the case of the application of biomimetic to architecture, sometimes changes have to be made regarding to the scale, the medium, or the time dimension, as shown in a scheme (Fig. 8) Gruber (2008), introducing biomimetic application to sustainable architecture. The main aspect of this biomimetic approach for architects is that it raises the prospect of closer integration of form and function (with regard to a holistic building design) (Abermann, 2011).

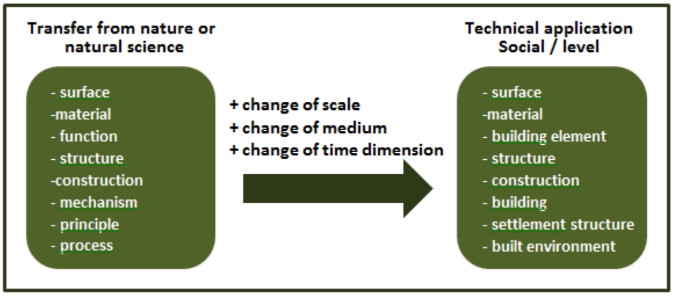


Figure 8
Possible transfers of various natural aspects into technical applications.
(Source: Gruber, 2008).

Regarding to these approaches seeks nature's advice in all stages of architectural design process, from scoping, creation, to evaluation in order to complete the grammar of architecture.

Biomimetic as a new approach to sustainable architecture

Biomimetic described as a tool to increase the sustainability of human-designed products, materials, and the built environment (Abermann, 2011). In the field of sustainable architecture, different types of biomimetic or bio-inspired it is reliably presumed that the widespread and practical utilization of biomimetic as an architectural design method remains a great extent undiscovered, as shown by the modest number of built case studies.

Levels of biomimicry

Regarding to Pedersen Zari vision (Zari, 2009) there are three levels of mimicry as following:

Organism level. Alludes to mimicking a particular organism resembling a plant or animal, may include mimicking the whole organism or a bit of the organism.

Behaviour level. Refers to mimicking a specific type of behavior or act that the organism does to survive or replicates on a daily basis in relation to larger context.

Ecosystems level. Refers to the mimicking of a specific and how it functions successfully as well as what elements and principles are required for it to function successfully.

Through each of these levels, a further five conceivable mimic dimensions exist. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function) (Table 2, Fig.9 and 10) (Zari, 2009).

Table 2. *A Framework for the application of biomimicry adapted from Zari (2009).*

Five possible mimic dimensions exist in building	**Levels of Biomimicry** [Example - A building that mimics termites]		
	Organism Level (mimicking of a specific organism)	**Behaviour Level** (mimicking of how an organism behaves or relates to its larger context)	**Ecosystem Level** (mimicking of an ecosystem)
Form	The building looks like a termite.	The building looks like it was made by a termite; a replica of a mound.	The building looks like an ecosystem (a termite would live in)
Material	The building is made from the same material as a termite; a material the mimics termite exoskeleton skin for example.	The building is made from the same material as a termite builds with; using digested fine soil as the primary material for example.	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example
Construction	The building is made in the same way as a termite; it goes through various growth cycles for example.	The building is made in the same way that a termite would build in, piling earth in certain places at certain times for example.	The building is assembled in the same way as a [termite] ecosystem; principles of succession and increasing complexity over time are used.
Process	The building works in the same way as an individual termite; it produces hydrogen efficiently through metagenomics for example.	The building works in the same way that a termite; by careful orientation, shape, material selection and natural ventilation for example or it mimics how termites work together.	The building works in the same way as a[termite] ecosystem; it captures and converts energy from the sun, and stores water for example
Function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.	The building functions in the same way it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example. It may also function in the same way that a termite mound does in a larger context	The building is able to function in the same way that a [termite] ecosystem would and forms part of a complex system by utilizing the relationships between processes; it is able to participate in the hydrological, carbon and nitrogen cycles in a similar way to an ecosystem

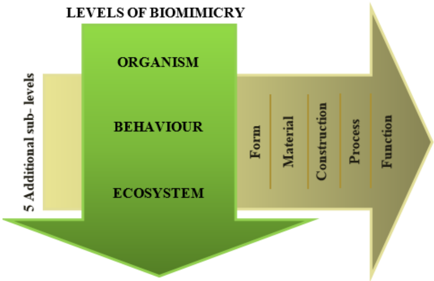
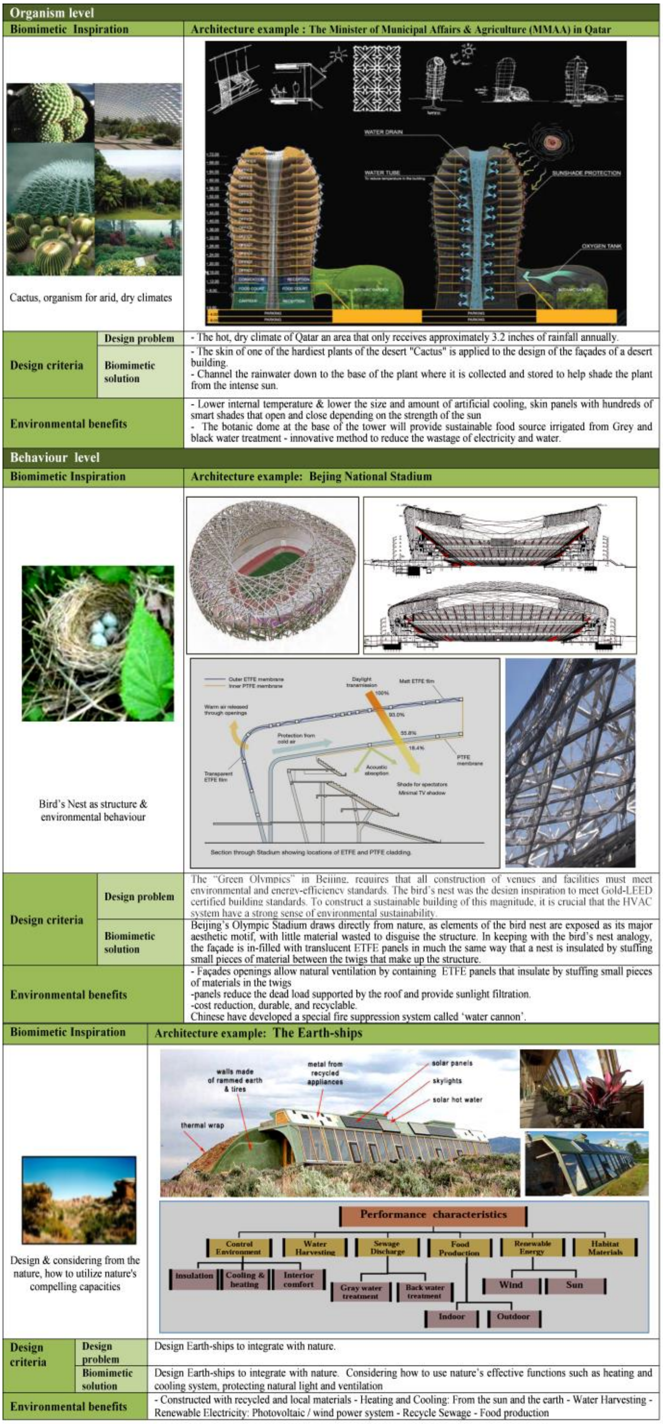


Figure 9
Levels of Biomimicry.
(Source: El Ahmar, 2011)



Organism level		
Biomimetic Inspiration		**Architecture example : The Minister of Municipal Affairs & Agriculture (MMAA) in Qatar**
Cactus, organism for arid, dry climates		
Design criteria	**Design problem**	- The hot, dry climate of Qatar an area that only receives approximately 3.2 inches of rainfall annually.
	Biomimetic solution	- The skin of one of the hardiest plants of the desert "Cactus" is applied to the design of the façades of a desert building. - Channel the rainwater down to the base of the plant where it is collected and stored to help shade the plant from the intense sun.
Environmental benefits		- Lower internal temperature & lower the size and amount of artificial cooling, skin panels with hundreds of smart shades that open and close depending on the strength of the sun - The botanic dome at the base of the tower will provide sustainable food source irrigated from Grey and black water treatment - innovative method to reduce the wastage of electricity and water.
Behaviour level		
Biomimetic Inspiration		**Architecture example: Bejing National Stadium**
Bird's Nest as structure & environmental behaviour		
Design criteria	**Design problem**	The "Green Olympics" in Beijing, requires that all construction of venues and facilities must meet environmental and energy-efficiency standards. The bird's nest was the design inspiration to meet Gold-LEED certified building standards. To construct a sustainable building of this magnitude, it is crucial that the HVAC system have a strong sense of environmental sustainability.
	Biomimetic solution	Beijing's Olympic Stadium draws directly from nature, as elements of the bird nest are exposed as its major aesthetic motif, with little material wasted to disguise the structure. In keeping with the bird's nest analogy, the façade is in-filled with translucent ETFE panels in much the same way that a nest is insulated by stuffing small pieces of material between the twigs that make up the structure.
Environmental benefits		- Façades openings allow natural ventilation by containing ETFE panels that insulate by stuffing small pieces of materials in the twigs -panels reduce the dead load supported by the roof and provide sunlight filtration. -cost reduction, durable, and recyclable. Chinese have developed a special fire suppression system called 'water cannon'.
Biomimetic Inspiration		**Architecture example: The Earth-ships**
Design & considering from the nature, how to utilize nature's compelling capacities		
Design criteria	**Design problem**	Design Earth-ships to integrate with nature.
	Biomimetic solution	Design Earth-ships to integrate with nature. Considering how to use nature's effective functions such as heating and cooling system, protecting natural light and ventilation
Environmental benefits		- Constructed with recycled and local materials - Heating and Cooling: From the sun and the earth - Water Harvesting - Renewable Electricity: Photovoltaic / wind power system - Recycle Sewage - Food production

Figure 10
Levels of biomimicry

DOI: 10.6092/issn.2281-4485/7855

Principles of biomimetic architecture

Regarding to previous biomimetic applications fields in architecture, learning from nature since it was able to survive more than 3.8 years of evolution, nature with its plants, animals and microbes gained a lot of experience, and has learned: what works; what is appropriate; what lasts. Mimicking nature is the biomimetic approach, and it is a new field that architects started giving attention to after biomorphism. In Biomimicry, architects work with biologists and chemists through creative experiment, trying to extract from nature techniques and ideas that could be utilized in architecture and they succeeded in six main disciplines:

- Efficient Structures
- Materials manufacture
- Waste management systems
- Water management
- Thermal environment control
- Energy Production

Moreover, because the building skin and the internal walls have a great effect on the internal temperature and behaviour of the building, so using conventional materials that do not respond to the surrounding stimulus as temperature, light or humidity, is no longer acceptable in buildings with the increase on energy demand and its negative effect on climate change. Through biomimetic, buildings need to function as the human skin does and interact naturally and automatically without any human interference. This could achieve by using smart materials in architecture combined with biomimetic design; this could contribute a lot to energy efficient design in architecture.

Building skin a new vision for energy management through sustainability

According to the vision of reaching zero carbon building, by reducing heat gain and as a result improving thermal comfort and reducing cooling loads. Therefore, the physical processes of heat transfer are the main criteria to manage skin performance through this vision. Generally, heat transfers through four main strategies, which are radiation, conduction and convection. In case of living organisms, the fourth strategy (which is related to phase-change of the matter is evaporation (Mazzoleni and Price, 2013) (Table 3). There are numerous building features that affect heat gain and loss, but according to the research‘ vision will focus only on features related to the building skin. The idea of the sustainable building means that it uses a very little energy, and then depends mainly on renewable energy resources in cooling, ventilation, and lighting processes (El Ahmar, 2011).

Also, there are passive cooling systems which are considered the most efficient way in conserving energy which are targets to make use of available technologies to cool building naturally without the need of power energy and it‘s mainly based on five main natural processes: radiation, evaporation, ventilation, shading, and insulation, all of this are mostly expressed through building skin.

Table 3. *Heat transfer processes and the influencing building skin features. (Source: El Ahmar, 2011).*

Radiation	Conduction	Convection	Phase-change
●Size/shape/location of openings ●Shading elements ●Skin overall morphology ●Reflectance/ emittence of outer material	●Thermal resistance (insulation) ●Thermal capacity ●Materials' thickness morphology ●Materials' arrangement	●Ventilation systen ●Size of openings ●Location of openings ●(De)Humidification	●(De)Humidification ●Ventilation system ●Permeability of building skin materials ●Phase-change materials

Building envelope as skin

To design within the environment, architects should design buildings better suited to its environment. This interface occurs in a building‗s first line of defense to the environment, the building envelope that includes the exterior walls, roof, and exterior openings. Commonly, the building envelope is referred to as ―building skin‖, but through Biomimetic design, Skin is most appropriate for its biological reference (Yowell, 2011). Regarding to this vision, skin acts as a filter, not an envelope, which selectively admits and rejects the environment based on the needs of the body across time Accordingly, skin is where the action is in the building and as a relatively thin layer; it is constantly working to protect the interior inhabitants. Additionally, the building skin is commonly the first impression people get about the design of a project. Even though it is:

- A thin membrane cladding the structure system,
- Regulating the systems [mechanical, plumbing and electrical],
- Defining the interior space,
- It is like a natural skin, plays a vital role.

Through this era of revolutionary techniques, modern buildings have the opportunity to employ technology and create new Interactive skins. The most amazing models for how building skins should behave are Natural skins. Therefore, current envelopes are seen as barriers from the outside world, instead of filters like a natural skin (Yowell, 2011).

Building skins criteria

To enrich and develop building skin‗s efficiency and construction, sustainable building skin functions should be identified accurately and clearly. Regarding to foster sustainable building skin criteria, it got functions as follows (Yowell, 2011):

- Protection from the natural elements.
- Environmentally-friendly manufacturing.
- Not be harmful to the natural environment at the end of its life.
- Integrate multiple systems within the thin membrane.
- Regulate transfer of heat, air and water efficiently.
- Be adaptable to its local environment and respond accordingly.
- Be beautiful.

DOI: 10.6092/issn.2281-4485/7855

According to these functions, a building (skin), will get multiple tasks. Therefore, architects should be creative and experienced to meet these challenges. That will be achieved through good concentrated reading for the environment and its creative lessons wherever we look.

Biomimetic to mitigate GHG emissions through building skin

Biomimetic new technologies illustrate on mitigating GHG emissions through building skin criteria, which could be divided into three categories (Zari, 2010). The first approach: by mimicking the energy efficiency or effectiveness of living organisms and systems. The motive is that by being more energy efficient, less fossil fuel is burnt and therefore fewer GHGs are emitted into the atmosphere. The second approach: by devising new ways of producing energy to reduce human dependence on fossil fuels, then prevent additional GHGs from being emitted. These strategies are the most common approaches to mitigating the causes of climate change associated with the built environment (Zari, 2008). A third biomimetic approach: for mitigating GHG emissions, by investigating organisms or ecosystems to find examples of processes within them that are able to sequester and store carbon.

Criteria of the analytical study

The study will analyze the elements of building skin according to the aim of it through three main basic elements, which will be:

- *Aims of design.* According to building function and site environmental aspects included in the design process. That means all environmental considerations that achieved through design creation within biomimetic inspiration, in order to create passive defense system in building skin;

- *Biomimetic inspiration.* It will be analyzing through; a- Imitation process from nature to help achieving design‘s aim through design‘s concept. b- Level of biomimetic. c- Type of approach to biomimetic. d- Analyzing building skin design; (function and criteria).

- *Architecture results.* According to RIBA (Royal Institute of British Architects), it will be analyzed through & LEED (Leadership in Energy and Environmental Design):

a. building technologies: materials, structural systems, technologies included;

b. energy efficiency: orientation-interactive with natural environment - natural ventilation, lighting, and filtration-heat isolation-environmental technologies;

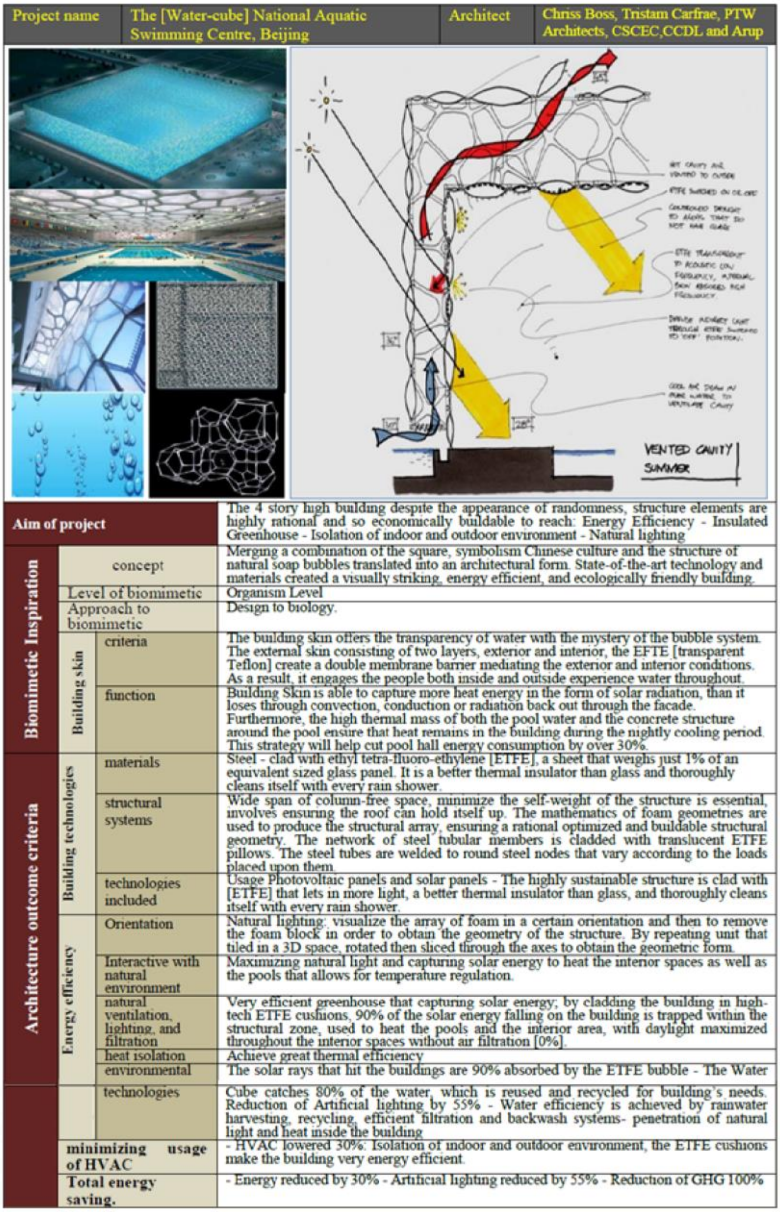
c. minimizing usage of HVAC;

d. total energy saving.

Case Studies

1. The (Water-cube) National Aquatic Swimming Centre, Beijing (Fig. 11), (http://www.arup.com/Projects/Chinese_National_Aquatics_Center/Facts.aspxGrossFloor).
2. Council House 2 (CH2) 10 stories sustainable building currently residing in Melbourne (Fig. 12) (www.containerconnection.com.au).

3. "Eastgate centre", Harare, Zimbabwe (Fig. 13) (The ARUP Journal, 1997).



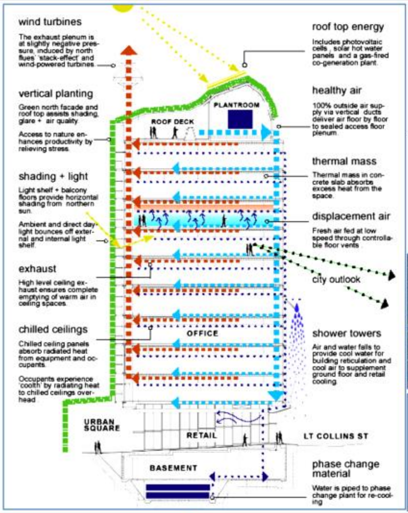
Project name	**The [Water-cube] National Aquatic Swimming Centre, Beijing**	**Architect**	**Chriss Boss, Tristam Carfrae, PTW Architects, CSCEC,CCDL and Arup**

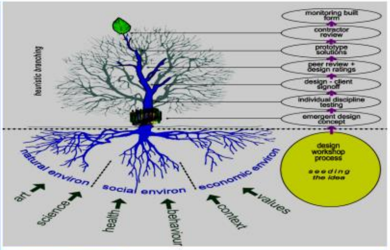
Aim of project			The 4 story high building despite the appearance of randomness, structure elements are highly rational and so economically buildable to reach: Energy Efficiency - Insulated Greenhouse - Isolation of indoor and outdoor environment - Natural lighting
Biomimetic Inspiration	concept		Merging a combination of the square, symbolism Chinese culture and the structure of natural soap bubbles translated into an architectural form. State-of-the-art technology and materials created a visually striking, energy efficient, and ecologically friendly building.
	Level of biomimetic		Organism Level
	Approach to biomimetic		Design to biology.
	Building skin	criteria	The building skin offers the transparency of water with the mystery of the bubble system. The external skin consisting of two layers, exterior and interior, the EFTE [transparent Teflon] create a double membrane barrier mediating the exterior and interior conditions. As a result, it engages the people both inside and outside experience water throughout.
		function	Building Skin is able to capture more heat energy in the form of solar radiation, than it loses through convection, conduction or radiation back out through the facade. Furthermore, the high thermal mass of both the pool water and the concrete structure around the pool ensire that heat remains in the building during the nightly cooling period. This strategy will help cut pool hall energy consumption by over 30%.
Architecture outcome criteria	**Building technologies**	materials	Steel - clad with ethyl tetra-fluoro-ethylene [ETFE], a sheet that weighs just 1% of an equivalent sized glass panel. It is a better thermal insulator than glass and thoroughly cleans itself with every rain shower.
		structural systems	Wide span of column-free space, minimize the self-weight of the structure is essential, involves ensuring the roof can hold itself up. The mathematics of foam geometries are used to produce the structural array, ensuring a rational optimized and buildable structural geometry. The network of steel tubular members is cladded with translucent ETFE pillows. The steel tubes are welded to round steel nodes that vary according to the loads placed upon them.
		technologies included	Usage Photovoltaic panels and solar panels - The highly sustainable structure is clad with [ETFE] that lets in more light, a better thermal insulator than glass, and thoroughly cleans itself with every rain shower.
	Energy efficiency	Orientation	Natural lighting: visualize the array of foam in a certain orientation and then to remove the foam block in order to obtain the geometry of the structure. By repeating unit that tiled in a 3D space, rotated then sliced through the axes to obtain the geometric form.
		Interactive with natural environment	Maximizing natural light and capturing solar energy to heat the interior spaces as well as the pools that allows for temperature regulation.
		natural ventilation, lighting, and filtration	Very efficient greenhouse that capturing solar energy; by cladding the building in high-tech ETFE cushions, 90% of the solar energy falling on the building is trapped within the structural zone, used to heat the pools and the interior area, with daylight maximized throughout the interior spaces without air filtration [0%].
		heat isolation	Achieve great thermal efficiency
		environmental	The solar rays that hit the buildings are 90% absorbed by the ETFE bubble - The Water
		technologies	Cube catches 80% of the water, which is reused and recycled for building's needs. Reduction of Artificial lighting by 55% - Water efficiency is achieved by rainwater harvesting, recycling, efficient filtration and backwash systems- penetration of natural light and heat inside the building
	minimizing usage of HVAC		- HVAC lowered 30%: Isolation of indoor and outdoor environment, the ETFE cushions make the building very energy efficient.
	Total energy saving.		- Energy reduced by 30% - Artificial lighting reduced by 55% - Reduction of GHG 100%

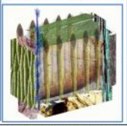
Figure 11
Case study: The (Water-cube) National Aquatic Swimming Centre, Beijing

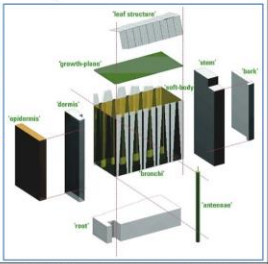
DOI: 10.6092/issn.2281-4485/7855

Project name	**Council House 2 (CH2)** 10 stories sustainable building currently residing in Melbourne	**Architect**	City of Melbourne in association with Design Inc





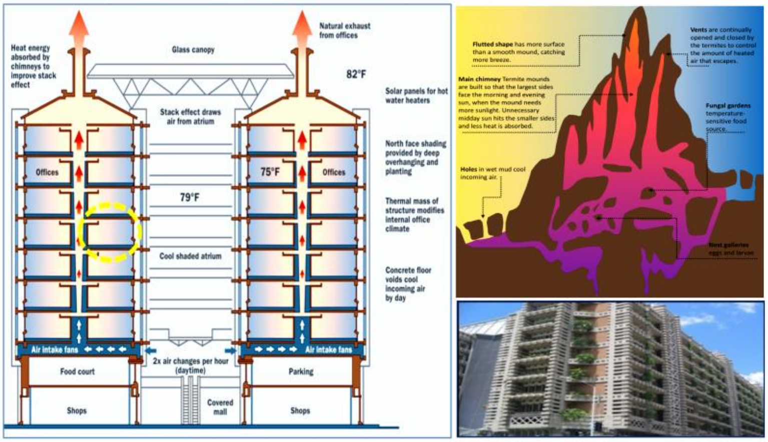




Aim of project			Revolutionary sustainable office building - reflected the planet's ecology, (an immensely complex system). The building's design set new standards for low energy and high occupant comfort; (interact with environment - express climate and culture - facades should express orientation).
Biomimetic Inspiration	**Concept**		A link between art and science, the building designed as it emulated a trees bark, also the concept of "biophilia" which deals with incorporating the natural environment into buildings.
	Level of biomimetic		Organism and behavior
	Approach to biomimetic		Design to biology
	Building skin	criteria	Overcome the cooling problems in hot climate and energy conservation through technologies in building skin: (Displacement ventilation system for fresh air delivery / high performance energy efficient façade / shading techniques / energy Conservation: natural lighting, energy generation, and green facade).
		function	The skin acted as a protective layer, which filters light and air in the ventilated wet area spaces behind. The overlapping layers of the facade are constructed with perforated metal with polycarbonate walling in order to fix the louvers.
Architecture outcome criteria	**Building technologies**	materials	All recycled (Timber – Steel – Concrete): (high recycle potential, durability and longevity, zero or low harmful emissions and toxicity, require less maintenance and have lower replacement costs, have greater flexibility under changing design requirements) over the life of the building. Recycling facilities for office waste - PVC minimization - Fully integrated with fit out through specific properties.
		structural systems	The concrete structure is relatively conventional inset construction, except for the use of precast curved concrete ceiling panels. Two rows of concrete columns are located at 8200 mm centers just inside the north and south facades, with a further row of columns offset from the center of the floor plate. The proportions of the site dictated a "deep space" floor plate, which presented design challenges in terms of lighting and ventilation. The undulating design of the ceiling has resolved difficulties arising from the 22m building depth by allowing for air distribution ducts, yet enabling a maximum ceiling height so light can penetrate deep into office spaces.
		technologies included	• Phase Change Materials (PCM) thermal storage • Reduced embodied energy from the use of 100 % post-consumer recycled content steel for reinforcement; • Design for reduced materials use, flexibility and demount-ability in the fit-out. • Savings for the project-wide emphasis on specification for the 100-year life-cycle costing model, with its emphasis on durability.
	Energy efficiency	orientation	The west facade is the epidermis of the tree (the outer living layer of an animal or plant). The north and south facades are the bronchi of the tree (windpipes), allowed for air ducts on the exterior of the CH2 with Day lighting sensors. The eastern core and the facade, consisting of the service core and the toilets, emulated the tree skin (bark).
		interactive with natural environment	Facade moderated external climate - windpipes came to symbolize expressed air ducts on the outside of the building – natural light – more shading.
		natural ventilation, lighting, and filtration	• Air is 100% filtered. • Daylight responsive light dimming - Shower towers for cooling • Night time cooling via natural ventilation • Refrigerants with zero Ozone Depleting Potential (ODP) • 80% reduction in sewer emissions through the Multi-Water Reuse (MWR) plant • Refrigerant leak detection • Storm water pollution management and treatment
		heat isolation	For cooling, automatic night-purge windows, wavy concrete ceilings, facade's louvers (powered by photovoltaic cells) that track the sun – (Maximizes natural ventilation - Works with Natural environment - Shading for visual comfort).
		environmental technologies	Novel technologies and concepts: Chilled ceilings - Multi-Water Reuse (MWR) sewer mining plant - Sprinkler water reclaim - Solar photovoltaic cells for electricity generation - Shower towers for cooling - Building integrated wind turbines- Refrigerants with zero Ozone Depleting Potential (ODP) - Refrigerant leak detection - Storm water pollution management and treatment - Phase Change Material (PCM) thermal storage - Gas boosted solar hot water.
	minimizing usage of HVAC		• Natural lighting and ventilation saved by 65%. • HVAC level lowered 20%
	Total energy saving		• 87% reduction in greenhouse gas emissions compared to the existing Council House of similar size. • 5 Star ABGR + 20% reduction in carbon dioxide • CH2's emissions will be 64 % lower, total energy saving 82% • Reduction of air temperature in the interior space was reduced between 4 and 13 degrees Celsius. • Waste heat utilization from electricity co-generation. • Low energy cooling system for offices via chilled ceilings. • Low energy T5 lighting system with small area zoning. • Sub-metering for tenants and substantive energy uses,

Figure 12 *Case study: Council House2 (CH2), Melbourne*

Project name	"Eastgate centre" (Harare), Zimbabwe	Architect	Mick Pearce1996



Aim of project			The largest commercial office and retail aims to: air cooling by passive means; complete sun control; natural and artificial light balanced and glare controlled. These aims to produce acceptable comfort conditions without air-conditioning (to reduce costs and environmental burden) provided the occupants accept some seasonal variation beyond that experienced in a fully air-conditioned environment.
Biomimetic Inspiration	**Concept**		A breathing skin for building based on principles and methods abstracted from Termite Mound. The center opens and draws more air to help fans and is pushed up through ducts that are located in the center of the building
	Level of biomimetic		behavior level
	Approach to biomimetic		Design to biology.
	Building skin	criteria	Massive protruding stone elements not only protect the small windows from the sun but also increase the external surface area of the building to improve heat loss to space at night and minimize heat gain by day. The horizontal protruding ledges are interrupted by columns of steel rings supporting green vines to bring nature back into the city. The model used was the termitary; an ecosystem not a "machine for living in
		function	Passive cooling by using readily available local & traditional materials and construction skills, no need to import specialist equipment and although the floor construction was unusual,
Architecture outcome criteria	**Building technologies**	materials	A combination of in situ concrete and double thickness brick (heavy masonry construction), in the exterior walls to moderate temperature extremes, light coloured finishes reduce heat absorption. Precast concrete semi-arch hoods projecting over windows provide external shading, as well as inter-floor fire barriers. Internal venetian blinds allow occupants to limit indirect solar heat gains and external glare when necessary. In the covered street, finishes are as pale as possible so that reflected natural light can penetrate the full office depth, while office interiors are also light-colored to render both natural and artificial light sources more efficiently. The combination of clear glass, light finishes, and Harare's natural bright sky provides good natural light in the offices.
		structural systems	The structure is predominantly reinforced concrete except for the steel work roof level beam structure to the covered pavement and all suspended links, stairs and lift cores. Shear walls give north/south stability to the office blocks, while in the 140m long east-west direction, it is provided by a column/beam sway frame. Such a system has uniformly distributed points of stiffness and enables larger spacing of movement joints - a single central one in this building.
		technologies included	• The stone Great Ruins of Zimbabwe, utilizing the natural cracking of the rocks, through diurnal temperature fluctuation, to provide precise stonework courses transferred course by course from the natural source to the built walls. Granite sand used in the numerous expressed precast elements on Eastgate has a brushed finish that enhances the natural stone language with vernacular wood-carved decoration in the portable stools of the Shona. • The 'light tech' steel trusses, suspension rods, internal bridges and balconies.
	Energy efficiency	orientation	The long axis is east-west, presenting short gables to east and west sun and facilitating sun control from high sun on long north and south façades. For sun control, extensive structural overhangs and precast concrete elements on all facades, including the facades facing into the atrium, combine with vegetation.
		interactive with natural environment	As the section shown above, The center opens and draws more air to help fans and is pushed up through ducts that are located in the center of the building, air entering the building and into every level, and warm air exiting through the chimneys. - Passive cooling - climate control- Temperature is regulated throughout the year with no need for HVAC systems.
		natural ventilation, lighting, and filtration	Ventilation system uses only 10% of the energy needed by a similar building. The building got a series of chimneys on both sides (North and South) for effective ventilation. Natural light is purposely restricted due to small windows, heavy sun shading, and façade vegetation. Via filters in the plant-room, the air passes to the offices through the network of concrete and masonry ducts in the central spine core of each wing. Air filtered 100%.
		heat isolation	Glazing was limited to 25% on the north and south facades. To investigate ways to minimize solar heat gain, a computer model was used to simulate the solar path, together with various side and top shading devices, and to predict internal temperatures. A difference of 1°C in peak internal temperature was predicted between a well-shaded, 25%-glazed, north-facing facade and one with 50% glazing.
		environmental technologies	Fans suck fresh air in from the atrium; blow it upstairs through hollow spaces under the floors and from there into each office through baseboard vents. As it rises and warms, it is drawn out through ceiling vents. Finally, it exits through 48 round brick chimneys. During summer's cool nights, big fans flush air through the building seven times an hour to chill the hollow floors. Ultimately, it enters the exhaust section of the vertical ducts before it is flushed out of the building through chimneys. As a results: • restricting larger energy using fans to night-time when electricity is cheaper (and lower maximum demand) • reducing air speed through the supply air grilles during the day, thus encouraging displacement ventilation in the offices (enhanced by maximizing floor-to-ceiling heights within)
	minimizing usage of HVAC		Maintains thermal stability without an HVAC system.- uses less than 10% of the energy
	Total energy saving.		Eastgate uses 90% less energy for ventilation than conventional building its size, reduction of GHG 60%

Figure 13
Case study: "Eastgate centre", Harare, Zimbabwe

DOI: 10.6092/issn.2281-4485/7855

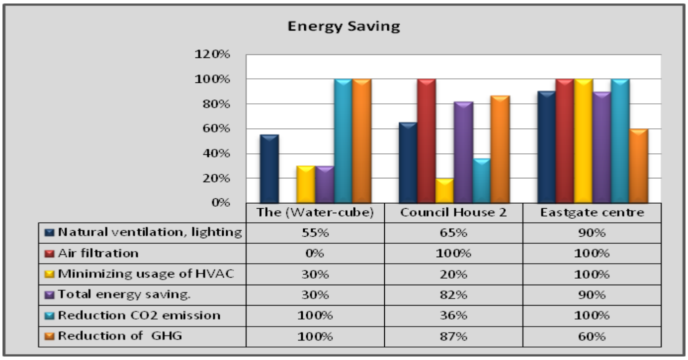
Results of the analytical study

According to previous analytical study, it is so obvious now the importance of building skin criteria. However, to make these results in a clear vision they will be collected in the summarized table 4. For obtaining a building skins design guidelines is to compare the case studies and their objectives. As illustrated in table 4 an analysis was conducted of the different criteria met throughout the three case studies in order to determine the level of energy efficiency and the strength of each case study.

Table 4. *Analitycal results*

Comparative aspects			The Water-cube	Council House 2	Eastgate centre
Biomimetic Inspira tion		Concept	Natural soap bubbles	Planet‘s ecology	Breathing skin
		Level of biomimetic	Organism level	Organism and behavior	Behavior level
		Approach to biomimetic	Design to biology	Design to biology	Design to biology
	Building skin	Criteria	Transparent teflon	Overcome the cooling problems in hot climate and energy conservation	Massive protruding stone elements
		Function	Capture more heat energy		Passive cooling
Architecture outcome criteria	Building technologies	Materials	Steel - ETFE sheets	All Recycled - Timber – Steel - Concrete	Concrete - double thickness brick
		Structural systems	Network of steel tubular members	Concrete structure	Reinforced concrete
		Technologies included	Photovoltaic panels and solar panels – (ETFE)	(PCM) - 100 year life – Cycle costing model	Utilizing the natural cracking of the rocks, ‗light tech‘ steel trusses,
	Energy efficiency	Orientation	Natural lighting	Façade express orientation according to tree behaviour	Interactive with orientation
		Interactive with natural environment	Maximizing natural light and capturing solar energy	Façade moderated external climate - Windpipes	Passive cooling – climate control - temperature regulation
		Natural ventilation	65%	55%	90%
		Filtration	0%	100%	100%
		Heat isolation	Great thermal efficiency	Works with natural environment - Shading for visual comfort	Minimize solar heat - a well-shaded
		Environmental technologies	80% of the water reused, 90% of solar rays are absorbed	Chilled ceilings - (MWR) sewer mining plant - Sprinkler water reclaim - Solar photovoltaic cells - Shower towers - Wind turbines - (ODP) - Refrigerant leak detection - Storm water pollution Management and treatment – (PCM) thermal storage - Gas boosted solar hot water.	Restricting larger energy - reducing air speed – enhanced (by maximizing floor –to ceiling heights within)
	Minimizing usage of HVAC		30%	20%	100%
	Total energy saving		82%	82%	90%
Reduction CO_2 emission			100%	36%	100%
Reduction of GHG			100%	87%	60%

The outcome of the total savings is a direct resultant of the different criteria that were met throughout the project. According to each case study description and through LEED the ratio of GHG & CO_2 emission were abstracted. For instance, the usage of solar panels, usage of the sun path diagram, and visual comfort all contributed the end product of the total energy savings, HVAC savings and natural lighting and ventilation. Figure 14 illustrates the percentage of savings for each case study.



	The (Water-cube)	Council House 2	Eastgate centre
🟦 Natural ventilation, lighting	55%	65%	90%
🟥 Air filtration	0%	100%	100%
🟨 Minimizing usage of HVAC	30%	20%	100%
🟪 Total energy saving.	30%	82%	90%
🟦 Reduction CO2 emission	100%	36%	100%
🟧 Reduction of GHG	100%	87%	60%

Figure 14
Percentages of total energy saved, reduction of CO2 emission and reduction of GHG in case studies regarding to each case study descriptions & LEED roles.

<u>Biomimetic architecture: creating a passive defense system in building skin to solve zero carbon construction dilemma</u>

Integration of biomimetic and sustainable architecture, a framework

Regarding to previous theoretical and analytical studies, within the vision of creating a passive defense system in building skin to solve zero carbon construction. This critical dilemma, which affected negatively on any building through all processes from designing, constructing, and using.

The framework for implementing biomimetic through building skin got steps to follow to achieve zero carbon construction:

- ***Efficient architecture design:*** by analyzing site, orientation, climate, topographical factors, local constraints and natural resources. While searching within biomimetic solutions for imitate the same design needed characteristics.
- ***Efficient structures systems:*** by searching and examine structural characters, permanence/temporariness, integration with building components.
- ***Modular applicable systems:*** criteria of construction and assembling methods to facilitate substitution, repair, maintenance, diversified lifetime.
- ***Materials manufacture and renewability:*** choosing efficient material or a product through its (size, standardization, structural adequacy, complexity, appropriateness, cost, labour involved, plantation origin, method of growth, embodied energy, recycled and reused content, toxicity).
- ***Building skin criteria:*** control of energy flows that enter (or leave) an enclosed volume, within consideration of orientation, seasonal variations, surrounding environment, function, and typology.
- ***Thermal environment control:*** using of renewable and non-conventional energy systems, by integrating sources of energy that do not reduce or exhaust their point of origin.

- ***Creative HVAC Systems:*** using of strategies that provide thermo-hygrometric and air quality comfort, exploiting mechanically regulated, hybrid, or, preferably, totally passive techniques.
- ***Water management systems:*** (collect and storage) by adopting methods, system and strategies that can positively collect, store, distribute, use, recycle and re-use water.

New design processes phase through biomimetic vision

Regarding to Benyus's challenge to biology design spiral, a new design process phases could be concluded with an innovative approach - through biomimetic vision. As shown in figure 15, in order to reach biomimetic effective skin.

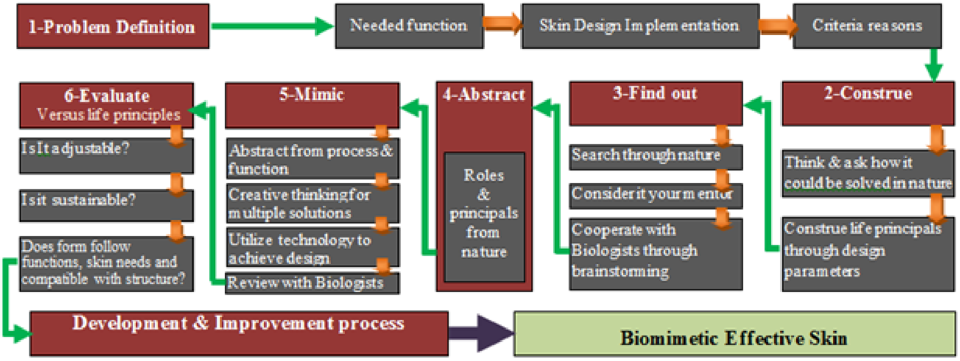


Figure 15. *New Design processes phase through biomimetic vision, abstracting from Benyus's challenge to biology design spiral.*

According to Figure 15 new design process phases will be:
- ***Problem Definition:*** reading the problem means to clarify all aspects needed for the design process, starting from function, skin criteria and why (reasons). Therefore, the idea here is to focus about what should be reached by design not only what you wish to design.
- ***Construe:*** then we should think how nature will deal with the same problem criteria. Searching for the same function needed in nature, then construe life principals through design parameters.
- ***Find out:*** by searching through nature as considering it your mentor and then start cooperation with biologists through brainstorming.
- ***Abstract:*** roles and principles from nature.
- ***Mimic:*** abstract from process & function, start your creative thinking for multiple solutions, by utilizing technology to achieve design, and then review biologists.
- ***Evaluate versus life principles:*** by asking some questions; Is It adjustable? Is it sustainable? Does form follow functions, skin needs and compatible with structure?

The study introduces a new criteria for evaluating project design processes - building skin design criteria through biomemitic - this through gathering three main factors according to the aim of the research (Biomimetic Inspiration + Building skin Criteria + LEED certificate credit) (Table 5). The design matrix includes the main criteria needed in order for the skin design to be energy efficient for each category. This will serve as a guide to design energy efficient Skin.

- ***Development & Improvement process:*** after evaluation architect should continue developing &improving project to fill in gaps appeared while evaluation to reach final project with *Biomimetic Effective Skin.*

Table 5. *Suggested criteria to check skin environmentally effectiveness through Biomimetic.*

Biomimetic Inspiration			**Building Skin Criteria**																		**LEED Certificate Credit**
Level of Biomimetic			**Building Technology**							**Energy Efficiency**											
			Materials				**Structural systems**		**Tecnologies included**	**Air**			**Heat**				**Water**		**Light**		
Ecosystem	**Behaviour**	**Organism**	**Self healing**	**Self cleaning**	**Recycled**	**Phase change**	**Normal**	**Innovative**	**Positively environment effectively**	**Air filtration**	**Natural ventilation**	**Air well diffusion**	**Heat isolation**	**Heat storage**	**Response to temperature change**	**Shade preservation**	**Recycle**	**Self cleaning**	**Natural light**	**Minimization of HAVC usdage**	
▓	▓	▓		░			░	░	░											░	**Sustainable site**
▓	▓	▓															░	░			**Water efficiency**
▓	▓	▓							░				░	░					░	░	**Energy & atmosphere**
▓	▓	▓	░		░																**Material & recourses**
▓	▓	▓					░	░	░	░	░	░			░	░					**Indoor quality Environment**

▓ Level of biomimetic chosen regarding to design problem

░ Building skin design criteria evaluation

Conclusions

Building Skin Energy Efficiency. One of the most important aspects in linking biomimetic visions with living nature is Energy efficiency. As building skin represents the interface between internal space and environment, skin innovation technology is a concentration of research in the energy efficiency of architecture. Apart from facade concepts, ventilation is another key issue.

Material/Structure/Surface. Nature as a model, differentiation between material, structure and surface is no longer valid, this is important also for biomimetic approaches to the energy efficiency through building skin. Research and development take place on more than one scale; so the topic of energy efficiency is strongly connected to the influence of nanotechnology in architecture, also the use of smart materials that can react to changing environmental conditions has already become common in building industry. From this vision there are many examples could be applied in building skin like:

- self-healing and damage repair: a standout amongst the most momentous properties of natural materials is their ability of self-repair; numerous life forms have the capacity to redesign the material;
- growth through functional adaptation: influenced by the outer conditions, for example, temperature, mechanical stacking, and supply of light, water or sustenance;
- intensive hierarchical structuring: an incredible accomplishment of the development procedure of organs. Plainly, various leveled organizing gives a noteworthy chance to bio-propelled material amalgamation and adjustment of properties for particular capacities. Various leveled cross breed materials can likewise give development and motility.

The inventive biomimetic configuration is ending up increasingly well-known crosswise over many fields of research because of its potential advantages, and the field of design is no special case. Tending to the issue CO_2 emanations, expanding cooling loads in hot atmospheres and how to profit by regular light and common ventilation, this paper speaks to an examination concerning plants to gain from them how to limit GHG. For planners who are intending to settle zero carbon-building predicament identified with the building skin. This paper shows the underlying period of this biomimetic configuration approach.

Advances in material science permitted the outline group to choose materials with suitable properties for the venture. A blend of common motivation, social design and imaginative building makes an extraordinary venture in its own right.

Biomimetic does not seek to make everyone into a biologist, but rather suggests that engineers, architects, designers, scientists and biologists (who all possess a wealth of knowledge of their own respective fields should share their knowledge with others through means of interdisciplinary learning. The vital cooperation of biological insight and engineering pragmatism is vital to success in biomimetic.

References

ABERMANN S. (2011) Utilization of the potential of biomimetics in sustainable architecture, Austria. Institute of Technology (AIT), Energy Department, Austria.

ANOUS I. (2015) Biomimicry innovative approach in interior design for increased sustainability. American International Journal of Research in Formal, Applied & Natural Sciences 10(1), March-May.

BAR-COHEN Y. (2006) Perspective biomimetics-using nature to inspire human innovation. Bio-inspiration & Biomimetics,1:1-12.Doi:10.1088/1748-3182/1/1/P01

BENYUS J.M. (1997) Biomimicry: innovation inspired by Nature. Harper Collins Publishers Inc: Perennial. 25

BERKEBILE B. (2007) Master speaker address, for sustainable architectural design. Master Thesis, Faculty of Engineering, Alexandria University.

El AHMAR S. (2011) Biomimicry as a tool for sustainable architectural design towards morphogenetic architecture, MSc Thesis, Asrchitecture Engineering department, Faculty of Engineering, Alexandria University, Egypt.
FALUDI J. (2005) Biomimicry for green design (A How To). World Changing.
GIUREA D. (2016) A didactic method for transposing natural forms in architecture. Procedia - Social and Behavioral Sciences, 116:3165–3168. Doi:10.1016/j.sbspro. 2014.01 .727
GRUBER P. (2008) Biomimetics in architecture (Architekturbionik). Architecture of Life and Buildings‖, TU Vienna, Vienna, Austria.
HARKNESS J. M. (2001) A lifetime of connections - Otto Herbert Schmitt, 1913 – 1998. Physics in Perspective, 4:456-490. http://www.thebakken.org/research/Schmitt/Otto.htm.
HELMS M., Swaroop S., Ashok K. (2009) Biologically inspired design: process and products. Elsevier, 606-622. Https://biomimicry.net/the-buzz/resources/designlens-biomimicry-thinking/
INGRID P., PRABHU K., ELVIN K., DAVID P., RENEE W. (2010) Nature inspired design: strategies towards Sustainability, Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft, The Netherlands, 25-29
IOUGUINA A. (2012) Biology to Design - A key to good design is a sense of responsibility (Bionics≠Biomimetics≠Biomimicry). https://biologytodesign.word press. com/2012/05/08/design-biology-linguistics/
IPCC (Intergovernmental Panel on Climate Change) (2007) Climate change 2007: Mitigation Contribution of Working Group III to the Fourth Assessment Report of the IPCC, Cambridge, Cambridge University Press.
LAKHTAKIA A., MARTÍN-PALMA R. J. (2013) Engineered biomimicry, Elsevier Inc., USA. ISBN 978-0-12-415995-2
MAZZOLENI I., PRICE S., (2013) Architecture follows nature: Biomimetic Principles for Innovative Design. Boca Raton(Florida): CRC Press.
MAZZOLENI I. (2013) Architecture Follows Nature. CRC Press, California. McDONOUGH W., BRAUNGART M. (1998) The Next Industrial Revolution, The Altantic, October.
MILES K., MICHAEL F., (2009) Interactive architecture: biomimetics. Princeton Architectural Press
MINSOLMAZ YELER G. (2015) Creating nature awareness in design education, Procedia. Social and Behavioral Sciences, 174:406–413 Doi: 10.1016/j.sbspro. 2015.01.682.
MUELLER, T., (2008), National Geographic Website: Featured Article: Biomimetic. http://ngm.nationalgeographic.com/featurehub
NESSIM M. A. (2016) Biomimetic architecture as a new approach for energy efficient buildings, MSC Thesis, Faculty of Engineering at Cairo University.
PAWLYN, M. (2011) Biomimicry in Architecture‖, RIBA Publishing, London.
RAO R. (2014), Biomimicry in Architecture, International Journal of Advanced Research in Civil, Structural, Environmental and Infrastructure Engineering and Developing, 1(3)
REDOLFI, G., SHIVA K., SH. (2015), Algorithms In Nature & Architecture (Biomimetic Architecture), University of Florence conference, January,
REED B. (2006) Shifting our mental model – "Sustainability" to regeneration, rethinking sustainable construction 2006: Next Generation Green Buildings, Sarasota, Florida.

ROSSIN K. J., (2010), Biomimicry: nature‘s design process versus the designer‘s process, Design and Nature, WIT Transactions on Ecology and the Environment, 138:559-570, WIT Press.
SCHMITT O. (1969) Some interesting and useful biomimetic transforms, In Proceedings of Third Int. Biophysics Congress.
STEADMAN P. (2008) The Evolution of designs-biological anology in architecture & applied arts, Oxon: Routledge.
THE STRUCTURAL GROUP (2008) The building envelope – A little-known key to energy efficiency. Quorum Magazine, retrieved from http://www.structural.net/tabid/434/contentid/692/Default.aspx
WASFI A. (2014) Architecture as a Second Nature, Journal of Sustainable Architecture and Civil Engineering, 7(2). Doi: http://dx.doi.org/10.5755/j01.sace.7.2.5981
WEEKS K. (2010) Perspective winner: Peter Busby. Eco-Structure, Retrieved from http://www.eco-structure.com/energy-efficiency/the-2010-evergreen-awards-perspective-winner.aspx
WILSON E.O. (1984) Biophilia. Cambridge, Harvard University Press.
WILSON E.O. (1993) The Biophilia Hypothesis. Washington, Island Press.
YOWELL J. (2011) Biomimetic Building Skin: a phenomenological approach tree barks as model, Mater thesis, University oF Oklahoma, USA.
ZARI M.P. (2008) Bioinspired architectural design to adapt to climate change, Paper presented at the World Sustainable Building Conference, Melbourne, Australia.
ZARI M.P. (2009) Biomimetic approaches to architectural design for increase sustainability. Scholl of Architecture, Victoria University, Wellington, New Zeland.