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THE IMPLEMENTATION OF NANO-BIOMIMICRY FOR SUSTAINABILITY IN ARCHITECTURE

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Abstract: Nanotechnology is one of the key technologies of the 21st century, which has a potentiality to offer sustainable solutions to contemporary architecture and lower building costs. It helps biomimicry (as a way of thinking which is going back to nature for inspiration) to be achieved at new levels, through producing (new materials, devices and robots), that function as the same way as organisms do. Both nanotechnology and biomimicry take their power from nature and could have extraordinary results if implemented in building design, systems and construction. This research is looking at the concept of nano-biomimicry (biomimicry on nano level) and its usage in architecture. The main concern of this research is to arrive to a better understanding of the levels of implementation of nano-biomimicry for sustainability in architecture. The research uses qualitative method and case study approach to analyze and evaluate the levels of implementation of nano-biomimicry in sustainable architecture. It leads to a new understanding of the levels of implementation for nano-biomimicry for achieving sustainability in architecture and considers an expansion of the old categorization into seven categories including form, materials, construction, function, system, computer modelling, and robotic strategies.

Keywords: *Biomimicry, Nanotechnology, Sustainability, Affordability, Architecture, nano-biomimicry.*

تطبيقات نظام المحاكاة النانو-احيائية لتحقيق الاستدامة في العمارة

الخلاصة: تكنولوجيا النانو هي واحدة من اهم التكنولوجيا للقرن الواحد والعشرين، والتي من المتوقع ان تحمل حلولا مختلفة لتحقيق الاستدامة في العمارة المعاصرة وتخفيض الكلف. وهي عنصر أساسي في تحقيق المحاكاة الاحيائية (أسلوب تفكير يرتبط بالطبيعة من جديد كمصدر للإلهام) وينقلها الى مستوى جديد كليا من خلال تصنيع (مواد جديدة، أجهزة وروبوتات) بحيث تشابه نظيراتها في الكائنات الحية. تستمد كل من تكنولوجيا النانو والمحاكاة الاحيائية قوتها من الطبيعة، ومن المتوقع ان تنتج نتائج مبهرة إذا ما أمكن تطبيقها في تصميم المباني وأنظمتها وبنائها. هذا البحث يتناول نظام المحاكاة النانو-احيائية (محاكاة الفعاليات الاحيائية من خلال تكنولوجيا النانو) واستخدامها في العمارة. الهدف الأساسي لهذا البحث هو الوصول الى فهم أفضل لمستويات تطبيق/توظيف تكنولوجيا المحاكاة النانو-احيائية في تحقيق الاستدامة في العمارة. يستخدم البحث منهج البحث النوعي وتحليل دراسة الحالة لتحليل وتقييم المستويات المختلفة لتطبيق تقنية المحاكاة النانو-احيائية لتحقيق الاستدامة في العمارة ويتوصل البحث الى اقتراح توسعة للتصنيف السابق الى سبعة مستويات تتضمن الشكل، المادة، الهيكل والبناء، الوظيفة، النظام، النمذجة الحاسوبية، والاستراتيجيات الروبوتية.

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1. Introduction

Nature functions do not produce waste over long time, therefore they are sustainable. Thus, researchers try to learn and mimic these functions to achieve sustainability. Although, the concept of learning and mimicking nature is not new, Biomimicry, as an approach of thinking looking at nature as a source of inspiration, re- emerged recently to imitate natural functions at more extended levels. The re-emerging attitude of learning from life is inspiring architecture to find new solutions to achieve sustainability. This in conjunction with the advances made by nanotechnology, which is the study of the control of matter with atomic precision, helped in developing materials or devices at Nano-scale which could be widely used for architectural applications to produce sustainable architecture at Nano level. Although biomimicry and nanotechnology are not new to building design, construction and system, the categorization of nano-biomimicry potential in achieving sustainable architecture needs to be refined and updated if we are to produce sustainable architecture on the grounds of nano-biomimicry technology.

This research is concerned with understanding the benefits of biomimicry for sustainability in architecture. Its goal is to re-categories and understand sustainability advantages that could be achieved through biomimicry on different levels in architecture. In order to answer the research question, the researchers have laid down a set of objectives and steps to follow:

- What is Nanotechnology, Biomimicry, Sustainability, Organic architecture and New Organic architecture, and what is the relation between them?
- What are the levels of applying nanotechnology-biomimicry in architecture to achieve sustainability from the academic literature?
- How and in what levels could nanotechnology-Biomimicry be implemented in architecture in practice?

2. Research Objectives and Methods

Materials at nano-scale have unique characteristics compared to same materials at micro or large scale. Most creatures employ these characteristics in their everyday functions and achieve high sustainability. Although biomimicry is used on macro or large scale to achieve sustainable architecture, nano-biomimicry is still new and need to be explored especially with the new technologies of the 21st century that allowed this development. This research is focusing on the role of nanotechnology for sustainable architectural applications. The main objective of this research is to analyze the different levels of applying nano-biomimicry in Architecture. An understanding of the categorization should lead to better understanding of the potential outcomes of using this technology, thus better building performance overall.

The research uses qualitative methods and case study approach to achieve its goal. It is arranged into three parts, it starts by giving brief background about bio-based architecture and defining/discussing important keywords such as Nanotechnology, Biomimicry, Sustainability, Organic architecture and New Organic architecture, and try to analyze and discuss the possible relationship between them. Afterwards, the research critically analyze the different usage of nano-biomimicry in architecture and the levels of usage as categorized in the academic literature. Finally, the research will try to examine and analyze the implementation of nano-biomimicry in practice through a series of case studies.

3. Defining Of Research Keywords

Nanotechnology: Nanotechnology is the science that study the ability to build systems, devices and materials at atomic precision. The US "National Science and Technology Council" states “The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization" (Mansoori & Soelaiman, 2005, p. 1). The promise and essence of the nanotechnology is because materials at the nano scale, nanometer equals 10-9 meter, have properties different from the bulk materials (Nanotechnology – An Introduction for the Standards Community, 2005, pp. 1-2).

Many innovations made by nanotechnology take inspiration from nature. Even though science concerning about nano scale is often regarded as a part of the future, it is really the basis for materials and systems in our living and non-living world. We can notice examples of nanoscience in many organisms, from geckos that can walk on a wall or a ceiling, defying against gravity, butterflies with different colors, to some insects that glow at night. In nature, we encounter some outstanding solutions to complex problems in the form of fine structures at nano scale with functions associated with forms. In recent years, researchers have had access to new scientific tools to study structures related to functions of nature in depth. This has further inspired researches in the nanoscience and nanotechnologies. Therefore, in depth, natural science is the inspiration for nanotechnologies (NANOTECHNOLOGIES Principles, Applications, Implications and Hands-on Activities: A compendium for educators, 2013).

Biomimicry: biomimicry as a term composed of (bios: which means living things, mimesis: which means imitation), is a new way of looking at nature, depending not only on the ability to extract from the nature, but on learning from it (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 75). However, this concept of finding inspiration from nature is not new. For example, Leonardo Da Vinci’s own sketchbooks were evidence for his designs that were found in the natural world (Alawad , 2014, p. 140)

Biomimicry started to appear as the beginnings of 1982, published as concept (Benyus, Biomimicry: Innovation Inspired by Nature, 1997) in the book titled "Biomimicry: Innovation Inspired by Nature". It is defined in the book as a "new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems". Biomimicry is inspiring architectural design to find new forms and functions (Benyus, A good place to settle: Biomimicry, biophila, and the return to nature’s inspiration to architecture, 2008).

Sustainability: Sustainability is *"The development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Adams, 2006), while we could define sustainable architecture as *"The creation of buildings for which only renewable resources are consumed throughout the process of design"* (RAIC, 2016).

4. The Development of Architectural Bio-mimicry Philosophies

Organic architecture:

The expression organic was first brought up in biology, and then it has been borrowed in architecture and continued for more than half a century. "Organic" can be used about the structure and skeleton of nature creatures (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 78). Organic architecture adopts a design approach inspiring from principles of nature, going back to local site and cultural connections to produce architecture related to nature (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 79)."Wright" as one of the effective pioneer of 20th century architecture, created a kind of Organic Architecture by designing non-symmetrical plans, creating movement, using the environment‘s materials and emerging the architecture with the nature. However, architectural form was designed without paying attention to the real function of the design (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 79). An example of the 20th century is the design of Frank Lloyd Wrights for Johnson Wax building (Pawlyn, 2011, p. 4). Organic architect designs a building that is based on organism stylistically or aesthetically, but it is built or has functions conventionally (Zari, 2014, p. 8). Arciszewski and Kicinger named this trend of design as "visual Inspiration", which involves only with a picture of living organisms to create similarity with (Alawad , 2014, p. 141)**.** In summary, Organic Architecture is concerned in the similarities in appearance with nature forms without giving any attention to construction, function or system, which make it the weakest in relationship with providing sustainability.

New organic architecture or Bio-Architecture:

A completely different a way of thinking that takes the idea of biomimicry further and imitates living materials to design a living object. This approach extend the idea of copying and merges biology with the architecture (Ofluoglu, 2014, p. 30). New (organic architecture) connects built design, structure and materials with sources of forms and functions found in nature, studies the natural principles of animal and human constructions from several different perspectives (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 79).

Biomimicry and sustainability:

Nature has the most optimized organization in terms of form and function, which can provide designs that are useful and sustainable, enabling architects to appreciate the real value an application of nature in creating and producing sustainable and efficient buildings (Alawad , 2014, p. 141). The need to conserve resources makes it necessary for going back to Nature. Researchers, architects and designers, move this idea to their fields, called as "Bioneers" and their way of designing called "biomimicry" (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 75), they learns by studying and imitating nature’s forms and functions to design better sustainable technologies. The question is about the nature mimicking level is needed to achieve sustainable architecture.

Nanotechnology and Biomimicry:

The implications of nanotechnology in the trend of biomimicry could be called Nano-biomimicry; it refers to imitation of living creatures nano and macro scale in materials or structures in addition to processes found in nature (Dumitrescu, 2014)**.** Nano biomimicry.The "bio" as from a Greek word means life; while "mimicry" means to copy. Adding nano narrows the field to the nano scale, from 1 to 100 nanometers." (ANTONESCU, 2014, p. 5).

Many smart materials are made by nanotechnology such as shape-memory materials, which can remember its shape at a particular temperature after expanding or stretching, piezo-electric alloys and plastic materials, which can be stretched by changing voltage and also other materials which can decrease their transparency and colors, or save information, or translate sound, and light to each other through sensors. (Altun & Örgülü, 2014, p. 6). Arciszewski & Cornell (2006) argued that Bio-inspiration in design can be used, according to scale, on several levels including nano, micro, and macro levels. The nano level deals with individual atoms, the micro-level deals with the system’s components, and the macro-level deals with the whole engineering system (Arciszewski & Cornell, 2006, p. 34).

5. Examples of using nano-biomimicry materials

Organisms use a variety of materials for different functions. That inspire nanotechnology engineers to mimic nature, in their use of materials and functions, some are:

- **Self-Assembly**: An organism has the ability to direct its own process of development. Many self-assembling systems have been developed by nanotechnology which range from biopolymers to complex DNA structures which could be useful for a wide range of applications (Zhang, 2002, p. 321).
  University of Michigan nano- engineers are working on creating self-assembling robots that can build themselves into any form required under remote control, it would assemble modules together with spray able foam (Yeadon Space Eagency New York City, 2015).
- **Self-Healing**: Living organisms can repair their bodies, if damage is incurred. Researchers at University of Illinois have developed materials at nano scale that can heal, and regenerate itself (Yeadon Space Eagency New York City, 2015).The Bombardier beetle's powerful repellent spray, for example, inspired a Swedish company to design a "micro mist" technology of spraying, which aims to make a neglected carbon impact (ANTONESCU, 2014, p. 11).
- **Sensing and Responding**: An organism has many levels of feed backing systems of sensing and responding (Benyus, Biomimicry Pop!Tech Lecture Series, 2004)
  Researchers at Seoul National University have made a new type of artificial skin from silicon nanoribbons that can sense strain, pressure, humidity and temperature. The skin, which contains stretchable multi-electrode arrays, can be used in application of robots (Yeadon Space Eagency New York City, 2015).
- **Self-cleaning**: The leaves of the lotus flower (Nelumbo) has very high water repellence which keep it always clean (Benyus, Biomimicry Pop!Tech Lecture Series, 2004).
  This property of lotus surfaces was studied and mimicked by nano engineers (by using nano TiO_2) to design self-cleaning surfaces that can keep themselves dry and clean themselves as the lotus leaf dose (ANTONESCU, 2014, p. 3).
- **Water Collecting**: The Stenocara beetle can gather water; it lives in a very hot, dry desert nature and can survive (Benyus, Biomimicry Pop!Tech Lecture Series, 2004).

Researchers and designers at MIT design surfaces on a concept inspired by the Stenocara's covering shell using nanomaterials. They have made a surface that can gather water from the air (ANTONESCU, 2014, p. 11).

- **Solar Transformations**: Many nature creatures act with respond and active behavior to the sun to maximize their energy needs (Benyus, Biomimicry Pop!Tech Lecture Series, 2004). Solar Botanic is a company "specializes in harvesting the energy from the sun and wind through nanotechnologies", focuses on energy solar cells, and have designed a concept called the "Energy Harvesting Trees", that can make use of solar energy from the sun as well as wind power to produce energy (MB-BigB, 2015).
- **Materials as Systems**: Nature builds their bodies from small to large with a fitness of function (Benyus, Biomimicry Pop!Tech Lecture Series, 2004). (Addington & Schodek, 2005) Nano technology make it possible to produce smart materials which can do the function as a system as:
  1-"Immediacy", which is a real-time acting and responding.
  2- "Transiency", which is a responsive to multi environmental state.
  3- "Self-actuation", which is material intelligence.
  4- "Selectivity", which is a response that can be predictable.
  5- "Directness", which is a response locally to the activating state.
- **Material Recycling**: Organisms create their skeletons using materials that can be fully recycled after their death (Benyus, Biomimicry Pop!Tech Lecture Series, 2004).
- **Energy Saving**: Nature systems use a minimal energy for their functions (Benyus, Biomimicry Pop!Tech Lecture Series, 2004).

Above are only few examples of what nature can offer as models to imitate for the creation of new materials, which are then can be developed by producing nanomaterials and devices and used into applications for energy photovoltaics, various sensors, water filtration, thermal or sound insulations and many other products (Dumitrescu, 2014). Architects can use these applications to improve the sustainability of architecture.

6. Levels of Biomimicry in Architecture:

Benyus (1997) explains the foundation of biomimicry with three aspects of nature:

1- Nature could be a model: where researchers and designers examines the nature's models and copy or imitate designs of nature for problem solving.
2- Nature could be a measure: where researchers and designers uses the natural ecological sustainable balance to measure if the design has benefits.
3- Nature could be a mentor: where researchers and designers follow an approach to learn from (Benyus, Biomimicry: Innovation Inspired by Nature, 1997, p. 9).

She said that "biomimicry inspires architecture in different levels as biology does in nature and these levels can be summarized under three categories: (1) form, (2) process, (3) ecosystem". She argued that good relationship is important between biomimicry research and production technologies (or architecture technologies) to improve sustainability (Benyus, Biomimicry: Innovation Inspired by Nature, 1997, p. 19). However, another classification of biomimicry levels mentioned by Arciszewski as "Bio-inspiration" in Conceptual Design. He classified it to three levels: visual, conceptual and computational inspiration, considering its character. He argued that Visual inspiration in design could be described as the use of pictures of living creatures or their organs to design similar-looking industrial systems or components.

Conceptual inspiration provides knowledge that improve our understanding of nature, that could be applied to the design using abstraction. Computational inspiration depends on the level of computational process, which are inspired by natural mechanisms of evolution (Arciszewski & Cornell, 2006, p. 37). Biomimicry approach leads to an important question about "*Form or Function" associated with "what are the levels could adopt in design?", which improve thinking about the patterns, shapes, systems or structures that found in the natural world and the way these can be translated to industrial design* (Kenny, Desha, Kumar, & Hargroves, 2012, p. 6). This question make it important to explore levels in more details to examine the biomimicry level which is make an architecture behaves as near as possible as nature does.

As shown above, there is a need in the literature to examine more levels of biomimicry than "form, process, ecosystem", "form and function " or "Conceptual Design". This research try to suggest an expansion of nano-biomimicry in architecture into seven levels. The new categorization are based on the main usage of nano-biomimicry in architecture.

7. Nanotechnology and Levels of Biomimicry in Architecture

7.1. Level 1: Form (what dose an architecture look like?).

Advances achieved in the field of microscope technology (enables researcher to discover new forms at nano scale. This helps to mimic biological forms in order to produce building solutions with similar properties. Architects got benefits to find new source of inspiration to imitate at nano scale, for example carbon nano tubes was inspired by Allard Architects to design the Nano Towers in Dubai. The form created as repetitive grid of hexagonal structure, while a nano scale carbon tube (Fig. 1) inspires the entire facade of the tower (Vanguarq , 2015). If the designer, only copy forms discovering at nano scale, this will make the biomimicry level is the least unless using the other levels of materials, function, etc. as will be described in the following levels.

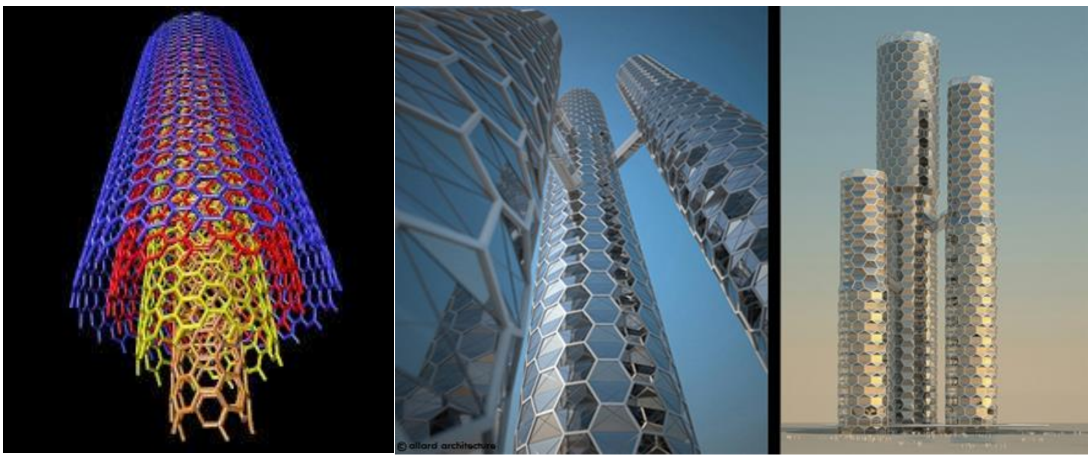

Figure 1: The Nano Towers in Dubai By Allard Architecture

7.2. Level 2: Material (what is an architecture made out of?).

Nature builds structures in a way searching for the least energy's consumption. Natural creatures chose materials based on function and conformity in harmony with their forms. They always look for making possible material at lowest amount of resources. Many examples occurs In the traditional Iranian architecture (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 80). In recent years, Nanotechnology provides necessary materials for "technology transfer" from nature to engineering.

Many nanomaterials have already been available , and nanoparticles could be added to traditional materials to produce better nano-composites and have new multifunctional properties. In addition, it is expected that these materials will greatly improve the function, durability, and strength of these materials (Altun & Örgülü, 2014). As an example, they have studied the adhesion abilities of the gecko's feet to produce nano adhesion that could be used in many applications (Fig. No.2). They discovered that the surface of a lotus leaf was made up of a form of nano structure that has the ability to be clean (Fig. No.3), which could be used in many architectural self-cleaning surfaces. The Manuel Gea Gonzalez (Hospital) project in Mexico (Fig. No. 4) was built using modules system (Salla, 2014). The building was covered with TiO_2, a nanomaterial that has anti-pollution and smog-eating properties as it help breaking down pollution particles into less dangerous particles, it can also prevent the growth of bacteria. Nanotechnology has the potentiality to produce materials mimicking nature with superior properties that improve mechanical performance, durability and sustainability. An architecture, if it is designed at this level, will be more sustainable.

Figure 2: the gecko's feet

Figure 3: Lotus leaf

Figure 4: The Torre de Especialidades facade at the Hospital of Manuel Gea Gonzalez

7.3. Level 3: Construction (how is an architecture built?).

This level is about (how is an architecture built?), it needs a knowledge about the way of assembling or chemical processing that nature applies to built (Kenny, Desha, Kumar, & Hargroves, 2012, p. 7). Some studies concerns about the possibility of an architecture that is following the concept of self-generating by its own DNA like nature creature's growing, surviving and even demolishing though using nanotechnology. This lead to develop sustainable and livable architecture derived from the nature, it is not only concerning of looking for different, attractive forms; it is about minimizing the needs of environmental resources. (Altun & Örgülü, 2014).

At this level, the building is built by imitating nature; it passes various life cycles. An example is the project the Fab Tree Hab design (Fig., No.5), a living structure single-family home, presents a complicated methodology to grow homes from living local trees. The method is to allow plants to grow over a computer-designed (CNC) removable plywood scaffold. Once the plants are grown and stable, the plywood is removed and if needed to be reused. The inside walls would be conventional materials as clay and plaster (Joachim, Arbona, & Greden, 2015).

There are few studies on a building that is self-generated like an organism, growing, surviving and even dying though using the potentiality of biomimicry and nanotechnology. That may be used by contemporary and future architects to develop sustainable architecture harmonized with nature to reduce using natural resources (Altun & Örgülü, 2014). This type of design approach could be named as "New Organic Architecture" based on more interaction with nature comparing with "Organic Architecture" of the 20th century that is defined before in the beginning of the research. Construction level of biomimicry not only use nanomaterials, but gets benefits from the advances made by other technologies available to mimic the growth process in nature.

Figure 5: Fab Tree Hab

7.4. Level 4: Function (what is an architecture able to do?).

Advances made by nanotechnology helped Engineers to study and mimic organisms (BARTHELAT, 2007, p. 2907). Nano engineers and designers tries to produce new nanomaterials and structures that active with the environment to minimize, re-act, self-heal, energy-save to produce smart building materials, nanostructured materials for solar energy conversion and storage, to obtain sustainability just like natural creatures (Kim, 2014).

Biomimicry at "the level of function" is following the use of nature's effective functions such as temperature controlling system, controlling light and providing ventilation, etc. One approach is to merge responsive materials with other materials that harvest energy from the sun or other resources to produce mechanical energy to change and reshape the structures into a wide range of variations of facade patterns. These merging systems generate a new types of smart materials that can be active with environmental conditions such as reversibly switching. That could design components with new functions important for various applications (Kim, 2014).

The advances made by technology, helps designers to develop a way to keep an architecture that can be naturally cooler by studying the nature principles, solutions is made by imitating an organism's physical solutions. An example at this level, based on biomimicry of form and function is "Waterloo International Terminal", designed by Nicolas Grimshaw & Partners where glass panels used by imitating a pangolins outer (Fig. No.6) (Ofluoglu, 2014, p. 33). Nature could introduce models for engineers, for example, copying solar cells from leaves (Benyus, Biomimicry: Innovation Inspired by Nature, 1997, p. 3) or imitating the unique texture of lotus leaves (Pourjafar, Mahmoudinejad, & Ahadian, 2011, p. 75). That leads to many design innovations like paint that enables facades of buildings to be self-cleaning (Pawlyn, 2011, p. 3), where surfaces can stay dry and clean themselves as this lotus leaf does (Alawad , 2014, p. 141). An example of using nano (TiO_2), as self-cleaning facade on the Torre de Especialidades at the Hospital Manuel Gea Gonzalez in Mexico City (Fig. No.4 and 3), where the modules used in facade contain nano (TiO_2), an anti-pollution technology that is activated by daylight. When stands near pollution sources, "the modules break down and neutralize NOx (nitrogen oxides), VOCs (volatile organic compounds), SO_2" (eVob, 2015). The building, if designed at this level, will be made from copying material from nature organisms; a material that imitates skin for example (Zari, 2014, p. 4). The building also could be built of new materials that make a good emulation of life, built on learning from nature or "doing it as nature way" (Benyus, Biomimicry: Innovation Inspired by Nature, 1997, p. 2). Architects got benefits for these advances made to look at the living world for solutions, to imitate organisms that have solved similar solutions (Zari, 2014, p. 2).

Figure 6: Waterloo International Terminal and the idea

7.5. Level 5: System (how does **an architecture work?)**

Several examples of organic species in nature, alters their own habitats and environments, due to increase in sustainable cycling and creating good benefits to relationships between natural creatures. The building imitating of organic species is often termed "animal architecture", which provide successful examples of sustainable systems to architects (Zari, 2014, p. 6). Mimicking the systems is the most complex level of biomimicry. It is important to consider that, in nature, nothing exists without relation to the whole. This concept could move to architecture by creating a sustainable system that works by a group of wide different companies having the benefits from each other's. It could work in large or town scale, that may include the cooperation of energy harvesting, water filtration and wastewater; and merge services to get benefits from each other's (Kenny, Desha, Kumar, & Hargroves, 2012, p. 7). Benyus (2008) mentioned, Biomimicry is not a style of building, nor is a design product. It is, rather, a design process, a way of finding solutions, which make the designer able to solve a problem of functions of design, like flexibility, adaptability, the ability to have strength under tension, wind resistance, sound isolation, cooling, heating, etc., by seeking out a local nature creatures or ecosystem.

In the light of these words, a whole system should get the advantages of the other levels to achieve a sustainable environment. It may begin from a micro scale and moves to be applied to a mega scale like green skyscrapers (Ofluoglu, 2014, p. 34). An example for using series of systems (with the aid of using nanomaterials and devices), is the design for the Garden by the Bay in Singapore, which design to be powered by Solar-Powered mega "Super trees", having two cooled conservatories, the Flower Dome (cool dry biomimicry) and Cloud

Forest (cool moist biomimicry) (Fig. No.7) (Atelierten, 2015). Biomimicry at this level could be a result of imitating organism with the aid of advanced building technology or materials to increase sustainability (Zari, 2014, p. 5). It can be achieved to explore and understand how an organism connected and behaves in its own local environment. It is possible to understand this level with observing how natural creature tend to behave in its environmental community and within minimum use of energy and material. The building works in the same way as a natural creatures would; form, shape, materials selection, natural ventilation and energy saving.

An advantage of designing at this level is the cooperation with other levels of biomimicry. In architecture, it is expected that a series of systems could be used and interact like biological system as complex relationship (Zari, 2014, p. 4). If building could be designed to function as nature systems, this would make the potentiality to improve building sustainable environment (Zari, 2014, p. 8). There is a potential application to achieve multiple scale to adopt benefit solutions. Indeed, using a "systems thinking" approach with biomimicry at the system level has the potential for urban solutions (Kenny, Desha, Kumar, & Hargroves, 2012, p. 9). This level is the best and most complicated level, because biomimicry here is based on designing architecture that behaves as a nature system, with a balanced biological system.

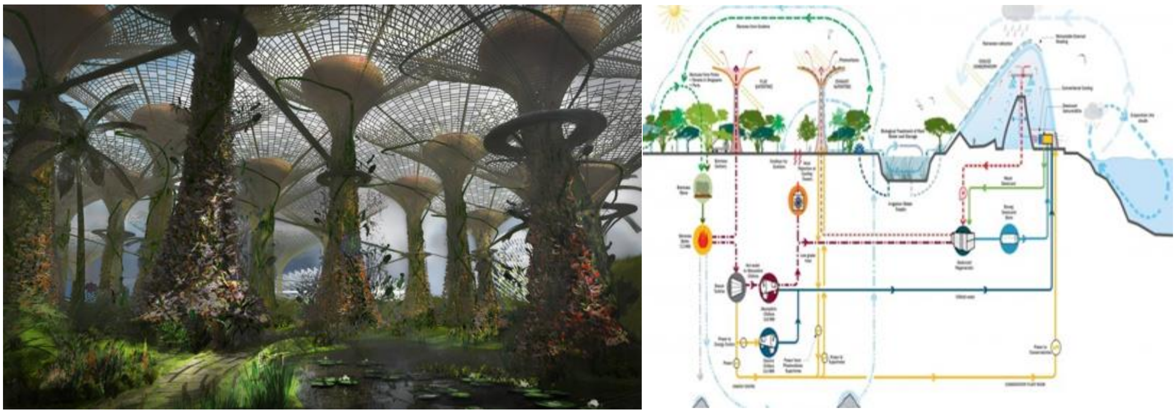

Figure 7: Gardens by the bay

7.6. *Level 6: Computer modeling (how does an architecture form generating from* **nature with the aid of computer modelling?).**

Architects use a wide range of design attitudes following nature using biomimicry as source of inspiration, but with the aid of computer modelling. The methods and using algorithms of generative modelling using special programmers can be improved by the study of computational models following natural processes and using their application to architectural design (HANAFIN, DATTA , & ROLFE , 2011, p. 176).

With the help of benefits of developed relationships between architecture and nanotechnology and computer modelling, the new organic forms inspired by nature could be derived using computational programmers and some of them are produced. Examples of tree-like façades in architecture, Omotesando building in Tokyo by architect Toyo Ito (Fig. No.8).

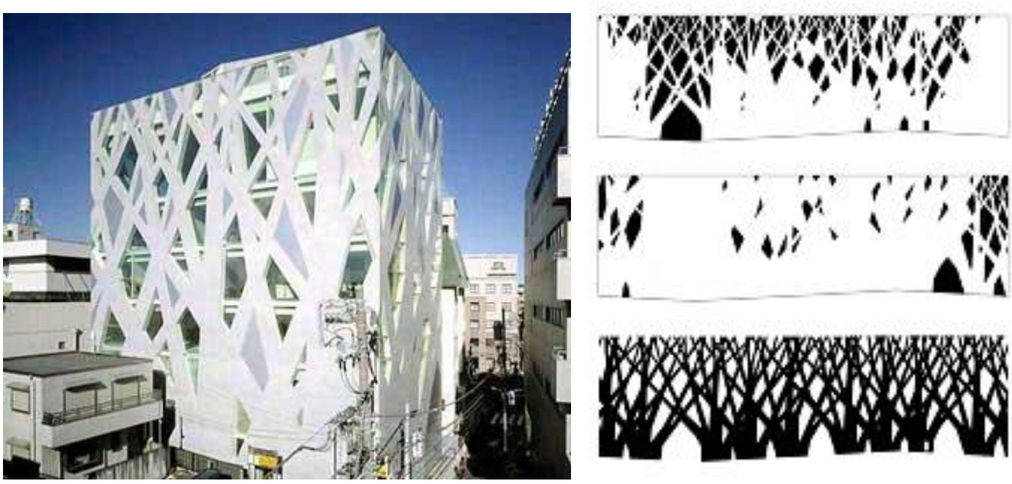

Figure 8: Omotesando building in Tokyo

7.7. Level 7: The role of robotic strategies in architecture biomimicry.

In the past few years, the use of robots in architecture has taken great steps, due to the advances achieved in the fields of digitalization, virtualization, and automating. Digital information is used not only for informing plans, but to create materials that will construct a building using architectural robots like (3D printers, robotic fabrication) by mimicking nature.

3D printers may help architects in future, to redesign their manufacturing patterns, while mimicking nature organisms like spiders. That make a potentiality to print large structures, using advanced concrete or other advanced materials, to provide extra strength where it is needed and conserve material where it is not, just as nature do (Woolley-Barker, 2013). For example, the team of "Architectural Association grads" designed on a concept called "Proto Home", which improve a new way of construction using the strengths of 3-D printing. The spindly structure designed to imitate, the grow of bones in human (Fig. No.9) (Fastcodesign, 2015). Robotic production applications designed to be applied from micro scale to mega scale. A new group of researchers, artists , designer and fabricators have begun to use robotic fabrication technology in architecture. An example is the project, the ICD/ITKE research pavilions (Fig. No.10), where it has been designed to use glass and carbon fibers that are woven depending on light steel structure to make each unique panel (Designboom, 2015).

Biomimicry at this level is improved when influenced by biomimetic processes, through copying material organization strategies which can be found in most natural constructions and play an important role in their material efficiency.

Figure 9: A 3-D Printed House That Grows Like Human Bone

Figure 10: The ICD/ITKE research pavilions

8. Conclusions

Nanomaterials and nano-devices may have unique properties. It could be used for self-cleaning, self-healing, sensing/responding, water collecting, solar transforming and other uses. It also provides the means to produce materials that function as system, be able to be recycled, or save energy and more. These new nano products move the old concept of imitating nature in "Organic Architecture" of the 20th century, which was connected with visual imitation to further extended levels of relationship with nature. Biomimicry is a new way of thinking in compliance with nature and considers it as a source of inspiration. The world have seen rapid breakthroughs in biomimicry research that happened simultaneously with the advances in nanotechnology. The interaction between these two technologies resulted in the formation of new methods for achieving sustainability in architecture called nano-biomimicry. Nano-biomimicry technology, used by organic creatures for centuries, can finally be implemented to help addressing some key issues facing current and future generations.

The use of nano-biomimicry in architecture to achieve sustainability is one of the main benefits of this technology in architecture. This research re-characterized the usage of nano-biomimicry for sustainable architecture into seven levels: form, materials, construction, function, system, computer modelling and robotic strategies. The case studies discussed and analyzed in this research shows these levels in practice. The following table illustrates and summarizes the different case studies in this research and the levels of nano-biomimicry implemented in the each of them that could help achieving sustainability.

Table 1: The different case studies discussed and the level of nano-biomimicry implemented

Levels of Nano-Biomimicry	Case studies discussed						
	The Nano Towers	The Torre de Especialidades	Fab Tree Hab	Waterloo International Terminal	Gardens by the bay	Omotesando building	The ICD/ITKE research pavilions
Level 1: Form	✓	✓	✓	✓	✓	✓	✓
Level 2: Material	✓	✓	✓		✓		✓
Level 3: Construction			✓				
Level 4: Function				✓	✓	✓	
Level 5: System					✓		
Level 6: Computer modeling	✓	✓	✓	✓		✓	✓
Level 7: Robotic Strategies							✓

Although, the case studies discussed differ in the levels of implementation for nano-biomimicry to achieve sustainable architecture, system level is by far the nearest to satisfy sustainability, because it is dealing with architecture as a whole system as nature do. With the help of interdisciplinary relationships between architecture, nanotechnology and biomimicry, a new architectural approach that relates to nature is formed and could be called "new organic architecture".

The concept of Nano-biomimicry, although huge with many variations, it could lead to rapid advances in achieving sustainability in architecture and building. Thus, further research and study is required to highlight the different potentials of this technology in building design, construction and subsystems. Additionally, this could be a much easier approach to achieve sustainability in buildings. By using Biomimicry, we are trying to mimic creatures that have been living in harmony with the nature for millions of years now that we have the technology to do that on nanoscale through nanotechnology.

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