Effects of Biomimicry on Architecture

Elif Gizem Yetkin

Dr., Lecturer. Alanya HEP University,

Department of Architecture, ANTALYA/ALANYA

Abstract

The sociological, psychological and physiological problems experienced by humanity, which have been exposed to dark offices, high flats and city life far from nature, have been strikingly exposed with researches. In addition, the nature-based design approaches that emerged due to the need to meet the need of humanity for nature and the desire to return to nature have taken their place among the design parameters of the new age in architecture However, concepts where biology and design come together have emerged. Biomimicry is a discipline that explores the best ideas for design processes by imitating nature. It takes all the ecological needs that users expect from architecture directly from the nature. It provides an integration model with the nature that people yearn for, and also creates a model that takes the solutions created by nature in architectural designs as an example. In this period of architectural design turning to nature, biomimicry has the feature of being a pioneer of a new architectural trend by providing designers with a different view of nature. The main purpose of this study is to determine the application areas and basic features of the biomimicry approach in architecture and to create a road map for designer architects. To achieve this goal, a research methodology has been designed to achieve two objectives. First, it will carry out an in-depth research on biomimicry, architecture and environmentally friendly designs with existing literature studies. Secondly, listing the biomimicry designs applied in architecture and classifying them according to their ecological gains to the building. As a result, a guide will be created for the designer architects to provide ease in producing more efficient buildings.

Keywords: Biomimicry, Sustainable Design, Biology based design, Biophilic architecture,

1.Introduction

Today, one of the most important obstacles to the experience of nature is the paradigm that dominates the design and development of the modern built environment. Because even though the human developed in the natural world, closed spaces where 90% of the time is spent today have taken the place of the people's “natural habitat”. While the need for interaction with nature is critical for people's health and fitness, it is very difficult to be satisfied in this respect in today’s-built environments. Because the dominant approach to the design of living spaces sometimes sees nature as an obstacle and sometimes an insignificant detail (Kellert & Finnegan, Heerwagen, 2011). However, if a person bonds with nature and can see himself as a part of nature, he can reflect this love in nature by feeling a love for nature. (Yılmaz, 2017).

Mankind has taken the nature as a guide and benefited from the structures and forms of nature in its designs. Although this has been an ongoing approach since the classical period, it should now take on a new dimension. In this sense, the architectural design based on ecology is understood as a return to the traditional or primitive, due to the application examples that are frequently encountered in the literature. However, this is an approach that needs to be hung. It is important to produce designs that can utilize all the possibilities of science and technology but go beyond the understanding of effective use of energy and that can be part of the system in a holistic, mutually beneficial relationship with its environment, in line with the principles included in scientific theories.

However, in this way, the holistic approach of the concept of ecology can also find a place in ecological architecture. Designing by imitating nature is one of the methods used by designers for years. When designing in architects, they are often inspired by nature. During the times when technical and material knowledge was insufficient, the solutions produced by nature were used directly to meet the needs of the period in living space designs. Today's architecture has evolved in a different direction with the development of technology. With the widespread use of energy in living spaces, energy consumption has reached high levels in the building sector in parallel with changing comfort conditions. However, with the energy crises experienced, like many sectors, the building sector changed its direction and started to work on strategies to reduce energy consumption.

In the 21st century, people started to live in high-rise buildings under artificial weather conditions. These conditions increased people's longing for nature. Because man is a part of nature and as he moves away from him, he starts to experience physiological and psychological problems. This increasing need of people for nature has also been brought to the agenda within the scope of sustainability strategies and various approaches have been created (Ebrahimpour, Majedi, Mahdiniya, 2017). Biology-based design strategies have been developed for designers, with solutions inspired by nature. In this study, firstly, the biology-based design strategies will be defined and the effects of the biomimicry approach that is used effectively on architecture will be examined. In the last section, sample structures suitable for biomimicry approach will be examined.

2. Biology Based Design Approaches

The main idea at the core of all concepts such as bionics, biomimetics, biomimics, biodesign, biomechanics, organic design is 'learning from nature'. The solutions developed by all living creatures against the problems they face have directed the designers to approaches such as learning from nature and imitating nature in their search for solutions. These approaches have been accepted in many fields such as medicine, architecture, engineering, design and art and have continued their development. The concepts of bionics, biomechanics and biodesign offer designers many possibilities in terms of creativity (Salingaros, Masden, 2008).

The realization of the solutions in nature by using the least amount of energy in the shortest way and its adaptation to the design caused positive results based on the sustainability of the design. The sensitivity of designers and companies in terms of increasing environmental pollution and reduction of natural resources has also been another factor that has led to solutions in nature (Senosian, 2003). Since the principle of nature to realize using the least for the most efficiency is a target that is aimed by the designers today, the idea of searching for the solution of the problems in the examples in the nature has been an accepted approach.

2.1 Biomimetics/bioinspiration

The term "biomimetic" was introduced in 1969 by Otto H. Schmitt. The word is made up of words that mean "bios" (life) and "mimesis" (imitation). There are various sources that the words biomimetic, bionic, biomimicry are synonymous. Although their basic meanings are similar, their emergence and usage areas have changed. While the use of bionic design in medicine has become widespread among these terms that relate to design discipline with expressions such as biomimetic design, bionic design, the expression of biomimetic design is the closest expression to the principle of inspiration-learning in the design of industrial products we mentioned in this study (Low, 2009).

Chiu and Shu (2007) argue that many designers and engineers have come to the conclusion with their own observations about inspiration from biology to find solutions to their design problems, but this method reduces the great potential of biology. In this context, he proposes a method by which the designer can access biological resources and reach more detailed biological resources with the right keywords and obtain more comprehensive results in biomimetic design. The history of biomimetic design existed before the concept of biomimetic emerged. Leonardo da Vinci used nature observations in many of his works, for example, he designed flying instruments by observing the flights of birds. In addition, the Crystal Palace built in London and the Eiffel Tower in Paris are examples of architectural biomimetic design.

We can define concept of biomimesis as follows. The nature-inspired / learning / adaptation and / or application forms in architecture can be handled in two ways: First, as explained in the previous section, the form of the natural object is taken and transferred to the building with formal concerns and an analogy, and the other is the form of formation observed in the building; (the process of material, form, and structure formation) to be transformed into an architectural form with experimental data (Antoniades, 1992). The concept of biomimesis becomes important at this point.

In the literature; It is seen that the concept of biomimetic is used instead of the concept of biomimesis. Briefly, it can be defined as a design that imitates some or all of the biological phenomena in whole or in part. In this chapter, this concept will be considered as the use of what is observed in nature, beyond mere form, as a source of inspiration.

2.2 Biomechanics

As a branch of science, Biomechanics is the field of application of biology and engineering sciences on living creatures. In biomechanical studies, by using engineering methods, how the creatures move, how their movements are controlled, the effect of the force system occurring in different parts during the movement, the conditions of strain on living and inanimate tissues are examined, treatment methods are tested and developed (Bar-Cohen, 2005).

It is a branch of mechanical physics science and examines how force turns into action. These movements provide growth and development and cause injuries if overloaded. Biomechanics provides the conceptual and mathematical tools needed to understand how living things move and how kinesiology specialists can make movements safer (Knudson, 2003).

Biomechanical discipline is based on the basics of physics, chemistry, mathematics, psychology and anatomy sciences. The first biomechanists were Leonardo da Vinci, Galileo, Lagrange, Bernoulli, Euler and Young (Winter, 2009).

Ergonomics is concerned with human-machine interaction and has an important place in the design of industrial products. According to biomechanical analysis, ergonomicists can support the development of human machine related systems (McLester and St. Pierre, 2008, p. 12). Ergonomics and biomechanics are very closely related, and in this sense, awareness of biomechanics is important in product design. Biomechanical science is a science that sheds light on engineers and designers in the design of moving objects. The awareness of the biomechanics of living creatures in nature will provide useful information in the context of learning from nature and learning.

2.3 Biomimicry

Biomimicry is a new discipline (Biomimicry Institute) that explores the best ideas of nature and imitates these designs and develops them for people's problems. Janine Benyus first used this term in her book "Biomimicry: Innovation inspired by nature" in 1997. The term "biomimicry", which aims to be a bridge between biology and many other sciences in benefiting from the principles of nature, is frequently used by academic circles today. We find examples of biomimicry in engineering, architecture and design. We can call designs created by using biomimicry in the field of design, biomimetic design. Janine Benyus is an important scientist who has done a lot of work in this field, enabling the emergence of an interdisciplinary concept biomimicry as her specialty. Janine Benyus also founded the Biomimicry consulting firm (Biomimicry Guild) in 1998. This company has worked with many brands and has achieved successful results.

The Biomimicry Institute, founded in 2005 by Janine Benyus, is a non-profit organization. Biomimicry Institute supports bringing together scientists, engineers, architects, designers and innovators who want to use interesting efficient solution models in nature to create sustainable technologies. The Biomimicry Institute consists of 12 employees and focuses on three main areas; developing training programs for students, professionals and the public, trying to create public policies that use biomimicry as a solution for sustainability, encouraging companies that benefit from biomimicry to provide financial support for biodiversity (biomimicryinstitute.org).

Janine Benyus uses the following statement when explaining her biomimicry approach:

“The biomimicry approach seeks the advice of nature at every stage of the design, from concept to creation and evaluation. Innovators discover and ask the correct functions of their designs that they want to finalize by working together with biologists at the design desk: What organism or ecosystem ensures their survival by performing these functions? ”

Reed (2004) explains the biomimicry approach as follows:

“We are in the middle of a paradigm shift in the way we view and interact with the natural world. This new line of thinking - biomimicry - has a tremendous impact on the technological products and systems we have already designed. Biomimicry, an extremely important component of technology literature, is also an excellent example of the interdisciplinary nature of science and technology. ” (Reed, Klumb, Koobatian, & Viney, 2009).

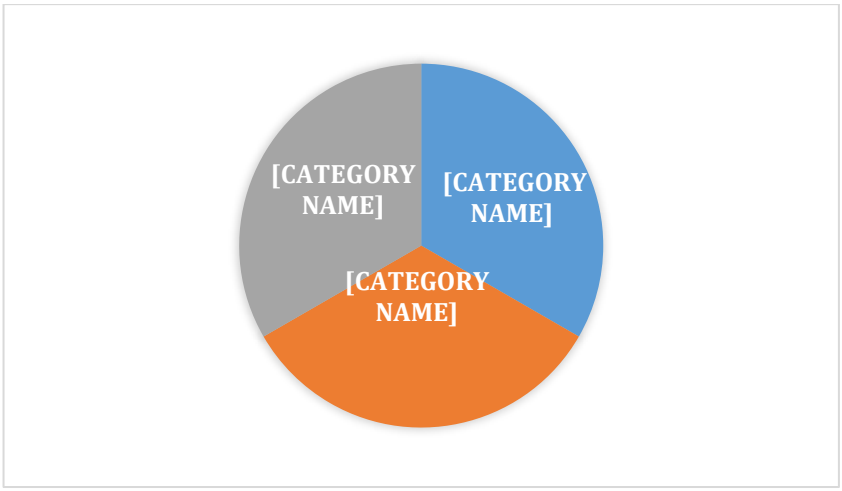

Figure 1. Three Motivations of Biomimicry (Zari, 2018)

Although the biomimicry approach is recognized day by day, new interdisciplinary fields in the academic field are gaining importance. Bio-inspired engineering center at Harvard, bio-design institute at Arizona State University, bio-inspired design center at Georgia Tech, bio-inspired materials and material systems center at Duke University, biomimetic research center at Doshisha University, Royal Insitute Biomimetic fiber engineering in Technology. The number of conferences and books in this area is also increasing. Bioinspiration & Biomimetics, Bionic Engineering, Biyomimetic, Biomaterials, and Tissue Engineering journals are publications related to biomimicry (Benyus, 1997).

2.4 Biophilic

The concept of biophile is defined as the innate emotional affinity that people feel towards nature and the living things in nature. This hypothesis claims that people are instinctively connected to all other life systems. In the field of architecture, it is expressed as a design that allows the human-nature interaction and the beneficial effects of nature to be sustained in built environments (Kaya, 2019).

The biophilic hypothesis is briefly defined as the innate trend towards life and life-like processes. The concept of "biophilic design" based on this hypothesis was first defined by Stephen Kellert in 2005 (Kellert, 2005). Later, the book titled “Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life” 1, published in 2008, which questions how to apply the benefits of biophily in urban design and architecture, provided a more comprehensive understanding of the subject.

Biophilic design is defined in this book as “transferring the understanding of closeness between natural systems and processes inherent in human to the design of the built environment” (Kellert, Heerwagen & Mador, 2008). It was again defined by Kellert and Calabrese (2015) as more comprehensive and explanatory as “an approach aiming to improve the physical and mental feelings of people's health and well-being by re-establishing the relationship between human and nature in the modern urban area”.

3. Biomimicry and architecture

The ongoing cycle and principles of nature are used by designers today to produce sustainable designs. In these studies, instead of imitating the nature, data is collected about what precautions taken by the living creatures in the face of the conditions they face, behaved or structurally changed, and then these data are evaluated during the design process. The entire solution generation and adaptation process constitutes the basis of the approach style that lies at the basis of the concept of biomimicry.

The term biomimicry (biomimicry) originated in 1982. The term "Biomimicry: Innovation Inspired by Nature", published by Janine Benyus in 1997, started to be learned by the masses: or to become a new branch of science inspired by these designs or processes. It is not exactly technology or biology: it is the technology of biology. ” It is defined as.

Biomimicry was developed as a method used by adapting natural system mechanisms to artificial systems. The points inspired / adapted here are patterns in nature as a system, behavior or form that occurs within certain rules.

As a general approach, biomimicry has three dimensions:

a) Nine principles of life

b) Nature as a model, criterion and guide

c) Design spiral informing the biomimicry practice (Beyus, 1997).

Benyus talks about nine functioning principles of nature to be a useful model in human behavior. These principles reflect the inherent characteristics of the ecosystem and underline that ecologically sustainable products will be produced if these principles are used in designs(McGregor,2003):

- The continuity of nature is provided by sunlight.
- Nature uses only as much energy as it needs.
- In nature, form and function match.
- Nature recycles everything.
- Nature depends on diversity.
- Nature rewards cooperation.
- Nature demands local mastery.
- Nature prevents excessive need.
- Nature pushes the limits of power

In the concept of biomimicry, it is emphasized that learning from nature should be done beyond analogy, based on concrete data and to understand the process. In order to use nature as a kind of intellectual or an example, it is necessary to first understand nature in the light of its own rules and then take its principles as an example. Benyus (Beyus, 1997) interprets the relationship between nature and architecture in three different ways:

In the proposition of nature as a model, it is emphasized that it takes the models of nature as an example or uses it as an inspiration to solve the problems of human beings. Here, the model

produces as the animals and plants do; It produces fibers, ceramics, plastics and chemicals that can biodegrade using the sun and simple components.

As a measure, nature uses ecological standards to decide on the problem solving and sustainable viability and validity of inventions. Billions of years after evolution, nature has learned what works, what is appropriate and what is based, and has come to today's conditions. For this reason, nature itself has determined the most suitable criteria that can be used as criteria.

As a guide, nature has been explained as the new way to observe and evaluate nature. It is not about what to extract from nature, but about what can be learned from it.

Designers, architects, engineers, managers and many more use biomimicry in their designs. With the design spiral, information about the solution to the problem, how to find a solution from nature and the application process methods can be accessed. The spiral includes methods of using nature for inspiration and making the method used in design to achieve the success of the system in nature (Kuday,2009).

Nature also designs structures like architects. The structures it designs adapt perfectly to its context, it contains solutions for all environmental problems by itself, its form and functions match each other without errors and contains neither missing nor more functions. (Emre GÜNDÜZ) Another important design feature seen in nature is that architects use similar design criteria that they use when designing living spaces for people. "For example; temperature control, oxygen and respiration, humidity control and water management, defense against predators, food storage, operating the soil-cultivation and structure are the basic ones "(Karabetça, 2018). Some animal structures can be given as examples. For example, the mounds of termites forming mounds, while having all these basic functions, are highly efficient and sustainable designs compared to human structures.

On the other hand, it is argued that a two-way approach in design can be maintained with biomimicry. The first is the design that questions biology, and the second is the biology that affects design. In the first approach, the designer works with biologists for identified design problems and tries to find solutions through an appropriate organism in nature. The second is the opposite. The designer and biologist work on an organism or ecosystem. They use the functions and behaviors they determine here in the design according to their current needs (Zari, 2007).

Architecture has often tended to imitate nature. In terms of forming analogy with nature, analogical work in architecture is full of references to shape and biological function. Human beings have taken nature as a guide and have benefited from the structures and forms of nature in their designs. Biomimicry is sustainable development ethics. It is necessary to imitate nature and transfer from nature for a sustainable life. Biomimicry is a multidisciplinary design approach. It has been used in architectural design for many years.

"Future architects will manage genetic engineers, not masonry workers.

The buildings will be self-renovating like living creatures. Forms that build their own ecosystem will be built decisively ... the architect just has to program this chain that will produce everything. "(Alberto Estévez, 2003)

A systematic study is required to find answers to existing design problems in nature, so that the correct answer can be reached in a short time with the right research. We can briefly list the path that this systematic study should follow;

- Identification of the problem
- Finding a biological response
- Observing Nature
- Finding nature models that have succeeded
- Apply the nature-based solution
- Formal imitation
- Functional imitation
- Ecosystem imitation
- Comparison of the compatibility of the solution to the principles of nature (Pawlyn, 2016).

4. Sample Architectural Structures Using Biomimicry

Figure 2. Exhibition building dome designed by Diatom (Ball,1999).

While the dome of the exhibition building was designed in Montreal, it was inspired by the diatom of aquatic microscopic creatures. When the diatom is examined, it is seen that the cage system consisting of triangles, pentagons and hexagons is fully fitted to each other and allows maximum clearance to be exceeded while providing minimum material usage to form the shape. The diatom form has been a model for the roof and ceiling designs for Buckminster Fuller (Ball,1999).

Figure 3. Qatar Cactus project. (Maglic, 2014)

One of the buildings built as an example of ecological architecture in Qatar, MMAA building uses the relationship of "Cactus" with its environment as a model to build in the desert.

- Functional processes that operate quietly in the workplace are inspired by cacti maintaining themselves in a dry and scorching climate.
- The sun shades on the windows are exposed to night sweating instead of daytime to keep the water in water, as well as turning on and off in response to heat.
- The project extends to the ecosystem level in the adjacent botanical dome, following the wastewater management system, which protects water and follows processes with minimal waste efficiency.

Energy quality and efficiency have been considered in the MMAA building, which is called the cactus project, and designs have been made according to this idea. The blinds in front of the windows are designed as a collapsible system to adapt to variable temperatures (thus, we would not be able to hold water, but mimic the activity of the cactus that sweats at night instead of during the day). The dome, green area and garden at the base of the tower will be located and the wastewater can be cleaned in the botanical garden inside (Spray, 2019).

Figure 5. Milwaukee Art Museum by Santiago Calatrava (Calatrava's Rising Pavilion, 2010)

Santiago Calatrava, one of the successful and unlimited architects of the modern era, has always designed in the light of the feature, difference, mathematics, physics, and scientific research that distinguished his works from others. Thanks to the search for technology and new materials, he created quite different designs working with the system of nature.

As a result of Calatrava's engineering researches, it has brought a sculptural architectural structure to the USA with a flawless wing mechanism.

While designing the building, Calatrava, which was designed based on the "wings beat and wing structures", connected the wing mechanism that was opened twice a day with 217 feet that folded.

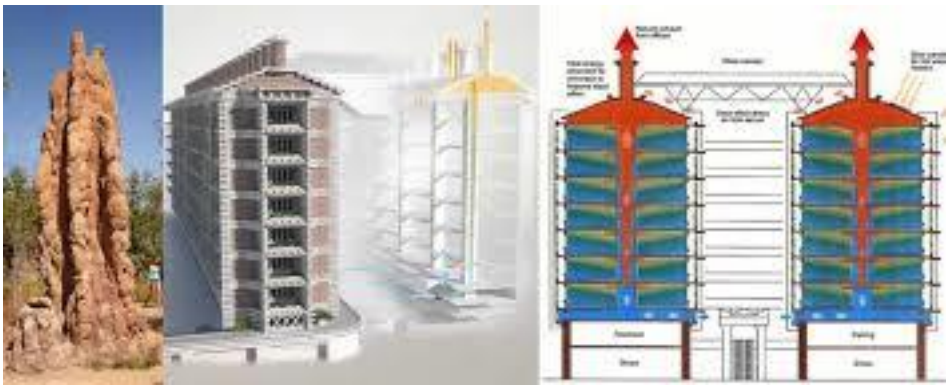

Figure 6. Eastgate Office Building Cross Section, Termite Hill Operation System.

One of the important examples given under the functional approaches in biomimicry design understanding is the Eastgate 26 Building, designed within the biomimicry consciousness of the 21st century. The building, designed and built by designer architect Mick Pearce, is the country's largest shopping and office complex in Harare, Zimbabwe.

The inspiration for the Eastgate building project is the hills and ventilation system built by M. Michaelsen (a termite type) to survive.

With the adaptation of the self-cooling feature of the mound made by incandescent, a sustainable solution has been found for the cooling and heating process that causes the most energy consumption in the building. The natural ventilation system of termites is both structurally and functionally located in the Eastgate Building. In order to ensure that the glass courtyard in the middle of the building consisting of two blocks provides equal light to the spaces and to provide this light equally to the spaces, the size of each neighborhood is considered proportionally to each other (Karabetça, 2016 and Alp, 2013).

5. Conclusion

Although architecture and biology are seen as different disciplines at first glance, they basically have very similar perspectives and goals. Both disciplines are based on material and organization; it's about morphology and structure. Both disciplines consist of systems that are connected simultaneously, and most importantly both have structures of collective parts. With the biomimicry approach, new methods can be developed not only in the fields of architecture

and biology, but also in collaboration with different disciplines such as engineering, materials and chemistry, and innovative projects can be created that will create innovative and sustainable products. Designs that are inspired by nature or produced for the purpose of protecting nature are environmentally friendly in terms of being in harmony with nature.

In designs based on the protection of natural habitats, it is aimed to ensure the continuity and ecological balance of living species. Both approaches are based on the purpose of maintaining the balance of nature from different angles. When these positive efforts are examined in depth, they may still have insolubility in themselves. However, it will be a pioneer in terms of designing living spaces in harmony with nature, creating ideas and developing in this direction.

A real biomimicry approach in architectural design is developing new design methods that combine both the model of behavior and the materialization process in addition to environmental factors. This situation requires understanding of form, material and structure.

Biomimicry has the potential to change our view of the world at the same time, but it also has the potential to develop approaches and possibilities to extend the usable life of the world and resources as well as the life of humankind.

In the coming centuries, studies in the field of Biomimicry will remin up to date. In order to ensure the sustainability of the systems in the designs, the integrity of biomimic applications should be increased. Biomimicry, which showed its effect in the time of Antoni Gaudi and came up with the concept of sustainability in the period of Michael Pawlyn, will continue to emerge with different concepts even in the 21st century and afterwards. The methods of making will also develop in parallel and become flawless.

References

[1] Antoniades, A. C. (1992). Poetics of Architecture: Theory of design. New York, NY: Van Nostrand Reinhold.

[2] Ball, P., (1999). The Self-Made Tapestry- Pattern Formation in Nature, Oxford University Press, 1. Baskı, New York.

[3] Bar-Cohen, Y. (2005). Biomimetics: mimicking and inspired-by biology. Proceedings of the SPIE Smart Structures Conference, San Diego, ABD. SPIE, (5759-02), Mart 7-10.

[4] Benyus, J. M. (1997). Biomimicry: innovation inspired by nature. New York: Quill.

[5] Ebrahimpour, M., Majedi, H., Mahdiniya, M. (2017). Biophilic planning new approach in sustainability (Proposing conceptual model of livable city). International Journal of Urban Management and Energy Sustainability, 1(2), 26-41. doi: 10.22034/IJUMES.2017.06.15.011

[6] Karabetça, A.R. (2018). Biyomimikri Destekli Tasarim Ölçütleri İle Yenilikçi Mekanlar Yaratılması, The Turkish Online Journal of Design, Art and Communication, TOJDAC 8, 104-111.

[7] Kaya, H., (2019). Biophilic Design and Healing Architecture: An Assessment On Children Hospitals. (M. Sc. Thesis). Gazi University, Ankara.

[8] Kellert S.R., Heerwagen J.H., Mador M.L. (2008). "Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life", Hoboken, NJ: John Wiley & Sons, p. vii, viii, 3, 13.

[9] Kellert, S. (2005). Building for Life. Washington: Island Press.

[10] Kellert, S. (2008). Biophilia. Yale University, New Haven, CT, USA. 462-466.

[11] Kellert, S. ve Calabrese, E. (2015). The Practice of Biophilic Design. Erişim www.biophilic-design.com. 3-21.

Knudson, D. (2003). Fundamentals of biomechanics. New York: Kluwer Academic-Plenum Publishers.

[12] Kuday, I. (2009). Tasarım Sürecini Destekleyici Faktör Olarak Biyomimikri Kavramının İncelenmesi, Yüksek Lisans Tezi, Mimar Sinan Güzel Sanatlar Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

[13] Low, K. H. (2009). Preface: Why biomimetics? Mechanism and Machine Theory, 44, 511-512.

[14] Maglic, Michael J., (2014) "Biomimicry: Using Nature as a Model for Design" .Masters Theses 191, University of Massachusetts Amherst, USA..

[15] McGregor, S., L., T., (2013). "Transdisciplinarity and Biomimicry", Transdisciplinary Journal of Engineering and Science, 4: 57-65.

[16] McLester, J., St. Pierre, P., (2008). Applied biomechanics: concepts and connections. Thompson, Wadsworth, Belmont, CA

[17] Pawlyn, M. (2016). Biomimicry in Architecture. RIBA, London, UK.

[18] Reed, E. J., Klumb, L., Koobatian, M., & Viney, C. (2009). Biomimicry as a Route to New Materials: What kinds of Lessons are Useful? Philosophical Transactions Royal Society, 367, 1571-1585.

[19] Salingaros, N., & Masden, K. (2008). Neuroscience, the natural environment, and building design. Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. New York: John Wiley, 59-83.

[20] Senosian, J., (2003). Bio-Architecture, Oxford, Amsterdam

[21] Winter, D.A. (2009) Biomechanics and Motor Control of Human Movement. 4th Edition, John Wiley & Sons, Hoboken.

[22] Yılmaz, S. (2017). Investigation of 5-year-old preschool children's biophilia and children's and their mothers' outdoor setting preferences. Middle East Technical University, Ankara, Turkey.

[23] Chiu, I., Shu, L.H., 2007, Biomimetic Design through Natural Language Analysis to Facilitate Cross-Domain Information Retrieval, Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 21/1:45-59.

[24] Zari, M. P. 2007. Biomimetic Approaches to Architectural Design for Increased Sustainability. Paper presented at the Toronto Sustainable Building Conference 07. Toronto, Canada.

[25] Zari, M. P. 2010. "Biomimetic Design for Climate Change Adaptation and Mitigation." Architectural Science Review 53 (2): 172–183.

[26] Zari, M.P. (2018). Biomimetic Approaches To Architectural Design For Increased Sustainability.