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# INFLUENCES OF THE LIVING WORLD ON ARCHITECTURAL STRUCTURES: AN ANALYTICAL INSIGHT

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**Abstract:** Structures in the nature motivate innovation in architectural and engineering disciplines in terms of aesthetical, functional and structural advantages. Using efficient, lightweight structural forms similar to those in nature reduces material and energy usage and waste amount. In this sense, it can be clearly seen that based on learning from nature in relation to meeting gradually increasing and changing requirements through limited resources and creating modern structural designs, biomimicry will provide much more contribution on architecture and related fields. In this direction, in the study based on comprehensive literature research, lots of varying living organisms in the nature have been analyzed in terms of structure; architectural structures developed by inspiring from natural structures have been sampled and influences of solutions inspired from nature on architectural environment have been focused.

**Keywords:** Nature, Living World, Structure, Architectural Form, Structural Design

**Mimari Strüktürlerde Canlı Dünyanın Etkilerine Analitik Bir Bakış**

**Özet:** Doğadaki strüktürler estetik, işlevsel ve strüktürel avantajları bakımından mimarlık ve mühendislik disiplinlerinde yenilikleri motive etmektedir. Doğada bulunan strüktürlere benzer etkin hafif strüktürel formların kullanımı malzeme ve enerji kullanımını, atık miktarını azaltmaktadır. Bu bağlamda sınırlı kaynaklarla günümüzün giderek artan ve değişen gereksinimleri karşılamak, modern strüktürel tasarımlar yaratmak noktasında doğadan öğrenmeyi esas alan biyomimikrinin mimarlık ve ilgili alanlarda daha pek çok katkı sağlayacağı açıkça görülmektedir. Bu doğrultuda kapsamlı literatür araştırmasına temellenen çalışmada, doğada çok fazla çeşitlilik gösteren canlı organizmalar strüktürel bakımdan analiz edilmekte, doğal strüktürlerden esinlenilerek geliştirilen mimari strüktürler örneklendirilmekte ve doğadan üretilen çözümlerin mimarlık ortamına etkileri üzerinde durulmaktadır.

**Anahtar Kelimeler:** Doğa, Canlı Dünya, Strüktür, Mimari Form, Strüktürel Tasarım

## 1. INTRODUCTION

Nature's design strategies and solutions are a rich source of inspiration for various branches of science and technology. Especially recently, as topics like active usage of sources, reusability of materials, recycling, economy and sustainability gain importance, researches on nature have increased. Additionally, with the increase in computer-aided design usage and production, pursuit of architectural aesthetic and structural elegance has changed today's structural industry and directed architecture and related disciplines towards learning from nature in the process of creating complex structural morphology.

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In this sense, the study aims, on one hand, to increase structural performance and, on the other hand, to search for nature-originated structures that create a different architectural language and to find what kinds of influences and transformations are resulted from solutions and developing ideas that are based on natural structures on the architectural environment of today’s world and future on behalf of producing sustainable solutions.

During study, firstly, a literature research has been made in a wide range and content of “biomimicry” concept mentioned frequently in the process of learning from nature has been discussed generally and specifically. For converting the design knowledge in architecture discipline in the most understandable manner based on that design knowledge exists in nature and this information is accepted to be real, two important questions underlie this study: What are the best structural models in nature? and How are these models utilized in the best way? In order to find answers to these questions, as a priority, living world is analyzed in the structural point of view. Organisms that are analyzed are those that come to forefront with their structural activity, that are source of inspiration in architecture and that are mostly mentioned in literature resources. Non-living beings have been excluded from the study. In the next step, this study is defined how the living world affects the architectural structures.

## 2. BIOMIMICRY IN STRUCTURAL DESIGN

Architects and professionals of many disciplines who are interested in design have been observing and analyzing biological models of nature and they can put the information they obtained into the practice while designing new products. Eilouti (2012) states that solutions which are produced according to the suggestion of natural organisms and such information described as biomimetic establishes the connection between building man-made products and solving design problems within the new perspectives models: The “Biomimicry” term represents a concatenation of “bio” which means life and “mimesis” meaning imitation. Janine Benyus’ book ”Biomimicry: Innovation Inspired by Nature” published in 1997 refers to a new scientific field that studies nature, its models, systems, processes and elements, and then imitates or takes creative inspiration from them to solve human problems sustainably. Benyus also co-founded the Biomimicry 3.8 (2014) emphasize that biomimicry’s solutions are sustainable, perform well, save energy, cut material costs, redefine and eliminate ”waste”, heighten existing product categories and define new product categories and industries. P. Zari (2007) state that through an examination of existing biomimetic technologies it is apparent that there are three levels of mimicry; the organism, behavior and ecosystem. Within each of these levels, a further five possible dimensions of mimicry exist. The design may be biomimetic, for example, in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function).

In this sense, study emphasizes that only when we change our perspective of nature and when we develop design approaches taking above mentioned advantages as basis can we produce sustainable solutions. In the study, stages of biomimicry design spiral that questions nature on all levels for inspiration and that evaluates design in this direction by biologizing existing problem. Thinking that structural design information exist in nature; learning structures that belongs to best models in nature by discovery, analyzing these, determining these correctly and realizing the best and sustainable applications by providing information transformation in terms of architecture discipline from this stages of the study (Figure 1).

Today, each element of nature continues to be studied for creating more lightweight, durable, flexible, economical and high-performance architectural structures. Stach (2010) states that structural optimization driven by limited resources, environmental impacts, and the technological race is targeted to maximize the performance of a structure or structural component. Stach (2010) also emphasizes that structural morphology originates from the relationship between form, forces and the material, and there is an important area of research for

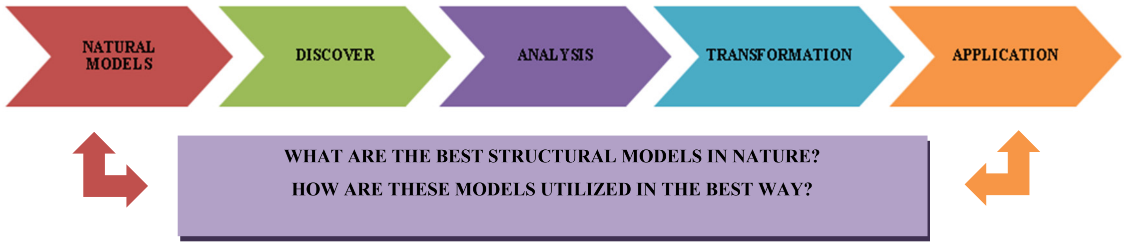



***Figure 1:***
*Transformation process of structural design knowledge exists in nature (created by author)*

the development of structural design. Ekinci (2010) also states that structure forms the architectural language of the construction by morphologies and the architectural language provides the connection between the construction and its user. Structure considered as a symbol with its elegance, beauty and impressive power, at this point aesthetics comes to the forefront. Aesthetics is the primary consideration in symbolic design and the designer's objectives directs the structural design. At this stage, in the structural design it is obvious that a holistic approach is unavoidable. Figure 2 shows that a model selected from the nature will reach to a design concept only with a holistic approach through the multi-dimensional process. At this stage, skills and abilities of the design team members are very effective for achieving results (Majowiecki, 2005).

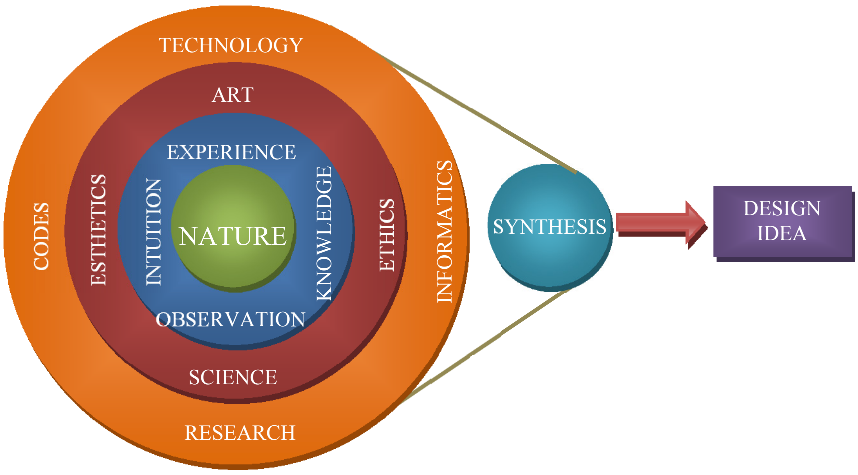



***Figure 2:***
*Holistic approach to structural design* (Majowiecki, 2005).

## 3. ANALYSIS OF STRUCTURAL SYSTEMS IN LIVING WORLD

Fisrt stage of discovery in scientific researches that are realized on the purpose of finding reliable solutions to problems is “observation.” During observation process, collecting data in planned ans systematic way is enabled by answering questions “what” and “how.” By this way, the opportunity to search for best natural models that gives answers to questions, to determine, find and define them, to detail what kinds of approaches are produced by the model, to think through metaphors and to cooperate with biology discipline reveals itself. The second stage is to analyse these data that is acquired.

The structural systems in nature have a large of variations. In this study, structures in nature have been analyzed taking living world, which is plants, animals, humans and microorganisms, as basis.

Structural systems that hold up and balance the organism against the force of gravity and provide resistance against many different forces, weight and stresses, show differences (internal skeleton, the exoskeleton and hydrostatic skeleton) in the living world. Each structural element from macroscopic organisms up to the small molecular components is formed by the combination of similar sub-structures, hence; distinction of "material" and "structure" is not possible. At the same time the forms of natural structures originate from the functional requirements covered by a structure (Kneppers and Speck, 2012). Thus structures of organisms, material, form and function form an intact structure which is related with each other. During development, structure of organism changes in terms of size and shape. This entire process is a result of the genetic information which exist in the design and development of the systems that consist of structural systems growing parallel and concurrent with each other (Mosseri, 2004). Natural structures' performance is based on complex geometry and differentiated material organizations. Natural morphogenesis facilitates the development of shape under the influence of multiple external and internal stimuli resulting in highly adapted performative morphologies (Dörstelmann, 2014).

In this sense, below-mentioned organisms are those that surpasses others in terms of integrity of function, morphology, structure and material, that inspired production of similar architectural structures by functioning with the least energy and material at maximum. Literature resources that examine structures in nature were used to determine organisms. Additionally, AskNature.org site of Benyus is a resource to be used in this specific topic and other topic related to nature. AskNature.org (2014) database is an open-source database about biomimicry and is the world's most comprehensive catalog of nature's solutions to human design challenges.

According to the literature survey, Senosiain (2003) have included cactus, skeleton of four-footed animals, animal legs, trees, human body, bones, insect and mollusk shells, eggs, radiolarians and spider webs as natural structures in his book.

Arslan and Sorguç (2004), have classified structures in nature as one, two and three-dimension according to their load bearing capacity: **One-dimensional** natural structures are usually lightweight elements. Such as tension-stressed fibers, hairs, sinews, muscles, intestines and compression and bending-stressed stalks, trunks, branches, bird feathers, bones. Membranes of cells, skins, intestines, and spider webs can be considered as **two-dimensional** structures resistant to tension, exhibiting membrane, or shell characteristics that are able to transmit forces through their surfaces. Structures composed of tension and compression-stressed elements, such as the wings of insects, bats, birds etc. are two-dimensional. Most structures in living nature are **three-dimensional**. These include particularly tension-stressed cells, organs, hollow bodies and all mollusks. Many compression and pressure stressed structures, such as vertebral bones as well as the compression and bending resistant skeleton systems of trees and bushes, the spongiosa inside bone and the three-dimensional skeletons of radiolarian are also included, in this categorization. The bodies of many animals consisting of tension-, compression- and bending-resistant elements are also three-dimensional.

Also, in their studies, Arslan and Sorguç (2004) and Garcia, P. and Gomez, F. (2009) have presented five prototypes of structural arrangements in nature: pneus, shells, trees, webs and skeletons (All are lightweight structures: active-form ones (pneus, shells and webs), lightweight column (trees) and lightened skeleton (skeletons).

Features of some structures in the nature have been mentioned below.

When living world is analyzed in terms of structural efficiency, the samples from the plants' realm that comes to the fore are the **tree branches**. Senosiain (2003) points out that pressures types on the trees such as pressure, stress, stretch, shear and bending are good examples. Flexibility of the tree leaves and small branches and deformability under the load caused by the wind is a very effective way of reducing aerodynamic loads. Burges and Pasini (2004) state that trees have lateral outward roots which connect itself to the ground and far exterior roots of the tree are supported with a soil layer which create a lot of weight to help the tree to take root.

Senosiain (2003) also considers the **human body** as an important example of the design in dynamic balance. The **skeleton** is body's internal structure in which the spine which is supported by the pelvis is the base. The whole structure is moved and held together with **muscle systems**. The network in this tension (muscular system) and human body's structural resistance can be explained by the linkage of soft and hard, flexible and rigid systems that resists against pressure. According to Baldridge (2003), **skeleton of the vertebrate** which exists in both human beings and animals is the most important invention of the nature. Along with rigid characteristics, it has capability of flying, maneuvering under the water, supporting large weights against gravity and protect the organs from outside effects. Also, the **bones** that consist of the dead and live tissues, constitute the skeleton which continues to work and support the organism as it grows and go through changes.

Like bones, **shells of insects and mollusks** form light and sturdy structures. This rigid structured shell situated outside the body is usually composed of calcium carbonate deposition. In spite of their thin structure, curved structured oyster shells' resistance to enormous pressures is provided by this figuration. If we consider that their three-dimensional form is shaped like spring, **shells of animal eggs** transmit the forces against the pressure with minimum material in an effective manner (Larsen and Tyas, 2003). Small air pocket inside the eggs provides them this feature.

Tension using structures like **spider webs** are thinner and they can support more weight with less material. Kishimoto et al. (2006) indicates that **insect wings** that can open and close create combined structure systems with the thin membrane and inflatable vessels. Membrane wings of bats also can be opened and closed very quickly. One of the design principles of this kind of biological structure systems is using stretchable material that reduces the overall weight.

According to Senosiain (2003), in nature, another structure composed of least material which is lightweight and very flexible besides being durable is micro cells (pneumatic structures) which have surface tension. Every **animal and plant cell** is a pneumatic structure (protoplasm) which consists of a membrane and the contents. Other examples for this kind of structures are transmission systems of plants, the internal organs in general (placenta, intestine, stomach, heart and lungs), soft fruits like grapes, tomatoes, corn seed, egg yolk, or soft eggs of fishes, insects and reptiles.

Cellular structures that repeat themselves in a regular or an irregular manner are also common in nature. These structures combine with closest packing system, in other words, with the combination of cells which are close to each other. The most common arrangements of cellular distribution within the biological morphology period are spherical and hexagonal models. For example, hexagonal structure is frequently seen in some **skeletons of diatoms** and **radiolarians**, some of the **eyes of insects** and in some **honeycombs**. These are formed with a certain rigidity and efficiency of the spaces in these structures. Bar-Cohen (2006) state that honeycombs consist of perfect hexagonal cellular structures and they offer optimal packing shape. For the honeybees, the geometry meets their need for making a structure that provides the maximum amount of stable containment (honey, larvae) using the minimum amount of material. Cellular structures are seen in porous zone of **human bones** called cancellous or spongy bone. Here, the structure is generally in network form not in regular morphologies. Having this structure, bone minimizes overall weight while carrying excess weight with its' structural capacity. These irregular cell structures are also seen in some **plants** and **insect wings.**

## 4. TRANSFORMATION OF STRUCTURAL DESIGN KNOWLEDGE

Many natural structures mentioned above have impacted the architectural world in multi-ways during innovative structure production stage. Biomimicry represents a transformation of design knowledge exists in nature into architectural design. Eilouti (2012) states that the epistemological and methodological assumptions underlying knowledge transformation in biomimetics are based on a cross-disciplinary understanding and approach to knowledge building. In this approach, knowledge is transformed from biology to other design-oriented disciplines such as architecture and engineering. In this stage, nature can be imitated directly or indirectly as a metaphor to solve design problems and to develop environment-friendly functions, systems and solutions. According to the Gruber (2010) abstraction is the key to transferring ideas from one discipline to another. Thus, models are abstractions from nature.

In structural context, nature's structures and forms continue to motivate architectural innovation whether it is aesthetic, functional or structural. Garcia P. and Gomez F. (2009) indicate that this combination of knowledge about structures in nature and the possibility of constructing new structural prototypes made architects and engineers turn back their eyes to nature to learn about optimal morphology, extreme lightening, functional integration and efficiency.

In a similar notion, Grigorian (2014) also indicated the necessity of taking some basic rules into consideration to catch the design information from a living organism (such as a tree) and to transform it. These rules are: Structural applicability (geometric and framing similarities, use and behavior of materials); functional similarity (being subjected to similar loading and environmental conditions); response homology (behaving the same way against comparable external effects); economic viability (being as cost effective and as energy efficient as possible).

So, this section of study includes man-made structures inspired by natural structures based this question: **"How should the natural structure systems which provide the most effective protection against the forces with less material in spite of their exposure to pressure be handled in order to produce lightweight, flexible, robust constructions?".**

According to Senosiain (2003), there are basically four light structures derived from natural models: Cable networks inspired by spider's webs; pneumatics inspired by bubbles; vaults inspired by shells and eggs and finally, geodesics inspired by radiolarians. Also, according to Arslan and Sorguç (2004) and Garcia P. and Gomez F. (2009), there are five main architectural structure categories derived from natural models: Tree-like structures, web-like structures, shell-like structures, skeleton-like structures and pneumatic structures.

Other resources that show the ways of making use of natural structures in architectural structures are: D'Arcy Thompson (1968) in his work 'On Growth and Form' explains the analogy between nature and structural design of many natural structures. Peter Pearce (1980)'s book "Structure in Nature is a Strategy for Design" is about discovering and understanding of structure and morphology of possible design systems and including some remarkable and surprising architectural structures developed by author. In "Nature and Architecture", Paolo Portoghesi (2000) refers the differences and similarities between the natural forms and structures and architectural forms and structures. In "The Monumental Impulse: Architecture's Biological Roots", George Hersey (2001) investigates the relationship between physical structures and living organisms such as insects, mollusks, and birds.

Based on all these resources, in this study, trees and branches in nature are analyzed as tree-like branching structures; skeletal structures are reviewed as vertebrate-skeletal structures since they are considered to be the carrier of the spine in nature; shell, web-like and pneumatic structures are discussed under the shell structure title since carrier and transporter elements are a whole together and this can be seen from their shell shapes. Inspirations from cellular structures which are constructed regular and irregular are discussed under the same title (Figure 3).

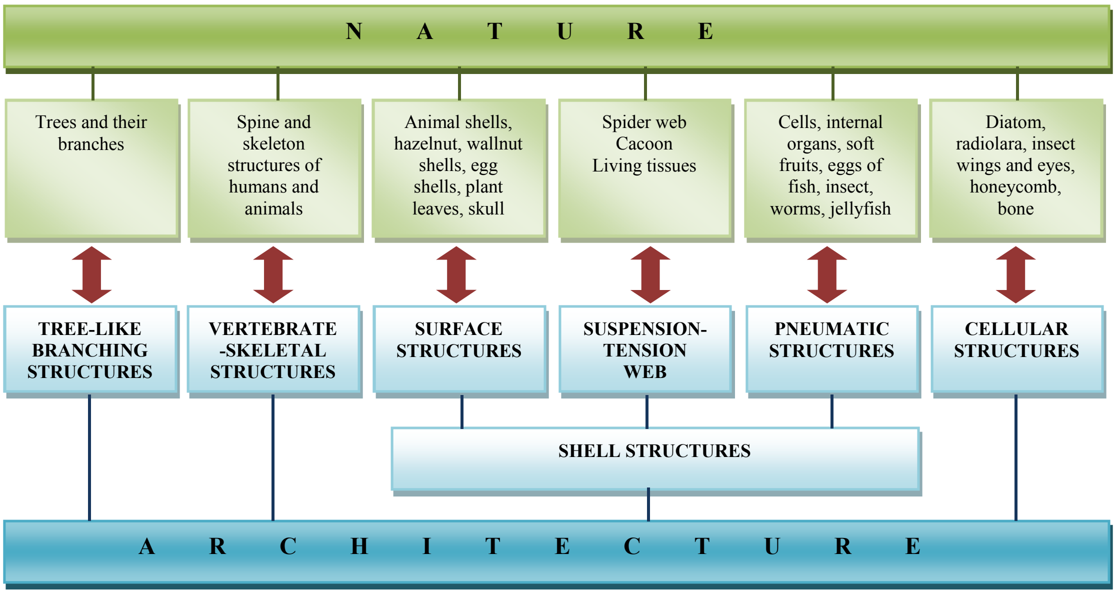



***Figure 3:***
*Influences of structural systems in nature on architectural structures (created by author)*

### 4.1. Tree-like Branching Structures

Trees and forests have been a source of great interest in architecture and affected structural forms throughout history. Tree columns or structures have been used for building lighter structures and taking advantage from the structure's hierarchical appearance among architects and engineers. However, movements of branching structures cannot be compared with the natural tree movements. Additionally, trees and their branches do not grow equally in all directions. Branching structures exhibit a close relationship between the direction and patterns of forces throughout nature and appearance of the structure. This situation is a functional combination between the roof construction and supporting structure. The advantage of tree-like branching systems is having a short distance between loading points and supports. However, in architecture, the growth of tree-like structure is not possible yet (Ahmedi, 2007). In Sagrada Familia Church, Gaudi's structural supports are one of the earliest and finest examples of making tree-like concrete-made branching structures inspired by nature. When in early 20th century the trend of structural minimalism was becoming popular, Gaudi's tree-like sculpted structural supports were stunningly appealing and uniquely special in the field of architecture. Gaudí imagined this church as if it were the structure of a forest, with a set of tree-like columns divided into different branches to support a structure of intertwined hyperboloid vaults (Rian and Sassone, 2014). Later, German architect Frei Otto has worked on tree-like columns and branching structures modeling and has developed many different branching structures. The uses of this type of structures are increasing nowadays and are used as three-dimensional supporting systems in steel, wood and concrete buildings. Examples of tree-like structures are exhibited in the book of Charleson (2005) named "Structure as Architecture". As we review the examples we see the structural usage of trees in both exteriors and indoors in buildings. Several branched structures are observed in Palais de Justice, France designed by Jourda&Perraudin Architects; at Stuttgart Airport, Germany designed by von Gerkan Marg+Partner; in Valencia Science Museum, at Lizbon Oriente Station and in BCE Place Complex designed by Calatrava (Figure 4). In the beginning of the 21st century, the computer-supported algorithmic and parametric technique has also helped enormously to recreate the branching forms similar to natural trees. An interesting example of using the L-system for the development of architectural form is the Tote Restaurant in Mumbai, designed by Serie Architects and constructed in 2009. As an analogy to the green areas surrounding the building, the architects proposed a continuation of tree-shaped (Rain Trees) branching structures inside of the restaurant (Serie Architects, 2013; Rian and Sassone, 2014) (Figure 4).

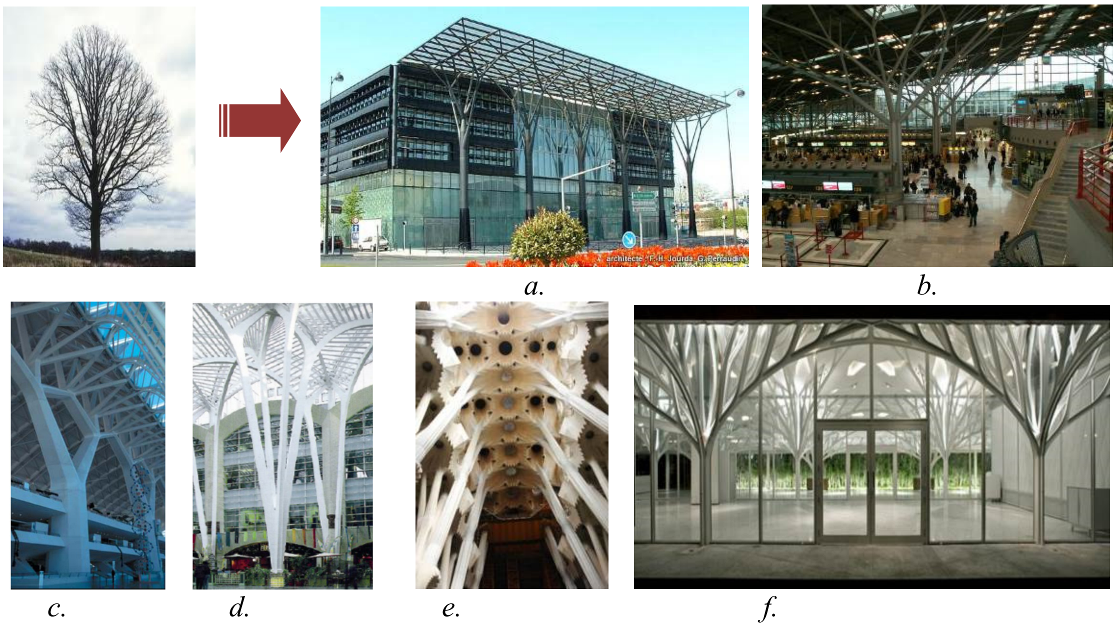



***Figure 4:***
*The effects of tree-like branching structures on the building's structural formation*
***a.** Palais de Justice **b.** Stuttgart Airport c. Valencia Science Museum **d.** BCE Place **e.** Sagrada Familia **f.**The Tote*

#### 4.2. Vertebrate-Skeletal Structures

Vertebrate-skeletal structures that are seen in spine and skeletal structures of animals and humans, and in leaves of plants such as lily, have been frequently used in architecture for building lightweight and rigid structures. Arslan and Sorguç (2004) indicate that spine and ribs in nature work together to provide support and protection, and this idea appears to make sense for buildings as well. Therefore, **spine and skeletal structures of humans and animals** are natural sources utilized since ancient times. Skeletal structures of vertebrate animals have been particularly effective in shaping the bridge structures. The connection of suspended cables and springs in the bridges have been seen in the structures of the four-legged animals for millions of years. The most striking example is the skeletons of dinosaur and buffalo. Royal Albert Bridge is inspired by the skeleton structure of a dinosaur and Forth Rail Bridge is inspired by the skeleton structure of a bison (French, 1994; Steadman, 2008) (Figure 5). Gaudi and Calatrava are the most remarkable architects who use the spine, skeletal systems and the bones in their buildings. Columns that are shaped like bones, the roof formation which reminiscent of a dinosaur's backbone back, can be observed especially at the Batllo Apartment of Gaudi. In Santiago Calatrava's work mostly skeleton and wing structures of birds are observed. Turning Torso is the work in which Calatrava is inspired of the human spine in motion. Spirally rising tower turns from the ground floor to the top with an angle of 90 degrees. The middle column at Milwaukee Art symbolizes the backbone skeleton of a seagull whereas other parts symbolize wings of a bird (Selçuk and Sorguç, 2007; Yıldız, 2007; Hallgren, 2007) (Figure 5).

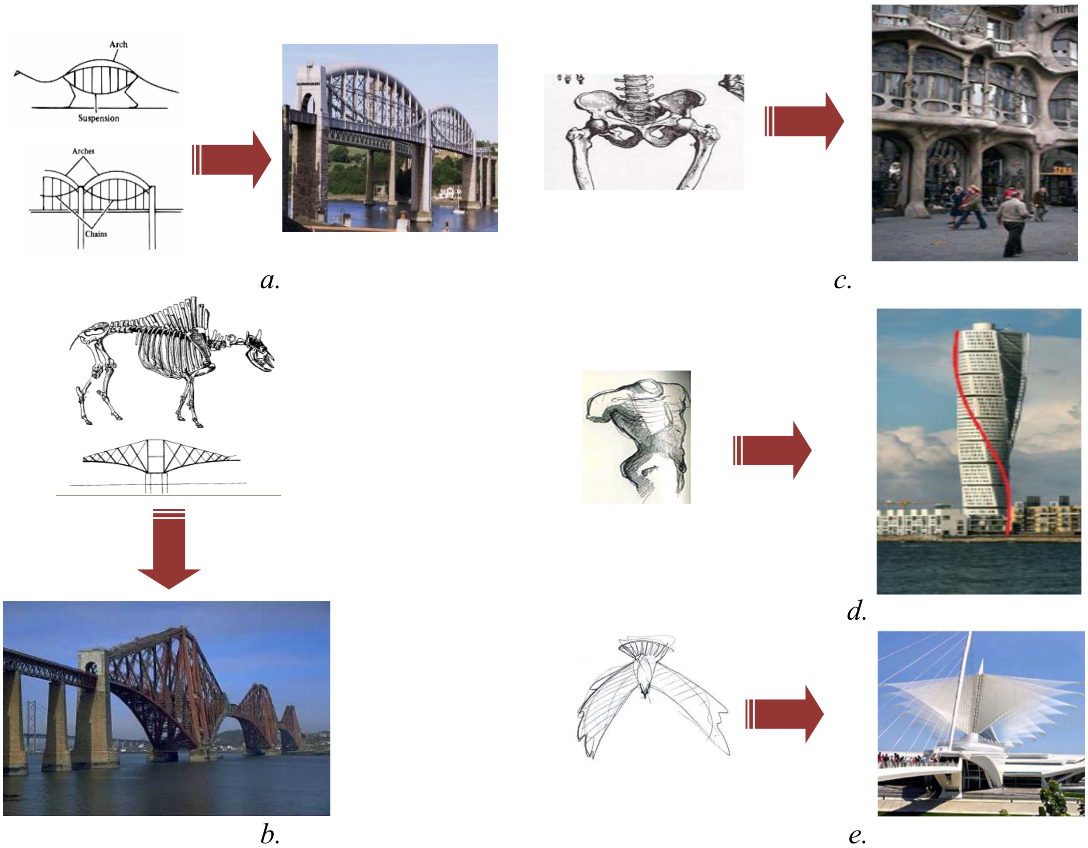


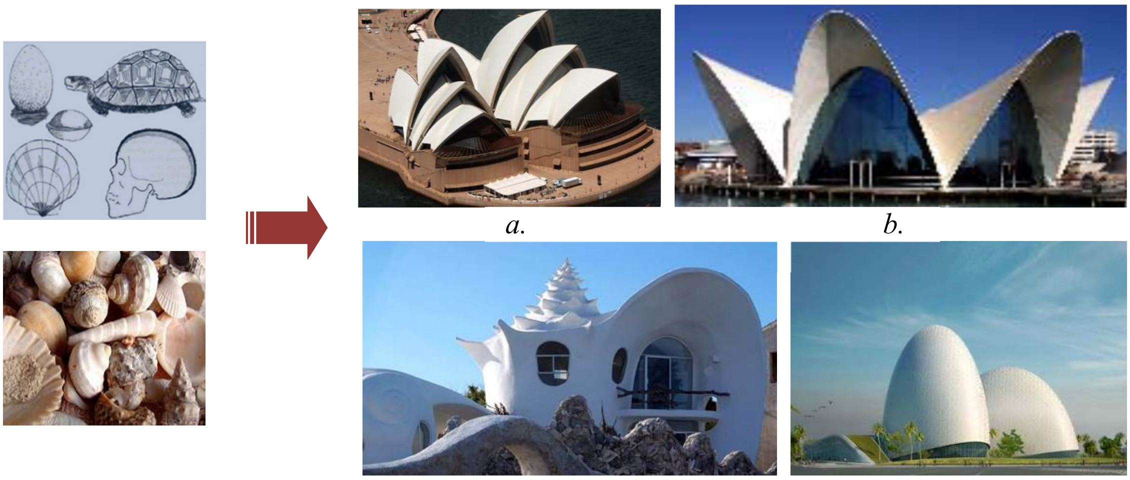

***Figure 5:***
*The effects of skeletal systems and bones on the building's structural formation*
***a.** Royal Albert Bridge **b.** Forth Rail Bridge **c.**Batllo Apartment **d.** Turning Torso*
***e.** Milwaukee Art Museum*

### 4.3. Shell Structures

Shell structures can be defined as the systems which do not exceed the spesific cross-sectional thickness, consisting elements that resist to the pressure and pulling and in which carrier and transporter elements considered as a whole, thus, the form itself creates the structure. Shell structures are the building elements which can cover the place with their mostly curved surfaces and very light thin structures, they constitute volume, they don't need extra carrier except support points and with those features they can cross large openings. Thinking in this context, in architecture, superficial structures, tensile structures and inflated structures can be considered as shell structures in a general since they exists in shell form in buildings. These structures are inspired from the nature quite a lot.

**Surface structures** in nature exist in animal shells, insects shells, turtle shells, egg shells, hazelnut shells, wallnut shells, plant leaves, and the skull. The purpose of works in which building new structural forms inspired from the nature is the main objective, also, as Senosiain (2003) state that, is shaping the rigid elements with least thickness as three-dimensional curvature within the laws of high degree efficiency with the least material. At this point, the structural properties of shells in nature become also valid for architecture. Throughout the twentieth century architects and engineers such as Eduardo Torroja, Félix Candela, Heinz Insler and Pier Luigi also have designed and built magnificent structures with thin concrete shells. The developments made in material field enable to obtain many different shell forms. Sydney Opera House designed by Jorn Utzon and L'Oceanogràfic designed by Felix Candela are prominent examples (Galand, 2009)

(Figure 6). Conch Shell House designed by Octavio Ocampo in Meksika and BioLab Squadron designed by Manifred Nicoletti in Tayvan are the others examples (Figure 6).



a. b.

c. d.

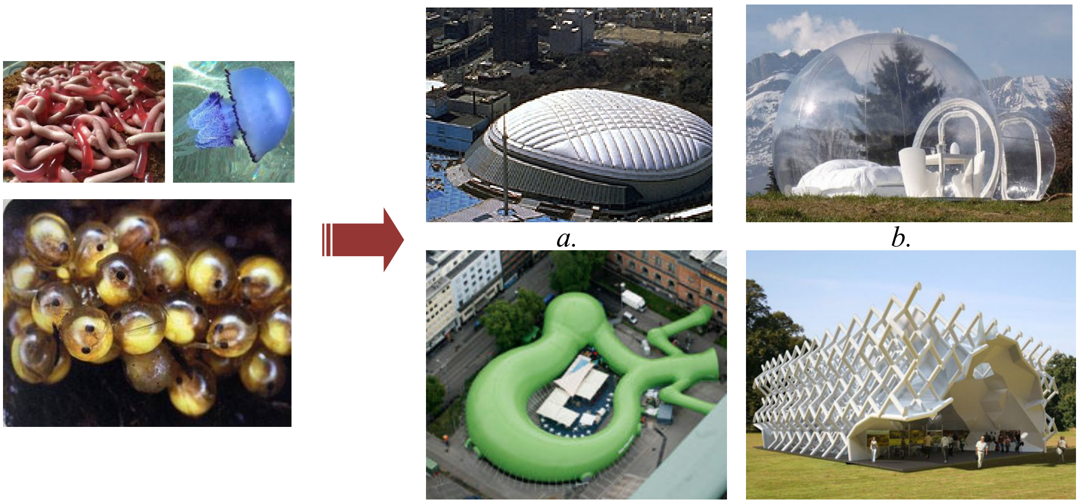
***Figure 6:***
*The effects of surface structures in nature on the building's structural formation*
***a.** Sidney Opera Building **b.** L'Oceanogràfic, Valencia **c.** Conch Shell House*
***d.** BioLab Squadron*

**Suspension-tension, web structures,** the most prominent inspiration for these structures beside the suspension that can be observed within the living tissues in organisms are spider webs and silk worm cocoons. The viscous-elastic web structure of the spider, which resists and absorbs the forces applied by the squirming of the bugs that stick to the web, is produced at incredible speed with the minimum amount of materials and is the prototype for many new structures. The history of using these static principles in a web structure goes back to the nomadic tribes, who built tents from animal hides to protect themselves from the winds in times BC (Senosiain, 2003). Today, large structures are prominently covered with synthetic materials such as acrylic, canvas, and fiberglass. Frei Otto, who is known as the father of contemporary tension structures, researched the types of structures that required less material to build, and found that this could be possible through increasing the number of tension elements within a structure. Web structures, which were directly inspired by spider webs and implemented by Otto, are widely used by contemporary architects through newer methods. The Munich Olympic Stadium and the Montreal Expo German Pavilion are the most important works of Otto (Figure 7).

**Inflated (pneumatic) structures** can be seen in plant, animal and human cells, internal organs, the conduction system of plants, soft fruits, the eggs of fish, insects and reptiles, and in animals such as worms and jellyfish. Academic studies regarding the production of forms in pneumatic structures have started with Frei Otto. Pneumatics are also a part of Fuller's work. Pneumatics can be used in architecture in many styles including beams, walls, floors, columns, and coverings. The facts that they can be produced in very large sizes, can form multifunctional spaces, that they are soft, round, light, and easily transported, repaired and reinstalled, that they have the lowest cost and highest energy conservation, and that they have a highly aesthetic appearance are the positive aspects of these kinds of structures (Asefi and Marzban, 2010). The Big-Egg Dome designed by Forster in Tokyo and the National Space Center designed by Grimshaw in Leicester, England are only a few of the world's pneumatic structures (Figure 8).

*a.* *b.*

***Figure 7:***
*The effects of spider webs on the building's structural formation*
***a.****Munich Olympic Stadium* ***b.****Montreal Expo German Pavilion*



*a.* *b.* *c.* *d.*

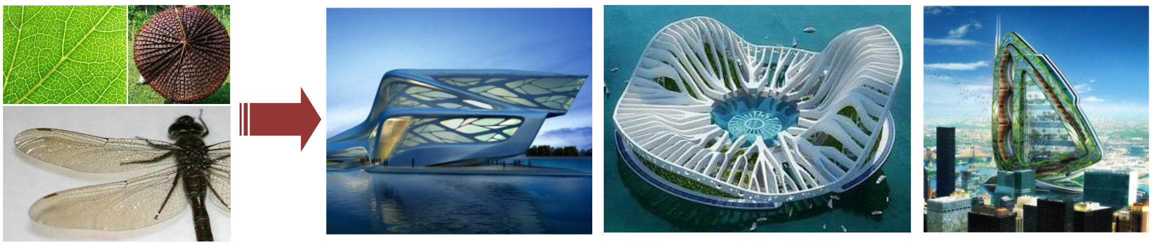
***Figure 8:***
*The effects of pneumatic structures in nature on the building's structural formation*
***a.****Big-Egg Dome* ***b.*** *Cristal Bubble* ***c.*** *Kiss the Frog* ***d.*** *Yorkshire Renaissance Pavilion*

### 4.4. Cellular Structures

Cellular structures, which are formed by closest packing arrangements, provide a lot of variety in terms of structure, volume, and shape in architecture applications. The most widely known example is the geodesic dome of Fuller, which is inspired by radiolarian. Fuller developed the geodesic system by repeatedly using similar elements in a highly effective fashion. This self-repeating and self-producing construction method was already in use in nature for a very long time. Among the other well known examples of polygon based cellular structures in architecture are the Eden Project designed by Grimshaw in England and the National Aquatic Center known as the Water Cube designed by PTW Architects in China (Figure 9). Alongside the structures inspired by the principles and forms of the cellular structures in nature, research and studies on producing new structural forms in a computerized environment are still ongoing. Uniform and non uniform cellular structures are lately seen to be used, especially in the formation of building shells. Examples such as Abu Dhabi Performing Arts Center designed by Zaha Hadid, The Lilypad Floating City and The Dragonfly designed by Vincent Callebaut in Roosevelt Island, New York City for other architectural shells inspired by the non uniform cellular structures in the leaves and insect wings can be seen in Figure 10.

a. b. c.

***Figure 9:***
*The effects of pneumatic structures in nature on the building's structural formation*
***a.****U.S. Pavilion Montreal Expo* ***b.*** *Eden Project* ***c.*** *Water Cube*



a. b. c.

***Figure 10:***
*The effects of non-uniform cellular structure in nature on the building's skin and structural formation*
***a.*** *Abu Dhabi Performing Arts Center* ***b.*** *The Lilypad* ***c.*** *The Dragonfly*

## 5. PROPERTIES OF THE STRUCTURAL SYSTEMS

In order to show the inspirations drawn from natural structures in architecture in the best way possible, Table 1 was built. Table 1 (Yeler, 2012) extensively examines the properties of the structural systems in nature and the architectural medium.

When Table 1 is examined, it can be seen that nature is very important in structural researches since it carries unique properties. However, the conventional structures that form most of the structures today can be seen to have no alignment with nature at all. In architecture, structural methods show a linear formation that can't form on its own and has separately working systems. This case, which causes many problems, has sped up the development of novel solutions.

The innovatively structures given in the context of our study as examples, which are produced by drawing inspiration from nature, show that the examples of nature are highly examined, evaluated and researched, and that similar systems have been used in the building process throughout history. The most important effects of structures in nature to today's architecture are the encompassment of large openings with minimal materials, are the ensure of minimal lightness with maximum effectiveness. Additionally, the facts that natural structures behave in a flexible and dynamic matter, have highly integrated systems, are formed through the interaction of force-form-material, are multifunctional and make them highly beneficial. In the examples, it can be seen that the structural forms of nature are also often used in producing architectural language such as aesthetics and symbolism.

**Table 1. Properties of the structural systems in nature and the architectural medium**

| NATURE | ARCHITECTURE | |
|---|---|---|
| | TODAY | |
| | CONVANTIONAL | INNOVATIVELY |
| • Self-organization | • Non self-organization | • Non self-organization |
| • Self-assembly | • Non self-assembly | • Non self-assembly |
| • Growing | • Non growing | • Modular growing |
| • Developing | • Non developing | • Modular developing |
| • Dynamic | • Static | • Dynamic |
| • Flexible | • Rigid | • Flexible |
| • Soft and hard | • Hard | • Soft and hard |
| • Roundly | • Angular | • Curvilinear |
| • Light | • Heavy | • Light |
| • Thin | • Thick | • Thin |
| • Multi-functional | • Single-functional | • Multi-functional |
| • Minimum material | • Maximum material | • Minimum material |
| • High performance | • Normal performance | • High performance |
| • High degree integrated systems | • Segregated systems | • Integrated systems |
| • Complex relationship between force-form-material | • Simple relationship between force-form-material | • Complex relationship between force-form-material |

In the structural systems that are predicted and mentioned in experimental studies, an understanding of the processes of nature is the focal point. Just like the self-assembly, self-organization, adaptation, and growth-development processes of an organism, architectural objects are expected to show signs of life. These kinds of changes and transformations in the architectural medium are sped up by the advancements in technology, constantly transforming the concepts. An architectural object that gains intelligence by reacting to stimuli can easily be produced, programmed, adjusted, and supervised in a virtual medium through digital technologies. These properties require the structure of an architectural object to be highly dynamic. These inclinations also bring inspirations from living systems to material sciences. Intelligent systems developing through nanotechnology and structures made of living materials can integrate with other architectural systems to adapt to any environmental condition and morphological change. Generally, the constant development of the relationship between structural morphology, material properties, production technologies, and architectural form is expected to speed up the development of new methods and tools even more; especially the digital revolution is expected to fundamentally changing the design and the style of buildings.

## 6. CONCLUSION

Nature keeps developing with the organisms that have adapted the best throughout billions of years. Nature keeps organisms alive with the least amount of damage possible through its dynamic and flexible structures. This is the main reason for nature being the focus of studies in every branch of science. Although we included a limited amount of examples in our study, nature has examples of complicated structures beyond number. It is clear that we have much to learn from nature. The ecological demands arising in recent years can only be met through understanding the basics and systems of nature. At this point, the architect should have the ability to interpret the laws of nature (both micro and macro) in both reimagining his own thought system and producing the architectural object. However, instead of simply copying and imitating organisms, the architect should be able to integrate certain concepts of nature into his structures such as effectiveness, economy, optimization, resilience, functionality, and aesthetics. The requirements of our age necessitate structures that are lighter, use less materials, conserve more energy, are more mobile, and are more adaptable. Architects should see drawing inspiration from nature not only as creating a new architectural language, but also as adopting a new environmental awareness. In order to create a responsible and aware architectural medium with this perspective, the education process should quickly change to support this responsibility. We think that a sustainable future can be achieved through wholly evaluating biological models, which aren't normally questioned much in architecture, on a scientific and methodological level by utilizing interdisciplinary relationships and utilizing the resulting mass of knowledge in our professional lives.

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