Biomimicry: optimization strategy from nature towards sustainable solutions for energy-efficient building design.

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ABSTRACT: The building sector has a key role to implement energy efficiency objectives: around 40% of the energy consumption and a third of CO2 emissions are attributable to buildings. Architects are attempting to find solutions for managing buildings energy consumption. Biomimicry is considered to be a new approach for achieving energy-efficient building design. Although, there have been several achievements of using biomimicry principals to provide guidelines for improving energy efficiency of buildings through applying the principals on building envelope and occasionally on other systems, but if we pose a question on 'sustainability' some biomimetic approaches could lead to disadvantages rather than advantages. So far, many architects have missed the heart of biomimicry as a mentor (guide) for design as a new way of viewing and valuing nature, not only mimicking its form. As a measure of design, biomimicry should represent an ecological standard to judge the rightness in innovations in sustainability. The purpose of this analysis is to outline a theoretical framework towards sustainable solutions for energy-efficient building design by overview 'energy consumption' and those 'beyond consumption' in comparison with optimization strategies from nature, in particular with structure built by animals and their criteria for sustainable architecture. Indeed, biomimicry is at present of growing interest, our research aim is to demonstrate how to use biomimicry as an approach to enhance sustainable solutions for energy efficiency building design.

1 INTRODUCTION

Social and environmental changes have increased focus on conservation of natural resources and sustainable living. Recent economic changes have also caused consumers to revaluate how they use energy, with new attention being given to maximizing efficiency. Employing more efficient building methods in new construction and in renovation could reduce the amount of energy consumed, thereby saving money and reducing electric load growth and air emissions resulting from electric generation. So far there have been many developments in the promotion of energy efficiency in the construction sector but still highly keen on embody high-performance rather than resource-efficient and ecologically sustainable design (Richard 2015). Before keeping apply new approaches to solve the problem, one must understand the energy consumed by a building throughout its life comprises, from the resource extraction until its demolition. There are two major types of energy within the life cycle of the building, which are operational energy and embodied energy. In comparison, there are two things that can make a product green. It can be green in its manufacture or it can be green in its application. One of the important topics for understanding the manufacture or delivery of a product is the concept of embodied energy –

how much cumulative energy went into the extraction of the raw materials, the manufacture of the product and the transportation of the product to its final application. Operational energy relates to how much energy the product uses or can save once it has been applied or installed into a system. The contradiction between operational and embodied energy is always a challenge in energy efficient building design. As many types of design (envelope, insulation) are actually very energy intensive in their manufacture, however once they are installed they can save energy many times over within the very first year of their application (Radwan & Osama, 2016). It is difficult to make a judgment solely based on the embodied or operational energy; we must look on the life cycle of the project to determine if it is positive or negative for the project itself as a whole.

Towards ecologically energy efficient building design is not just the result of applying one or more insolated technologies, rather it is an integrated whole-building design process including its life cycle along with an understanding of building occupancy and activities. Biomimicry is a process of innovation that encourages transfer ideas, concepts, and strategies inspired from nature and living world, with the objective of designing human applications aimed at sustainable development. Biomimicry uses analogies to biological systems for developing solutions for various human problems. The objective of this paper is to analyze and understand the life cycle energy through the whole lifetime of the building. And we propose to observe structure built by animals and their criteria, which could help architects to improve the design and process of building's energy life cycle. In particularly the constructive process in birds, as a nature's model, not only the architecture itself but their behavior in relation how birds create their structures, their material's choices, their sophisticated features that adapt to local environment and etc. as a key approach of nature's strategy to improve energy-efficient building design for the total impact of all energy issues in building.

2 BUILDING AND ENERGY

When we talk about energy conservation, it is customary to say that the design process is done in three phases (Klen & Schlenger, 2008). Indeed, one of the key approaches to low-energy design is to invest in the building's form and enclosure. The first is to reduce energy needs by carefully designing the building envelope so that the heating, cooling and lighting loads are reduced. The second is to offset the remaining needs for efficient systems and appliances, and the third aims to make the most of resources, which means free energy that are available in the occupation site. These three phases can be reduced considerably the energy consumption effectively for the new building without user's impact (Low-Energy Building Design Guidelines). Nevertheless, if we want to concern deeper it is necessary to consider the building throughout its life cycle, that means to reflect its operations and maintenances, refer to its demolition. These phases according to their support during the design process will require more or less energy. We must also add to the embodied energy necessary for its implementation, its rehabilitation and demolition. This is a global vision that provides an essential place in the energy criterion (of all kinds of uses) among other architectural criteria we must have. In view of the crisis of the source that the world is currently living (Huygen, 2008), is another point to add. This aspect highlights the need to optimize the use of the material to see the establishment of a re-employment system.

Buildings consume a vast amount of energy during the life cycle stages of construction, use and demolition. Total life cycle energy use in a building consists of two components: embodied and operational energy. Embodied energy is expended in the processes of building material production, on-site delivery, construction, maintenance, renovation and final demolition. Operational energy is consumed in operating the buildings. Many studies have revealed the growing significance of embodied energy inherent in building and have demonstrated its relationship to carbon emissions (Houssin & LaFrance, 2013).

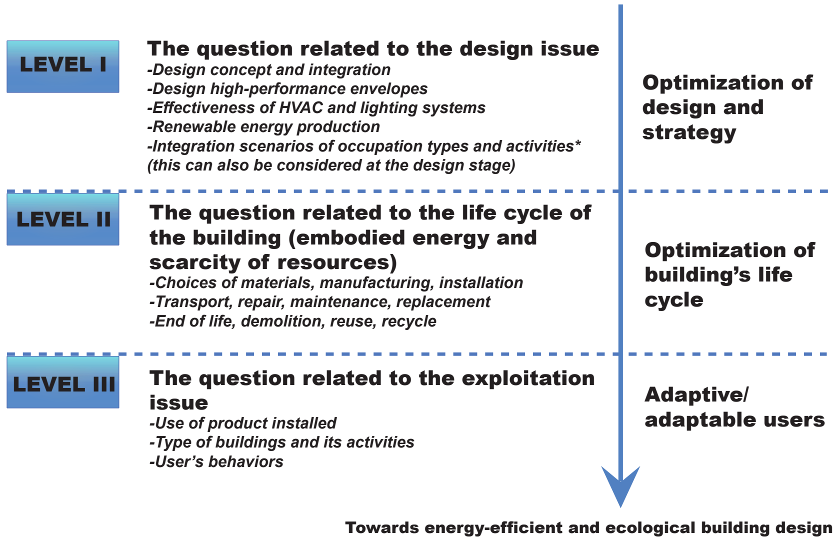


Figure 1. The three issues related to energy-efficient building design towards sustainability

2.1*The question related to the design issue*

During pre-design and design phase can effect the whole operational and embodied energy, including carbon emission in a life cycle of a building because architects can envisage multi-criteria requirements, some criteria such as, climate change, user type, activity, material choice that effect transportation, manufacturing and end of life issues. Also now, architects can also conceive to envisage maintenance phase during the pre-design and design development (Hannachi-Belkadi, 2016).

Building skin or envelope is the first design concern to reduce overall energy of the building; it is the 'boundary through which the buildings interaction with the environment occurs' (Mazzoleni, 2013). The building envelope is the building shell, fabric or enclosure as; it is the boundary between the interior of a building and the outdoor, thus the design for the building skin is a first tool for energy management. There are many examples of high-performance building envelopes but today we question on top of how much energy to put on manufacturing process of these high-performance envelopes, we keep continue to put more technologies to solve the problem but we don't concern on the overall environmental impact of processing these technologies. In many cases designers will employ a high-tech approach in order to minimize operational energy consumption, using highly processed materials, complex plant equipment and a sophisticated, automated control system. In terms of whole life performance, this tends to shift the carbon cost from operational consumption to the end body carbon of the building fabric. For examples, the solar cells for renewable energy, their production and its end of life treatment have lately been questions form the ecological point of view (Chayaamor-Heil & Hannachi-Belkadi, 2017).

There are two types of approaches (technology and low-cost) one that is more towards new technologies and the other more passively oriented. We need to understand the advantages and limitations of the two approaches according to multi-criteria requirements and specificity of the project. Achieving an energy-optimized and low carbon building requires the investigation of both operational and embodied energy of alternative design options during early planning stages. Overall, the question related to the design issue enables the quantification of the impact of the embodied energy and shows the effects of certain design solutions in terms of comfort, energy demand and ecological performance. This approach provides useful information during the early design stages, where the influence potential is still high and improvements are possible at less cost.

2.2*The question related to the life cycle of the building (embodied energy and scarcity of resources)*

As refer in overall energy-efficient building design, if we want to concern deeper it is necessary to consider the building throughout its life cycle, that means to reflect its operations and maintenances, refer to its demolition. Buildings demand energy in their life cycle right from its construction to demolition. Studies on the total energy use during the life cycle are desirable to identify phases of largest energy use and to develop strategies for its reduction. Buildings, building materials and components consume nearly 40 percent of global energy annually in their life cycle stages.

Buildings are constructed with a variety of building materials, each building consumes energy during its life cycle in stages, such as raw material extraction, transport, manufacture, assembly, installation as well as its disassembly, demolition and disposal. Energy is expended in various construction processes of a building during the pre-construction phase. Post construction phases, such as renovation and refurbishment, and final demolition and disposal also consume energy. The energy consumed in these life cycle stages of a building is collectively interpreted as embodied energy.

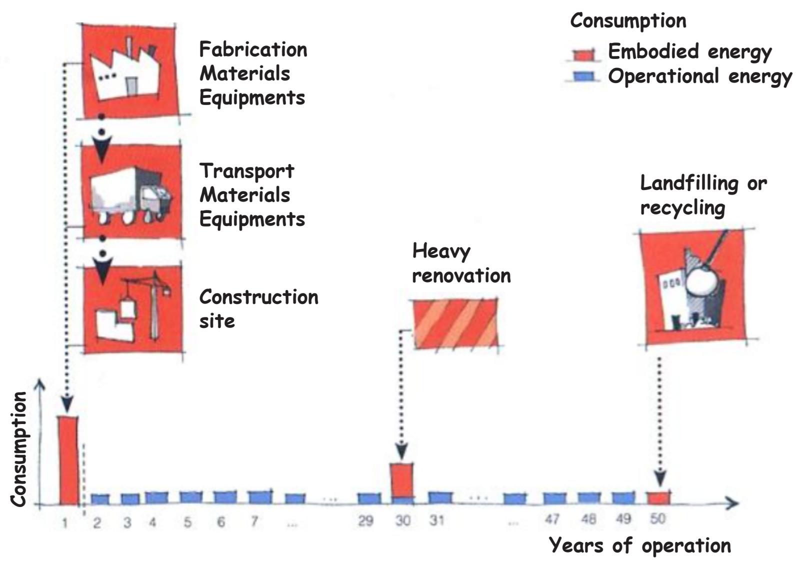


Figure 2. Example of distribution of consumption on an office building (adapted from Brisepierre, 2013)

The total life cycle energy of a building includes both embodied and operational energy (Ding G., 2004) (Crowther P., 1999). The necessary energies throughout the life cycle of the building start from production, construction, energy consumption and maintenance until end of life as show in figure 2. It is necessary to open our eyes to the scarcity and depletion of resources, the pollution of our soils, the acidification of the air, so we must take an interest in the overall environmental impact of the construction and years of energy consumption.

2.3*The question related to the exploitation issue*

The use phase in life cycle energy of a building is mainly related to operational energy and the use of installed product such as, HVAC, Lighting and hot water system and other related supplies. There are part of renovation and maintenance during the year of operation, which are related to embodied energy. In designing energy-efficient buildings, it is important to appreciate that the underlying purpose of the building is neither to save nor use energy. Rather, the building is there to serve the occupants and their activities. An understanding of building occupancy and activities can lead to building designs that not only save energy and reduce costs, but also improve occupant comfort and workplace performance.

Energy and indoor environmental performance of buildings are highly influenced by outdoor/indoor climate, by building characteristics, and by occupants' behavior. The behavior of occupants in a building can have as much impact on energy consumption as the efficiency of equipment. One of the most significant barriers for achieving the goal of improving energy efficiency of buildings is the lack of knowledge about the factors determining the real energy use. Often, there is a significant discrepancy between the designed and the real total energy use in buildings. The reasons of this gap are generally poorly understood and largely have more to do with the role of human behavior than the building design. Recently, there are many studies focus on investigate the influence of occupant behavior on the energy performance of a building (Hannachi-Belkadi, 2016).

2.4*Types of energy*

The total life cycle energy of a building constitutes the embodied as well as the operational energy. Embodied energy is the total amount of energy consumed during the production, use (renovation and replacement) and demolition phase, whereas operational energy is the energy required to operate the building in processes, such as space conditioning, lighting and operating other building appliances (Ding, 2004). Compared to embodied energy, operational energy constitutes a relatively larger proportion of a building's total life cycle energy (Hegner, 2007).

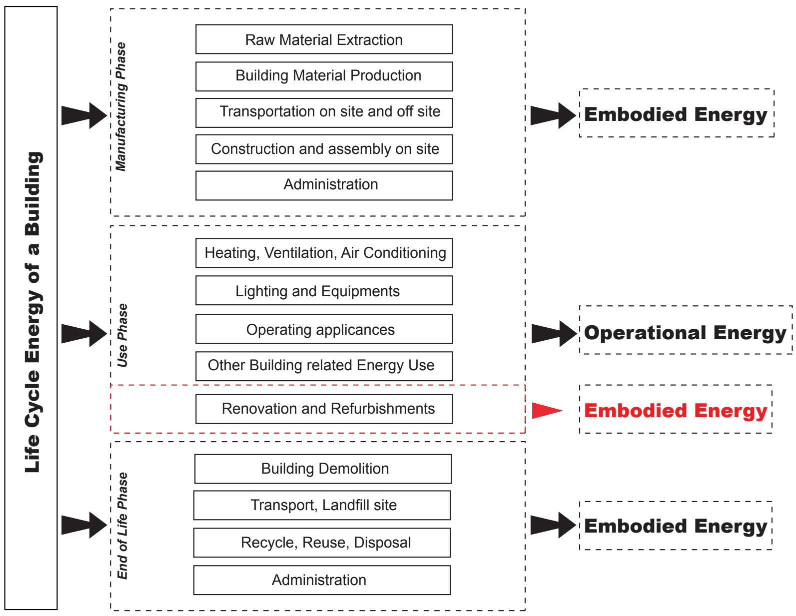


Figure 3: Life cycle energy of the building and types of energy in each phrase (Adapted from Ramesh et al., 2010 & Cabeza et al., 2014)

Energy types and usage during the life cycle are show in figure 3. Within the Life cycle energy of the building, three phrases are recognized: manufacturing, use and demolition (Cabeza et al., 2010 & Ramesh et al., 2010). Embodied energy is mainly used during the manufacturing and demolition phases. The manufacturing phase includes production costs, transport and installation of materials in a new building, and also costs connected with the renovation of the building. The operational energy is largely used in usage phase, which includes energy costs connected with usage and operation of a building during the course of its lifetime. The demolition phase includes costs for building demolition, transport of materials to disposal sites and material recycling.

2.4.1*Operational energy*

Operational energy includes energy consumed during the course of the usage phase. These energies include heating, air-conditioning and ventilation (HVAC), lighting, domestic hot water and other appliances (Sharma et al., 2011) state that HVAC forms approximately 40% of the total operational energy used in buildings. The share of energies consumed for heating in the winter period and cooling in the summer period is affected by the climate in the locality of the evaluated building, the materials used and the required level of comfort for the building.

2.4.2*Embodied energy*

Embodied energy is the energy utilized during manufacturing phase and end of life phase of the building. It is the energy content of all the materials used in the building and technical installations, and energy incurred at the time of erection/construction and renovation of the building. Energy content of materials refers to the energy used to acquire raw materials (excavation), manufacture and transport to the building site. Demolition energy is part of the embodied energy. It is energy essential for demolition and transport waste materials. This is an important phase that we normally overlook, if we don't pay intention on the choice of material for construction and installed products from the pre-design development phase, the impact of overall energy consumption and GHG can arise at the end of life phase of the building itself (Dixit et al., 2012). End of life treatment of a building concerns transport, landfill site, recycle, reuse, disposal and administration issue. Demolition energy at the end of life phase consider as an indirect embodied energy of a building life cycle. Today, it becomes an important study for the demolition that can be more environmentally preferable in comparison to conventional demolition in all assessed environmental impact categories. It is concluded that selective demolition is environmentally preferable because when it is conducted the materials may be re-used. Since production of new building materials is not needed, the environmental load of production from raw materials is avoided. From an environmental perspective it is beneficial to re-use construction and demolition materials.

As we describe energy consumption and those beyond consumption in the overall life cycle energy of a building, divided in four main phases, 1) building material production phase, 2) construction phase, 3) use/ occupancy phase and 4) end of life phase, as refer above that the total life cycle energy of a building includes both embodied and operational energy, thus to reduce total energy consumption and those beyond consumption in concerns with environmental issue by applying a single technology or a high-performance design is not enough. Humans are becoming increasingly dependent on our ability to connect via technology and easily access the energy grid. Practically every facet of our lives is somehow plugged in and powered up. Yet as our demand for power increases, so must the innovative and life-friendly ways we access and use that energy. Here's a light bulb idea: *how does nature make and manage energy?* For the billions of species that have existed on planet earth, humans are the only ones who have placed such a premium on unsustainable and non-local sources of energy. How then, does nature balance its energy books while producing relatively little energy waste? Efforts made in research and existing boundaries and openness to nature explore how nature has discovered brilliant ways to their needs to survive within a sustainable system.

Looking to nature to solve some of our most pressing energy issues is the next logical step. The dominant industrial development model of present-day based on a linear output process. During this period that lots of energy and resources are consumed, the production of waste is so much and the most of these wastes cannot be recycled. On the contrary, in nature there is no waste; nature's close-loop system is a perfect model for construction industry. During the process of creating a sustainable construction environment, wastes can be prevented through designs based on full life-cycle thinking. Energy, source consumption and waste production increased by wrong decisions in the design process feature innovative design approaches such as "biomimicry, cradle to cradle, restorative and regenerative based on nature in architecture discipline. McDonough and Braungart (McDonough & Braungart, 2003) state that, by clearly understanding the chemistry of natural processes and their interactions with human purpose, architects can create buildings that are delightful, productive and regenerative by design.

3 BIOMIMICRY

We are in the midst of a paradigm shift in the way we view and interact with the natural world. This new line of thinking 'biomimicry' is already having a tremendous impact on the way we design technological products and systems. It is also an excellent example of the interdisciplinary nature of science and technology, which is an extremely important component of technological literacy (Clough, P. et al. 2000). The word biomimicry comes from the Greek words bios (life) and mimesis (imitation). In short, biomimics imitate nature. We now have the capability, however, to not only imitate the products of nature but also nature's materials and processes. Biomimicry involves learning from and emulating biological forms, processes, and ecosystems tested by the environment and refined through evolution (Zari, 2007). Biomimicry can be applied to solve technical and social challenges of any scale. Biology has inspired design since prehistoric man spears from the teeth of animals and mimicked the effective sneak-and-pounce hunting technique of large predators, but the development of a methodological framework for translating biological strategies into design innovations is a recent one. American inventor, Otto Schmitt, coined the term 'Biomimetics' in the 1960s to describe to transfer of ideas from biology to technology (Nachtigall, 2003). Three decades after, the term biomimicry appeared in 1980 and was popularized by the biologist and environmentalist Janine Benyus, author of the book, Biomimicry: Innovation Inspired by Nature (Benyus, 1997). Biomimicry is defined in her book as a new science that studies nature in order to imitate it or to draw inspiration from it to solve human problems. The concept of biomimicry, as supported by J. Benyus, proposes to draw inspiration from the brilliant ideas developed in nature to design our innovations from a perspective of sustainability. Benyus suggests looking at nature as a model, measure or mentor.

1. Nature as a Model: Biomimicry studies the models of nature, then imitates or draws inspiration from their characteristics to solve human problems.
2. Nature as Measure: Biomimicry proposes to use the standards of ecology to judge the 'rightness' of our innovations. After 3.8 billion years of evolution, nature has learned: what works, what is appropriate, what lasts.
3. Nature as a Mentor: Biomimicry is a new way of considering and appreciating nature. It introduces an era based not on what we can extract from the natural world but on what we can learn from it.

Benyus also stresses nine laws of nature in her book (Benyus, 1997). She argues that each property should be of vital consideration to any truly biomimetic design, as following; Nature runs on sunlight, Nature uses only the energy it needs, Nature fits form to function, Nature recycles everything, Nature rewards cooperation, Nature banks on diversity, Nature demands local expertise, Nature curbs excess from within, Nature taps the power of limits.

In nature, there is always a limit to the resource or energy available, because organisms multiply until a resource is exhausted. Because of this limit, nature constructs to stabilize their immediate environment and support whatever function they perform within their ecosystem.

The industrial sector has rapidly seized biomimicry, which has led to innovations in different fields but has not necessarily always taken into account the challenges of sustainable development (Nacthigall, 2003). Biomimetic is defined as translating good design from nature into design technology. As such it has arrived at a stage, where its acceptance as an innovation method is no longer questioned. Beyond technical innovation, looking at principles from nature provides us with insight into deep principles governing life and cohabitation on the planet. In the field of architecture, one can see many examples that are influenced and learned from the nature. Constructions like branches of a tree, analogies of flowers, network configurations, etc. inspired the architectural design thinking since the ancient times. This inspiration can be observed in two ways; (1) to reproduce the form with the concern of form finding, (2) or to transfer the process of emergence of a living entity (like material, form, structure, etc.) to design thinking. The first is to concern of form finding and most of the time does not refer to a functional and an ecological approach. The second way is a different approach though, which offers to observe and understand the functionality and harmony within the nature.

3.1*Approach and levels*

Approaches to biomimicry as a design process typically fall into two categories: (1) Defining a human need or design problem and looking to the ways other organisms or ecosystems solve this, termed here *design looking to biology*, or (2) identifying a particular characteristic, behavior or function in an organism or ecosystem and translating that into human designs, referred to as *biology influencing design* (Biomimicry Guild, 2007).

Biomimicry inspires architecture in different levels as biology does in the nature and these levels can be summarized under three categories: the organism, behaviour and ecosystem. The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism. The second level refers to mimicking behaviour, and may include translating an aspect of how an organism behaves, or relates to a larger context. The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function. This approach is methodized by Zari (Zari, 2007) to apply to a design or an architectural problem. Within each of these levels, a further five possible dimensions to the mimicry 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) (Zari, 2007).

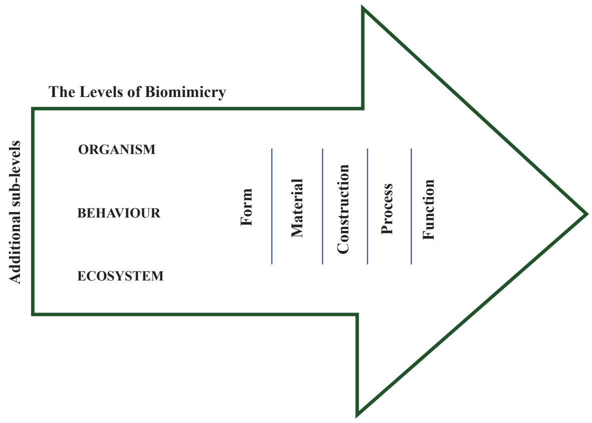
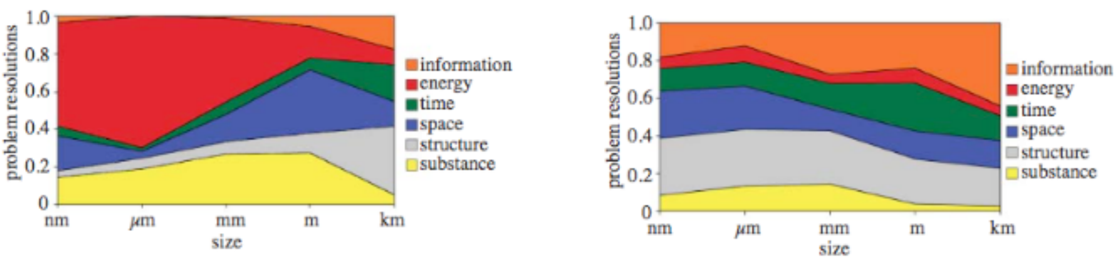


Figure 4. Framework for biomimicry model in architecture (adapted from Zari)

It is expected that some overlap between different kinds of biomimicry exists and that each kind of biomimicry is not mutually exclusive. For example, a series of systems that is able to interact like an ecosystem would be functioning at the ecosystem level of biomimicry. The individual details of such a system may be based upon a single organism or behaviour mimicry however, much like a biological ecosystem is made up of the complex relationships between multitudes of single organisms.

3.2*Optimization strategy from nature could provide guidelines for improving energy efficiency designs*

The main force related to the way nature can inspire sustainable design. The term ‘inspire’ means enabling the designer to look for creative design solution (Benyus, 1998). One source of inspiration comes from the shapes of organisms. The second level of inspiration relates to the manufacturing process that operates in those organisms. At the last level, inspired by the interactions of the species between each other and by the global functioning of natural eco-systems (Allard, 2012). A conceptual model of biomimicry has further classified the design approaches, which range for a ‘direct’ approach that is a simple mimicking process to an ‘indirect’ which involves more diverse forms of analysis of nature (Hyde, 2015). The question for research is largely a ‘how’ question to use biomimicry in design. One of the major challenges of using biomimetic strategy today is to provide sustainable technologies. To imitate nature solution per se, without an intention to implement nature sustainability design principles, is not a guarantee for sustainability. Seeking nature's guidance for sustainable models and measures is reasonable and has expanded in recent years. Biological processes operate within restricted living constraints without creating waste; in contrast they enrich and sustain the ecosystems. Nature forms and structures provide a wide range of properties with the minimal use of material or energy and nature systems demonstrate efficient flow of energy and material. Not only nature solutions are distant from technology, but they are also based on a different paradigm (Vincent, 2006). The different is well demonstrated the comparison between design solutions in biology and technology, by the assistance of the TRIZ (Altshuller, 1999) an acronym in Russian known in English as ‘Theory of inventive problem-solving’. TRIZ based analysis showed that there is only 12% similarity between the principles of solutions in biology and technology. While in technology usually energy and materials are being used to solve problems, in biology solutions are based on information and structures (Vincent, 2006) (Figure 5). Further more, biology system usually follows the principle of multifunctional design. Each component has several functions, offering an elegant and cost effective design. Technological systems don’t always follow this principle; in many cases each component has one or only few functions.



(a) (b)

Figure 5. (a) The type of problem-solving strategies that human technology employs on different length scales. Technology tends to function by manipulating energy and substance. (b) Types of effects observed in biology at different length scales. Natural systems tend to function on account of how they are structured and the way information is managed (Vincent, 2006).

Biomimicry has much to contribute especially during the concept generation stage with well understanding of performance optimization in nature. An appropriate sustainability tool for the concept design stage maybe derived from the nature itself, where nature sustainability design principles are identified and gathered as a tool such as database. If we look at biomimicry theoretical framework on how a particular organism is sustained in a healthy way within an ecosystem, it attempts to understand the system as it connects between form, process and ecosystem as a whole. For example, comparing with the design process, we question ‘form’: *what is the shape that can help to optimize?* Then we question ‘process’: *how does it perform and how is it made?* And lastly, we question ‘ecosystem’: *how does it fit with the whole?* An innovative design form requires an investigation and understanding of the synthesis of internal forces, functional integration and external forces, and environmental adaptation (Gamage & Hyde, 2006).

4 BIOMIMETIC DESIGN CONSIDERATIONS

If we look closer, animals, plants, and microbes are consummate designers. Nature takes distinct approaches for coping with the environment. We take a look at structure built by animals for biomimetic design consideration by learning from their strategies. Most animals find a home for themselves by taking shelter in caves, trees, underground, or hollows. Some opt for parasitic arrangements. But, we also know of certain animals like the birds, ants, bees etc. that make for themselves private places like nests, hives or colonies to rest, mate and nurture offspring. There are also some animals that build themselves elaborate living places, such as the termites.
Structure built by animal, or animal architecture (Mandel, F.B., 2010)(Hansell, M., 2005) is bound with nature, unlike human-made. Animals create their construction with sophisticate features that allows them to survive, such as, ventilation, temperature regulation, structural strength, multiple escape routes, traps, bait, special - purpose chambers and many other features. Animals build their constructions with a limited energy and within an eco-system. For example, Termite's mound is one of a perfect natural construction, with efficient passive ventilation system that can keep the interior temperature always stable whatever exterior temperature would be. Termites make their mound from wasted materials of plants and animals around their local area, the process of their construction produce nitrogen, phosphorus and organic materials that help to enrich the soil, fostering more plant and animal grow in the area (Turner & Soar, 2008). This is the best example to show that apart from the termite mound construction is efficient, the process of their construction also gives a positive impact to their environment. This is an important lesson for us, architects, to learn and improve our construction design process and industry.

In this study, we have chosen the design, construction and exploitation of bird nests and bird's behaviors as a nature's role model. The constructive behavior of birds thus seems likely to indicate potential paths towards a sustainable architecture.

4.1 *Nature's role model: The constructive process in birds and their criteria for sustainable architecture*

The constructions of birds are durable. They have been modified and perfected by the process of natural selection and only the most suitable nests have allowed species to reproduce until today (Mainwaring et al, 2014). Given the rise of biomimicry, their study seems legitimate to give possible paths towards a sustainable architecture. This study demonstrates the design and the functions of the bird's nest in parallel with the way they have influenced the constructive disciplines.

Figure 6. Bird nests: Left, Taveta golden weaver building pendant nest. Right, Many raptors, like the osprey, use the same huge platform nest for years, adding new material each season (Source: wikipedia).

The architecture of birds shares several points with that of men. They both produce the distinction between an interior and an exterior, often by assembling materials into a coherent structure. They follow the same principles of solidity, utility and even appearance. The nest like the house must be solid, meet a need and give a specific image, like birds whose construction is camouflaged in their environment so as not to alert the predators. There is therefore the implementation of a particular technique with particular materials, on a particular site.

Chronologically, the first concerns the selection of a locality in which a type of nest is made of specific materials. The construction can begin in a second time; effective constructive techniques are adopted because they meet the constraints related to the site and the morphology of the constructor. The cycle is completed by the exploitation of the built nest and the end of life. We extract the strategies of how birds design their nests, how they construct and how they operate with limited energy and sustainability in comparison with the way we design, construct and operate our buildings.

Birds are the most consistently inventive builders, and their nests set the bar for functional design in nature. Birds build some astonish structures, from nest the size of walnuts to makeshift rafts and even apartment complexes (Mainwaring et al, 2014). The bird chooses the nest site with the utmost care, for the reasons of safety, accessible construction, and suitable local materials for transportation. For every type of nest, finding the right building materials is essential. Birds can spend a whole day in their quest for the building materials their structure needs. These nests' features depend on the materials and techniques used in their construction. All building materials for their architectural masterworks must be pliable and compressible. Nests are built taking into account the elasticity, durability and toughness of the different materials birds use—mud, leaves, feathers, cellulose and other organic materials. This increases the structure's durability. Using plant fibers mixed with mud, for instance, prevents cracks from developing for example (Goodfellow, 2011).

4.2*Biomimetic Design Methodology*

Biomimetic is defined as the 'abstraction of good design from nature' (Vincent et al., 2006). The approach of biomimetic design methodology is basically in three-step process: *Research →Abstraction → Implementation* (Nachtigall, 2010). The research concerns the selection of nature role models to suit specific problem in design, abstraction concerns the analyze of nature's strategies and transfer into design phase, and Implementation concern the ability to built the biomimetic design concept according to construction criteria (Figure7).

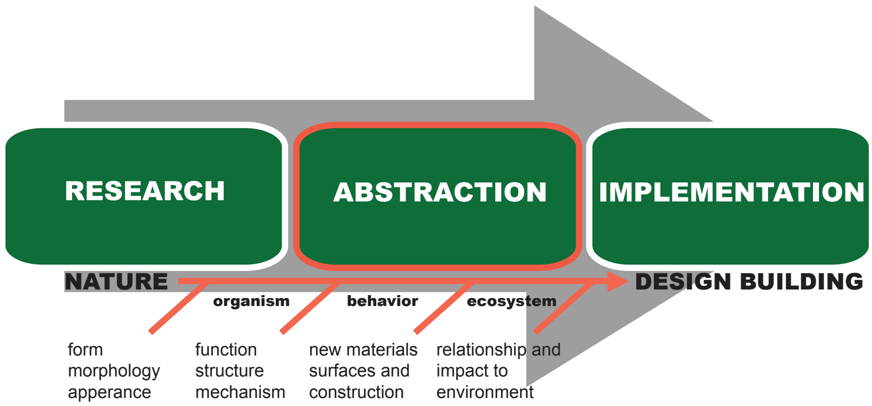


Figure 7. Biomimetic design process

The transfer of information from one discipline to the other is the most interesting part of biomimetic process. The transfer of form, the application of morphological characteristics is most common in architecture and design and cannot be excluded from discussion. Even more general than the investigation and transfer of 'natural constructions' is the transfer of qualities that can be found in nature. Nature's phenomena can include surfaces, materials and/or structures, functions, mechanisms, principles (e.g. self-organization) or processes (e.g. evolution), delivering models to be analyzed, abstracted and applied to architectural solutions on all scales and levels of design (Figure 8)

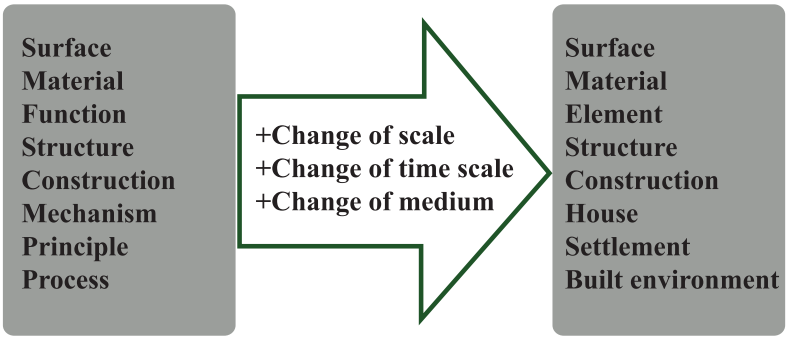


Figure 8. Scheme of nature's categories, information transfer and application, based on Gruber, 2011

In the method of Biomimicry, the transfer of functional aspects is the most favored approach, stemming from the hypothesis that all existing constructions and structures in nature have a functional cause, and that function is the key to the establishment of suitable analogies. In contrast to biomimetics, environmental responsibility and sustainability are directly implemented into the innovation process. Innovation is understood in the notion of a necessity to push industrial developments towards a sustainable future. Biomimicry principles are used as guidelines and evaluation parameters for the innovation process (www.biomimicry.net).

The issues related to energy consumption of a building	**CRITERIA OF BIRD NEST DESIGN STRATEGIES**	**LIFE CYCLE ENERGY OF A BUILDING (Design principles extract from nature)**	**Biomimicry levels**
The question related to the design issue	**A. Design: Morphology, Site and Materials** ***1. The definition of a form*** -Diversity of morphologies -The morphology as a strategy to external menaces ***2. Insertion into the site*** -The challenges of integration environment -The influence of the geo-climatic conditions of the environment -Setting site value ***3. Selection of Materials*** -Common and abundant materials -Local materials -Materials and Future Needs -Materials adapted to physical capacities	Morphology and functions of the building in relation with the site to optimize and adapt to local environment Management of contradictions designs with multifunctional structures or devices; for example *how we can have more light in the building but less heat?* Envisage activities in the building and type of occupants in a period of time	**Organism** ***+Structure*** ***+Information***

The question related to the life cycle of a building	**B. Construction: Choices for Implementation** ***1. A local construction*** -Energy Savings in Times of Construction -Local specification of assemblies -Influence of geo-climatic conditions ***2. Constructive responses to implementation constraints*** -The start of construction -A superimposed layer process -Lengths of reciprocal materials and structures ***3. The nest life cycle*** -The life of the nest -The challenges of nest reuse -Destruction of the nest and becoming material	Run to free energy resource from local site Resource management, use local material without the need of distance transportation Selection of materials for accessible and easy assembly to save energy for material production. Selection of the construction site to suit with materials use and production Making wastes becoming resources and reuse materials	**Eco-system** ***+Information*** ***+Space*** ***+Time***
The question related to the exploitation issue	**C. Operation: Space and Time Management** ***1. Control and maintenance of acceptable internal conditions*** -The heat transmitted by the body of the bird: conduction and homeostasis -Adaptation of behavior to external conditions -Maintenance of nest performance by external conditions ***2. Time of exploitation and natural cycles*** -Temporalities of species -Synchronization of species -Common problems, various behaviors ***3. The relationship to the body in the building*** -The body as a tool -The curve in the nest -The body and the scale	Adaptability and behavioral pattern of occupants in relation with their activities to optimize the use of product installed in the building Evolution with time, adding and reuse rather than change	**Behavior** ***+Information*** ***+Time***
Information Energy Time Space Structure Substance			

Figure 9. Biomimetic design analysis based on Ideality tool (Helfman Cohen & Reich, 2017)

From the figure above, we look at how birds build their nests and analyze what make the bird nest efficient and sustainable in three issues related to energy efficient design toward sustainability (design, life cycle and exploitation). Each issue falls in to different levels in biomimicry. We can also learn adaptable strategy from bird's behavior constructing and exploiting their nest in relation with the behavior of occupants in relation with their use of building. Human's behaviors have as much impact on energy consumption as others issues. Recent studies have shown that human behavior is at least as important as the physical characteristics of a building in influencing energy use, and that carbon emissions from dwellings are most sensitive to internal temperature changes, largely dependent on human behavior (Hannachi-Belkadi, 2016). By understanding the interaction between human behavior and the physical variables of buildings they occupy, we can untangle the complex relationships affecting energy use and get a clearer idea where energy and emissions savings can be made (Kelly 2013). In addition, we can also use operation system analysis in BioTRIZ tool (Vincent et al., 2010) for contradiction design matrix, captured by the mantra: things do things somewhere. This establishes six fields of operation in which all actions with any object can be executed: things (substance, structure), do things (requiring energy and information) implies also that energy needs to be regulated and somewhere (space, time). Thus nature designs tend to function on account of how they are structured and the way information is managed with time evolution, in contrary human designs tends to function by manipulating energy and substance (Vincent, 2006).

5 CONCLUSIONS

At each stage of nest construction, birds behave according to a set of criteria. The construction of the nests is thus regulated by a plurality of data organized in a complex manner. Despite the diversity of species, techniques used and ways of using the nest, birds share the same goal of ensuring reproductive success. And for the vast majority of them, this victory involves building a structure that meets their needs. In this major phase of bird life, the environment is perceived as both a hazard and a resource. This is why the nest serves both to protect against a hostile environment while drawing from the same developmental environment. The man's building faces the same paradox. The building shelters and protects from the outside but its design, construction and use draw from the resources of the environment. Our constructive responses, however, appear to be much more hermetic to our environment to such an extent that it seems difficult to sustain such a practice of architecture in the future. The performance of contemporary buildings, on the other hand, offers the possibility of isolating themselves from the external environment. Technologically assisted buildings ensure an optimal interior climate without even resorting to the active participation of users.

Recently, we have employed several methods to reduce energy consumption in the building but mainly to implement a single technology or design that can efficiently reduce operational energy consumption but not concern to overall hidden embodied energy and total environmental impact. Thus in this study we propose to learn from nature to improve towards both energy efficiency and ecological building design. Biomimicry is a possible answer for the 'sustainable' energy issue in the building, since 3.8 billion years of evolution nature generally makes materials with a minimum of resource input, at ambient temperature and pressure and does so in a way that enhances the environment rather than polluting it. Biomimetic design analysis by Ideality tool suggests architects to observe construction built by animal and extracts their principle strategies into man-made design, in particularly, the principle strategies can be used in pre-design development to see the overall impact of a building's life cycle. Note that, in this study we give an example to analyze bird nest in relation with bird's behavior, in other case, the nature role model can be changed to suit specificity of the design project. Furthermore in the near future we should start to think about opportunities for buildings to become net producers of energy rather than net consumers. Also the impact of the process of making building, should give positive impact to the environment as we shift from economical cycle that has left us an unhealthy footprint into the new era of ecological cycle towards a more healthy living in our built-environment of tomorrow.

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