



Bioarchitecture - Inspirations From Nature

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ABSTRACT

Engineers, architects, and artists often refer to nature as a basis. Many engineers find their structural inspiration from plant life, in a spider's web, a piece of coral, a beehive, or in the structural development of animals. Bioarchitecture is a particular moment in which architecture, engineering, and art converge as they are using the same inspirations. By taking a look around, designers can find inspiration everywhere – particularly in nature. Nature provides us with an amazing array of solutions for many complex problems that we face today – the quest to learn from nature in this way is “Bioarchitecture or biomimicry”, and architecture can benefit from this kind of approach. Animals, plants, and microbes are the consummate engineers. They have found what works, what is appropriate, and most importantly, what lasts here on Earth. Nature can teach us about systems, materials, processes, structures, efficiency and aesthetics (just to name a few). By delving more deeply into how nature solves problems that we experience today, we can extract timely solutions and find new inspirations.

This paper deal with Aesthetic as a branch of philosophy dealing with the nature of beauty, art, and taste and with the natural environment, which still fill us with a sense of awe and amusement.

Keywords: *Inspiration by Nature, future architecture*

1. INTRODUCTION

Is Nature beautiful? We find an infinite variety of shapes, colors and species in it. The only imperative for living in harmony with nature is mutual respect. However, in the process of modernization we have a worldwide issue as environmental problems, especially global climate change. In spite of solving environmental problems, we still build the unnatural buildings of past decades. Therefore, to solve today's problems we need the new integrated architecture.

The new architecture will encourage peaceful cohabitation and make social self-regulation processes possible. Despite the amount of scientific knowledge mankind has gathered, nature still holds great mysteries that we may never be able to unravel. Humanity tries to control nature by enforcing order. As a result, we have distanced ourselves from the earth, even though our survival is completely dependent on it.

Why don't we respect the nature, proportions, materials, colors and the beauty of the spaces so to find a way of connecting them with the architecture of nowadays?

At times what may seem as “simple” in nature can translate to better design solutions that are more efficient, sustainable, ecological and healthy. Nature is inspirational but it is also a part of our world which we can study more deeply – extracting creative solutions that we can apply today.

2. The First Steps to Biomimicry

The idea described in this paper evolves analogies between architecture and nature, specifically between architecture and biology. Biology is a recursive source of architectural inspiration due to the tight relationship between form and function, the natural balance of forces and the corresponding geometric solutions found in living beings. A fascination with biology has always encouraged designers to look at the natural world to

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draw inspiration from. Antoni Gaudi is well renowned for taking not only inspiration but directly translating ideas in nature such as the hyperboloids and paraboloids into his architecture. Sir Norman Foster undoubtedly saw a gherkin and thought that would look great 41 stories high in central London.

“Engineers, architects, and artists often refer to nature as a basis. Many engineers find their structural inspiration from plant life, in a spider’s web (often a reference for Peter Rice), a piece of coral, a beehive, or in the structural development of animals.” (Rappaport Nina, 2006). Joseph Paxton was inspired by the giant water lily, the Victoria Amazonina, which led to the development of the beam structure for the greenhouse at Chatsworth Park and the Crystal Palace (1851).

Nature provides beautiful examples of elegantly simple and sustainable engineering, chemistry, manufacturing, architecture and agriculture. The web of a spider is stronger, gram for gram, than steel. It’s also wholly natural and renewable, a simple by-product of the spider’s bodily processes.

It is biodegradable, its chemicals resorbed and reused in nature. In comparison, steel is enormously costly and polluting to smelt. Some inspirations from the nature came as case studies from the Biomimicry Institute-the beetle was a muse for Qinetiq which developed plastic water-harvesting sheets that mimic the beetle’s bumps. Also the Pax Scientific has designed fans, propellers, impellers and aerators based on the shape of a mollusk. The way that the nature clean itself without toxic detergents as the leaves of many plants, large-winged insects, most water birds and other organisms is the new motivation for cleaning the surfaces of the buildings “taking a gravity shower”. (www.biomimicryinstitute.org)

Looking to modern robotic science and technology, a strong correlation can be made between biologically-driven functions of living structure and the adaptive processes that once gave form to architecture. Although architecture has embodied a variety of different designs and styles throughout the ages, the most successful buildings and urban environments have an essential commonality with living forms, i.e. material properties and an assembled nature. It is important, however, to distinguish between superficial resemblance, which can lead to dysfunctional and inhuman buildings, and an approach based upon a genuine understanding of life processes. Curiously enough, many of the twentieth century’s pioneering architects have been strongly influenced by the same properties of living structure.

Which are the first steps to the architecture of the future?

“There can be a classification in historical analogies between architecture and biology into two main categories. The first tries to mimic biological forms and the second biological processes.” (Coucherio. M. 2006) For designers, the first appeal to biology is usually related with the way living beings integrate harmonically form and function. In each life form, the way nature achieved a perfect balance between internal

and actuating external forces can be observed. Another appeal to biology is related to the simplicity of some geometric canons and tools that nature uses to generate an almost infinite number of forms. It is very common to see life forms represented in architecture. We have all seen buildings with biomorphic allusions to plants, animals or even anthropomorphic allusions.

The world’s best designer, bio-architecture seeks to emulate the principles in naturally occurring constructions. In studying the natural principles of the most long-held designs, this form of aesthetic design looks at fundamental shapes in nature – the most recognizable being the seashell. The seashell is the best representation of a math-centric natural element that shows why nature is the best designer. Encompassing the Fibonacci Sequence, or “the Golden Ratio”, a seashell shows perfection in proportion that has been the foundation for some of the greatest designs, including the Parthenon, and by some of the greatest minds, including Leonardo Da Vinci. The pattern has also been replicated in some of the world’s most cherished poetry by regulating rhyme and meters, as well as in music, such as Beethoven’s Fifth and many of Mozart’s sonatas. The term “bio-architecture” is also often referred to as “organic architecture”, a thinking that has gained popularity with the rise in eco-awareness. A shift toward green thinking took bio-architecture a step further and had creative-minded people thinking of how building could merge with the environment as well as reflect it.

Human beings have been learning from nature and using nature as a model for a very long time.

Frank Lloyd Wright introduced the word ‘organic’ into his philosophy of architecture as early as 1908. It was an extension of the teachings of his mentor Louis Sullivan whose slogan “form follows function” became the mantra of modern architecture. Wright changed this phrase to “form and function are one,” using nature as the best example of this integration. Although the word ‘organic’ in common usage refers to something which has the characteristics of animals or plants, Frank Lloyd Wright’s organic architecture takes on a new meaning. It is not a style of imitation, because he did not claim to be building forms which were representative of nature. Instead, organic architecture is a reinterpretation of nature’s principles as they had been filtered through the intelligent minds of men and women who could then build forms which are more natural than nature itself. “Organic architecture is also an attempt to integrate the spaces into a coherent whole: a marriage between the site and the structure and a union between the context and the structure” (www.pbs.org)

Perhaps the most inspiring examples of biomimicry combine functional properties with aesthetic expressions. Consider the Johnson Wax building by Frank Lloyd Wright: a beautifully lit hypostyle hall with columns that expand as they rise, evocative of lily pads floating on the surface of the water. These columns were the first thin-shell concrete structures in the world, designed with innovative use of steel-mesh

reinforcement, inspired by the natural structure of the staghorn cholla cactus. The result was a “cathedral of work,” a workspace designed with the serenity of a walled garden.

There is a range of expressive precedents from the early 1920s onwards, from Erich Mendelsohn’s *Einsturmturm* in Potsdam, Germany (1921), to Le Corbusier’s *Chapelle de Ronchamp* (1955) and Eero Saarinen’s *TWA Terminal* in New York (1962). It is worth remembering that it was Le Corbusier’s “free plan” and “free façade” that allowed for elements of variable curvature to emerge in the modernist projects of the mid-twentieth century. Eero Saarinen attributed the reemergence of the plastic form to the advances in building technology, while acknowledging that “it is the aesthetic reasons which are the driving forces behind its use.” “Alvar Aalto broke with the pristine geometries of the International Style fairly early, applying sinuous curves to his designs from furniture and glassware to buildings. His Finnish Pavilion at the 1939 World’s Fair in New York, one of his best known projects, featured dramatic undulating curves in the interior of a modest, rectilinear shell.”- (Kolarevic.B, 2005)

The second step to the nature is Bionics (also known as, biomimetics, bio-inspiration, biognosis, and close to bionical creativity engineering) which is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology. “The word bionic was coined by Jack E. Steele in 1958, possibly originating from the Greek word βίον, *bíon*, pronounced [bi:on] (“bee-on”), meaning ‘unit of life’ and the suffix -ic, meaning ‘like’ or ‘in the manner of’, hence ‘like life’. Some dictionaries, however, explain the word as being formed from biology + electronics.”-(www.en.wikipedia.org)

Several decades ago, a few creative thinkers started redefining the traditional idea of home and began building with eco-inspired homes. Hawaii’s famous *Onion House* is one popular example of a creative idea, now a national landmark and a beautiful testimonial to shift toward bio-architecture. Designed in tune with the curves of an onion, with a layered feel that mirrors the lucid skins of an onion, the house is a beautiful demonstration of the possibilities when design with nature as an icon.

Also the well-known German Architect Frei Otto (1961) and Bodo Rasch’s introduced a new type of architecture- Bioarchitecture- also known as green architecture or green construction or sustainable building, which is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and deconstruction.

Throughout the history of architecture, especially early on, great interest has been taken in the models for structure that nature offers. At the end of the twentieth century, technological advances and research by some architects and engineers has made it possible to build

lighter structures on the same bases as those of the natural world. One of the greatest achievements in the fields of architecture and engineering is in the development of lightweight structures. Scientists have studied light stable structures such as bones, insect and mollusk shells, skins and larger shells. The story of ‘Lightness’ deals with the building structure. The skeleton of a dinosaur, for example, inspired Frei Otto to build a crane. Frei Otto is concerned with the fundamentals of structure. In pursuing the age-old question of all construction – how to achieve more with less, that is, less material and effort – he has elevated the traditional tent to a modern building type capable of remarkably large spans. The architects of the future should believe in modern technology, and, from the beginning, envisioned structures of extreme lightness as well as extreme strength, which are to make optimum use of new materials such as thin cables of high-strength steel or thin membranes of synthetic fabric.

From the earliest days of human civilization, man has taken inspiration and design guidance from structures found in nature. We can use to create our own structures from many of shapes and forms in the natural world. ‘Structure in nature suggests that there must be some fundamental principles and laws, an intrinsic force system, which can form the basis for the design of minimum diversity building systems’, says Peter Pearce in his book ‘Structure in nature is a strategy for design’ (1980). There is mutual understanding between biology and technology. Nature is as role model to improve our architectural environment.

With the publication in 1917 of D’Arcy Thompson’s *On Growth and Form*, the understanding of nature’s interior structures of cells, honeycombs, crystals, snowflakes, shells, even direct comparisons to skeleton’s and bridge structures, carried through to the formation of study centers for biomimetics. These analyses indicate that with holistic structures in particular, such as crystals, there is no distinction between structure, decoration, and the thing itself. Robert Le Ricolais (1894-1977) the noted French engineer revealed that when working with the structure of bone “If you think about the voids instead of working with the solid elements, the truth appears. The structure is composed of holes, all different in dimension and distribution, but with an unmistakable purpose in their occurrence. So we arrive at an apparently paradoxical conclusion, that the art of structure is how and where to put holes. It’s a good concept for building, to build with holes, to show things which are hollow, things which have no weight, which have strength but no weight.” (XZ.Zhao...2006)

Nature hold special psychological significance, thanks to her shapes, elements, sensory, colors, forms. Studies by Roger Ulrich have consistently found that passive viewing of non-threatening nature stimuli through windows, videos, or photographs reduces the physiological indicators of stress and increases positive moods. Rachel Kaplan reports similar results in a field study of office workers.

When shape or procedural analogies with biology have functional applications in architecture they are referred also as biomimicry (Janine Benyus, 1998). Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is a design discipline that seeks sustainable solutions by emulating nature's time-tested patterns and strategies, e.g., a solar cell inspired by a leaf. The core idea is that Nature, imaginative by necessity, has already solved many of the problems we are grappling with: energy, food production, climate control, non-toxic chemistry, transportation, packaging, and a whole lot more. Biomimicry offers solutions hidden in plain sight for many of the modern world's environmental problems. The natural world is teeming with models for energy production and conservation. Models are there for strong, durable, flexible materials. Designs for air conditioning and recycling waste can be found. This new science, called biomimicry, studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems. It is a new way of viewing and valuing nature based on what we can learn from it rather than what we can extract from it. "Biomimicry takes advantage of nature's wisdom gleaned from 3.8 billion years of evolution to determine what works, what is appropriate and what lasts." (Wolf V. 2005)

Scientists working in biomimicry foresee nature-based innovations that will change the way we grow food, make materials, harness energy, heal ourselves, store information and conduct business. With biological knowledge doubling every five years, designers now have the instruments and the capacity to mimic nature like never before. According to Benyus, if we adapt nature's design methodologies, if we ask, "how would nature do it," we will not only make great progress, but through reverse engineering we will find solutions to both common and complex problems. Mimicking the functional biology of cacti, snails, termites, pine trees, and even bone cells could lead us into a new age of buildings that sprout, grow, decay, and harmonize with surrounding environs. In the future, the houses we live in and the offices we work in might be designed to function like living organisms, specifically adapted to place and able to draw all of their requirements for energy and water from the surrounding sun, wind, and rain. The architecture and design will draw inspiration, not from the machines of the 20th-century, but from the beautiful flowers that grow in the landscape that surrounds them. (Bob Berkebile . 2003)

To us the most compelling model for the buildings of the future can be found growing almost everywhere on the planet—Flowers. Flowers are marvels of adaptation, growing in various shapes, sizes and forms. "They are the perfect metaphor for buildings in the future because, like buildings they are literally and figuratively rooted to place, able to draw resources only from the square inches of earth, and sky that they inhabit." (Jason McLennan, 2003).

The flower, must receive all of its energy from the sun, all of its water needs from the sky, and all of the nutrients necessary for survival from the soil. Flowers

are also ecosystems, supporting and sheltering microorganisms and insects like our buildings do for us. Equally important is that flowers are beautiful and can provide the inspiration needed for architecture to truly be successful. "To emulate nature, our first challenge is to describe her in her terms. The day the metaphors start flowing the right way, I think the machine-based models will begin to lose their grip" Biomimicry pg. 237

"For the first time in history, we have the instruments – the scopes and satellites – to feel the shiver of a neuron in thought or watch in color as a star is born," said Benyus in an interview with the Boston Research Center. "When we combine this intensified gaze with the sheer amount of scientific knowledge coming into focus, we suddenly have the capacity to mimic nature like never before. Biomimicry in building design can help us make materials stronger, self-assembling and self-healing, like the spider's web, Biomimicry also encourages us to use natural processes and forces for basic building functions. It allows buildings to produce resources by integrating natural systems."(Benyus, 1998)

Architecture today for the most part seems empty and lifeless, devoid of the requisite innate information necessary to engage sentient human beings in their everyday lives. Drawing analogies from living structure and artificial intelligence, we find the promise of a new direction for architecture in the 21st century.

Turner and Soar in their article "Beyond Biomimicry: What termites can tell us about realizing the living building" raise the intriguing idea that building design can go "beyond biomimicry", to design buildings that do not simply imitate life but are themselves "alive". Realizing the living building is predicated upon there being a clear idea of what distinguishes living systems from non-living ones. Unfortunately, "most of the criteria that are commonly put forth by biologists—cellular organization, replication, heredity, reproduction, self-organization, low entropy—are not very informative for building designers"-(Salingeros, 2006). In living systems, however, no such distinction is possible: structure is function and function is structure. At present, simply stating this offers little practical value in telling us how to realize a living building, but it at least points us the right way: toward buildings that are extended organisms, where function and structure meld, and are controlled by the overriding demands of homeostasis.

"Living structure is known to satisfy several natural properties such as: organized-complexity (information storage); metabolism (energy use); replication (self reproduction); adaptation (the organism changes itself to better profit from its environment); intervention (the organism changes its environment); situatedness (embedded in the world through sensors); and connectivity (information processing)." (Salingeros N. A. 2006. pp 54-61)

As Salinger mentioned-the reason that a non-adaptive architecture was able to develop is that the selection process among buildings and architectural styles is not as direct as selection among organisms. Selection in architecture is driven by forces external to the natural process of adaptation, i.e. fashion, opinion, and politics. Finally, species adaptation occurs via natural selection. When an organism's physical mechanisms cannot cope with changing external conditions, some variants of a species die off, leaving those that might already have a slightly better adaptation. By evolving through survival, a species gradually changes its 8 physical characteristics. An architecture of adaptation must follow certain rules. The design process should consist of a large number of steps, so that feedback can influence the final product.

A modern architect that takes inspiration and solutions from nature is the Spanish architect Santiago Calatrava. "The shape represents the elements, the idea of fluidity and growth, the beauty and perfection of the geometrical force. If you discuss proportion, rhythm, and nature, you are almost using musical terms."-(Calatrava S.) The graceful Quadracci Pavilion is a sculptural, postmodern addition to the Milwaukee Art Museum completed in 2001, designed by Spanish architect Santiago Calatrava. Calatrava, inspired by the "dramatic, original building by Eero Saarinen, the topography of the city" and Frank Lloyd Wright's Prairie-style architecture.

These fields of study are concerned with the study of analogies with living nature to provide tools that solve conceptual and design problems. Instead of harvesting organisms, or domesticating them to accomplish a function for us, biomimicry differs from other "bio-approaches" by consulting organisms and ecosystems and applying the underlying design principles to our innovations. This approach introduces an entirely new realm that can contribute not only innovative designs and solutions to our problems but also to awakening people to the importance of conserving the biodiversity on Earth that has so much yet to teach us.

Most all designers will benefit from studying certain aspects of nature. As buildings now face a whole myriad of problems that need solutions, it may be in nature that architects can find some answers. "Life has had millions of years to finely-tune mechanisms and structures (such as photosynthesis, or spider's silk) that work better than current technologies, require less energy and produce no life-unfriendly waste. The emulation of this technology is the goal of biomimicry, the art of innovation inspired by nature." (Benyus, 1998)

How will be the future architecture?

Though "passive buildings" are still the norm, a massive change is emerging. Within our lifetimes, we will see the construction of living-breathing buildings all over the planet. "The buildings are intended to be well lit by natural light and thermally comfortable. To do this it should be used three strategies. First, carefully

shape the building to take advantage of the natural light, wind, and shade of the site. Second, develop a passive, self-balancing building that uses mass and water to heat and cool itself, with chimneys throughout the building to draw in fresh air. Finally, incorporate in the design the use of renewable power sources, such as photovoltaic panels, fuel cells, methane gas, and wind, which provide environmentally impact-free energy for night lighting, fans, boilers, and chillers." (Teresa Coody, 2008)

No one has ever produced a perfect building. Architecture is a complex art with a long history. To effect the radical changes needed to create living-breathing buildings, many traditional parameters must be relinquished. Kibert and Grosskopf propose the key strategies for radical Green building refering to the LEED reference guide:

- Harvest all its own water and energy needs on site.
- Be adapted specifically to site, and climate and built primarily will local materials
- Operate pollution free and generate no wastes that aren't useful for some other process in the building or immediate environment.
- Promote the health and well being of all inhabitants-consistent with being an ecosystem.
- Be comprised of integrated systems that maximize efficiency and comfort.
- Be beautiful and inspire us to dream."(Kibert Charles J., Kevin Grosskopf, 2006)

(LEED- Leadership in Energy and Environmental Design)

As architects, we can benefit from bioarchitecture to make buildings better by pushing for more natural, integrated, efficient and healthy solutions. We also need to take a look at the role aesthetics plays in nature – with the way function and form so synergistically merge. Perhaps this is a way for buildings to harmonize with nature in renewed ways – making built environments more environmentally sound and healthy for occupants. As Buckminster Fuller phrase "The best way to predict the future is to design it"

Following "the nine basic laws of the circle of life" architect Mick Pearce build a mid rise building in Harare, Zimbabwe that has no air-conditioning, yet stays cool thanks to a termite-inspired ventilation system. "The designs may provide a blueprint for self-regulating human buildings". Analyzing this building Turner and Soar shows that this structure should be functioning more like lungs than like termites. Charles Lee and Bios Design Collective proposed even new ways of inspiration for the future architecture as "the hair".the homeostatic equilibrium for new Strategies for thermal Design".

Knittel hopes that buildings, like nature, will react to environmental conditions and support biodiversity. "We don't want merely to imitate the way something looks," he explains. "We are hoping to understand the logic of nature, and how it will perform in buildings."

3. CONCLUSION

Instead of exploiting the resources that are so generously afforded to us we should take advantage of the wisdom that is rooted everywhere we look. The onus is on finding the appropriate biological systems. If we are capable of tapping into the wealth of knowledge that surrounds us then we will be able to create a better world. **A sustainable one.** Working together and developing a clear dialogue between the fields of engineering, design and biology will be essential. How do you start looking for answers in the natural world? How do you know if you are looking in the right area for a particular solution? Is the solution above or below? There can't be many questions but it illustrates the point of how would we know where to look?

Biomimicry is more of an instruction than a prescription. Look at the natural world, learn from the

REFERENCES

- [1] Bob B., McLennan J., "The Living Building: Biomimicry in Architecture, Integrating Technology with Nature" *BioInspire*, 18 07.17.04 (2003)
- [2] Biomimicry Institute, "Case Studies" http://www.biomimicryinstitute.org/case_studies.php (20.03.2010), 16:40
- [3] Kolarevic B., "Digital Morphogenesis", Architecture in the Digital Age- Design and Manufacturing, Taylor & Francis (2005)
- [4] Lee C, "Bios Design Collective - The thermal organism and architecture", *ACADIA* (2008).
- [5] Mauro C., "Architecture and Biological Analogies, Finding a generative design process based on biological rules", (PHD thesis, Universidade Tecnica de Lisboa, Portugal (2006).
- [6] David J. - Biomimicry Naturally., <http://www.mrjolly.co.uk/Portfolio/Biomimicry/David%20Jolly%20-%20Biomimicry%20Naturally%202008.pdf>. - 30.03.2010, 12:05
- [7] Turner J. S., Soar R. C., "Beyond biomimicry: What termites can tell us about realizing the living building", First International Conference on Industrialized, Intelligent Construction (I3CON) Loughborough University, 14-16 May 2008)
- [8] Benyus J. M., "Biomimicry, Innovation Inspired by Nature" William Morrow and Co., New York (2007).
- [9] Charles J., Grosskopf K., "Radical sustainable construction: envisioning next-generation green buildings" (12th Rinker International Conference, Sarasota, Florida, USA 19-22 September 2006)
- natural world but it won't have all the answers, some may take a little more work to find. Through the synthesis of these ideas and the application of this knowledge designers, engineers and architects are in the unique position of being able to shape the world. For the moment, the natural world is our greatest teacher, it is wise and we should pay close attention to it as it gently tries to usher us in the right direction. "Biomimicry. It is not about invention, but discovery."(David Jolly, 2008)
- Biomimicry as a study dealing with nature it should be also connected with the philosophical theory or idea of what is aesthetically valid at a given time and place: the clean lines, bare surfaces, and sense of space that mark the machine-age aesthetic. This should be the architecture of the future.
- [10] LEED-<http://www.usgbc.org/> (31/05/2010- 21:25)
- [11] Pearce P., "Structure of Nature Is a Strategy for Design", *Leonardo*, (1981).
- [12] Rappaport, N. "Deep Decoration," *Architectural Journal*, (2006).
- [13] Nikos S.A., "Anti-Architecture and Deconstruction" Solingen, Germany: Umbau-Verlag, page 142 (2004).
- [14] Nikos S.A., Masden K. G., "Architecture: Biological Form and Artificial Intelligence", *The Structurist*, 45/46: 54-61(2006)
- [15] Nikos S.A., "A Theory of Architecture" Solingen, Germany, Umbau-Verlag, (2006).
- [16] <http://www.pbs.org/flw/legacy/essay1.html> (16.05.2010), 20:15
- [17] http://en.wikipedia.org/wiki/Bionic_architecture (16.05.2010), 21.00
- [18] Zhao X. S., Su F., Yan Q., Guo W., "Templeting methods for preparation of porous structures", *Journal of Materials*, (2006).
- [19] Vicki W., "Biomimicry solution hidden in plain sight- Citizens League for environmental Action Now (CLEAN), (2005).
- [20] Coady T., AIA, MAIBC, MRAIC, LEED® AP, "Living breathing buildings" (2007).