EVALUATION OF BIOMIMICRY IN TERMS OF SUSTAINABLE ARCHITECTURE

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EVALUATION OF BIOMIMICRY IN TERMS OF SUSTAINABLE ARCHITECTURE

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ABSTRACT

EVALUATION OF BIOMIMICRY IN TERMS OF SUSTAINABLE ARCHITECTURE

In architectural designs, technological studies that will help to reduce the negative effects on nature and some methodologies that will make our environment more sustainable are included. In order to achieve a more efficient structure, there is an approach to using innovative natural tools that imitate the environment itself to minimize the negative effects of the building on the environment with low cost sustainable methods by observing the nature. These solutions used in design are introduced with an approach known as biomimicry, biomimicry uses nature in design. In this thesis, various biomimic aspects and levels that can be used in a building to make it sustainable are tried to be presented; In addition, possible solutions are found by examining how all these systems are / can be used in a building. No organism in nature uses as much material as necessary to fulfill the function it undertakes without any excess. In architecture, the aim is to find ways to design the building by making minimum expenditure in cost and resource consumption. It can be inspired to pass wide openings from the spider web with light materials, for a strong structure from bee combs, to obtain natural light from water sponges, to produce self-cleaning glasses from the lotus plant. This thesis is not just the appearance of a building; In addition to aesthetics and appearance, it advocates that the building must be sensitive to the environment. Organisms in nature face challenges like humans, but they meet them in a sustainable way. By watching the animals, plants and their natural processes around us, we can see what works and what doesn't. These observations are helpful both in the design procedure and in generating new ideas using natural skills. Based on this approach, some biomimic solutions are proposed at the end of the thesis.

ÖZET

BİYOMİMİKRİNİN SÜRDÜRÜLEBİLİR MİMARLIK YÖNÜNDEN DEĞERLENDİRİLMESİ

Mimari tasarımlarda doğa üzerinde olumsuz etkileri azaltmaya yarayacak teknolojik çalışmalara ve çevremizin daha sürdürülebilir olmasını sağlayacak bazı metodolojilere yer verilmektedir. Daha verimli bir yapı elde etmek için doğayı gözlemleyerek düşük maliyetli sürdürülebilir yöntemlerle, binanın çevreye karşı olumsuz etkilerini en aza indirgemek için çevrenin kendisini taklit eden yenilikçi doğal araçlar kullanma yaklaşımı söz konusudur. Tasarımda kullanılan bu çözümler biyomimikri olarak bilinen bir yaklaşımla tanıtılmaktadır, biyomimikri doğayı tasarımda kullanır. Bu tezde, bir binada onu sürdürülebilir hale getirmek için kullanılabilecek çeşitli biyomimik yönler ve düzeyler ortaya konmaya çalışılmakta; Ayrıca tüm bu sistemlerin bir binada nasıl kullanıldığı/kullanılabileceği incelenerek, olası çözümler getirilmektedir. Doğada hiçbir organizma fazlalık içermeden üstlendiği işlevi karşılamak için ne kadar gerekli ise o kadar malzeme kullanır. Mimarlıkta da amaç, maliyet ve kaynak tüketiminde minimum harcama yaparak binayı tasarlamanın yollarını bulmaktır. Örümcek ağından hafif malzemelerle geniş açıklıkları geçmek için, arı peteklerinden güçlü bir strüktür için, su süngerinden doğal ışık eldesi için, nilüfer bitkisinden kendini temizleyen camlar üretebilmek için esinlenilebilir. Bu tezde, bir binanın sadece görünüşü ve işlevini değil; bunlara ek olarak, çevreye karşı duyarlı olması gerektiği savunulmaktadır. Doğadaki organizmalar insanlar gibi zorluklarla yüzleşir, ancak sürdürülebilir bir şekilde onları karşılarlar. Çevremizdeki hayvanları, bitkileri ve onların doğal süreçlerini izleyerek neyin işe yarayıp neyin yaramadığı görülebilir. Bu gözlemler hem tasarım prosedüründe hem de doğal becerileri kullanarak yeni fikirler üretmede yardımcıdır. Bu yaklaşım üzerinden hareketle, tezin sonunda bir takım biyomimik çözüm önerileri getirilmektedir.

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LIST OF SYMBOLS/ABBREVIATIONS

BIQ	Bio Intelligent Quotient
ETFE	Etheylene tetra foil ethylene
LAVA	Laboratory for Visionary Architecture
MAKO	Mako bus terminal
TiO2	Titanium dioxide
TWA	Terminal TWA

1. INTRODUCTION

Nature According to the Turkish Language Association, the lexical meaning of nature is defined as "all living and non-living things that are constantly evolving and changing within the framework of their own rules." Nature has a harmony that can circulate within itself, and all living and non-living constitutions in it need each other. For example, an animal or a plant needs soil and water to survive. The British philosopher and historian Collingwood presents Plato's view in his book as follows:

> Nature functions in a hierarchical order, and the extinction of one part of this system leads to the decay of the whole system. People cannot live independently of their environment, and they are also a part of nature [1].

Since the world's creation, beings have acquired mastery over time by trial and error to survive. The best solution can be reached for the issues encountered when this mastery is examined. The main target in architecture is to produce the lightest and most durable design solutions by consuming the least resources while providing aesthetics. In this regard taking nature as a role model can be the most organic and most effective way since nature carries out its cycle without intervention. The method of observing nature, which provides new and effective solutions, entered the literature in the 1950s with the term "biomimicry." Trying to understand natural procedures has led to developments in many fields such as energy, transportation, art, and architecture. The use of biology and technology in architecture will enable to leave minimum better than today's conditions to the next generation. The adventure of observing nature with the technological possibilities that developed after the Industrial Revolution went beyond direct imitation and helped to understand its functioning.

> As in many other design disciplines, learning from nature in the field of architecture includes the process of transferring the obtained information to the design language appropriate to the context. Although this process does not result in design solutions that directly correspond to the living organism inspired by different contexts, it is important to examine in detail how living organisms deal with similar problems and then adjust the functional principles for their implementation [2].

Some scientists, excluding humans from nature, describe every living and non-living thing as nature, such as the remaining organism and soil. On the other hand, a human is a being that can survive by getting help from nature. In this context, it should be noted that the German thinker Arnold Gehlen, who is well-known for his contributions to philosophical anthropology, states that;

> Human is the only living creature that tries to reach its expectations by constantly changing its environment in line with its developing needs [3].

To survive, human uses nature and interfere in it. Architecture, which is at the forefront of these interventions, should be conducted responsibly to nature.

> In architecture, which is the art of creating space, nature has attracted people's attention and has been an inspiration and solution method. Along with this interest, human has researched nature and used what it learned from it, imitating and interpreting it, metaphorically and analogously in architectural design [4].

Sustainable spaces can be achieved if the adverse effects of buildings on the environment are reduced. In this context, positioning the building to benefit from the sun, designing the building openings to support natural ventilation, constructing the building in harmony with the topography, developing natural methods by observing the natural life rather than artificial production can enable healthy urbanization that works holistically with nature. Thus, efficient, effective, and economically sustainable cities can be provided to future generations with at least the same opportunities as us, or even better.

1.1. OTHER STUDIES RELATED TO THE SUBJECT

Other important studies on the subject are given below with general summary explanations. In Gülay Yedekçi's book "Designing with Nature: Biomimicry and Future Architecture" (2016), the critic "a sustainable design, that is responsible for nature" is made [5]. By courtesy of the ever-increasing technological developments in our age, innovative solutions are made in every branch, from structural building elements to materials used in architecture. Cost-free solutions that minimize their organic-resource consumption are sought. The book emphasizes that architecture should work together with multiple disciplines such as nanotechnology, biology, and genetics. Inspired by the biology/principles of living things in nature, a sketch of the architecture of the future is presented, linking it to technology.

Humanism cares about humanity/the human mind. Utopias reached the dimension of spatial design with the appearance of the understanding of humanism in the Renaissance period. During this period, the human body was accepted as a microcosmic representation of the macrocosm. Designs similar to the human body were made, and many utopias were designed considering that they contained ideal proportions [6]. Scientists of the era believed that development was through understanding nature and was interested in natural sciences to achieve successful solutions. A look at the literature shows that utopias arose due to significant developments. Biomimicry is an approach that argues that the self-sustaining formation/operation of nature should be taken as a role model for an ideal design.

Innovative designs constituted and inspired by nature enabled the production of effective forms and functions. Biomimicry, which offers smart systems compatible with nature, also gives innovative ideas about building envelopes. The increasing temperature resulting from global warming, the rapid consumption of existing resources, and the need for energy to be obtained naturally have led to the sensitive building facade design to be created with rational systems, due to the developments in technology and materials. Buildings are formed by consuming existing resources. They damage nature with carbon dioxide and other gases they emit throughout their use, thereby disrupting the world's climate order with global warming. The building envelope is the transition layer between natural and man-made environments. Using biomimicry, effective energy is obtained, sustainable, recyclable, and efficient material-based designs can be made [7]. Another biomimetic approach to building envelop design is treating leather's analogy. The effort to restore the frazzling structures due to use to their original state is called "retrofit." Frazzling structures (retro) enter the design process for conformity to the skin structure (fitness), thus adapting to changing conditions [8]. Biomimicry can be used at every step, from the facade envelop to the inside of the building. In interior design, nature-based innovative materials are designed, and solutions to issues are provided. There are design criteria such as transferring the biological processes of nature to architecture, bio-adaptation, preservation of climate order, eco-mimicry, socio-architectural interactions, spatial savings as eco-mimetic, and providing a comfortable interaction between the building and the environment [9].

A large amount of energy is used in the heating and cooling of buildings. The struggle to keep the indoor temperature of the building at a suitable level and to keep the temperature outside the building envelope at a minimum is called the thermoregulation of the building envelopes [10]. To reduce energy consumption in architecture, passive methods such as natural ventilation are used, while passive methods are not sufficient to obtain efficient and effective energy, and it is tried to imitate nature, which is the source of these energies. Organisms can adapt to the difficult conditions they encounter in nature, with physiological, morphological, and behavioral adaptations they have developed since their existence. The applicability of the thermoregulation methods of these creatures to architecture and the investigation of heat control systems is an energy-saving biomimetic approach that can be applied on the frontage.

Another critical resource such as energy is water, which has no alternative and is a limited resource that can be depleted if not controlled. A clean water source is essential for every living thing. However, in today's conditions, the changing climate and pollution resulting from consuming and polluting society is an alarm for destroying existing water resources. Efficient solutions are also sought in buildings for the recycling of unlimited water. Nature offers rational tips for "water harvesting" with organisms that have developed systems that use water efficiently and consume enough water to provide the necessary function. Surface designs and gray water recovery systems are being developed for water harvesting by seeking an answer to the question, “Can there be architectural solutions that can acquire the water needed in design with natural methods and use it effectively?” [11].

Since its existence, humans have made discoveries by understanding and observing nature. The scope of these inventions starts with small hand tools that make daily life easier and continues to increase until the construction of the place they live. Observation of the environment sheds light on designs regarding structure, color, texture, and process due to their organic, pure, perfect form and continuity [12]. For example, ventilation systems in principle similar to termite nests, paints that can clean themselves by examining plants, carrier systems, systems identical to the bone form in terms of strength, and the search for material similar to spider web in terms of lightness lead to innovative ideas.

1.2. AIM

This thesis focuses on the fact that not only the exterior of a building is essential, it also focuses on the building's need to be environmentally responsible. Organisms in nature face challenges like humans, but they sustainably meet them. Observing these natural forms/organisms or their natural procedures shows what works and what does not. Observations are helpful both in the design procedure and in motivating new ideas using natural skills.

Designers and engineers constantly look for rational methods to create environmentally sensitive, durable, sustainable, and aesthetic spaces. The essence of design is curiosity. The innovations learned by imitating nature offer a different range of not off-the-shelf solutions. While some designers imitate nature only visually, biomimicry gives architects opportunities to provide useful function rather than visual. The unity of form and function creates both aesthetic and sustainable structures. While realizing this, the curiosity of "how would this problem be overcome by another living form, not me," which goes beyond the ordinary, leads to pure, easy, practical, and inexpensive natural solutions, rather than known/scientific engineering calculations and architectural solutions. The fact that the natural cycle has continued for centuries without any problems is because it is multifunctional, one action serves another purpose, and the circulation continues undisturbed. For example, an animal's waste is beneficial for developing a plant; before leaves fall, they obtain energy from starch, store starch, and turn it into respiration in autumn. Therefore, multifunctional building systems can be designed with many natural and simple designs. Rather than consuming resources to provide a function in designs (such as air conditioning and ventilation), natural processes that will provide that function (a natural ventilation system such as in termite nests) can be adopted, and the cycle can be provided with the existing natural energy without fighting the climate by consuming energy.

In the light of the thoughts, publications, and researches on the projection of the biomimicry issue explained so far in the design; the main objective of the thesis study was determined as "To explore all possible ways that are part of biomimicry and will benefit architectural design in terms of sustainability."

1.3. SCOPE

With the rapid consumption of existing resources in architecture, the living spaces of organisms that live in those areas without any problems and flawlessly while constructing our own living spaces by constructing houses, workplaces, schools, hospitals, gigantic strong heavy buildings are destroyed. Rather than rapidly consuming non-renewable resources, inexpensive natural resources used by organisms can serve as a guide. The second part of the thesis explains the definitions, principles, application levels, and history of biomimicry, which is based on the principle of imitating nature. When looking at the environment, it is noticed that there are systems that can make heuristics that humanity has struggled to achieve for centuries and developed techniques. Examples are animals that swim underwater by taking air and birds that can fly without fuel. Since organisms in nature have continued their life for 4.5 billion years without consumption and incorruptible cycle, nature can be replicated in any field, considering that a problem that can happen to man today can be solved with any organism sustainably. While creating the form in architectural designs, the place of biomimicry is important to obtain to add meaning to it. The third chapter specifies biomimicry pioneers and examples, while the place of biomimicry in architecture is explained with the green architecture movement and sustainable architecture approach.

The scope of the thesis is the use and analysis of biomimicry for sustainable architectural designs, focusing on the benefits and possibilities that can be used in the architecture of the future in this light to outline them. Structures can be built by hand by understanding the production methods in nature and acting as a part of it. Natural beings, with their instincts, create places for shelter that can meet their needs, are suitable for their biological system, are healthy, and have energy conservation. In the fourth chapter, the sustainable usage aspects of biomimicry in architecture are examined according to the natural form imitation levels determined by the author through examples. By researching the behavior, visual, structure, ecosystem, genetics, and geometry of the forms found in nature, all kinds of exploration paths are examined and fictionalized by the author while respecting the aesthetics that can be used in the design, but with the awareness of creating a functional and sustainable space as the primary goal. Towards the last part of the thesis, the achievements in architecture due to biomimetic design such as visual comfort, aesthetics, sustainability, economy, energy gain, improvement of life quality and protection of nature, and biomimetic building elements were constructed in line with the findings examined.

Our buildings can resemble the living spaces of other living things in nature, instead of heavy irreversible and non-functional buildings, natural aesthetic biomimetic envelops, natural energy instead of electricity, skin-like self-renewing facades, etc., all kinds of possible ways are being explored. In this way, as we always say, we can answer the question "What is the place where we live?" in the real sense of "nature" rather than concrete structures.

1.4. METHODOLOGY

The basis of the research is the findings in the book reviews, the doctorate and master thesis reviews on biomimicry. Apart from the book, articles and booklets from scientific publications were used, and comprehensive research was tried to be conducted by examining the public institutions and private sector publications on the subject.

First, the subject was entered with the definitions of the concept of "Biomimicry" made according to various perspectives. Within the framework of these definitions, the basic characteristics of biomimicry are explained within the scope of its principles and application levels in the design. The development of biomimicry from the past to the present has been revealed in light of these explanations. All these levels of review and a summary of available information are in Chapter 2.

Afterward, in Chapter 3, it is investigated within which currents the relationship between biomimicry and architecture can be established. In Chapter 4, the sustainable use of biomimicry in architecture is analyzed through examples. In this analysis, for architectural, functional gains thanks to biomimicry, i.e., for light that will extend from nature to design, the development of the thesis focuses on the progress from natural forms in nature (elements already present in living inanimate nature) to architectural design. Based on the analysis in question, natural forms are classified in various categories determined by the author, and following the classification, the architectural achievements are investigated as a result of the findings obtained by examining the organisms. Three steps were followed to strengths strengthen be conveyed; The first is to examine the sustainable contributions of ready-made forms in nature according to the level of examination, the second is to associate these contributions with architectural building elements (from nature to architecture), and the third is to examine the designs created by following the first two steps (from architecture to nature). In the 5th chapter, the contributions of the designs obtained by biomimicry to the architecture in terms of visual comfort, aesthetics and sustainability are emphasized. In Chapter 6, some design suggestions are given at the level of architectural building elements brought by the author by the biomimetic approach.

As a result of the method followed in the thesis and the steps mentioned above, by looking at the nature that shapes the architecture in terms of form and function and trying to obtain new products, the importance of the desire to design clean living spaces with zero consumption, maximum efficiency and without the need for intervention like nature is emphasized.

2. THE CONCEPT OF BIOMIMICRY

Biomimicry, which brings innovative solutions to design problems, has many definitions stating that it examines nature's circulation, structure, content, functioning, and order. To improve and increase the studies done so far, studies have been investigated at certain levels, and human life has been tried to be made sustainable by imitating nature with the principle of functional gain from living things.

Conceptually, biomimicry has been around since ancient times. Utopias, which were a result of radical changes during the Renaissance, did not remain verbally and began to affect the living spaces. In order to construct the areas in a spatial context, the human body was examined by the virtue of the popular idea of the Renaissance period, humanism, and utopias containing the golden ratio were specified. Nature was kept as a guide for innovation and development by the intellectuals of the time [6]. The way to develop science has been adopted as nature, which has constant experience and can solve its own problems. Nature has the golden ratio and a sustainable system. Biomimicry, which symbolizes the ideal design, is expressed as the imitation of this flawless functioning.

2.1. DEFINITIONS

According to the Biomimicry Institute, biomimicry is an approach that enables the use of proven procedures in nature in the rational solution of problems faced by human beings. Since other beings around us are in a nature/adapted state to nature, a new lifestyle that achieves this is sought for humanity. Suppose we apply the fact that the assets live in nature without any problems for humanity. In that case, the design of the buildings we live in should be improved to reduce the negative impact on the natural environment, with approaches such as reducing carbon emissions, obtaining instead of energy consumption, and utilizing existing resources. Discoveries that will ensure sustainability in designs are found in nature. Şafak Altun, who wrote her book with the question "Can't we switch to production systems that do not harm nature?", states in the book that nature is a role model for nature-friendly innovations with low material use, sustainable, aesthetic, effective energy use, imitation of self-feeding nature, which has been producing without producing garbage for centuries [13].

Biomimicry is of Latin origin, derived from the words "bios" for life and "mimikos" for imitation [14]. With the ever-increasing technology, the perfection of nature, which is 3.8 billion years old, is being researched with innovative approaches. In addition to revealing a product as a result of observation, the biomimicry approach is an inspiration for innovative inventions in analyzing the observed entities' genetic/functioning/biological/physiological processes. Biomimicry covers innovations in every branch that can be made with the breeze from the natural system, such as fireflies producing light without loss of energy, while lamps lose more than half of the energy as heat, oysters can produce hard shell while consuming resources for a solid structure [13]. According to Steadman, “Nature itself is a great inventor and has already produced all kinds of devices, structures, and materials by natural selection” [15]. Benyus, who used biomimicry as the first terminology, summarizes the subject as follows:

> When we ask nature, we first silence our human intelligence, then ask and listen. The echo that bounces off the ground is the answer. Animals, plants, and microbes are the best designers and engineers to show what works, what's appropriate, and what doesn't spoil on earth [16].

The popular concept of energy efficiency and sustainability requires a return to nature.

2.2. PRINCIPLES AND LEVELS OF APPLICATION IN DESIGN

The index of biomimicry to design is achieved by imitating it visually or biologically. The principle of this thesis is to scan biomimicry for functional benefits from organisms in nature to architectural design rather than visual imitation.

2.2.1. Biomimicry Principles

The basis of the biomimicry approach developed with tested natural skills combines the principles of nature, design, and engineering. Keeping natural production superior to artificial production can provide design benefits in sustainability, efficiency, and durability. Benyus, in her book "Biomimicry: Innovation Inspired by Nature," states:

> The biomimicry approach seeks nature's advice at every stage of design, from concept to creation and evaluation. Innovators are exploring and asking about the correct functions of their designs by working with biologists at the design desk: Which organism or ecosystem provides their survival by performing what functions?

and summarizes the principles of nature in terms of solving problems as follows: expenditure of as much energy as necessary, maximum use of the sun, which is the inexhaustible resource, recycling, creating a form for the realization of the function [17]. Another principle of biomimicry put forward by Primlani is an adaptation to different conditions, developing while struggling against issues and meeting the needed material from nature [18]. Looking at the design principles, it is clear that it appeals to a function, while there is the idea of providing sustainable benefits, achieving maximum efficiency with fewer resources, staying away from extremes, and adding ourselves as a ring to the perfect cycle by treating nature as nature does. There is no production alone in nature; by converting one product into another with the integrated working principle, no waste or garbage is produced, the principle's goal is efficiency.

2.2.2. Biomimicry Levels

While aesthetics is given importance as a criterion in design, it is an innovative move that the space made in addition to aesthetics serves a global purpose as a whole. For this reason, nature, which is a perfect example of design, is a source of inspiration for designers in determining project decisions. Biomimicry looks for ways to act like nature in design. In construction, where material and energy consumption is very high, plants, animals, and other organisms are consultants on resource use. The design is guided by natural forms' knowledge, essence, and characteristics without generating waste.

Researchers have studied biomimicry at different levels for good design. Radwan and Osama determined three levels for the biomimicry-based design by looking at the biology of the living thing: organism level, behavior level, and ecosystem level [19]. In the solution of the issues of the natural form itself, the form itself indicates the level of the organism, the level of behavior of the procedures to cope with the issue, the response to the issue from the nature indicates the level of the ecosystem.

Pedersen Zari also used the same levels as Radwan and Osama in the biomimetic design. While Radwan and Osama use the organism level as solution-oriented towards the organism's issue, Zari uses the organism itself or its part as an imitation. The ecosystem level is an imitation of an ecosystem that has been successful in performance and efficiency [20]. Mazzoleni, another researcher who sets levels in the study of biomimicry, deals with the relationship between the organism and its environment and lists the levels as follows as a result of the synthesis of the principles he developed for the adaptation of the organism to the environment in which he lives: thermal compatibility, communication, defense, and water balance. Mazzoleni tried to convey the impulses of the forms that fit and blend into the environment, at the determined levels, into the designs [21].

2.3. HISTORY

While living creatures in nature live in an unspoiled circulation, human beings see nature as a benchmark for continuing their generation with curiosity. Nature in its texture, function, proportion, order, and stability sheds light on designers when it comes to design. Nature, with its way of working, is an inspiration for humankind. Biomimicry is an innovative science that uses the shark's tail for propeller logic and takes inspiration from bird beaks to fly like birds.

In retrospect, there have been many attempts at flying. Studies on this subject date back to İsmail Cevheri, Abbas İbn Firnas, Leonardo da Vinci, Sir George Cayley, Wright Brothers, and Hezarfen Ahmet Çelebi. Leonardo da Vinci, who researched the act of flying with the biology of birds, obtained a flying vehicle in the 1480s [22]. Leonardo da Vinci said;

> Human intelligence… It will never be able to make a more beautiful, simpler, or more direct discovery than the discoveries of nature. Because in the discoveries of nature, nothing is too much or too little [23].

A century later, the Orville and Wilbur Wright brothers, who prioritized the physiology of birds in the design of flight systems, invented the first airplane, inspired by the pigeon wing technique, which easily performs the rotational actions in the airflow [24]. Due to the Wright Brothers, who achieved initial success in the flight attempt, this "imitation development" movement increased as time progressed in line with growing technology and new needs [25]. When we look at Turkish history, there are many discoveries of researchers using nature as a consultant. İsmail Gevheri went to a mosque about a millennium before the Wright brothers' flight attempt and let himself down with the wings he designed on his arms. Although his flight was short-lived and he lost his life by falling, his last words were as follows:

> O people, no one has ever made the invention I made. I'm going to fly right in front of you. The most important thing to do in the world is to take to the skies. That's what I'm going to do [26].

Landscape architect Joseph Paxton built a 990,000 m2 structure called Crystal Palace for the world's first international fairground in London in the 1800s. Inspired by the nervous system that supports the weight of the lotus leaf in water, he designed a special transverse structure to construct the approximately 300,000 glass blocks used in this construction process [24]. According to Aristotle, the design is ready in nature, the only thing left is the perfect imitation of the seamless design. The project here can be defined as another presentation of nature. According to him, imitation is not only visual but also the way of life, quality, and essence of existence. Farabi also added the ideas of Aritotales to Turkish thought and included inspiration from nature in his works. Examining similar ideas with Aristotle, Farabi conceptually processed biomimicry by processing the harmony between bodies such as soil, death, plants, and the sky [27].

The biomimicry method was used as “Bionics” by Jack Steele of the US Air Force Base in 1960, and as “Biomimetics” in 1969 by the American biophysicist Otto Schmitt in his article presented at the International Biophysics Congress in Boston [28]. Janine Benyus included the term biomimicry in her 1997 book, Biomimicry: Innovation Inspired by Nature, and in 1998, she established the "Biomimicry Guild" to inspire/guide humanity and AskNature, the largest web base on biomimicry, highlighting natural ways to deal with difficult problems, leading the concept of biomimicry to gain worldwide popularity. Biomimicry Institute, founded by Benyus and her academician friend Bryony Schwan in 2006, is an independent organization that uses biology for effective and innovative production. This institute establishes AskNature, a deep knowledge cumulative in biomimicry research, and offers global solutions open to everyone on this website [16].

Pedersen Zari used biomimicry functionally. Zari has adopted the principle of understanding the organism rather than formal imitation in biomimicry and solving the problem from nature with biology and other disciplines. Biomimicry offers efficient design strategies by extracting useful methods from natural assets. Zari mentioned biomimetic benefits in his article Biomimetic Approaches to Architectural Design for Increased Sustainability [6].

In addition to interaction at the architectural level, biomimicry has been and continues to be active in all other areas of design. The scope of biomimicry has entered our lives in almost every field, from architecture to engineering, from textile to automotive. For example, grooved wings in the aircraft industry, non-friction swimwear in textiles are made by looking at shark skin. Colorful organisms such as butterflies are taken as role models in the material sector, and dirt-free dyes are obtained from plants [29], [30]. Steve Jobs said;

> I think the biggest innovations of the 21st century will be at the intersection of biology and technology. A new era is beginning.

and David Oakley emphasizes, that the biomimicry approach can be effective in every field in the future supports it with these words:

> Nature is my mentor in business and design, a model for my lifestyle. The system of nature has been working for millions of years. Biomimetics… It is a way of learning from nature [31].

3. THE PLACE OF BIOMIMICRY METHOD IN ARCHITECTURE

Biomimicry, which enables the transfer of sustainable architecture by using the possibilities of nature in energy conservation and the meantime, carries the green of nature to the buildings, and the sustainable architecture that uses the functioning of nature functionally, sees the spaces we live in in a broader framework instead of buildings and directs human shelters to systems that solve the problems such as the living space of plants, animals and other organisms.

3.1. BIOMIMICRY AND GREEN ARCHITECTURE MOVEMENT

As we run around between built environments in our lives, our connection with nature, which is the environment we live in, is becoming more severe. Beings in nature are the designers who create their spaces, and architects and engineers should follow their logical methods and strategies. The built environment both causes separation from the natural environment and harms it by causing environmental and even global problems with its interventions. To make cities livable, the aim of architecture should be to cause the least damage to nature. Adaptation to nature, topography, and vegetation protection requires the design of the building with approaches such as the positioning of the design and the "natural and local" of the materials to be used.

Green architecture, which tries to minimize the destruction to nature and gains importance today, aims to protect nature with environmentally sensitive materials. The goal of a green design is to make it fully sustainable. The use of local vegetation and minimum enough non-toxic materials, efficient use of energy in heating and cooling, conservation of natural energy resources, and recycling are necessary for green building. However, regulations should be developed to realize the green building design. Green building regulations, such as fire prevention systems and applications used in buildings, should be introduced to implement green architecture with low cost and high functionality and leave nature in minimum living conditions for future generations.

Ecological design, which is damaged by buildings that do not respect the environment, tries to re-establish the world order with the system of being from nature/camouflaging in nature. The design should be done with nature for the buildings to be suitable for the region built; the environment should be protected with its current values. An ecological structure is an attitude that conserves energy and resources, is compatible with climate, vegetation, and topography, and observes the communication between humans and nature [32]. The facade of the office building in Japan, which is an example of a building camouflaged in nature, is kept green instead of heavy, non-recyclable material, giving it the appearance of a naturally formed green hill. As seen in Figure 3.1., the frontage consists of terraces resembling a rising park view. Psychological and economic gain is provided in addition to nature.

Figure 3.1. Fukuoka International Hall, Emilio Ambasz [33].

Green roofs, which are an example of green architecture, make our spaces feel like shelters for organisms in nature, both economically in energy efficiency and because they allow planting/caring for plants and animals. The green roof, which can be applied throughout the city, will perhaps enable the construction of a natural cover on earth at a height / new wildlife. Because of its energy efficiency, it provides economic benefits in insulation.

Other achievements in the context of sustainability are; oxygen contribution to the ecosystem through plant cultivation, reducing the ozone effect, gaining arable land, filtering dust from the heavy noise of the city and harmful rays of the sun, protection against physical impact and fire as it is dressed on the carrier system. Another example of green architecture, the building by Gaetano Pesce in Osaka (Figure 3.2.), used green aesthetically on the frontage, not on the roof. While the plant is grown through the potted elements placed in the building shell in the sense of a building element like a window, indoor air quality is improved. As in this example, the integration of plants into architecture as a building component contributes to sustainability as it increases the intertwining with nature. Here, it can be put forward that the planted building design, which is included in the green architecture movement, supports the building-plant association and biomimicry.

Figure 3.2. Organic Building, Osaka, Gaetano Pesce, 1993 [34].

In Figure 3.3, where the union of building designs with nature is demonstrated, "typology of plant use systems in buildings," developed based on the combinations created by plants in the use of plants on the building, can be seen.

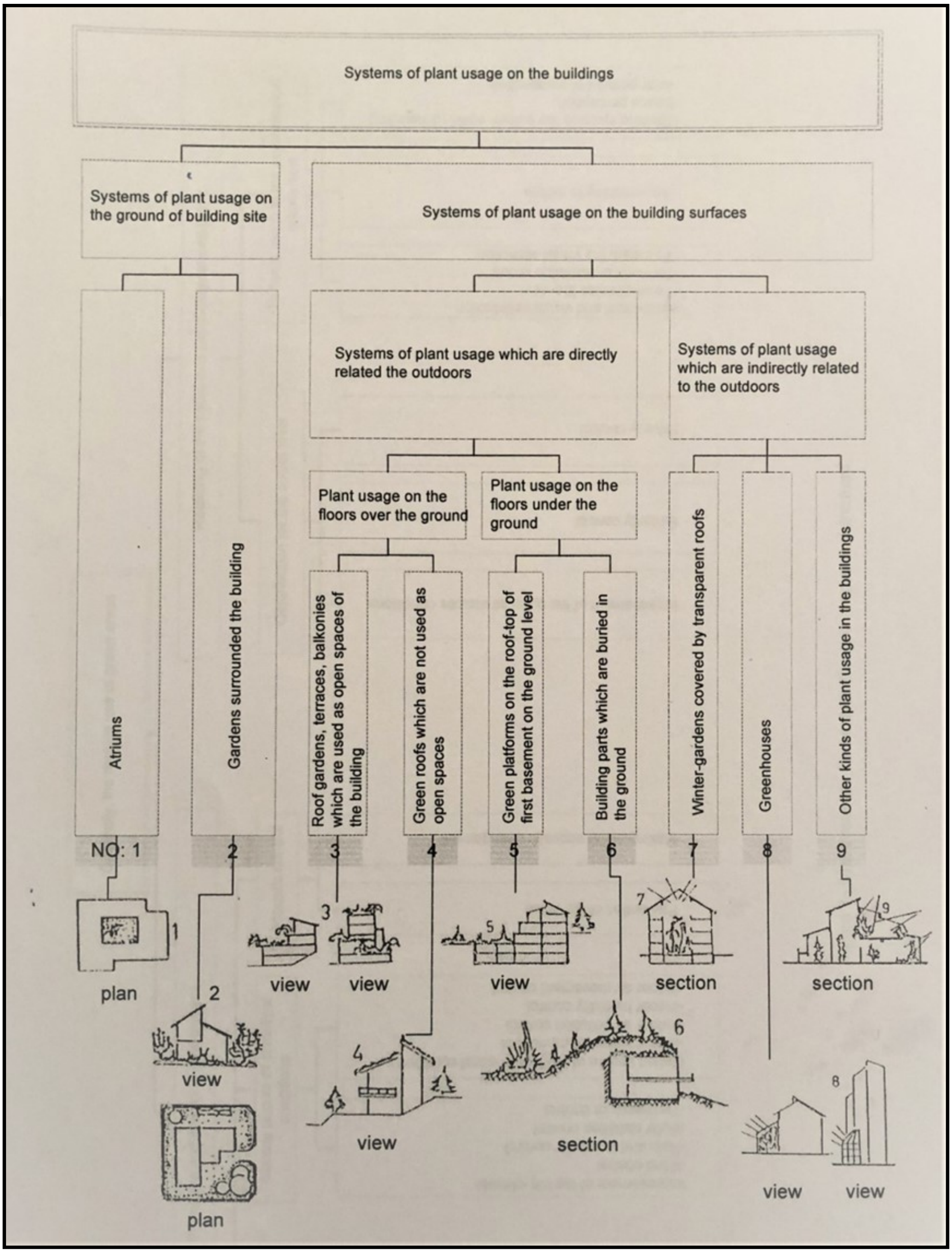


Figure 3.3. The typologies over the system of plant usage on the buildings [35].

3.2. BIOMIMICRY AND SUSTAINABLE ARCHITECTURE APPROACH

Architecture is a human model and serves to organize the environment in which we live, maintain human interaction with that environment, and create an environment that encourages human activity. Instead of buildings that make the environment worse with continuous construction, living space is sought suitable for architecture with sustainable design and human-nature relationship. Architects take inspiration and advice from nature to replicate nature by investigating and exploring how living things should be. Production means understanding the formation process of form. In addition, the colors, patterns, consistency, and self-cycle in nature is flawless creation. Understanding how nature evolved during exploration and learning is crucial to bringing new ideas to current and future designers [36].

Until today, factors such as art, environment, climate, sustainability, and economy have not been used together in architecture. There are ergonomic and non-functional environmental models that are sustainable and non-aesthetic. Therefore, the goal of achieving all-natural approaches has led to advances in human design. With all this in mind, biomimicry also seems to support economic, environmental, aesthetic, durable, functional, and sustainable designs. Given the principles of biomimicry science, working with other sciences should be considered, and resources should be collected to find new spatial designs in architecture. When an artist claims that a design is original, inspiration is usually an organism, but it is not only an imitation of the shape or color of a cell; that is, it is not by the principles of formal imitation biomimicry [37]. Integrating biological processes or biological sciences into architecture is achieved by incorporating biological thinking into design principles. Briefly stated, spatial design principles should work interdisciplinary as a way to find a permanent solution for a sustainable space.

The perfect balance between the perfect design of all living things in nature and the earth's natural state leads to more in-depth research on sustainability. With the consensus that all art in nature is perfect, researchers, architects, and engineers begin to apply innovative methods with the simulation of nature. The life cycle of the planet on which we live is immaculately continuous. Therefore, it is essential to create an environmentally friendly sustainable environment by taking this life as an example to leave a suitable environment for future generations. As mentioned earlier, the priority of sustainable architecture over integrating architecture and nature brings a biomimicry approach. In this context, natural systems should be considered environmental management systems and a tool for sustainability in buildings. Sustainability in buildings is important for clarifying the main idea of design innovation. Ecological and sustainable design criteria in architecture can be summarized in the following order;

- Maximum benefit from the sun: Building location, optimum orientation, use of solar panels, hot water energy supply, building form, floor height, energy-efficient selection of building height
- Reducing heat loss: Selection of building depth, insulation, optimization of the number of exterior walls and floors in the building plan
- Harmony with nature: Providing natural ventilation, increasing natural lighting, compliance with climate and topographic conditions, evaluation of building waste and garbage
- Optimization in material usage: Material selection in material production, transportation, construction technology
- Optimization in infrastructure systems
- Making use of plants

In this direction, in the thesis, the reflection of the concept of biomimicry in architecture is explained and analyzed through various examples, and the achievements in architecture and possible solutions are presented. The solution is to see ourselves as part of the natural form processes around us and adapt to them. The transfer of innovative knowledge obtained through scientific research to the construction field will play a key role for future generations [38].

3.3. PIONEERS AND EXAMPLES

Rather than copying natural forms, biomimicry's target is to grasp the perfectly self-circulating cycle of these forms. Natural methods are efficient and straightforward; natural forms do not contain unnecessary things. Civil engineering and architecture also aim to find a way to haul the building with minimal equipment; Hauling loads with biological forms such as eggs, shells, branches, and spider webs are simple and effective practices learned from nature. The Sagrada Familia church, designed by Antoni Gaudi, has an ecological architecture inspired by nature. Gaudí's innovations inspired nature. As seen in Figure 3.4, spiral staircases, conical top cover and tree-like carriers, a bee-comb-like door as a natural decoration, a grapevine-looking frieze, and microscopic algae-shaped windows with different shapes were designed structurally [39].

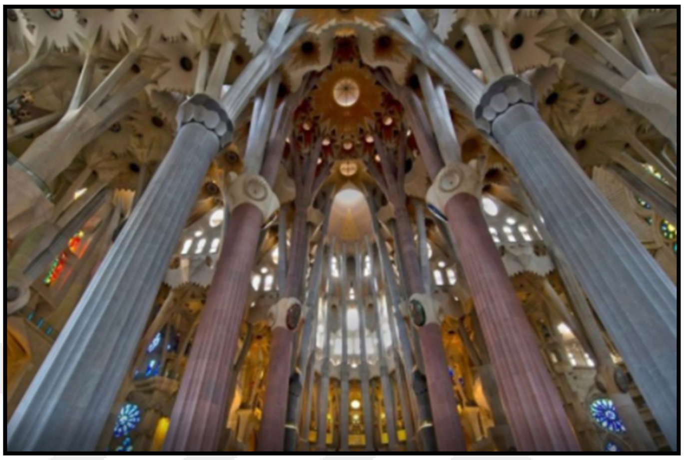


Figure 3.4. Sagrada Familia, Antoni Gaudi [39].

Beijing National Stadium, designed by Swiss construction company Herzog & de Meuron for the 2008 Olympics, is nicknamed the bird's nest (Figure 3.5.). Just like the bird's nest appearance, the roof cover consists of intricate nets, and these nets are kept semi-transparent.

Figure 3.5. Beijing National Stadium, Herzog & de Meuron [39].

Fariborz Sahba's Lotus Temple was designed according to the Bahai faith. According to this belief, all places of worship should be in a nine-dimensional circular structure. Sahba made this happen, inspired by the Lotus flower, and formed the frontage with twenty-seven kabuki in the crown. (Figure 3.6.)

Figure 3.6. Lotus Temple, Fariborz Sahba [39].

30 St Mary Ax (The Gherkin), designed by Norman Foster in London in 2003, is popularly known as the Gherkin Tower. The cucumber pattern was inspired by the Venus Flower Basket sponge, a kind of glass sponge that survives in the deep sea due to its spherical shape, eliminating the forces of water flow with its lattice-shaped coating (Figure 3.7.). The skeleton acts as a seawater filtered basket for food supply. Cucumbers exhibit sponge properties by acting like a sponge in the air. The oval view of the structure causes a pressure difference that improves air circulation. Compared to the classic straight massive skyscraper line, the air glides around the building more easily. By courtesy of the structural system of the facade-lining, an open view is achieved without internal columns, allowing the sun to enter comfortably.

Figure 3.7. 30 St Mary Axe (The Gherkin), Norman Foster [39].

Frank Lloyd Wright supported organic architecture, advocating designing buildings and decorations in harmony with nature. Subsequently, Eero Saarinen built the TWA (Terminal TWA) station, one of the most iconic architectural buildings symbolizing birds' flight in New York City, in 1962. Since 1970, Santiago Calatrava and Frei Otto have changed organic projects and continued to develop, focusing on biomimicry-approached projects. As seen in Figure 3.8, the system used in the Munich Olympic Stadium, designed by Frei Otto and built-in Germany in 1972, is also inspired by the Alps.

Figure 3.8. Munich Olympic Stadium, Frei Otto [40].

The starting point of Santiago Calatrava's design is to benefit from nature. The Milwaukee Art Museum's Quadracci Pavilion, completed in 2001, is an example of mimicking nature and incorporating new elements into the system. The structure is similar to feathers and has a movable top cover (Figure 3.9.). The wings open during the day to ensure natural enlightenment and close to protect the museum at night or in inclement weather.

Figure 3.9. Milwaukee Art Museum with indoor and outdoor wings, Santiago Calatrava [40].

Santiago Calatrava used an imitation of nature in most of his designs. In another work of his, the Lion Satolas Tgw Station, the architect, a civil engineer, and sculptor used bird and human eye figures. As shown in Figure 3.10, the arches used in the structure, which reminds of a bird's wing, merge on the ground and resemble a beak.

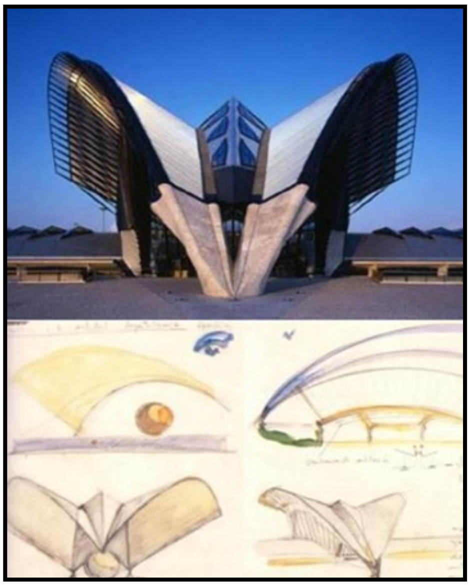


Figure 3.10. Lion Satolas Tgw Station and its sketch, Santiago Calatrava [41].

The Torso Tower, designed by Santiago Calatrava, is based on the buckling in its axis due to the body's rotation and is therefore referred to as a single-screw skyscraper (Figure 3.11.).

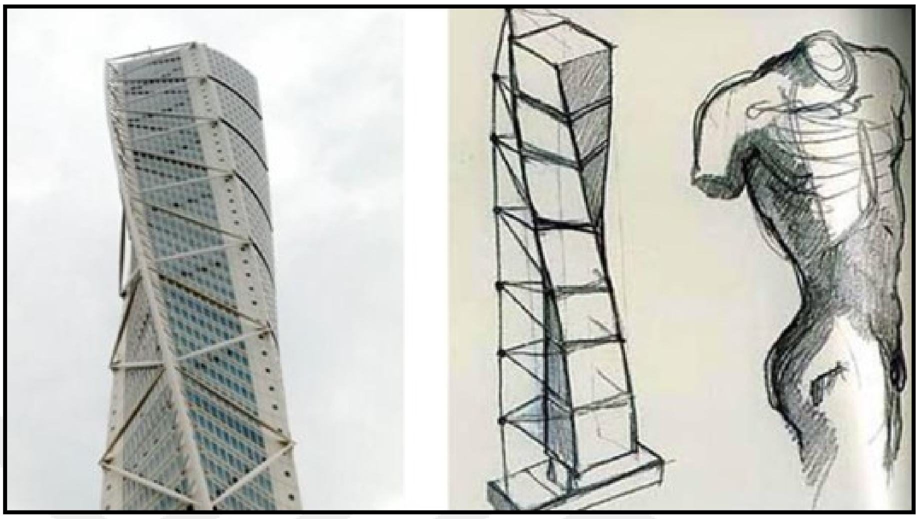


Figure 3.11. Torso Tower and its inspirational drawing, Santiago Calatrava [41].

The BIQ (Bio Intelligent Quotient) building, designed by Splitterwerk and Graz using the biomimicry approach, won the Smart Material House competition and was named the unprecedented facade. The designed house aims to reduce carbon use in the construction industry. This allows it to generate, store and use its energy using the algae biomass provided by the sustainable facade and natural heat from the sun (Figure 3.12.). This experimental project in Hamburg features a 200 square meter algae board that provides all the energy for the users and reduces the amount of carbon dioxide by 6 tons per year while developing microalgae to provide energy and generate heat. In this way, the bio-reactive building envelope provides shading, indoor heat preservation, and noise reduction. With the BIQ system, which produces carbon-free energy, urban planning can be improved by cutting the city's pollution [42].

Figure 3.12. BIQ Building [42].

Italcementi company, headquartered in Italy and the world's fifth-largest cement supplier, provided the self-cleaning property of concrete by using photocatalytic TiO2 in cement. When this material receives light, it breaks down the impurities coming to the surface by photocatalytic reaction and destroys them with wind and rainwater. This new system, which uses the sun and natural weather events without the need for artificial energy for facade cleaning, was designed with this system on the facade of Manuel Gear González Hospital in Mexico City, one of the most polluted cities in the world (Figure 3.13.).

Figure 3.13. Torre de Especialidades Hospital Outbuilding [42].

4. ANALYSIS OF SUSTAINABLE USE OF BIOMIMICRY IN ARCHITECTURE BY EXAMPLES

Researchers followed the principles and levels specified in 2.2. in examining biomimicry. Here, all non-human beings in nature are described as "natural forms," and the struggle and lifestyles of every species in nature against itself, its environment, and the problems it encounters are examined within the framework of benefiting architecture and researched in the context of biomimicry in the categories determined by the author. Biomimicry reveals that the subject of bringing our living spaces to this level can be achieved by imitating these natural forms in various aspects, while nature lives without waste and consumption without requiring any intervention. In this context, since they are precedent, it was necessary to examine many natural forms that can do this, considering them in line with the imitation aspects of the form classified below.

4.1. IMITATION ASPECTS OF THE FORM

Sustainability is an important part of architecture and construction activities, and it is necessary to consider how to establish harmony between people and nature to achieve its goals. Buildings, which are serious energy and material consumers, damage the environment and natural resources. Innovative ways are needed to indicate that people are an element of the environment in structuring. While human beings harm nature with their spaces, every form found in nature circulates the environment of life at zero cost. Nature does not pollute, don't harm. By examining the structurally light but high load-hauling capacity of the forms (plant, animal, organism) in nature, the use of efficient materials, the ability of an organism's waste to be food for another organism, their recycling, and non-degradable cycles, forms in nature can be imitated, and solutions can be sought for the problems of structures. As a result of the literature review, it was concluded that the imitation of forms in nature could be classified according to 6 different aspects in terms of the use of biomimicry in architecture, as imitating the behavior of the natural form, imitating its visual appearance, imitating its structure, imitating its ecosystem, imitating its genetics and imitating its geometry. In this context, it is revealed that innovative solutions can be reached in architectural design by trying to understand the behavior, visuality, structure, ecosystem, genetics, and geometry of existing forms in nature. The subject of imitation of natural form is discussed in the sense of "imitating living (organism) or inanimate (shape) entities from nature."

4.1.1. Imitating the Behavior of the Natural Form

In this regard, examples of desert beetles and termites that are important are given, and their behavior is examined. The functional benefits that can be used in architecture are emphasized.

4.1.1.1. Desert Beetle

The desert beetle (Stenocara), an African beetle, is found in deserts with low rainfall, such as Namibia. Annual precipitation is less than an inch, but daytime fog is high. Therefore, the creatures living here have developed strategies to effectively manage this limited resource, to accumulate and use moisture as water, in other words, to continue their lives. The science of ecophysiology, which investigates how natural forms obtain water in an arid environment, has shed light on their imitation for humanity. To obtain water from the fog, this insect passes from a slightly higher sandhill, where it can give itself to the wind and gives its body an angle of forty-five degrees. In this way, its hardened grainy wings retain moisture, as seen in Figure 4.1. This water-retention ability of the Namibian beetle is due to the natural formation of the organism, through its wax-free water-loving ridge surface and the waxy water-hating areas between the mounds. The moisture droplets evaporate rapidly with the desert heat and fly parallel to the ground due to the wind. The Namibian beetle, which has adapted to this and has experienced centuries, uses its special back design accordingly and holds its back to the wind at an angle of forty-five degrees by standing upside down. The water particles in the environment are collected in the waxless hydrophilic lumpy mounds on the back; when sufficient droplet size is obtained (0.5 cm diameter), water flows from the back of the insect to its mouth by flowing from there to the waxy hydrophobic interstitial spaces of the mounds [42].

Figure 4.1. Namibia Desert beetle [42].

Matthew Parkes was also impressed by the Stenocara beetle and studied how plants and animals live in the desert, observing the type of flora and fauna to use solutions from nature in architecture. The architect who worked in Africa observed the behavior of the Stenocara beetle, which uses water vapor from the Ocean of Atlantis, and established the Hydrology Building of the University of Namibia, as seen in Figure 4.2, and encouraged Parkes to find a permanent solution to create a water source since the Namibia landscape is quite dry and its agricultural area is almost nonexistent. Just like the insect's back, it has some curved shells that face the sea and collect fog while turning, and webs are stretched between the curved arches, just like the gaps between the mounds on the insect's back. Parkes combined this setup with the basement of the building. In this setup seen in Figure 4.3, the water coming from fog number 1 reaches a sufficient level and is sent to the underground tank indicated by the er 2, where it remains fresh by flowing down in its usual flow, and it is prevented from evaporation by being drawn into the basement from the current high temperature of the region as shown by the number 3 [43].

While a water source is obtained with a simple system, it is seen that this system also affects the form in architecture. Since fog is a sustainable water resource, its collection and use do not have the slightest disadvantage to nature, but it helps solve the problem of the resource used in buildings, decreasing day by day.

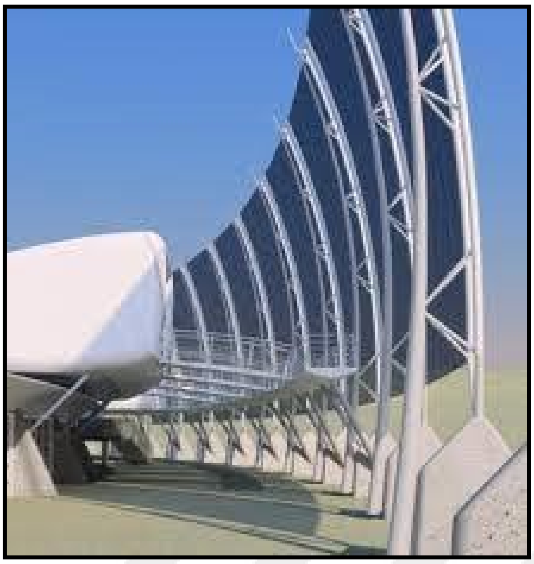


Figure 4.2. University of Namibia Hydrology Building, Matthew Parkes [43].

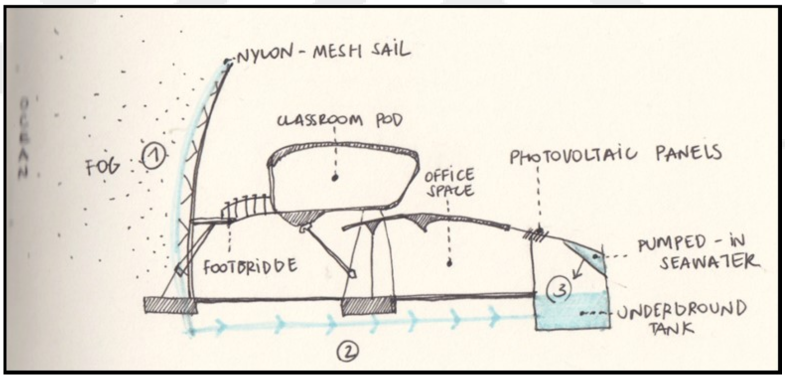


Figure 4.3. Water collection scheme of the University of Namibia Hydrology Building [44].

4.1.1.2. Termite

The relationship of the natural form to the environment in which it lives is investigated at the behavioral level. The Eastgate Building in Zimbabwe, which integrates the action of termite ants into the structure, is also an example of the imitation of natural form at the behavioral level. Termites were used to achieve ventilation and thermal regulation in their nests according to the climate in which they are located to create a sustainable area in the building. Termites are insect species known as white ants that usually live in tropical regions. However, they are visually reminiscent of the ant species but are in the family of cockroaches. They build huge towers on the ground. Using technology, the shapes of natural air and temperature circulation systems are much more advanced than artificial instruments developed. These creatures can control the temperature at the desired level by improving the indoor temperature with the sun's heat, the natural heat source. The damp basement tunnel built under the tower delivers evaporated water to the tower's soaring floors to prevent overheating, and thick walls prevent the internal steam from escaping. The Eastgate building, built by Mick Pearce in Zimbabwe in 1996, was inspired by this enormous air circulation [45].

Architect Pearce implemented the system simulation in the building, based on the building-termite tower relationship specified in Figure 4.4, and received the title of the first artificially cooled building in history. The heavy building mass provides thermal insulation, and underground spaces draw hot air during the day and cold air in the evening, providing airflow that sends hot air to the roof. The cold air that can be stored through the holes acts as an office air conditioner for the next day. With this planning, 3.5 million dollars of energy savings have been achieved for users in a few years [45].

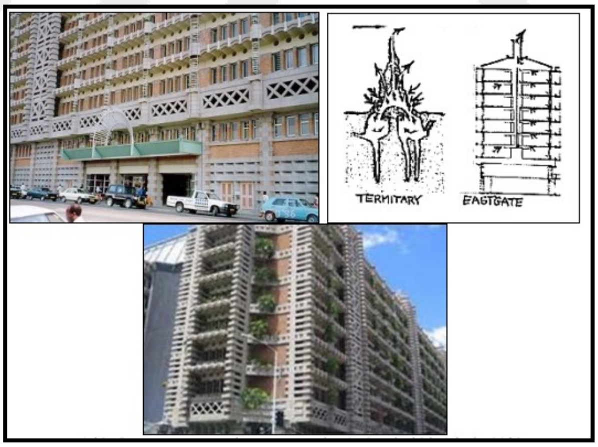


Figure 4.4. Relation between Eastgate building and termite tower [45].

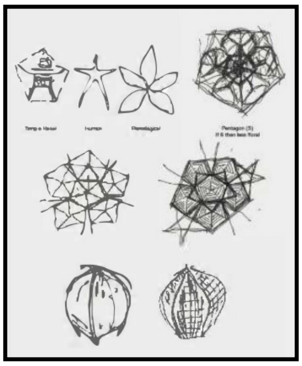
4.1.2. Visual Imitation of Natural Form

The use of natural form in the direction of visual imitation has been given many places in architectural applications. In the following subsections, the most prominent of these examples, lotus flower, sunflower, oyster shell, bat, and eye organ images, are examined, and the gains that can be obtained from the images are investigated.

4.1.2.1. Lotus Flower

Lotus Temple, built by Fariborz Sahba in 1986 in India, takes its name from the national flower of Vietnam. The nature breeze can be seen in this temple's interior and exterior building elements in New Delhi. As seen in Figure 4.5, the form of the lotus flower that has not opened its leaves is outdoor, and the leaf texture of the flower is used as the upper cover in the interior. Looking at the flowers from a bird's eye view resembles a pentagon filled with lines. The human who takes nature as a role model seeks a connection between nature and itself, and this pentagon can be seen as a reflection of the human head-arms-feet (Figure 4.5) [46].

(a)



(b) (c)

Figure 4.5. Lotus Temple, Fariborz Sahba. (a) Frontal use of the lotus flower, [47] (b) Lotus leaf indoor use,[46] (c) Pentagonal relationship of human and lotus flower [46].

Functional gains achieved by being inspired by the image of the lotus flower in the building; By making the ceiling look like a leaf texture, natural light is obtained by covering the spaces between the veins with glass, the middle courtyard was built later, and the side surfaces allow the light to filter through, under the favor of the closed leaf shells on the facades. Thus, 24 percent of the city's total electricity use of 500kW is obtained from solar energy [48].

4.1.2.2. Sunflower

Sunflower, also known as helianthus because it moves according to the sun's direction, has a very long sunbathing period. The panel, designed by taking the image of the sunflower shown in Figure 4.6 as an example, consists of parts resembling sunflower leaves, which can distinguish the thermal difference according to the sun and the sunless place by taking the behavior of the sunflower as an example. This unit does not require a power supply and increases the energy produced by the system [49].

Figure 4.6. Sunflower-shaped solar power unit [50].

4.1.2.3. Oyster Shell

Built-in 1958 in Xochimilco, Mexico, the system is made by combining four curved shells that bend like an oyster pattern (Figure 4.7.). Due to this bend, the structure with the thin top cover can withstand much pressure. By using oyster blood in the building envelope, large-scale structures can be constructed with high material savings [51].

Figure 4.7. Los Manantiales Restaurant [51].

4.1.2.4. Bat

The nature-inspired tracking and tracing device developed in the military is the bat-derived Com-Bat (Figure 4.8.). The United States Navy uses only 1 watt of electricity to collect data with the vibration-driven system achieved by wind power. Using the microphones on it, it controls the sound coming from different places and dangerous oscillations (gas, rationing, etc.) with its sensors [52].

Figure 4.8. Com-Bat mimics the bat [52].

This system, which can supply itself with energy from natural sources, is suitable for security control in buildings and can also be used in smart buildings because of its toxic gas detection function.

4.1.2.5. Eye Organ

City of Arts and Sciences, designed by Architect Calatrava, one of the most magnificent buildings of Valencia in Spain, was built based on space science and animal textures. The complex consists of five large buildings; it houses an opera house, a large aquarium, an oval pool, a science museum, and an herb garden. It is seen that there are examples of biomimicry in the parts of the building described below.

The L'Hemisfèric Building was built in 1998. Its function is IMAX cinema, planetarium. The structure is designed to resemble a large eye and covers an area of approximately 13,000 m². As seen in Figure 4.9, the building opening to the water around it, which resembles an eyelid, is a reinforced concrete curved sphere 110 meters long and 55.5 meters wide. The periphery of the hemisphere is brought up by the folding of the aluminum awnings, just like an eyelid movement, revealing the pupil, and the awnings provide shade by forming the eyelashes of the eye [53].

Figure 4.9. City of Arts and Sciences/ L'Hemisfèric [53].

The visual structure of the eyelid and iris can be compared to the wrinkles and sun lashes that occur when the eyelids are opened on a curved surface. Since the structure can be opened and closed, it allows creating a light and dark environment as desired.

4.1.3. Natural Form Structural Imitation

In nature, no living creatures contain excess and use the material most effectively. Easing the load in the building is very important in terms of both material and energy consumption. In this context, while designing load-bearing elements, being inspired by structures that sustain natural forms can provide sustainable contributions. Whale skeleton, lotus plant, femur, c60 molecule, and tendons described in the subsections are discussed and examined in this regard.

4.1.3.1. Whale Skeleton

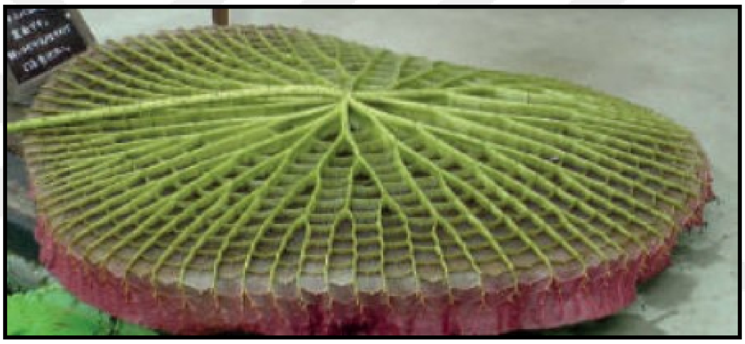
Museo de las Ciencias Príncipe Felipe is a building of the City of Arts and Sciences complex designed by Calatrava, built in 2000. Resembling a whale skeleton, this science museum in Spain is spread over three floors and covers an area of 40,000 square meters (Figure 4.10). The ground floors are used for basketball play in exchange for sponsorship, while 26,000 m2 constitutes exhibitions along with the floors. The first floor overlooks the Turia Garden, with its waterhole covering more than 13,500 square meters. On the top floor is the exhibition "The Legacy of Science" by Santiago Ramón y Cajal and Severo Ochoa y Jean Dausset, while the top floor is known as the "Chromosome Forest," which shows the DNA sequence of humans. The design of the Museu de les Ciències Príncipe Felipe is renowned for its science and mathematics in design. The building covers an area of 42,000 square meters, making it the largest in Spain. The building is 220 meters long, 80 meters wide, and 55 meters high [53]. Structural imitation of the whale skeleton, the carrier system of this large-volume museum can be optimized in wide place formations in a sense.

Figure 4.10. City of Arts and Sciences/ Museu de les Ciències Príncipe Felipe [53].

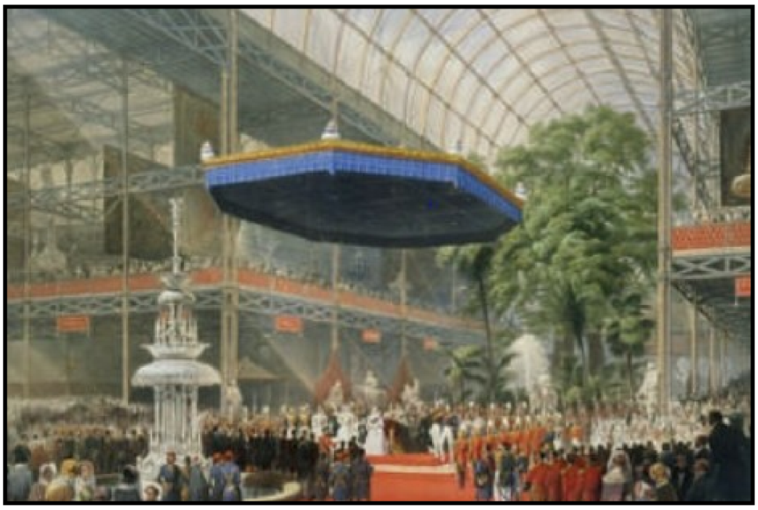
By examining the skeleton of animals, designers can build strong earthquake-resistant structures.

4.1.3.2. Lotus-eater (Victoria amazonica)

The structure of the Crystal Palace, designed by architect Joseph Paxton in Hyde Park, London, England, in 1851, was inspired by the lotus plant called “Victoria amazonica” (Figure 4.11). He observed that the lily was reinforced by the diagonal ribs and carried by a radial rib. The glasses are inspired by nature in a structured sense with their lily structure; conversely, the steel construction was inspired by nature in a structural sense by associating it with the leaf's veins [52].



(a)



(b)

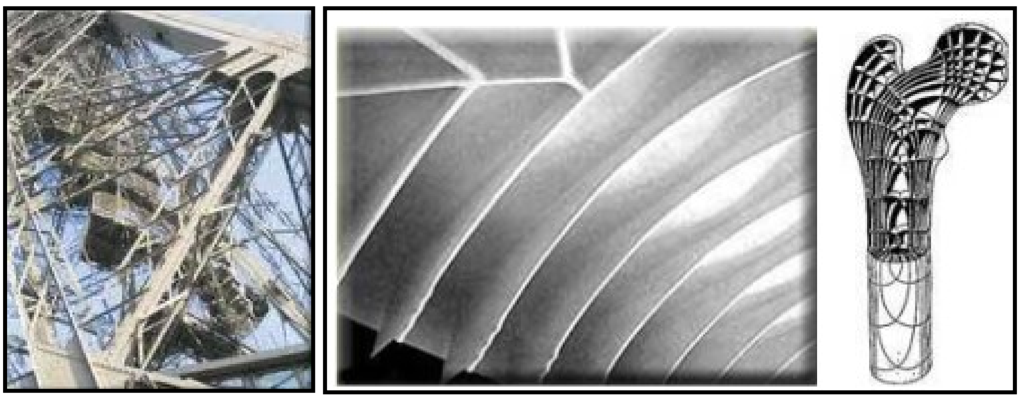
Figure 4.11. Crystal Palace. (a) Veins under leaves of Lotus Plant (Victoria amazonica), [52]. (b) Inside view of Crystal Palace [52].

The height of the structure is 35 meters and covers an area of 7,500 square kilometers. Apart from the steel structure, since the facade element of the building is glass, glass claddings measure 30x120cm on 200 thousand pieces. These two materials do not require heavy loads and cross a larger area with fewer carriers than reinforced concrete [52].

Inspired by the structure of organisms in nature, lightness and easy passage of wide openings can be achieved in materials.

4.1.3.3. Thighbone

The unique design of the Eiffel Tower dates back 40 years before the tower was built. This was revealed in the 1850s in Zurich, Switzerland, by examining the part's curvature connecting the dorsal bone to the hip. The bone was examined, starting from its capacity to lift a tonne in the vertical state. Researcher Hermann von Meyer stated that the situation that allows the femur to stand is formed by the fact that the bone consists of cross-shaped ligaments parallel to each other instead of a single piece. Examining Anatomist Meyer's research, engineer Karl Culmann identified this structure that can withstand heavy loads and observed that it consists of regular networks running along the bone, just as it can withstand load and pressure when standing. As shown in Figure 4.12, this vertical formation based on load and pressure, like a kind of support chain, was taken as an example during the construction of the Eiffel Tower [54].



(a) (b)

Figure 4.12. (a) Eiffel Tower [53]. (b) Comparison of Femur Appearance and Structural Detail [54].

The Eiffel Tower, made with iron ties, nails, nails, and interlocking folds, can withstand the pressure and bending of the wind through this mesh. Just as the Eiffel, as mentioned above Tower takes its shape from the human skeletal system and its internal structure, many advanced technologies are being created to transport objects today, with the knowledge of how the human body survives and is adaptable to incoming movements.

4.1.3.4. C60 Molecule

The C60 molecule is 60 carbon molecules with the appearance of a cage, just like the surfaces of the football being removed and left in the middle with the lines. The molecule, whose real name is "Buckminster Fullerene," is called "Buckyball" by chemists. In the fight against HIV, this system took the virus into its cage and made it unable to replicate itself [55].

While working on energy, scientist Buckminster Fuller indicated that there are mobile and functional systems within our body and environment. The final product is light. The advanced architecture produced in this way contains the basic characteristics of the human ecosystem. Geodesic domes, which we started to see in the late 20th century with different structural forms, also comply with this logic. When Fuller investigated the polio-fighting protein capsule under the microscope, as shown in Figure 4.13, he revealed it has the same structure as the geodesic dome [56].

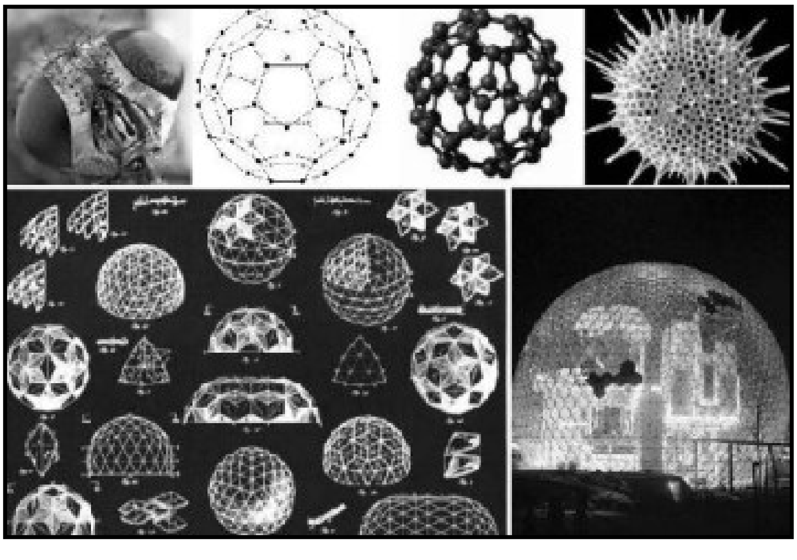


Figure 4.13. Bee's Eye, C60 Molecule, Rays, Geodesic Dome Working Sketch, Fuller's Expo 67 Geodesic Dome [56].

4.1.3.5. Tendons

Another example of the simulation of microscopic dimensions in obtaining architectural products is the tendon tissue that connects our bones to our muscles. Many collagen-based fibers strengthen this tissue. The main thing that gives it this hardness is how the fibers are connected. Metal technology used for suspension bridges is built by looking at tendon tissue in the human body (Figure 4.14.) [54].

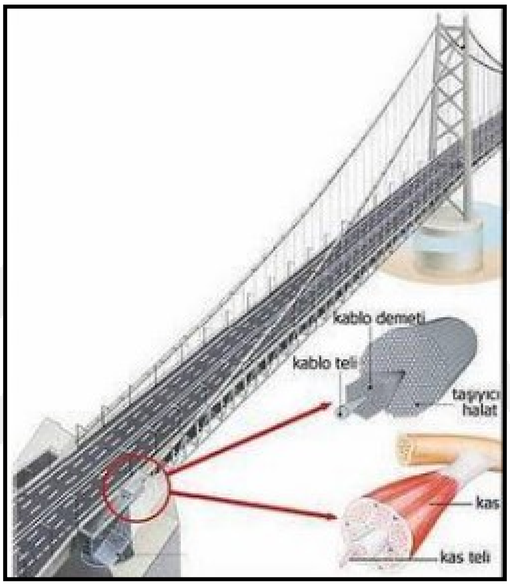


Figure 4.14. Bridge Analogy Inspired by Tendons [54].

The fact that even a microscopic system (tendons) acquires an extremely rigid structure via the connections (fibers) that make it up can allow for solid and durable constructions by observing and applying this system.

4.1.4. Imitating the Ecosystem of Natural Form

In this imitation classification, there is the integration of "nature," which is the habitat of flora and fauna, and "buildings," which is the habitat of human beings, with the imitation of the main principles that provide the functions that enable the entire ecosystem and its faultless functioning.

4.1.4.1. Coral Reef & Collective Housing

When Haiti was shaken by the severe earthquakes that devastated the country on the Richter scale in 2010, ecological architect Vincent Callebaut, believing that the solution to the problem in nature will again be found at the source of what nature offers, examines the principles behind the abundant coral in the ocean for the Hitti region surrounded by the ocean. Coral is an underwater structure containing calcium carbonate and is strong enough not to be affected by waves and thus shaking. The coral reef inspired Callebaut by setting a single standard again to solve the victimization of earthquake victims with an easy, fast, practical, and self-renewing energy-free system, applying it with prefabricated home logic and replicating it to each other. The roof of each prefab serves the other above as a terrace and for growing vegetables and fruits. Just as vegetative and animal organisms form a heap while the coral reef is forming, this futuristic prefabricated order can be reproduced by adding to each other in an endless order like the wave of the reef. Electrical energy is provided by converting kinetic energy from the sea with hydro-turbines under the pier. As seen in Figure 4.15, in the Coral Reef Haiti Project designed by Callebaut, a series of photovoltaic panels were placed on the roof to absorb solar energy [57].

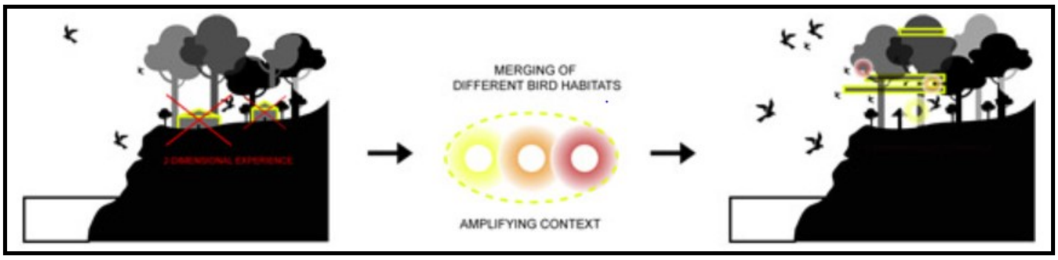
Figure 4.15. Coral Reef Haiti Project [57].

4.1.4.2. Bird & Observation Hotel

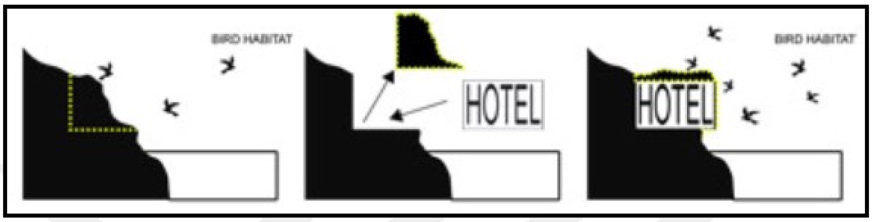
For the regular and healthy functioning of the ecosystem and to avoid global problems, the balance of plants and animals must be preserved and not deteriorate. These steps are necessary to prevent or solve common problems. To achieve this goal, the relationship between plants and animals with their homes (nature) where they can meet all their needs without problems can be examined, communication and layout between each other can be imitated, the current layout in nature can be maintained or opportunities for animal and plant life can be integrated into human constructions.

Models are developed for designs that sustainably meet their needs from nature, without requiring intervention in the natural environment or by doing so in a minimum way (Figure 4.16). Flora and fauna can be integrated into the buildings where we live, as can be seen in Figure 4.17, by creating living spaces for us humans directly in the places where these species live in nature, the trouble-free way of living of other living species can be closely imitated, the continuation of the species in its natural environment can be ensured, and nature can be shared and used as a common shelter for every living species [43]. If our shelters are accepted as natural instead of buildings, we can protect and benefit from them like other plants and animals.

Bird watching is an activity loved by almost every society for centuries and is good for the soul. The idea of building in a way that does not disturb them in nature, which is the shelter areas where the birds live, rather than going directly to the place of watching and looking back, was derived by Morris Architects in the Costa Rica and Alaska regions for the International Radical Innovation Competition in 2008 and won the Honorable Mention award. Costa Rica The Birdwatching Hotel area witnesses large birds such as 450 pairs of Scarlet macaws and their circulation and migration. Alaska, The Birdwatching Hotel region, is home to about 5-12 million bird species, including abundant wildflowers and bald eagles, and offers a pleasure to watch their migrations [58].

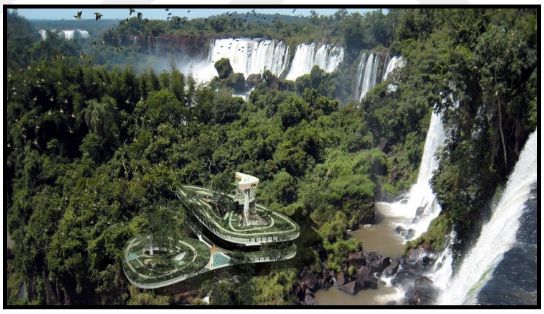


(a)



(b)

Figure 4.16. (a) The design process of Costa Rica Hotel [59]. (b) Design process of Alaska Hotel [59].



(a)

(b)

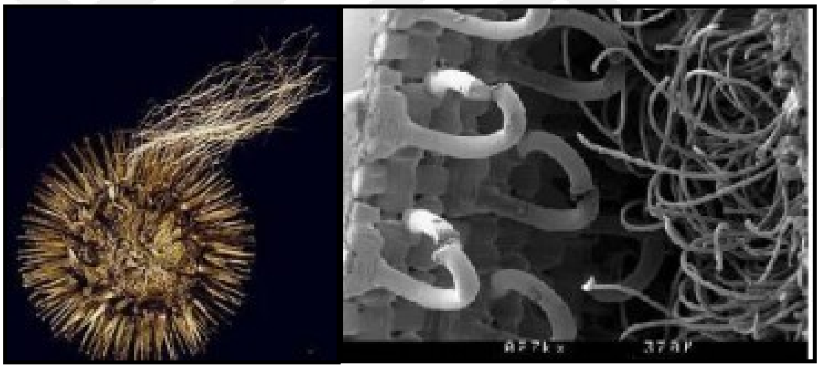
Figure 4.17. (a) The Birdwatching Hotel in Costa Rica [58]. (b) The Birdwatching Hotel in Alaska [58].

4.1.4.3. Imitating the Genetics of the Natural Form

The physiological structures of the burr, peacock, gecko lizard, crocodile skin, lotus plant, and whale fin, which are important in this regard, are examined on a microscopic scale, and design suggestions that can be used in the design are indicated.

4.1.4.4. Burr

In the mid-20th century, scientist George de Mestral, seeing the plants stuck to his dog's plume after hiking (Figure4.18-a), wondered about the basis of this adhesion and examined this plant in-depth under the microscope (Figure 4.18-b). Mestral discovered hook and loop fasteners called “Velcro,” as seen in Figure 4.18-c, and observed that the fastening was due to the many microscopic-sized hooks on the plant surface [60].



(a) (b)

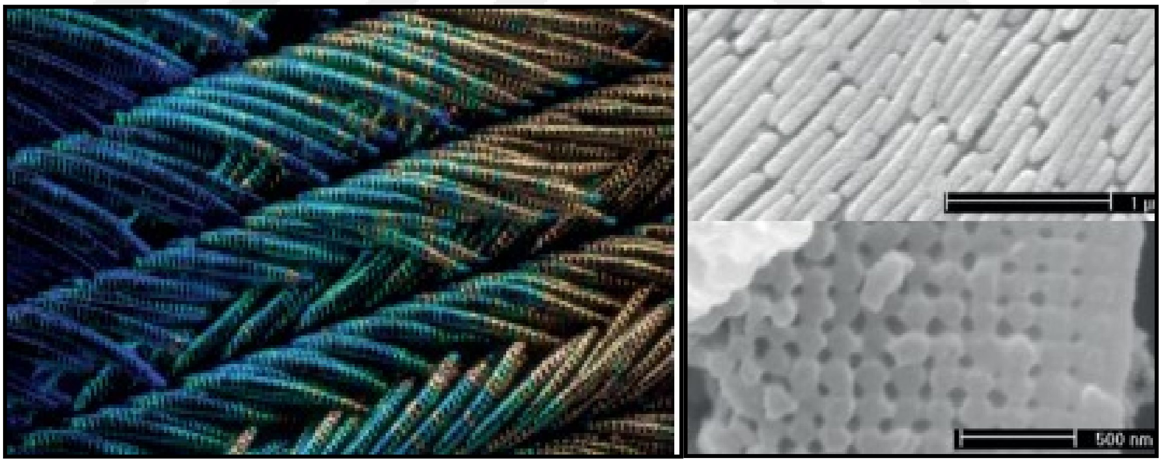
(c)

Figure 4.18. (a) Burr Plant [60]. (b) Microscopic Velcro [60]. (c) Velcro [60].

These plants, which are readily found in nature, can be an organic solution on roofs with floor and wall coverings for fastening and insulation purposes instead of environmental pollutant products (screwing, glue-like chemicals, etc.).

4.1.4.5. Peacock

Peacocks, which open their wings and turn them into a feast of colors, actually have only brown pigment when faced with a problem. But the secret of this technique is that the protein in the feathers receives and reflects the sun in different ways. Japanese scientists have used this situation for traffic school warning signs, which are entirely colored by sunlight without containing toxic and harmful substances [60]. Inspired by the peacock, Guo and his team at the University of Michigan combined this with nanotechnology, producing curved glass particles that absorb the light without any energy source and chemicals, and discovered the property of showing different colors on glass coated with silver (Figure 4.19). Today, this nano-sized invention is used in devices such as tablets, laptop computers, mobile phones, plasma technology, and glasses [52].



(a) (b)

Figure 4.19. (a) Peacock Feather [52]. (b) Peacock Microscopic Structure [52].

This technology can be used to construct colorimetric windows that do not have toxic properties, gain color without chemicals and electricity in a completely natural way, obtain sheets, facade coatings, and break sunlight.

4.1.4.6. Gecko Lizard

Gecko lizards have the comfort of navigating on flat ground while walking around the ceiling and wall with the help of about a million hairs that allow them to hold on to a microscopic-sized set on their feet (Figure 4.20). Geckos carry 14 thousand bristles per millimeter square and can resist up to 133 kg due to the sets, although they weigh 70 grams. Inspired by this system in biology science, researchers have developed a method to create a surface in body cuts that are not affected by water and do not allow to produce harmful substances. This innovative product, called "Gecko tape," also carries a hundred times the gram weight of the cm area it covers [52].

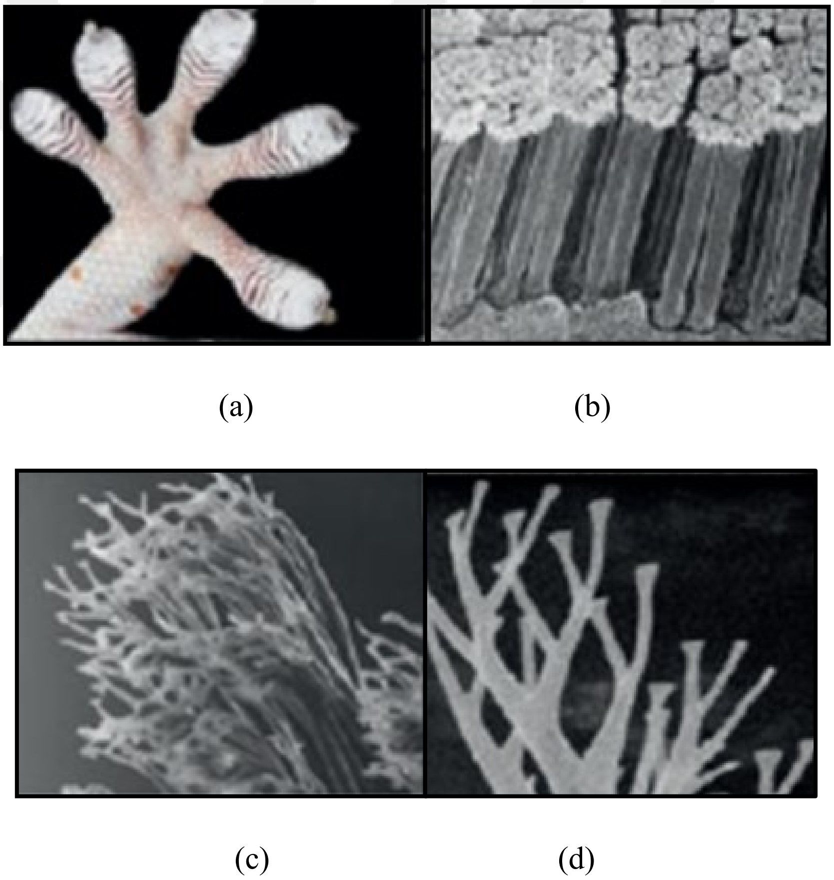


Figure 4.20. a) Lamellar foot structure of gecko. (b) Millions of microscopic bristles cover the surface of each foot (seta). (c) Around 1000 blunt ends at the tip of each seta (spatula). (d) The appearance of blunt ends [52].

Attitude strength is provided without the need for binders/chemicals, which are naturally obtained by lifting more weight than itself and adhering to the surface. This can be used to hold the foundation to the ground in buildings in case of earthquake resistance.

4.1.4.7. Crocodile Skin

The structure of the glass fibers used in reinforcing the plastic and polyester parts of the glass melted at high temperatures is similar to the crocodile skin and is inspired by it. Because of the collagen protein fibers in the crocodile skin core, it is in a structure that can resist piercing and cutting most heavy blows (Figure 4.21). These fibers, which strengthen the crocodile skin, are obtained by adding glass fibers to the plastic fluid with the same logic in glass fibers [52].

Figure 4.21. Crocodile Skin [52].

It can be used in air and land vehicles, prefabricated materials, pipes, bathtub construction, materials made of wood and metal, PVC systems, buildings to obtain sound and heat insulation.

4.1.4.8. Lotus Plant

The lotus plant, also known as the lotus, which can clean its leaves by itself without being polluted by keeping the upper surface dry even though it has large leaves on the water, inspired the scientists Barthlott and Neinhuis in 1997. After examining the lotus plant in the laboratory environment, it was revealed that the area that remained the cleanest during the same period was the area with the most roughness (Figure 4.22) [52]. The dirt that will come with the wind or external factors does not adhere directly but can be swept away on the curved surfaces and cleaned with a small drop of water [61].

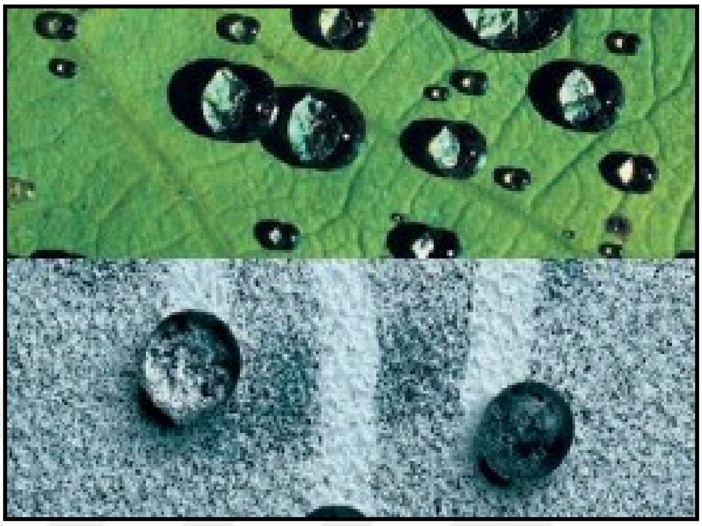


Figure 4.22. The surface of Lotus Plant [52].

By dint of the lotus plant, just as the upper surface of the leaf can be dry despite remaining above water, water-repellent clothing, walls and floors, and facade material guaranteed to keep itself clean for up to five years are also made. More efficient use can be achieved by designing materials that reduce bacteria formation when there is water and dressing them on devices/surfaces that can receive effective energy, such as photovoltaic systems, allowing them to wash [52]. When surfaces are obtained that cannot create toxic bacteria and viruses; this situation can also be used in the showers and sinks of our homes and hospitals that require hygiene.

4.1.4.9. Whale Fin

Nature has also been applied to increase the efficiency of wind turbines, which provide electricity by converting the natural resource wind into mechanical and then kinetic energy. As shown in Figure 4.23, the notched and curved backs of whales, which move agile despite their large bodies in the seas, are taken as an example to make the rotation movement more comfortable in large-scale tribunes [62]. The benefits of the protruding wing over a wing with a flat surface: by storing the wind between the rake, it is slower to stop as it gets more of the current wind, and because of the folds high efficiency is achieved by allowing movement in the same direction as the wind even in the light wind [52].

Figure 4.23. The Whale Fin and The Wind Turbine Inspired by The fins [52].

In high vertical structures such as skyscrapers, jagged surfaces against wind forces can contribute to preventing building oscillations.

4.1.5. Imitating the Geometry of a Natural Form

Since the curling of the rotating surfaces at the correct rate is not calculated, the fans of mixer and air conditioning-like vehicles that we use daily in buildings among the turbines working by rotating cause noise pollution. This mathematical ratio, known as the golden ratio or Fibonacci series, based on the compatibility of a part used in science and art with the whole and the correct ratio, appears in nature in many forms such as the daisy flower, the human body, the snail, the shell and the spider's web. Following this example, Pax Scientific designed rotary systems produced in gold ratio and saved 10-85 percent energy and 75 percent noise compared to a conventional propeller for the propellers seen in Figure 4.24 [52].

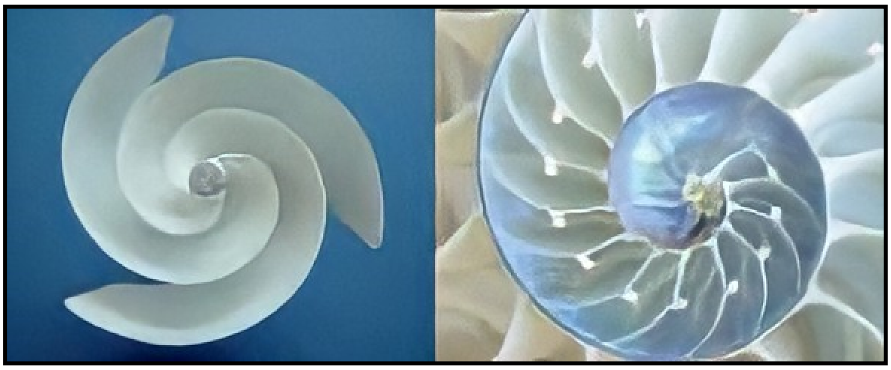


Figure 4.24. Altın oran ve pervane ilişkisi [52].

Since the snail has the golden ratio, that is, the ratio and proportion are close to perfect, it can provide a more solid carrier with less space by saving the space to be covered by the stairs in the building circulation element. Similarly, by imitating it geometrically, the structural structure of the snail shell can be used in the design of the building shell, which can create large spaces. Furthermore, much of the noise pollution from air conditioners and fans used in the cooling of buildings can be reduced, and a lasting contribution to energy conservation can be made.

4.2. RELATIONSHIP OF NATURAL FORM AND FUNCTION WITH ARCHITECTURAL BUILDING ELEMENTS ACCORDING TO THE LEVEL OF IMITATION

Table 4.1. Correlation with the function and architectural building element obtained from the natural form according to the level of imitation, created by the author.

Natural Form	**Function**	**Imitation Level of the Natural Form**	**Associating with Structural Element**
Namibia Desert Beetle	With an anesthetic system installed on the facade, as shown in the figure (Figure no: x), the water taken from the system is collected in a reservoir, and the water needs of the building can be met.	Behavior	Aesthetic facade element
Snail	Ground scraping with less space occupancy, Structural strength can be gained	Visual Structural	Stairs
Lotus Plans	Through the flower image, since	Visual	Facade Interior

	large shells (leaves), are used on the facade, the energy needs of the building can be met with solar energy since the middle part of the flower's leaves are open, natural light intake is provided indoors, in-building heat protection can be provided because the shells are successive.	Structural	Architecture Skylight
Sunflower	Obtaining energy from the sun without the need for an electrical source	Visual Structural	Solar panel in the garden of the building
Oyster Shell	Resistant facade systems can be made with less material	Visual Structural	Facade
Bat	This system, which can provide almost all of its energy from natural sources, can be used in security control in buildings and smart building applications due to its toxic gas detection feature.	Visual	Smart Building Applications
Lily	Lightness can be achieved in materials, and wide openings can be easily passed, more robust buildings with high bearing capacity can be obtained	Structural	Facade Carrier system
Thighbone	How can resistance to moving and fixed loads be achieved with the pressure resistance created by the bending and shearing forces of the wind?	Structural	Carrier system
Tendon	A system of microscopic scale (tendons) gains an extremely rigid structure through the connections (fibers) that makeup, which can be observed and applied to make solid and durable constructions	Structural	Bridge Carrier system
Termite	Regardless of the climatic conditions, it can be ensured that the desired temperature is obtained and kept constant; no need for mechanical ventilation, energy-saving, noise pollution, unexpected wind pressure, and hot air inflow can be prevented.	Behavior	Facade Window Ventilation Systems Roof
Coral Reef	A self-sufficient, carbon-neutral residential area can be created by growing food in an organic garden, placing arrays of photovoltaic panels on rooftops to capture solar energy, and spiraling wind turbines	Ecosystem	Modular homes, Roof garden

	generating power from the tropical wind blowing through the valley at the center of two coral waves.		
Birds	With an approach modeling living creatures that can survive in the environmental conditions in which they live in nature, a structure can be designed based on protecting this area and being intertwined with nature in the region where an existing species lives. Ecologically viable species can be maintained	Ecosystem	Species-specific building design
Burr	The product with a retaining property obtained from burrs as a natural material; can be used as natural solutions by eliminating the adhesive, screwing, and riveting processes that pollute the environment, and an environmentally sustainable environment can be prepared by using it in floor insulation, wall panels (table, frame bonding), insulation and insulation.	Genetic	Interior architecture Insulation
Peacock	Plates without toxic properties, gaining color without chemical and electricity by entirely natural way, can be obtained	Genetic	Facade cladding
Gecko Lizard	Attitude strength is provided without the need for binding/chemical obtained by a natural way to lift approximately twice the weight from itself and hold on to the surface. This situation can be used to hold the foundation to the soil for earthquake resistance in buildings.	Genetic	Building foundation
Crocodile Skin	It can be used in buildings to obtain sound and heat insulation.	Genetic	Prefabricated materials, pipes, bathtub construction, materials made of wood and metal, door and window systems
Lotus Plant	Water-repellent walls and floors can be produced. There is also an exterior material called Lotusan, which is guaranteed to keep itself clean for five years. In addition, materials can be designed that reduce bacterial	Genetic	Walls Floors Facade

	growth in the presence of water. By dressing these materials on solar panels, they can be used more effectively, and energy savings can be achieved by ensuring that the panels wash.		
Whale Fin	Tubercles on the fins have been found to increase efficiency at the edge of the aircraft wing by up to 32 percent. A significant contribution can be made to efficiency in the forms of buildings.	Genetic	Carrier System
Snail Shell	A large part of the noise pollution of air conditioning systems and fans used to cool the buildings can be reduced, and a sustainable contribution can be achieved as energy savings are achieved.	Geometry Structural	Ventilation building envelope

The functional benefits of all non-human beings, namely natural forms, are explained in the previous section at the levels determined by the author. In this section, the functions obtained according to the determined imitation level are tried to be integrated into the architectural building elements. The teaching taken from the natural form is associated with the problem in architectural design and the sustainable solution proposals to the problem are presented by the author in Table 4.1. is also fictionalised. There are many forms that are examined according to the levels. Since nature can sustain itself without hand, economic and ecological maximum benefit can be provided to the design. As a result of the inferences, structural solution proposals for a more sustainable, lighter and more biomimetic building were produced by the author in the sixth chapter.

5. ACHIEVEMENTS FROM BIOMIMETIC DESIGN IN ARCHITECTURE

Architecture creates a visual product, but this visual aesthetic makes sense by appealing to one or more functions. The function is a beneficial action that facilitates sustainability and human life; its concretization is possible with form. The "form follows function" statement of American architect Louis Henry Sullivan, pioneer of master architect Frank Lloyd Wright and one of the founders of Modernism, which is still mentioned as a principle in schools today, supports that both concepts should work together in architecture [63].

By addressing the function, forms generated using the architect's designs can gain uniqueness and ecologically. Nature is the guide in this regard. For example, an ant builds the shape of its nest and the climate inside its nest according to the ecosystem of its place. Mick Pearce's East Gate building, created by observing an ant's nest, a species that lives in nature, is a case in point. A more sustainable world can be achieved by examining the adaptations of natural forms around us according to the environmental conditions and transferring them to our spaces. In this context, design strategies are tried to be developed by associating the organism and its behaviors to sustain its life with architectural building elements. Imitation of nature is achieved by imitating it as form or function. Helicopters in the form of dragonflies, the use of columns similar to the Sagrada Familia tree designed by Antoni Gaudi, the design of Fariborz Sahba's Lotus Temple in the image of a lotus flower imitates nature as a form. Making high-speed trains by looking at bird beaks, designing solar panels inspired by the way the sunflower turns to the sun, using bats for locating and tracking in the navy, designing hygienic products with shark skin, using the lotus plant in exterior cladding with its self-cleaning feature are functionally imitating nature.

By combining today's technology with the nature strategy, buildings and materials can be designed with the desired function. The main thing in architecture is to keep it sustainable, nature-friendly, long-term, and robust by using materials as needed without redundancy, together with visuality. In this context, the answer to all issues can be integrated into spaces by looking at nature.

5.1. VISUAL COMFORT AND AESTHETICS

'Architecture? The colors you hear with your ears; The sounds you see with your eyes; The spaces you touch with your palms; The taste of space on your tongue; The smell of measures; It is the juice of the stone' Marcel Breuer [64]. The size and pattern of all organisms in nature are functional and aesthetic. The visible face of the design is its outer form. An elegant and aesthetic space is at the same time a whole that contains functional, ecological, ergonomic, and sustainable space design criteria. Aesthetics, which gives an attractive effect and provides visual psychological comfort, is not just decoration; it requires a qualified perception. When we look at nature, a dry branch that looks simple blooms and bears fruit after a while because it is in harmony with nature. The aesthetics of the place is work with nature, its harmony with the topography, the opening of ventilation gaps according to the ecosystem, its color, its rhythm.

The golden ratio, which we encounter in most products we look at in nature, such as pine cones, seashells, and sunflowers, is used in every area we size in the design. E.g., Islamic Architecture's Great Mosque (Figure 5.1), Classical Western Architecture Palladio's Emo Villa (Figure 5.2), and from modern architecture, Le Corbusier's Villa Savoye (Figure 5.3) are examples [65].

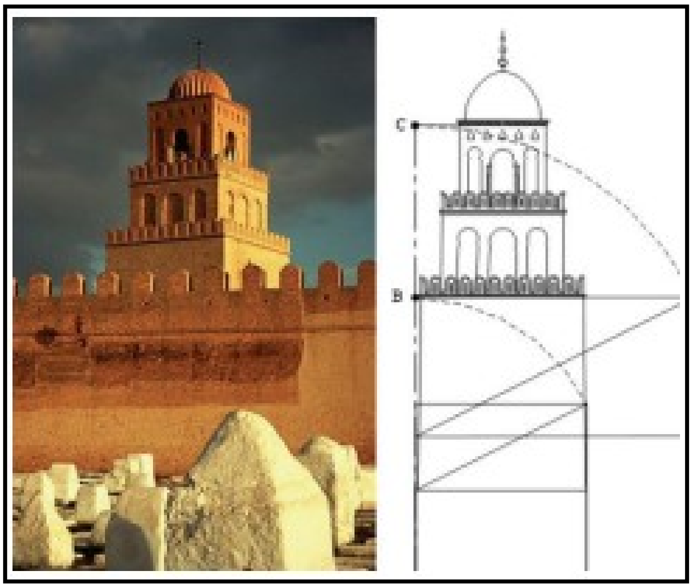


Figure 5.1. The golden ratio of the minaret of the Great Mosque in Kairouan [65].

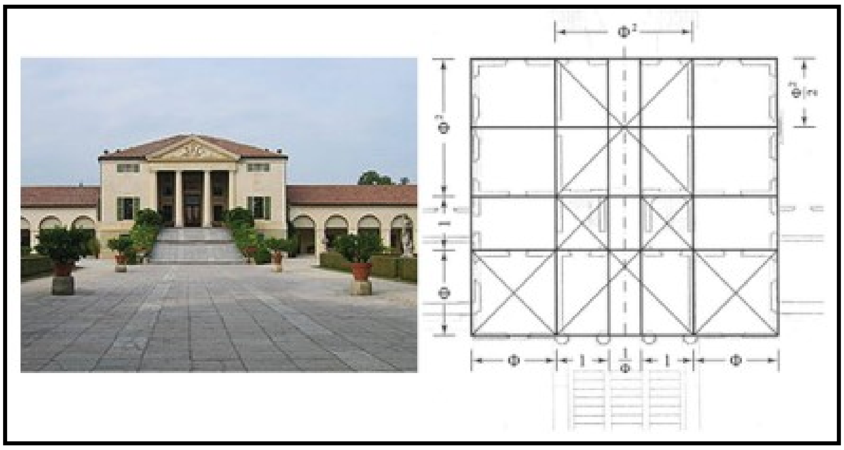


Figure 5.2. The plan of the Emo Villa golden ratio [65].

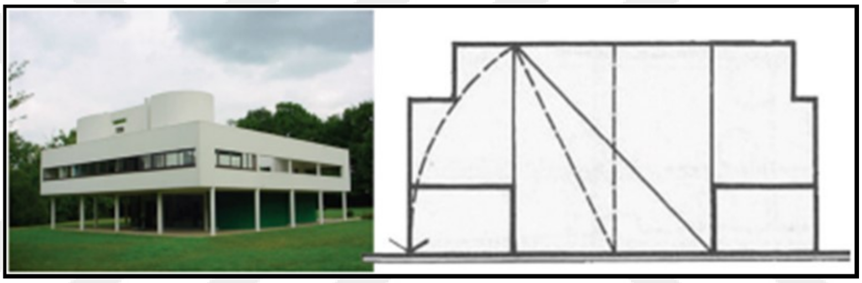


Figure 5.3. Villa Savoye plan golden ratio [65].

The art movement, in which elegant, ornamental, and floral motifs emerged in architecture towards the beginning of the 20th century, carries the breeze of the biomimetic approach. This movement integrates the undulation and curling movements, branching and flower patterns, human-animal motifs on surfaces, which are observed in nature, into interior-exterior designs and the design of tools used in daily life. Despite the heavy, fast, non-aesthetic, and nature-damaging style after the Industrial Revolution, the solution to architectural issues with this trend has been sought in art. The aesthetics of nature is the source of artistic inspiration.

Transferring his admiration for nature to his style and incorporating the biological style into his forms, modernist architect Antonio Gaudi combined arches with geometric shapes and parabolas with organic forms. He has incorporated the growth patterns of humans, animals, plants, briefly angles in nature into his designs. Casa Batllo's work, which he completed in Spain in 1912, has a facade resembling a bubbling wave (Figure 5.4.). The visual source in architectural decorations has been nature [54].

Figure 5.4. Casa Batllo facade [54].

Hungarian architect Imre Makovecz, the founder and president of the Art Academy, also applied to architecture with organic designs with his interest in art. In his narration, originality is symbolized by the tree branches on the columns and the bird wings on the doors. By giving place to the tree trunk theme in the works of Makovecz Arpad Vezer College and Mako Bus Terminal seen in Figure 5.5, visual aesthetics, the feeling of being integrated with nature are used to have a positive effect on human and user psychology.

(a)

(b)

Figure 5.5. (a) Arpad Vezer College [53] (b) Mako Bus Terminal and Details from MAKO Gym [54].

The growth model (branch-fruit) in nature, its incorruptible cycle throughout the climate, its criterion, the questioning of the golden ratio in every living thing in nature, the index of efficient energy and sustainability to design can be used to increase aesthetics in design through nature.

5.2. SUSTAINABILITY

Architecture obtained by biomimicry serves sustainability by carrying all the features of being economical, ecological, functional, recycled materials, efficient energy use, resource conservation, robust, aesthetic, and ergonomic. Rather than imitating the form and color of an organism in nature, the issue here is to imitate its behavior, way of life, and way of dealing with problems without cost and waste.

Other organisms in nature have been making their home and life from available, free natural resources for billions of years. For example, the dorsal tissue of the desert beetle shown in Figure 4.1 is developed for water supply. Frei Otto's Munich Olympic Stadium, shown in Figure 3.8, and Fuller's geodesic dome indicated in Figure 4.13 have a maximum efficiency effort with minimum material. The Eden Project (Figure 5.6.), a large greenhouse concept designed by Nicholas Grimshaw in England, takes the large opening as an example of the hexagonal form of bee nests by passing through a transparent material called ETFE (ethylene tetra foil ethylene), which is a hundred times lighter than a recycled and conventional glass. It has used resources effectively by making more use of solar energy and saving a significant amount from the foundation due to its light structure [66].

Figure 5.6. Eden Project [67].

Designed by Chriss Boss, Tristam Carfrae, PTW Architects, CSCEC, CCDL, and Arup, Beijing National Aquatic Center in Beijing, China, was designed for the 2008 swimming Olympics. In the Water Cube project, the waving in nature seen in Figure 5.7 was inspired by the formation of foam, and it was expected that the facade would receive the maximum amount of solar energy with bubbles resembling soap bubbles. The building, which emphasized the water element inside and outside during the Olympics, saved 30 percent from the energy cost through its soap bubble-like surface; sustainable gains were achieved with biomimicry by 55 percent of the artificial lighting by the capture of solar energy [68].

Figure 5.7. Water Cube [68].

A building that was requested but not implemented for China is the Habitat 2020 project, which draws attention with its futuristic feature. The project, which directly adapts the living natural organism as a living building and aims to construct a living building with technological means, reflects a dynamic structure that can move according to the climatic conditions of its location (Figure 5.8.). The building envelope, designed similar to the leaf surface of a plant, is designed to maximize light and air production by directing light to where it comes from and by its gutters to store and filter rainwater [68].

Figure 5.8. Habitat 2020 Facade [68].

With the bio-imitation method, a solution can be found against global warming, which will have serious negative consequences soon, by looking at the world's past. Functional gains can be achieved by combining increasing technology with nature. The greatest source of inspiration for sustainable design in nature.

5.2.1. Economy

All organisms face the same problems as humans, but they meet these issues sustainably. Since organisms live integrated and with nature, they meet their nutritional, shelter, and breathing needs like us; even if there is any natural disaster or explosion, they have survived since the existence of the world with their methods and live a life without cost-free, environmental pollution, and environmental damage, without using fossil fuels. Some of the methods developed by organisms in nature superior to man-made products are summarized in Benyus's book;

- Bee-eaters can travel across the Gulf of Mexico on less than 10 grams of fuel,
- Dragonflies make better curling motion than helicopters,
- Termite ants are building their nets according to the ecosystem in which they live and to keep the internal ventilation system at a constant temperature without being affected by the outdoor temperature,

- Due to its multi-frequency transmitter, the bat works more effectively than the radar, etc. used for tracking systems.

Javier Senosiain, one of the first organic architect designers, states in his book "Bio-architectural Press" in 2003 that the architecture of the future will take nature as an example, and the reason for this is that it is the most durable, rational, and economical of all methods [69].

The project designed by Norman Foster, which has been implemented but not yet completed, is the first carbon-neutral city in the world in the Masdar region of the United Arab Emirates. Integrating large-scale sunflower-like umbrellas (Figure 5.9) into the project, LAVA (Laboratory for Visionary Architecture) created systems that shading with branching visual elements and moving according to solar radiation and storing energy, taking the movement of sunflowers as an example. It aims to contribute to the economy by providing 82 percent of the city's energy requirement with stored energy [70].

Figure 5.9. Masdar Design [70].

In the context of biomimicry, the organisms in nature being the source of inspiration for the projects, the gain is to include the uninterrupted self-sustaining cycle of that plant or the simulated organism, together with aesthetics, rather than just visually simulating the project. The Lilypad Project (Figure 5.10), designed by Vincent Callebaut in the form of an Amazonia Victoria Regia plant leaf magnified by 250 times, is designed similar to the visual and lifestyle of the plant, which is self-sufficient, meets all of its needs from edible sources, obtains its water from rainwater, and does not cause pollution. Since the facade is covered with titanium dioxide (TiO_2), this chemical also collects environmental pollution because of the photocatalyst [70]. The futuristic project, designed to consume less energy than it gains by obtaining its energy from the sun and wave tides, from the rainwater that it filters the drinkable water, and from the gardens it grows by itself, has not been implemented yet. It is an inspiration for biomimicry to compare the building with all its features to an organism and thus to a self-sufficient natural form.

Figure 5.10. Lilypad Project [70].

In line with the previous articles and the examples examined above, benefiting from the sun/wind energy obtained due to biomimicry, providing sound and heat insulation with organic means, obtaining the facade paints without chemicals and self-cleaning, providing ventilation without the need for mechanical ventilation systems, adjusting the indoor temperature according to the need and maintaining a constant temperature allows therefore to obtain a healthier living space, while a large gain in the economy can be achieved because of the effective use of natural materials and energy.

5.2.2. Energy

For a sustainable, quality life, production efficiency should be achieved, and energy consumption should be reduced. In this context, economic gains also affect energy savings. The common point of the solutions produced with the teachings coming from nature is that they reduce the damage to the environment while increasing the quality of life for people. These solutions provide effective performance (lower energy, less toxic substances, higher profitability, better business results). Our world contains ten million design wonders due to ten million living species. This means that ten million neighbors around us have faced the problems we face.

The golden ratio was seen in the elephant trunk, ocean wave, inner ear bone, and skin pores, where water and air transfer were provided and shed light on industrial design. The engineering firm Pax Scientific has used this mathematical ratio in rotating products such as fans, mixers, and propellers; Compared to the conventional propeller, it has reduced energy use by 10-85 percent and noise by 75 percent. Energy savings can be achieved by using these efficient fans for building ventilation [62]. Although the use of the golden ratio in architecture is generally thought to be an aesthetic perception, the main thing is the functional return of this geometric order. For example, the determination of the golden ratio in the Pyramids of Cheops (Figure 5.11.) adds aesthetics to the structure, while it shows the maximum height assumed by the long large-scale masonry design relative to the floor area [65].

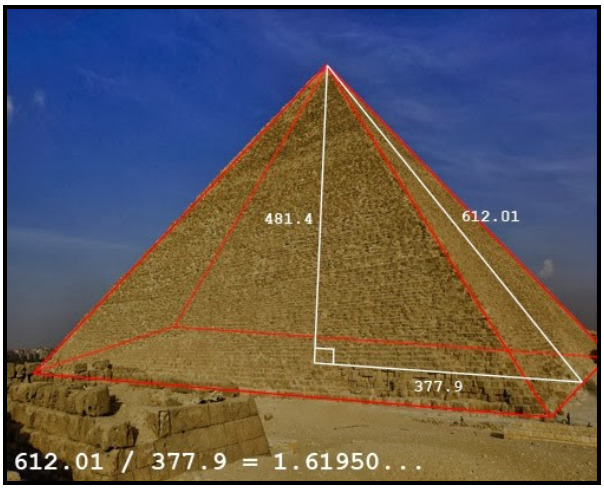


Figure 5.11. Golden ratio in the Pyramids of Cheops [71].

Since the energy consumption of the buildings covers 40 percent of the overall energy consumption, design solutions are sought by the architects. If the form to be created is designed to meet heat loss, heat gain, ventilation, air conditioning functions, i.e., if the form function follows, non-consumption energy can be obtained without using mechanical systems used in the building that lead to heavy energy consumption. In this way, the heat in a building will appeal to all kinds of regulations, and the regulations that provide the user's thermal comfort are called thermoregulation. The design of the facade element, which is the shell between the user and the outside, is essential in gaining and protecting heat. According to Benyus, the methods of nature are to make maximum use of the sun, not to consume more energy than necessary, form with function, and use recyclable local materials. By applying the principles of nature in this way, in Mick Pearce's CH2 Building (Figure 5.12, 5.13) in Australia, the facade of the building was likened to the breathing of tree bark, and the building was ventilated effectively [11].

Figure 5.12. CH2 Building [72].

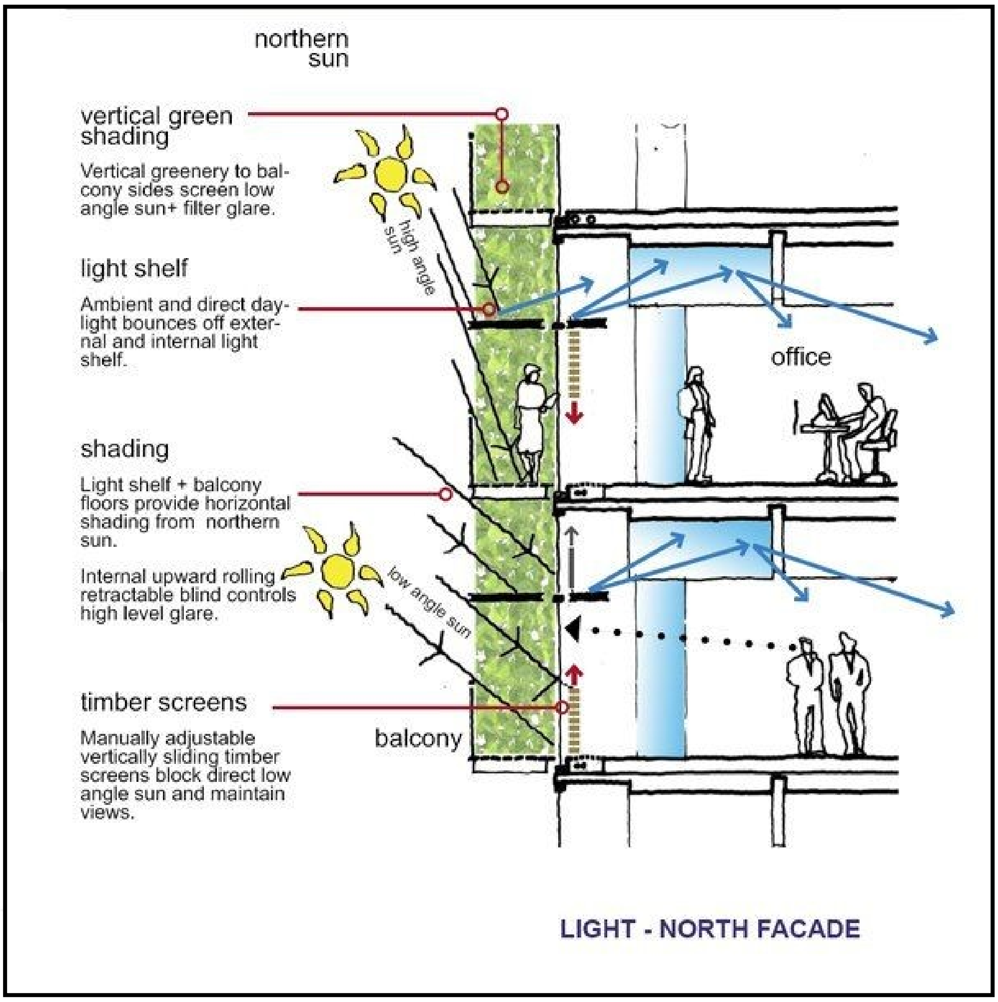
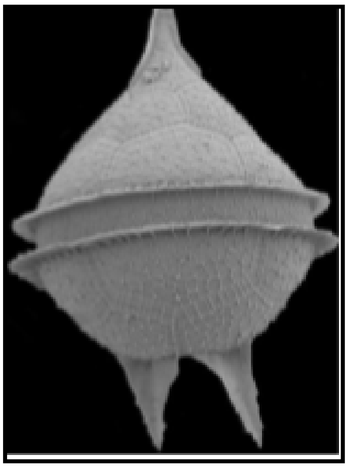


Figure 5.13. CH2 Building Design Concept [73].

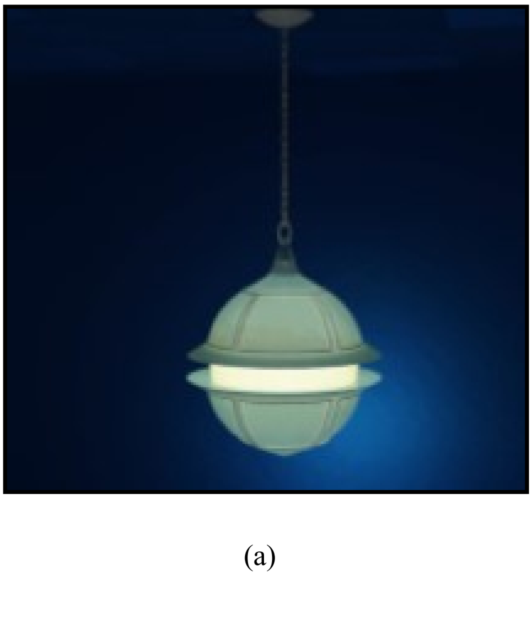
Another issue that causes energy consumption in places is lighting fixtures. Artificial lighting used when daylight is insufficient causes electricity and energy consumption. However, it does not cause visible problems such as water scarcity, light pollution, and consumption cause eye health diseases, damage to the country's economy, and environmental pollution due to energy consumption. Due to the need rather than the concern for the future, the answer to this problem has started to be sought. There are many power outages in Kyrenia, a part of the Turkish Republic of Northern Cyprus. Researchers turned to biology to search for an efficient lighting energy source in this context. They discovered an organism called dinoflagellates, shown in Figure 5.14, that can glow in the absence of light. To provide the action it needs to prevent hunting, the organism obtains cold light by reacting with a chemical called luciferin with the luciferase enzyme. The organism was sampled at both the visual and behavioral levels [9].



(a) (b)

Figure 5.14. (a) Dinoflagellates [9]. (b) night luminous dinoflagellates [9].

Upon examining the specified biological organism, effective energy lighting products were designed for the Kyrenia Biomimetics Office (Figure 5.15.). This product stores the sun rays to the sensors inside when the sun is out, and when the sun is withdrawn, the sphere resembling the shell of dinoflagellates stimulates the light bulb inside [9]. Energy savings can be achieved in virtue of efficient and resource-free systems.



(a) (b)

Figure 5. 15. (a) Designed ceiling fixture [9]. (b) Designed desktop fixture [9].

When every organism in nature also has problems, it struggles with the limited resources around it, like humans, and it reaches the best solution over time. As seen in the example, in obtaining thermoregulation for non-consumptive thermal comfort, clean, resource-free energy can be obtained by utilizing nature.

5.2.3. Improvement of Quality of Life and Protection of Nature

Understanding nature's strategies, taking an example, adapting to nature, being a conscious consumer, creating efficient resources can raise our standards by improving the environment we live in. In this case, to be able to make improvement movements, it goes either from biology to design or from design to biology. When going from biology to design, a problem is solved by using the organism. Examples include gecko lizards. It clings to surfaces by dint of its feet shown in Figure 4.20. Using this function makes it possible to prevent earthquakes and reduce the risks in human life by working to keep the foundation on solid ground. Bats' multi-frequency transmitters can be used to make man-made radars work more efficiently. Another example; Com-Bat, a bat-derived tracking and tracking device developed in the military, inspired by nature. The United States Navy uses only 1 watt of electricity to collect data with the vibration-driven system achieved by wind power. Using the microphones on it, it controls the sound coming from different places and dangerous oscillations (gas, rationing, etc.) with its sensors [52].

This system, which can provide its energy from natural sources, can be used in safety control in buildings and can also be used for building in smart building applications because of its ability to detect toxic gases. Design is about collecting design problems in biology and studying how other organisms in nature and our environment respond to and solve them. An example is the lotus plant. Since the lotus plant shown in Figure 4.22 does not hold water due to its surface structure, it is used in paints that do not create pollution so that the facades of the buildings we live in can remain clean without the need for effort and resource consumption.

Design compatible with nature is possible with sustainable construction. Ergonomics, which regulates the harmony with the surrounding buildings, machines, and nature according to the physical and psychological conditions of the person, is essential in increasing the quality of life. Biomimicry, based on acting in harmony with nature and even like nature, also contributes to ergonomics. In residential life sciences, Prof. Elena

Lurie Luke talked about the development of material technology with biomimicry and the achievement of non-slip, fireproof, clean surfaces that affect human comfort [74].

Ergonomics, which makes us comfortable with the tools and nature around us, and biomimicry, which offers a cost-free, efficient, clean-sourced life with teachings from nature, increases our quality of life.

6. GENERAL EVALUATION

In this section, some structural solution suggestions and evaluations inspired by natural forms are made due to the literature review and the examination of living and non-living forms in our natural environment at various levels.

6.1. STRUCTURAL SOLUTION SUGGESTIONS

There are many teachings to be taken from nature to gain functions that will make sense of the form in design. This way, the highest efficiency is achieved when solving the problem. Biomimicry, which brings an innovative approach by adhering to nature, first focuses on the issue, identifies organisms that have experienced the same problem, and integrates their solution tactics into human life. Because the order in nature is the best, most efficient design and an unbroken cycle. The answers to the questions that we try to overcome with our technical means are solved naturally in our environment. Why not shed light on our designs when nature hosts durable, reliable, clean, recyclable systems?

As a result of literature reviews and inferences, a building idea was designed by observing nature. The structure's efficiency that sustains the buildings can still be found in nature. Nature and organisms do not contain unnecessary products; they use as much material as necessary. An economic plus in design is to find ways to transport the building with the least amount of material. For ecological advantages, the facade factor, which can provide maximum heat comfort in the building and relieve the building load by keeping it to a minimum, has been revisited by returning to nature.

The front of organisms is their skin. Because of their skin, they stay warm in winter and cool in summer, maintaining their body temperature by the ambient temperature. The general diagram of the skin section of the animals is shown in Figure 6.1. Although animal fur is only a few cm thick, it keeps it warmer than a 20 cm insulated wall, which is why furs are used in textiles. However, the main thing is to understand/gain nature's incorruptible cycle instead of harming and using/spending it. In this way, it is to ensure that we live a clean, reliable, resource-free life. The color of animal skin surfaces is also crucial in keeping the sunlight. Desert animals are bright because light colors reflect the sun, and arctic animals have a dark cover because dark colors absorb the sun more. In addition, in animals that spend the summer and winter in the same environment, many mammals switch to finer, short-haired, and light-toned summer fur, as the thick fur they use in the winter makes it difficult to cool off in the summer [75].

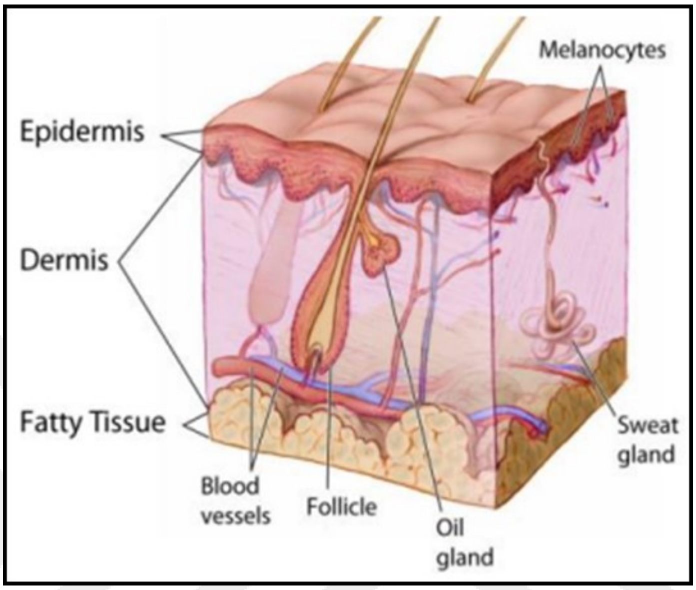


Figure 6.1. Biological structure of animal skin [76].

A well-known feature of architecture is the principle that form follows function. The form contains aesthetic concerns. For this reason, instead of heavy iron casting or insulation materials on bricks that can provide the same function by taking the working principle of animal skin/fur as an example and starting from the fur-like; can we achieve a facade with leathers/fabrics that are flexible, resilient, able to oscillate in the force of the wind and recuperate and prevent breakage and cracks in the fur functional, resistant, thin, light, and with the pattern we want? By applying this to the facade; It is aimed to obtain facades such as living tissue that can use the energy stored from the sun dynamically, change color-thickness as we move from summer to winter, and even when absorbing precipitation, do not cause moisture to exfoliate like brick walls and facades that absorb that precipitation, and use rain such as animal skin to wash and clean without damaging the tissues/items inside. In this way, functional gains, less thick material, maximum insulation, dynamic system, changing the facade thickness and color according to variable climate conditions to ensure heat comfort, self-renewing cleansing surfaces, less thick and flexible areas such as aesthetic patterned fabrics resembling leather, lighter and more earthquake-resistant facades can be obtained with the capacity to oscillate.

Today, buildings such as old and new residences, shopping malls, and stadiums are completed and dressed with patterned textile materials. However, this is achieved by directly covering the existing surfaces whose walls are built and whose completed structure. Textile facades are obtained by hanging flat PVCs, perforated meshes, telephone, or ETFE materials on the steel or aluminum friction material on the facade of the building. In Figure 6.2 below, examples of today's textile facade cladding are given.

(a) (b)

(c)

Figure 6.2. (a) Cheops Technology, France [77]. (b) Charleroi Danse Theatre, Belgium [77]. (c) Cité Internationale de la Tapisserie, France [77].

In the 4th chapter, the natural forms examined with the imitation levels determined by the author are examined, and the architectural building elements that can be obtained from them are fictionalized by the author. With these findings, a building proposal is presented by the author. As a result of the inferences and research in Table 4.1., the building was designed to resemble a living natural form, a living thing.

The facade is designed by combining the textile facade's aesthetic appearance with the leather's thermal comfort capacity (by printing textiles on the elastic wall designed like leather). When viewed from an aesthetic perspective, it will be inevitable to go beyond the classical in every building on the facades to be constructed in this way.

The windows of organisms are their eyes. By courtesy of the convex design of the windows in the shape of an eye, solar radiation can be easily taken from every angle, and the source can be used effectively. With the energy that can be stored, eyelids/sun breaks can be designed to cover the curved glass, which can perform the reflexive eye closing action when the windows are dynamic, harmful, and over radiation, similar to the living organism. Through to the forward-moving glasses, which can store thermal radiation and receive sunlight perpendicular to the curved tangent of the glass in winter, optimum use of sunlight can be made and the trapped radiation can be used for electricity. Since the daylight will not come from below, the camber of the glass is kept shorter than the hemisphere. The mosquito net design that can be made on the linear openable surface of the curved glass surface can support clean breathing. The nose, which is the breathing organ of animals, consists of filtering to prevent germ ingestion. Functional gains; maximum sunshine duration with the curved window design, prevention of harmful rays with dynamic reflex sunshades, and clean air inside the building by filtering the outside air can be achieved. The natural form itself can be looked at again when it comes to cleaning the glass, which will be made similar to the eye, so that it appeals to biomimetic functions rather than formal imitation of the natural form. In order to ensure the cleaning of the glass, a mechanism can be set up to collect the rain water with the rain water gutter, which will resemble the cleaning of the eye with the tear principle, which is its own natural way, and to pour it into the eyelid, that is, the curved window when necessary.

The color of the glass can be thought of as the "eye iris." The functional benefits of pupil-like tinted glasses, which can be obtained by changing the color of the transparent pigment that can be injected into the glass in the light of harmful radiation (peacock principle), are aesthetic glasses that retain harmful rays.

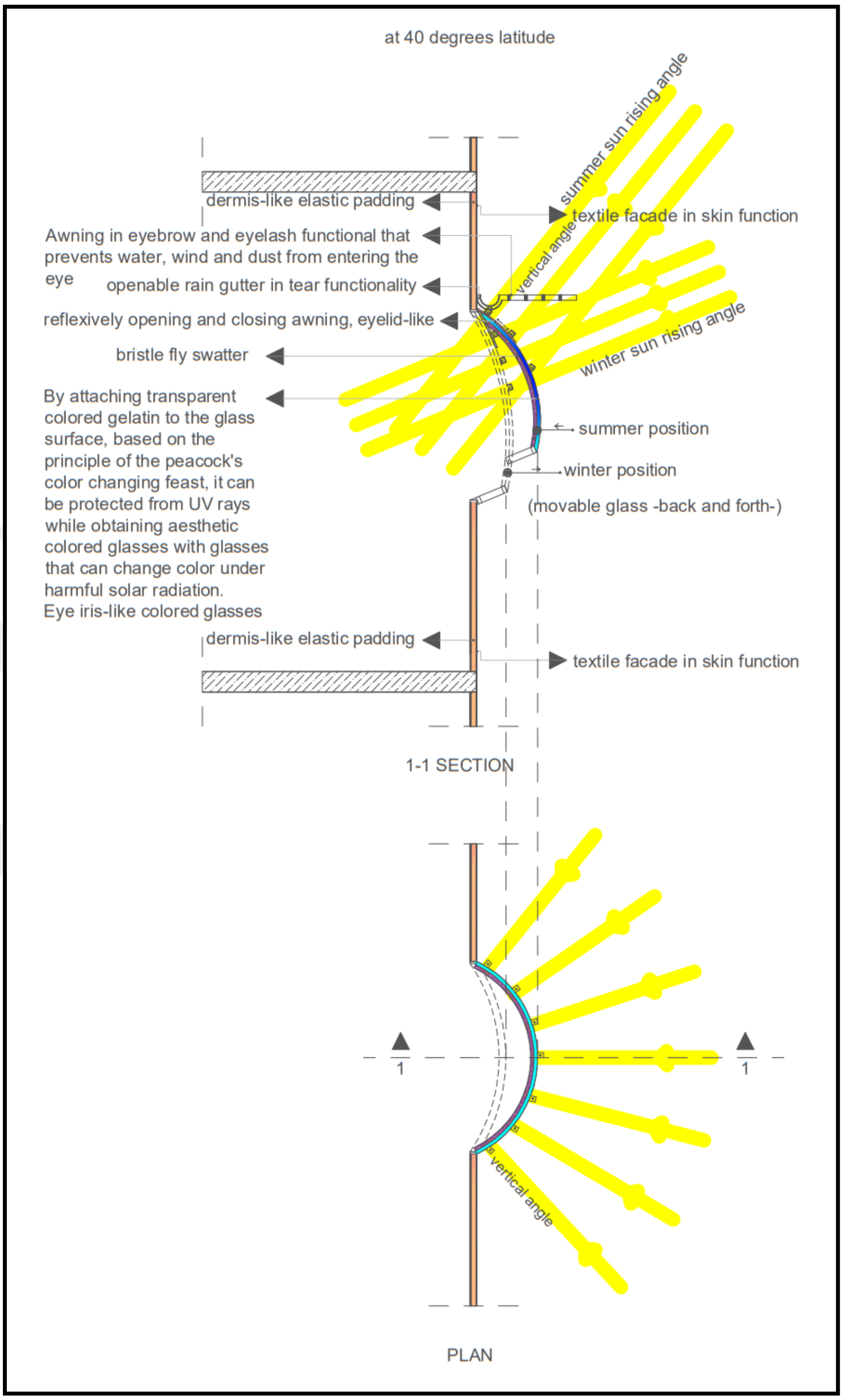


Figure 6.3. (a) Plan and section of architectural elements that the biomimetic way can generate, created by the author.

Since the winter sun rays are more oblique than summer rays in the design, the curved glass is drawn inward in winter. In this way, it is ensured that the sun's rays come at a right angle to the tangents of the camber of the glass in winter. If the glass is pushed out, the tangents of the curved glass are perpendicular to the more steep summer sun rays. These right-angled positions are designed to save artificial energy use by storing the maximum solar radiation throughout the year on the window glass surface. The horizontal circularity of the glass shown in the plan is for the purpose of reflecting the sun's rays from all directions throughout the day to the depths of the space, again perpendicular to the tangents of the glass, in terms of natural lighting. The gutter, which will collect the rain water designed to clean the glass by providing the tear principle, is attached to the eyelash element. Inspired by eyelashes and eyebrows, the horizontal visor has dust-retention and sun-blocking features. The shield has horizontal gaps for the rays to pass through when necessary, and is designed as a continuous mechanism to cut the rays and keep dust when necessary.

Natural forms at various levels determined by the author in 4.1 were examined, and functions that could be used in the building were obtained from the organisms examined in 4.2, according to the determined imitation level, and associated with architectural building elements. Table 4.1, in which many architectural elements from many organisms are generated by the author. created the desire to make the building like a living creature. If the building structural elements module (Figure 6.3.), which is derived by combining the functions of many organisms, is adapted according to table 4.1; One of the natural forms used is the eye, and the level of imitation can be listed as genetic (eye iris), geometric (convex eye structure), behavior (reflex closing eyelid) and visual (eyelashes). The second natural form used is leather, and the level of imitation is the genetic (dermis) structure. Third, the natural form used is the nose, and the imitation level is behavior (nose hair).

As a result of the analogies mentioned above on facades and windows; heating capacity despite the thinness of the skin texture, leather-like textile facade cladding that thins and thickens and changes color with the solar energy stored from the surface when necessary, similar to the transition of fur from summer to winter, elastic filling material similar to the dermis structure in the skin section instead of brick, glass model that can collect the sun resembling an eye from every angle instead of a flat window, dynamic awning on the upper part of the fixed glass, which can exhibit the reflexive movement of the eyelid when the harmful ray comes, and based on the idea of nose hair on the opening window part of the glass, an attempt was made to create a building with mosquito nets in germ-retaining hair tissue (Figure 6.3.).

6.2. DISCUSSION AND EVALUATION

The main theme is to accept nature as the guide in every subject and to provide architectural efficiency. When the word design is mentioned, the primary thing that comes to mind is the aesthetic effort and the integration of the design with the functional equipment that will crown it. To date, the skyscrapers built using technology in the design effort, factories that are rapidly changing, heavy cast-iron structures, the world itself has encouraged us to change the direction in the design effort by giving us the red alarm that we are approaching the end of consumption. Nature, which returns itself without intervention, can at least be a guide in replacing the consumed. For example, although the yarn named aramid is the strongest artificial yarn obtained by damaging the environment with high temperature and pressure, it is weaker than the spider web produced without pressure from the current air temperature [46].

While nature does its job naturally without consuming resources, it adds functional pluses with what it does. The scope of this study is to transfer the achievements of plants, animals, and other organisms around us during their struggle for life to the design. Here, the author described all kinds of non-human living and non-living beings as natural forms and examined the transition to architectural form with the teaching taken from the natural form. The aim is not only to obtain energy from the sun at hand but also to aim for a new architecture with analogies from nature that will increase efficiency in each procedure and building element that will form the building. In this context, there is a desire to build a home-like that can meet all their needs from nature. The human from the soil is still looking for a solution in the soil.

If architecture is done with the eye of creating a living space for people instead of a need for shelter, both the aesthetic effort like architecture can increase, and design solutions that are sensitive and adaptable to environmental elements can be emphasized since it will be viewed from a more psychological perspective. Looking at nature, which shows humanity what to do and how to do it, can make design fully sustainable.

7. CONCLUSION

Biomimicry, a natural method known to live creatures, has started to develop in the 20th century; however, its conceptual name is not given; it also includes many experiments and applications with the same meaning as inspiration from nature dating back to the 1400s.

Biomimicry, which aims to develop design by observing nature in design, offers clean and minimal resource consumption living spaces intertwined with nature with innovative ideas that can be produced. This idea has emerged as a solution to the problems we face in our daily lives. Humankind has already faced these problems for millions of years. However, the idea of biomimicry gained importance when the global issues of rapidly depleted resources and pollution to nature became severe, and humanity went back to the beginning and questioned where it went wrong. The architecture, which occupies nature artificially, has started to try to cover this damage naturally. In this context, while struggling with problems, it has been noticed that billions of species of organisms around us/our neighbors near our homes naturally struggle with these problems and meet them sustainably. These natural forms around us shed an innovative, bright, and organic light on design because they can nest at the desired temperature, produce naturally, are waste-free, and meet their needs from nature at no cost.

With the teachings taken from nature, biomimicry can be seen as a basic approach that ensures every field's sustainability in-vehicle, tools, shelter-structure, and settlement designs. By collecting the functional surpluses of the assets that are already present in nature, sustainable building designs based on biomimicry can be directed. The main achievements of biomimetic design to architecture, “Visual comfort-aesthetics,” can be presented as sustainability that provides economic, energy-efficient, and quality life. The analysis of the natural forms examined due to the scope can be achieved by imitating them in ways that the author can classify as behaviour, visual, structure, ecosystem, genetic and geometric.

The principles of biomimicry are partially overlapping principles introduced by different pioneers. These principles can be summarized as future-oriented principles in every field, such as consuming as much energy as necessary, recycling, creating the form to perform the function, adapting to different conditions, meeting the needed materials from nature, developing while struggling against problems, and providing maximum efficiency with fewer resources.

The "ecological and sustainable design approach," which is by the design principles specified as the use of biomimicry in architecture, maximum use of the sun, reduction of heat loss, adaptation to nature, optimization in materials use and infrastructure systems, and use of plants, is also a method that is entirely in line with the "green architectural current" that develops in parallel with it.

By imitating forms in living or inanimate nature at different levels, it is possible to create design elements with varying functions in architectural design. By accepting the fact that humans are also a part of nature, biomimicry demonstrates harmony with the laws of nature by imitating nature in the spatial arrangements and construction of buildings created by humans.

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