BIOMIMICRY ARCHITECTURE

Structures improving by imitating nature

Final Degree Project
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"the architect of the future will be based on the imitation of nature, because it is the most rational, durable and economical of all methods";Gaudí (1)

Abstract

This Final Degree Project consists of a research paper on Biomimicry Architecture, learning from other authors and drawing my own conclusions. It is a topic that I am passionate about because you can understand the way of designing from another point of view based on what nature provides us. Learn where the term comes from, how it applies to architecture and ways to apply it. I think that the structures have to be considered from the beginning when creating to obtain a good project.

Purpose

Nature is a clear example of optimal structures. Architecture should take more advantage of it, and continue to investigate its structural patterns, how different models work in nature and learn from it to be able to project and design in architecture achieving new forms.

Nature is wise. There are many types of organisms in the world, both in the animal and plant kingdoms, and each of them has a form that has evolved according to its function. Therefore, there are thousands of examples of structures with different sizes that correspond to different stresses and situations. Clearly you can learn many things from nature, not only the structure. Therefore, this is the area in which the work will focus, the idea is to learn how to apply knowledge that nature gives in architecture.

Architecture arises from the need to protect oneself from the environment and to provide a better quality of life. If we go back to prehistoric times, the first architectural constructions were built from the materials that were available in their context and learned from the influence of their surroundings. This can be seen both from their peers and from the observation of nature. Nowadays, we have it so incorporated that we do not stop to observe. We learn a way of designing by imitating other architects, and we follow that idea without taking into account that those architects did it for an older reason that is not necessary in today’s world. We should not be satisfied with this. Instead, we should seek to go beyond and design with more experience. That is to say, not to forget the essence of the why.

Additionally, we now have a great diversity of natural or artificial materials that have one function, and we are not looking for new ways to manipulate them. Not every building has to have a different and innovative form, but at the same time, not all of them have to have the same vertical and horizontal elements. For example, we use concrete with load-bearing walls and floor slabs, but we could give it another form like vaults. We become independent and isolated looking to create a new solution when we can start from prior knowledge coming from natural examples.

In nature, we find organisms with specific and perfect structures. The idea is to see if applying nature's laws to solve questions and problems in architecture is possible.

Methodology

This work gathers information about biomimicry architecture in its different fields, focusing on the formal and structural field. First it focuses on a more theoretical part of research and then on a more practical part that compares a traditional architecture project with one of biomimicry architecture.

This project tries to seek inspiration from nature, which corresponds to biomimicry. Applying knowledge of natural examples when designing buildings taking into account the structure. There are ways of designing that seek bio-utilization, that is, the use of organic elements in architecture, in this work what is sought is not to use these types of materials but that any material, both organic and artificial, follow a form that mimics that of nature, not for a sustainable or stylistic aspect but for the optimization of resources to find perfect structures.

To do this, you have to understand how nature works. See what examples are seen in architecture and try to make an approach to the field to then see a way in which to apply this knowledge in a small case study example.

In the case study, the author will present a case study created by herself in the Architecture and Projects Workshop V. It is a multi-family building with a first floor, plus five floors located in Sant Cugat del Vallès and has a structure of 20 cm reinforced concrete walls and waffle slabs (two-way slab), with a strip footing foundation and a load-bearing wall. The second is a prototype that was also made by the author in order to develop the TFG, is located in the same plot, which is a triangular terrain that faces different heights at each vertex of the triangle. This building will also be of the same use, multi-family housing, but will be inspired by the shape of the trees, therefore it will be based on thick pillars that will be branching in height and its foundation will be micropiles. Once exposed the two projects will be related to see formal differences, amount of materials used and see what positive features each one brings.

Finally, a series of conclusions will be drawn from both the theoretical and practical parts. And it will be discussed what biomimicry brings to architecture.

State of the art

In order to contextualize, the subject matter has been determined by following a historical path, taking into account interesting authors and characters but emphasizing a change in criteria when designing buildings (figure 1).

Understanding nature in order to apply it to solve problems has always been done intuitively in all fields. During the 5th-4th century BC. Democritus defined the term *mimesis* as the imitation of nature's functioning. At the end of the 17th century, thanks to great advances in the observation of fauna, biology was defined as a part of science. Jack Steeve is the first to use the word *Bionics*, which is defined as the science that studies the creation and development of technological devices and procedures that replace or assist the natural functions of living beings.

The name *Biomimicry*, 1997, became popular thanks to the book: Biomimicry, Innovation Inspired by Nature, by Janine M. Benyus, becoming a movement. In the book she explains how she became familiar with this subject: "I found not one, but many biomimics. [...] they are learning that there is more to discover than to invent" Benyus, Janine M., Biomimicry, Innovation Inspired by Nature, 1997
(2)

Today there is the Biomimicry Institute, founded in 2006 by Janine M. Benyus and Bryony Schwan in Montana, United States of America, which focuses on studying nature and disseminating that knowledge.

In the field of architecture, it is known that in its beginnings it was built and created by understanding and imitating nature. At present, some architects stand out, even though they may not have known the term Biomimicry, their way of designing was based on examples from the animal or plant kingdom, such as the architects: Pier Luigi Nervi, Félix Candela or Antoní Gaudí.

For this work we have taken into account concepts extracted from the book Biomimicry by Janine M. Benyus, academic articles and for the most practical part the book Design in Nature, *Learning from Trees by Claus Matteck.*

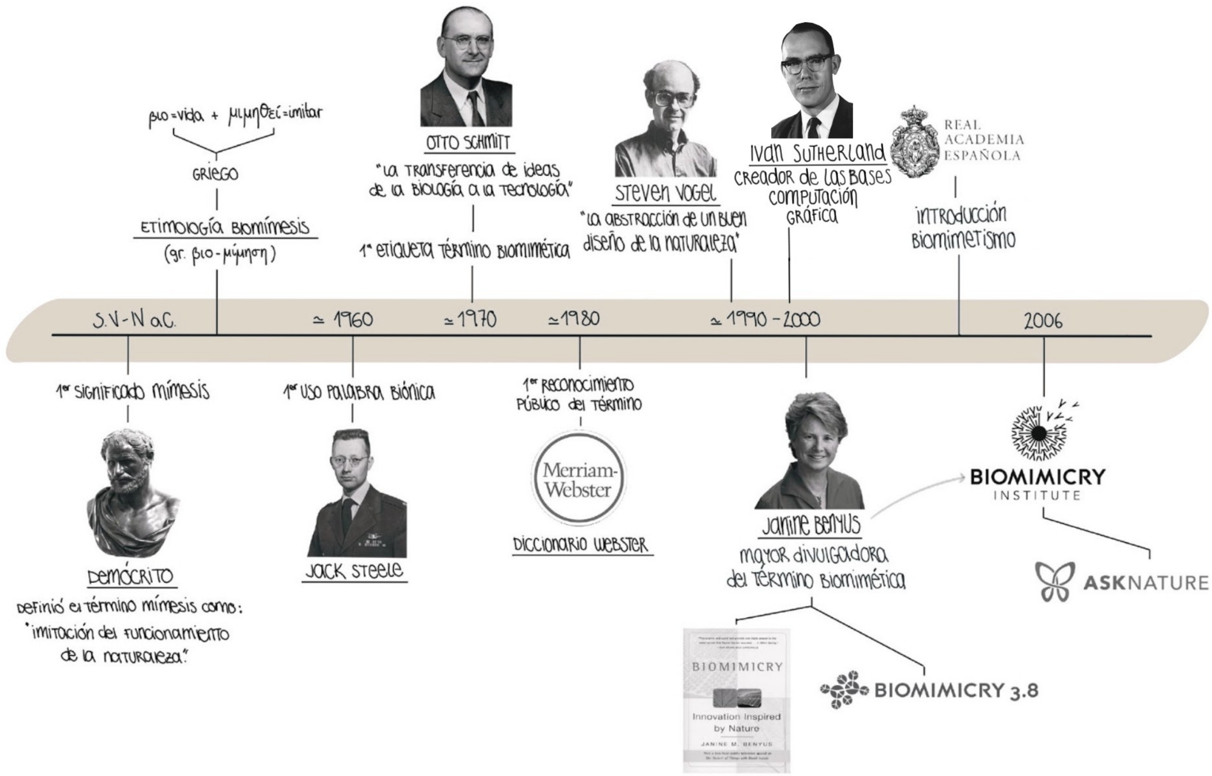

Fig. 1. Chronology,

Source: López-Maroto, Andrea (2020), *Biomimetic architecture and biomimicry*.

(with my own modifications)

Key words

Biomimicry, biomimetic, biomorphism, bio-utilization

Definitions

Biomimicry: the design and production of materials, structures, and systems that are modelled_on biological entities and processes.

Biomimetic: 1. describing a laboratory procedure designed to imitate a natural chemical process.

2. describing a compound that mimics a biological material in its structure or function.

Biomorphism: the attribution of biological (rather than just human) qualities to God; the attribution of the qualities of living organisms to inanimate things.

Definiciones de: Oxford Languages

Bio-utilization: Bio-utilization Sometimes confused with biomimicry, bio-utilization entails acquiring or harvesting a product or producer, such as gathering medicinal plants to obtain the medications they produce, or growing algae to make biofuels.

Glossary of Terms - Biomimicry Toolbox

I. Introduction

A. Definition of Biomimicry

Bios: life Mimicry: imitate

Biomimicry architecture imitates the designs and processes of nature to solve technical problems.

To understand what biomimicry architecture is, we must first study how nature works. In the formal aspect we can distinguish different patterns that respond to the functionality and efficiency of organisms. This theory was disseminated by Alan Turing in an article published in the early 1950s, this mathematical analysis later developed to become the basis for explaining self-organization in nature.(3)

To understand the geometry of nature, one must study the morphogenesis of organisms. This term refers to the biological process responsible for the development of their specific forms and how their elements are spatially distributed.

Explained in a simple way we can detect different growths: spiral, symmetry, undulations, etc. One of the best known, complex and used in architecture are fractals. This system follows a constant pattern that repeats itself in multiple scales.

To explain this I will use the following examples:

A pine tree, *pinus*, is composed of a main trunk that divides into branches, which have the same geometry but of less dimension, which in turn divides into leaves, again the same pattern but of less dimension. What is observed is an organism that as it develops subdivides into its own form.

A sunflower, *Helianthus annuus*, in its achene are the seeds, also known as sunflower seeds, which are arranged in a fractal spiral. This aereal-angled growth, which follows the Fibonacci number sequence, makes it possible to use as much space as possible.

Fig. 2. Sunflower. Personal elaboration.

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B. Importance of Biomimicry in Architecture

Biomimicry in architecture can bring breakthroughs: impact on sustainability, resilience and innovation.

Impact on sustaniability

Sustainability is a very important issue in architecture, as the construction sector contributes to 23% of air pollution, 40% of drinking water contamination, and 50% of waste in landfills according to an Archdesk article by Karolina Dobrowolska.(4)

Sustainability refers to the balance of a species with the resources of its environment. Architects are currently seeking to design more sustainable architecture with different methods. In the case of biomimicry architecture it is sustainable because it uses less material by following efficient forms, but these materials do not have to be organic or recycled.

On the other hand, within biomimetic architecture, which is a more general term that encompasses topics such as biomimicry or bio-utilization, other aspects of sustainability could be taken into account.

For example, energy efficiency, following strategies of nature that control air flows, the use of natural light and the regulation of different temperatures. As is the case with Harare's Eastgate Centre in Zimbabwe, by architect Mick Pearce, 2017. This building is inspired by mound-building termites. Its design is based on two models that account for the functionality and energy efficiency of termite mounds. (5)

Another example is the selection of materials, a material is determined and studied based on how it works. Such as bamboo that offers strength, is fast-growing and has low environmental impact, or bio-inspired composite materials that mimic the strength and lightweight properties of natural structures (6)

Resilience

Resilience in architecture refers to the capacity of constructions that, without resisting or, on the contrary, giving up, can recover from impacts caused by their environment. (7)

If we use biomimicry architecture, we are able to create buildings with structures based on natural examples. These examples allow us to know that these structures will be efficient and diverse. Therefore, they are more likely to adapt to changes, while maintaining their functionality thanks to their flexible systems.

Innovation

Biomimicry design allows the introduction of new forms and techniques in the field of architecture. By creating new structures, buildings will require new construction methods and at the same time provide new ways of creating spaces. Architects have not been the first to build, there are many organizations that have created optimal spaces, therefore, we can build on them, adapt and even improve them. If a structure is well designed, it has to work at all scales, so we must be able to make it work for us.

Currently, in order to innovate in construction, new technologies such as 3D printers or new forms of formwork for concrete, which will be mentioned later, must also be considered.

II. Basic concepts of Biomimicry

A. Basic principles of Biomimicry

Biomimicry: functions like nature

Biomorphism: looks like nature

Bio-utilization: uses nature

Janine M. Benyus proposes to understand nature as a model, as a measure and as a mentor:

1. *"Nature as model*. Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.
2. *Nature as mesaure.* Biomimicry uses an ecological standard to judge "the rightness" of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropiate. What lasts.
3. *Nature as mentor.* Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on wht we can *extract* from the natural world, but on what we can *extract* from the natural world, but on what we can *learn* from it.

Benyus, Janine M., *Biomimicry, Innovation Inspired by Nature*, 1997 (prologue)(2)

For me biomimicry architecture has to be learning from nature, as if it were a teacher who teaches you the basics and once the student learns it, he/she has the ability to think and develop and keep them in mind in his/her future achievements.

B. Relationship between Biomimicry and Architecture

Biomimicry can be a very useful knowledge in architecture. As architects, before designing we have to ask ourselves: what would nature do?

We learn by imitation. Although the term biomimicry is a new discipline, it is what has been done intuitively for centuries, the challenge is to understand the relationship between design and nature.

"Every natural action is performed by nature itself in the shortest possible way and time. No natural action can be abbreviated, for nature generates it in the shortest possible way." Leonardo da Vinci (8)

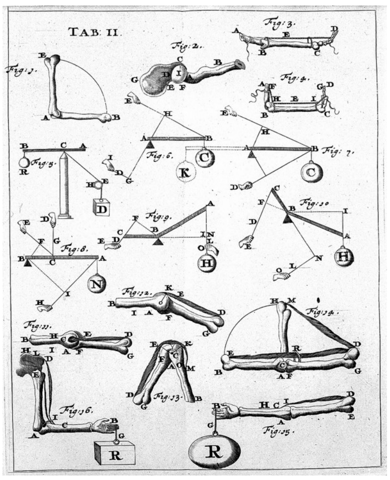
A good method for designing architecture might be to first think about the function of the building, foresee the space needed and look for an example in nature that can fulfill those objectives.

Currently there are few biologists interested in the world of construction due to the lack of engineers and architects with biology backgrounds. All knowledge is good, knowledge does not take up space, we should be able to learn from biology to make new designs. This design process is not straightforward, it takes time and several tests, but the key is to understand it and once achieved, to evolve it.

For example, at the time of the Renaissance, the philosophical movement of rationalism returned together with a scientific revolution. The interest of different fields is reflected in others, science uses drawing as a language and artists emerge to represent science, such as the works by Leonardo da Vinci.

The inventor Galileo Galilei was interested in the growth of various species in the animal kingdom and realized that the way animals grew, the bones also grew in a certain way in order to adapt. This statement helped years later in the construction of structures imitating bones, which are tubular and hollow, obtaining efficiency with maximum resistance to bending with less material.

Giovanni Alfonso Borelli, one of the major promoters of biomechanics, made several researches mainly focused on the functioning of the body of birds. He was the first to manufacture artificial wings for the human body, although they did not work because the body was not powerful enough to make them work.



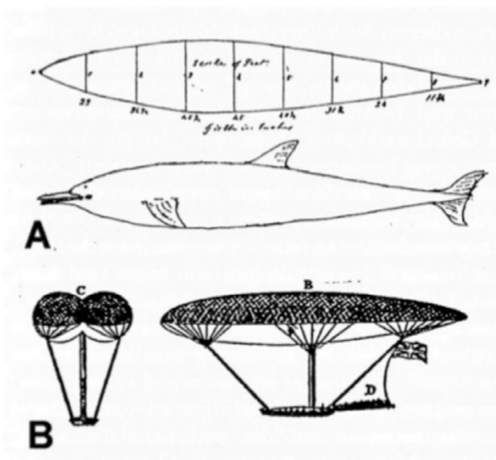


Fig. 3. Borelli, Giovanni Alfonso. (1680) *De motu animalium.*

Fig. 4. Caley, George. (1829) *Studies on form and desing of a balloon.*

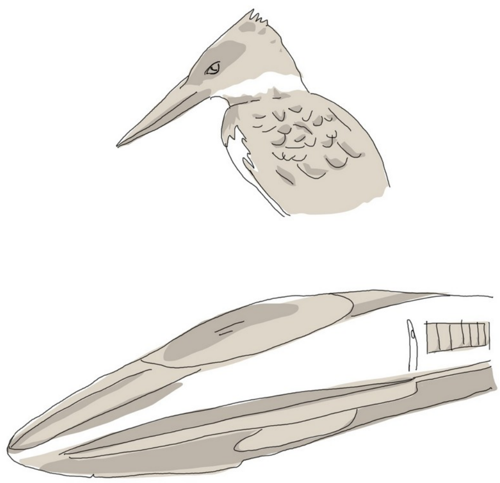
Everything is related, for centuries we have been looking for ways for humans to fly, and the most successful have been those based on natural beings. Although an airplane and a bird come directly to mind, there are approximations of non-flying animals that have helped to design devices to fly. In the early 19th century, at the time of the Industrial Revolution and the consolidation of science, George Cayley designed a hot air balloon inspired by the aerodynamics of dolphins, providing less air resistance.

Therefore, it is a symbiosis, architecture also contributes to biomimicry, since we are part of nature. The relationship between architecture and biomimicry should be seen as a whole. Creating a type of construction that emulates nature allows us to provide examples and new biomimetic places. Architecture should not focus only on its field. The more open it is to other knowledge outside of the realm of architecture, the more it will be able to evolve and improve.

III. Application of Biomimicry in Architecture

A. Application of Biomimicry

Before being able to understand the advantages of biomimicry, comprehending how it works is necessary. Two different examples of how biomimicry works will be explained.



The bullet train, in Japan, goes at a speed of 200 miles per hour, but when leaving a tunnel the air pressure generated a great noise.

The kingfisher (*alcedo atthis*), goes from air to water, both with medium density, without making a splash. The engineer modeled the front of the train as the beak of the kingfishers. This solution muted the train and was so efficient that it made it go 10% faster with 15% less electricity. (9)

Fig. 5. Bird and train. Source: Personal elaboration

This is a Galapalos shark. It has no bacteria on its surface, and it does not do it with chemicals. It has a particular kind of pattern. The skin denticles keep bacteria from being able to land and adhere. There is a company called Sharklet Technologies that is now putting this on the surfaces in hospitals. This way, hospitals are free from bacteria without the need for chemical products. .(10)

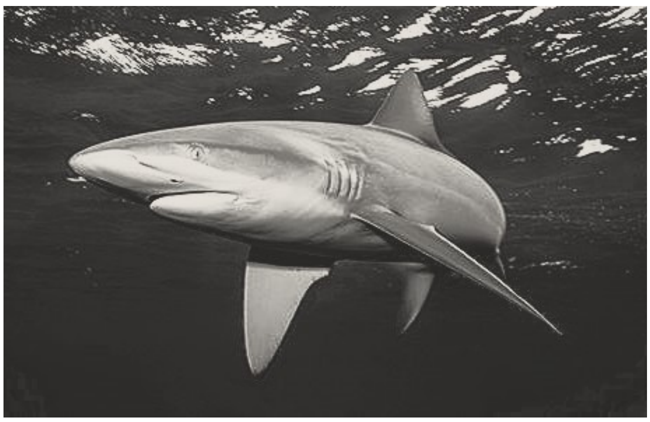


Fig. 6. Galapagos shark (Carcharhinus galapagensis) underwater. Source: © Doug Perrine

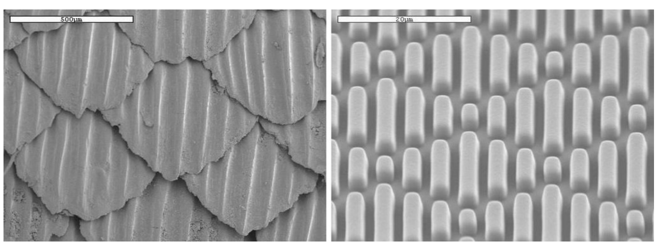


Figura 7.Shark Skin Inspired Microbiological Control. On the left is an image of a shark skin denticle. On the right is the Sharklet micropattern. Note the similarities in design – diamond pattern and ordered feature lengths. Fuente: Sharklet Technologies, Inc.

It can be seen how these examples use the essence of an organism, but not the organisms themselves. They replicate their form but with another materiality to achieve an objective. This is a great advantage for architecture because it can create buildings with malleable and ductile materials for its project based on the study of nature.

Another advantage is that they will be optimal structures. Jorge Wagensberg, in his book "La rebelión de las formas o Cómo perseverar cuando la incertidumbre aprieta" (2005), studies some of the forms that we find in nature, under the premise that everything that exists, exists because it has gone through a process of natural selection. (11)

B. Examples of successful applications in Architecture

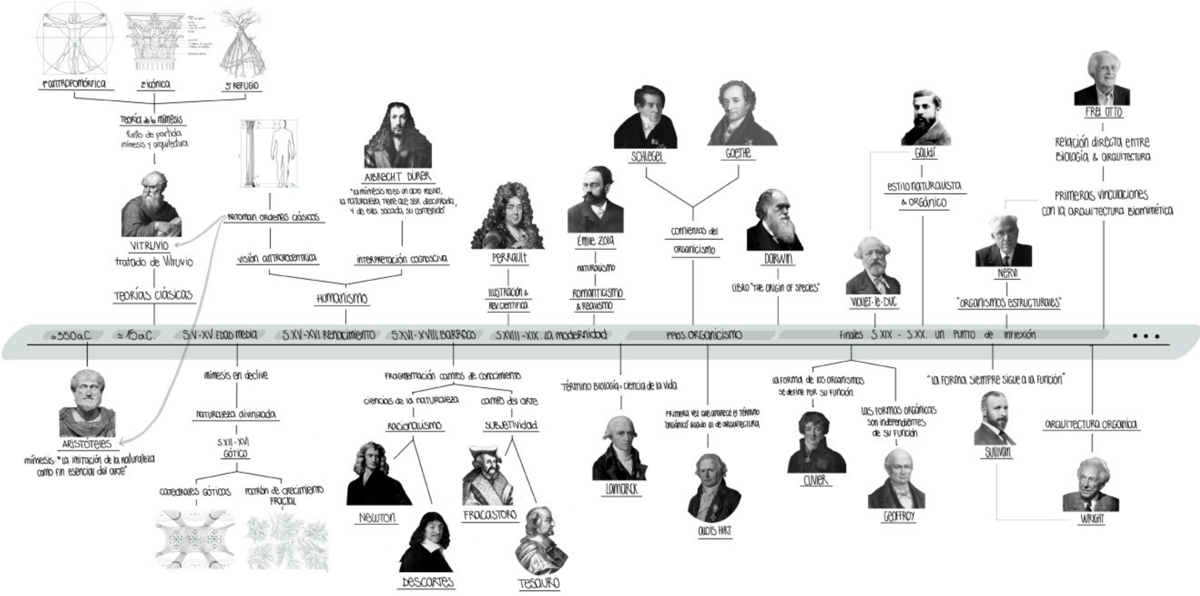


Fig. 7. Chronology 2. Source: López-Maroto, Andrea (2020), *Arquitectura biomimética y biomímesis*

Clearly, the connection between architecture and nature has been a recurring theme in architectural design processes throughout time. It has been explored from different perspectives and approaches throughout history. Following a chronological order, different examples will be discussed, but our focus is on more recent buildings.

The vision of biomimicry architecture has evolved over the centuries. At first it was a simple aesthetic imitation, and then a deeper understanding of the natural principles and processes that enable efficient, adaptive and sustainable design began to develop. This focus on the functionality of nature is increasingly opening up new possibilities for the creation of more innovative architectural structures and will certainly in the future also involve thinking about the construction process of these new forms.

In the ancient age, the Doric and Ionic columns stand out, which thanks to the influence of Vitruvius began to use the proportions of the human body, and the Corinthian columns, which use decoration based on natural examples.

In the Middle Ages, mimesis went into decline or became idealized because it was a period strongly influenced by Christianity, therefore the aesthetic and ethical style changed. However, it was also a time when many Gothic cathedrals were built, making the figure of the architect very important and highlighting the influence of an idyllic nature. Indirectly, the gothic cathedrals found inspiration from nature to add height. For example, the shape of the columns are very similar to the shape of trees and probably follow a growth model of fractal geometry.

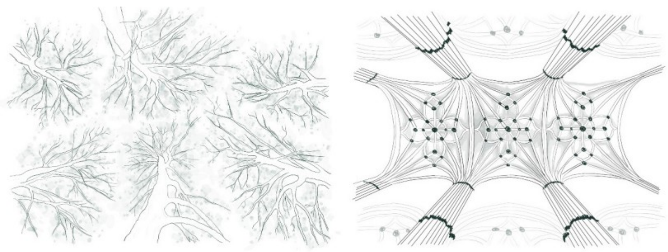


Fig. 8. Growth pattern of the trees and central vault of the cathedral of Salamanca. Source: López-Maroto, Andrea (2020), *Arquitectura biomimética y biomímesis*

In the Renaissance, there was a revival of interest in nature and the study of living organisms. Artists and architects of that period were inspired by the beauty and harmony found in nature, and sought to imitate its forms and proportions in their creations.

Italian architect and theorist Leon Battista Alberti in his work "De re aedificatoria" emphasized the importance of observing nature and taking it as a model in architectural design. Alberti emphasized proportion and symmetry, principles also found in nature, and promoted the idea that architecture should imitate the beauty and balance found in the natural world.

Alberti (1565), *L'architettura*, Venice. Alberti Figure, L'architettura, Venice, 1565

In the Baroque, more influence of the scientific field is observed in the artistic field, but at the same time it is not so much reflected in architecture. Baroque architecture stands out for its great ornamentation, which was inspired by the diversity and complexity of nature, such as curves and organic forms, but in general lacked efficient designs in the structure.

In the modern age, antagonistic currents were maintained in the understanding of nature.

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In the modern age, antagonistic currents were maintained in the understanding of nature.

Nature can be viewed from a scientific vision that uses a rational and objective approach. The use of observation and scientific empiricism must be used for this view. On the other hand, nature can be viewed from a romantic vision. This view values human subjectivity and the capacity for expression.

Although these visions had opposite approaches, they showed a strong interest in discovering the secrets of nature. Architecture was nourished by both visions, with a predominance of the scientific vision that applied the rational knowledge acquired from nature while also incorporating elements of the romantic vision in the design process. In fact, the human being is considered as part of nature. (12)

At the end of the 19th century and during the 20th century, significant changes occurred in the perception of nature. Influenced by the publication of Charles Darwin's "The Origin of Species" (1859), nature ceased to be seen as an extension of divine creation and began to be admired for its own virtues.

In that period, a relevant debate also arose in relation to architecture, led by the biologists Georges Cuvier and Etienne Geoffroy Saint-Hilaire. This dispute centered on the relationship between the form and function of organisms. Cuvier argued that the form of organisms was determined by their function, while Geoffroy defended the idea that organic forms were independent of their function.

Architecture began to appreciate and celebrate the intrinsic virtues of nature, exploring new forms and solutions inspired by the diversity and adaptability of living organisms.

Antoni Gaudí was very interested in natural forms, not only aesthetically but also functionally and technologically. The remarkable accomplishments in the realm of sustainability and biomimetics in architecture primarily revolve around advancements in structural design. These achievements stem from the persistent pursuit of mechanical optimization and structural efficiency.13

Gaudí did not seek simplistic solutions; instead, he meticulously examined the merits and drawbacks of each of his innovations. Some of his creations were the result of extensive research, testing, and experimentation over many years.

The Sagrada Familia stands out for its use of different forms based on nature. On the one hand, he calculated the structural system with catenaries, he made a model from which chains were hung holding different weights to foresee the arches for the descent of loads.

On the other hand, Gaudí's objective in the construction of the Sagrada Familia was to revolutionize architectural structures by creating a more harmonious and resistant design compared to traditional European Gothic cathedrals. To achieve this, he devised a unique system of pillar structures that resembled branching trees. This innovative approach allowed him to determine the diameter and angle of the pillars, as well as the load distribution in the central core.

By utilizing this method, Gaudí maximized the compression forces within the structure, reducing the reliance on flexion. This resulted in a more balanced distribution of the load, with the inner pillars sharing the weight alongside the perimeter elements. Consequently, the need for extensive Gothic flying buttresses and other external supports was eliminated. This not only saved materials, but also optimized the layout of the building, making efficient use of space.(13)

Architectural masterpieces such as Frank Lloyd Wright's Johnson Wax building exemplify the exploration of biomimicry's potential in design. This particular building showcases the application of nature-inspired concepts, with its remarkable thin-shell concrete and steel-mesh columns resembling the shape and structure of mushrooms. The essence of incorporating biomimicry in architecture lies in harnessing the inherent wisdom of nature's forms and structures.

(14)

Fig. 10 . Funicular model of the Colonia Güell Church. Source: C. Salas Mirat (2020), *“Diocesano” Museum in Barcelona*.

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Fig. 11. Frank Lloyd Wright-inspired by mushroom shape. Source: Khoshtinat, S. (2015). *Algorithms In Nature & Architecture (Biomimetic Architecture)*.

Fig. 12. Work area at the Johnson Wax Building, headquarters of the S.C. Johnson and Son Co., Racine, Wisconsin. Source: Highsmith, Carol M. (1946)

Nervi carefully studied undulations in nature. In this project he employed the principle of using ribs to give effective structural depth to a thin flat surface. The Palazzetto dello sport is inspired by the pattern of the Amazonian water lily, and this structure is more efficient, due to the little material and large distance.

Fig. 13. Vintage Giant Water Lily (Victoria Amazonica) *Illustrations.*

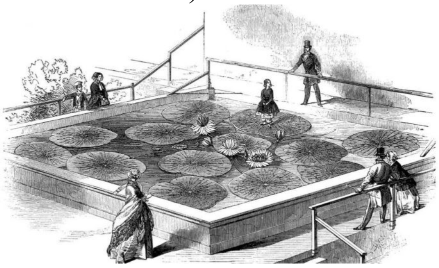
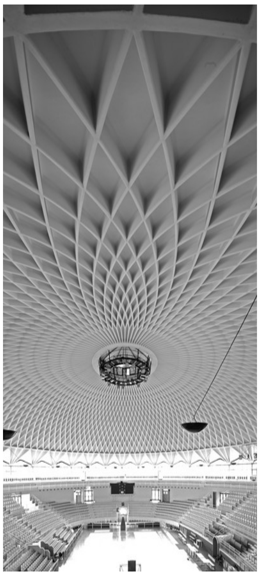


Fig. 14. Palazzetto dello sport. Source:

Michael Pawlyn (2012), *Biomimicry in Architecture*



C. Challenges and limitations in the application of Biomimicry in Architecture

Biomimicry architecture has several advantages but at the same time it can be a complicated branch and subjected to several challenges. We are in a time where this term is just becoming popular, although our way of building has always been based on examples of our environment.

Thanks to the latest scientific advances, environmental awareness, and diffusion through the media, more and more emphasis is placed on sustainability issues. Every little contribution can have a great influence in the future and create awareness for the movement.

At the same time, as it is a recent term, there are still many bases to cover, that is to say, there is still a lot to learn. We also have to be prepared to "fail" because our tests may become possible in the future with other means.

Technologies are becoming more sophisticated every day and this is an advantage with respect to biomimicry architecture since it will be able to use these technologys to its advantage to utalize new materialities and forms.

For example, 3D printers are becoming increasingly known for their production efficiency and are often used to make small-scale models. But they are now starting to be used in construction, as in the case of a group of researchers at the ETH Zurich who are using 3D printers to create concrete formwork with recyclable mineral foam, which they claim can make precast concrete slabs lighter and more insulated using 70 percent less material.(16)

We may not have, or know of, the means to develop them, but we are finding more and more flexible materials. Zaha Hadid's Knit Candela project proposes digitizing design to make construction easier, inspired by architect Felix Candela and applying new design technologies. This construction does not use foundations, which makes it self-supporting and, above all, it takes into account that it will be supported during construction.

Fig. 15. Printing machine Source: *FoamWork*

Fig. 16. *KnitCandela,* 2018, Zaha Hadid Architects Source: Juan Pablo Allegre

Through architecture we are able to see how we have become more sophisticated in our construction process over many years, such as in the case of prefabricated buildings. Surely in biomimicry architecture the same thing happens. First we have to find out what forms can be useful when designing a building. Then, with the passage of time, it will be improved until the form is not an impediment to its construction.

We must also take into account that the current building regulations are not designed for biomimicry architecture. This implies that the more consolidated the city is, the more difficult it will be to realize very different forms. However, you can always try to provide elements that mimic nature within its regulations as a further restriction of the project.

IV. Types of biomimicry applied in architecture

It can be seen that the examples explained above can be classified into different aspects of architecture.

A. Biomimicry in form and structure

Natural forms are determined by their function, processes, mechanisms and patterns. Their geometric forms seek the law of minimum effort.

The spherical shape uses the smallest surface area in relation to the volume it contains. In the animal kingdom this shape helps to maintain body heat or food. Turtle eggs are spherical which allows them to be structurally strong with a simple thin shell.(17)

Bird eggs are conical ovals. Their shape is not completely spherical because it has the function of protecting them from predators by deflecting the pressure exerted by their jaws. The vault in architecture resembles this shape because it works well under compressive stresses.

They also have the function of returning to the same position in case of falling. This oval shape allows movement, as in the case of seeds that disperse in order to ensure the reproduction of their species.

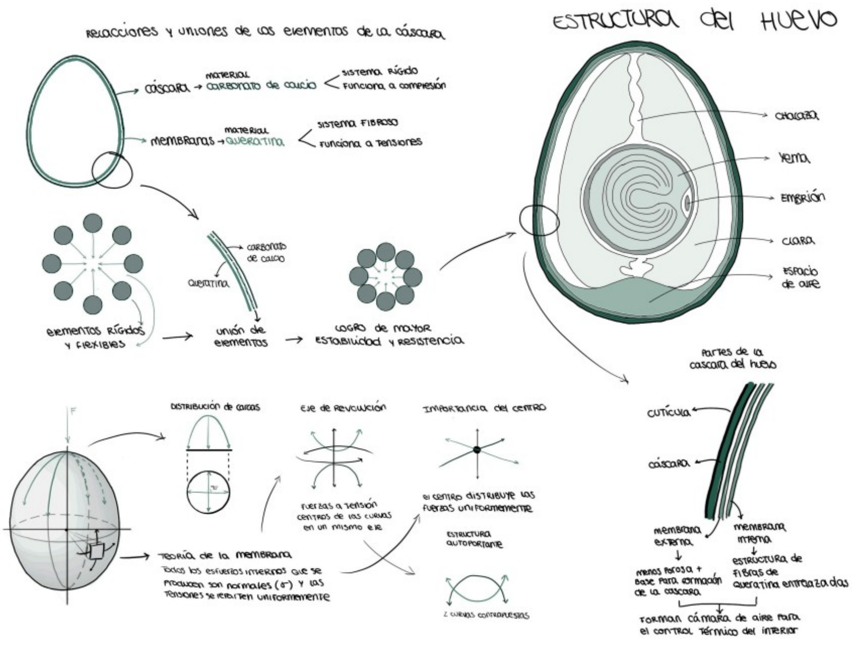


Fig. 17. Functioning of the materials and structure that form the egg. Fuente: López-Maroto, Andrea (2020), *Arquitectura biomimética y biomímesis*

In the introduction, growth in nature is mentioned. Spiral growth is determined by the number phi, the number of the Fibonacci series. For Wagensberg, the spiral is the most optimal way to represent growth, it responds to the need to move and grow while occupying the minimum space, including the need for protection.

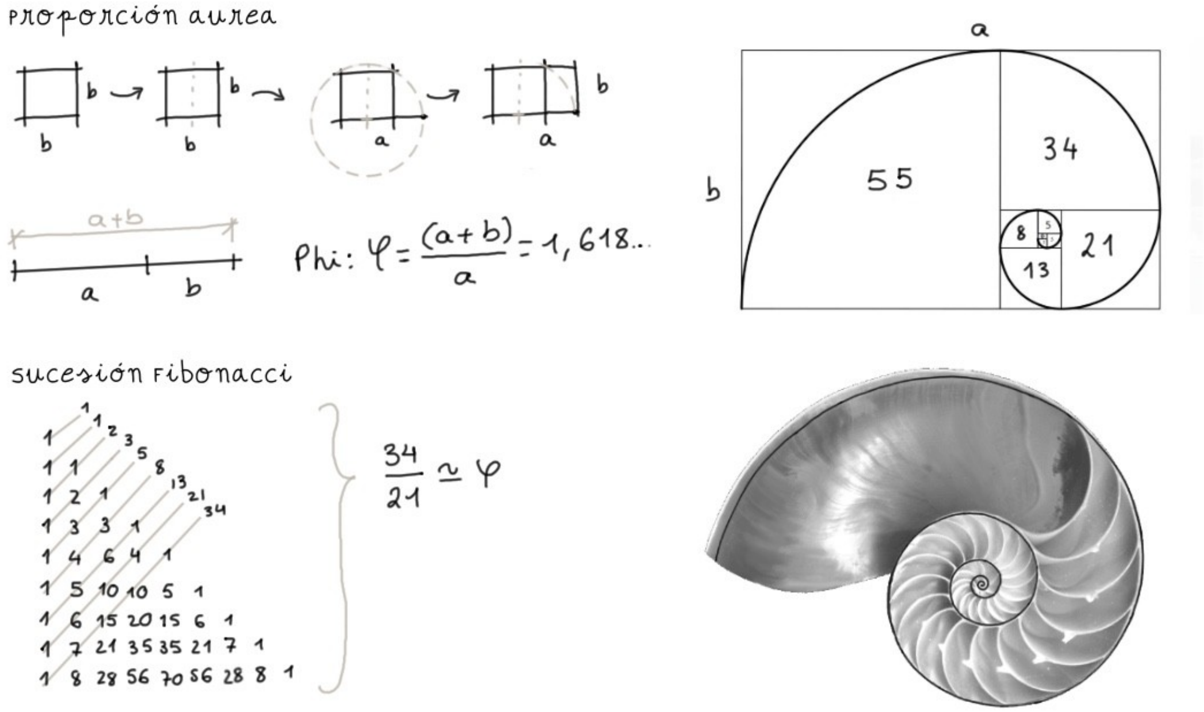


Fig. 18. Golden ratio and Fibonacci spiral at nautilius. Source: Personal elaboration.

In biology, it is known as Ludwing's Law. Apply this spiral growth in three dimensions. For example, the stems around the leaves grow in a helix.

"The ratio between the thickness of the main branches and the trunk, or between the main branches and the secondary branches (the thickness of one equals Φ taking as a unit the upper branch)." (18)

This geometry achieves the highest efficiency with the least amount of matter, since with this distribution the sun can reach all the leaves of the tree

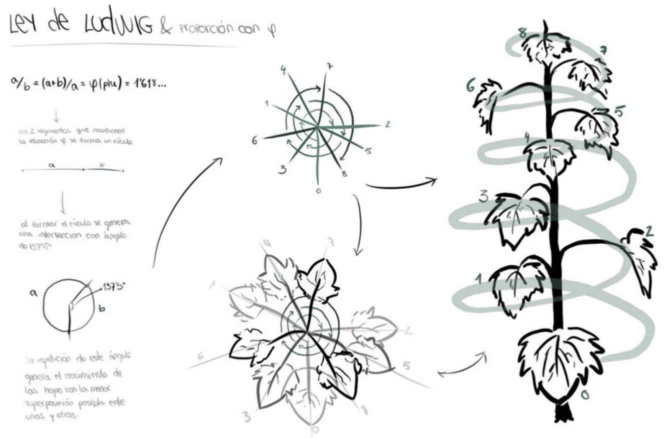


Fig. 19. Scheme of Ludwig's Law in relation to Phi number. Source: López-Maroto, Andrea (2020), *Arquitectura biomimética y biomímesis.*

The catenary is a tool that can be useful in architecture.

"The catenary arch is a curve formed by a chain, string or similar object suspended between two points located on different verticals. This arch if inverted has the virtue of working perfect to compression." (19)

Elements of nature, such as the spider's web, follow this curve because it follows the line of stress taking into account the force of gravity.

Fig. 20. Bridge Kintai-Kyo (1673), Japan

Ramirez in his book "The metaphor of the beehive: from Gaudi to Le Corbusier", explains how the bees are hooked together forming a catenary arch to then form their honeycomb. (20)

The hexagon is a geometric figure that helps to tessellate surfaces, that is, to cover surfaces completely without overlapping figures. The triangle and the square are also useful for tessellation, but the hexagon is more optimal because it occupies more space with less material, explaining why honeycombs are composed of hexagons.(21)

The basalt rock formation, known as the Giant's Causeway, is created when liquid lava cools at high speed with water. Hexagonal section towers are created that follow the principle of minimum energy or second law of thermodynamics.

"In this case, the energy of the system will be minimal when the force generated between the cores is distributed over as much surface area as possible, thus minimizing the pressure. This occurs when the entire surface area of the walls of each core is in contact with each other and all the cores fit together. The shape that maximizes the contact area is the hexagon, so this is the shape that the crystals adopt when they are crushed against each other. "(22)

Fig. 21.Giants causeway in Ireland Source: wikimedia commons.

Fractals explain the functioning of shapes that a priori appear disordered and chaotic. The fractal was discovered by Benoît Mandelbrot, based on other theories (Figure) and thanks to computation. New computers allowed him to iterate the different functions that determine the points of these components. Fractals provide the characteristic of self-similarity, for example a tree starts from a central trunk that branches into different parts and then branches again into smaller ones.

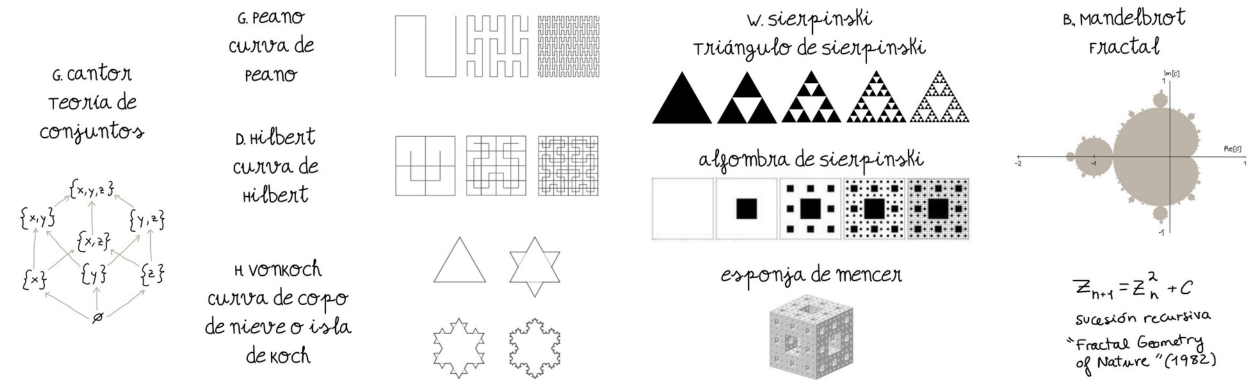
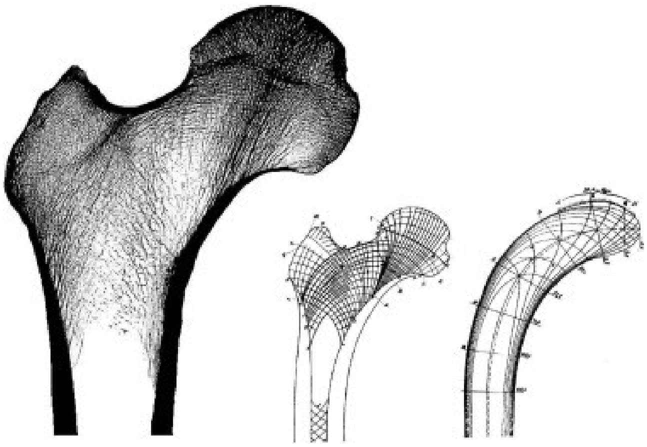


Fig. 22. Fractals and referents. Source: Personal elaboration.

Biomimicry can be applied in architecture by drawing inspiration from natural systems using them as a model for a building design. In this way, you can achieve optimal structures.

Fig. 23. “beams-bone”, Miguel Fisac Source: Alex del Río

Fig. 24. Trabecular architecture in the mid-frontal section of the proximal femur (left). To the right comparison between a sketch of the trabeculae by the anatomist Meyer and the trajectories of principal stresses in a crane model analyzed by Culmann in the second haft of the 19th century.



This work focuses on the behavior of structures based on biomimicry. But within this movement there are other aspects applicable to architecture. For example, imitating the shape to achieve improvements in energy performance or extending the study to cities in the field of urban planning.

B. Biomimicry in thermal and energetic behavior

Biomimicry can inspire designs of buildings that adapt to changes in the environment, just like natural systems.

For instance, The Davis Alpine House at Kew Gardens, designed by architects Wilkinson Eyre and environmental engineer Patrick Bellew in 2006, showcases an innovative solution for displaying alpine plant collections. Unlike conventional methods of refrigerated shelves or air-conditioned enclosures, the team sought a more creative approach.

They incorporated a thermal labyrinth within the building, which essentially consists of a basement with a network of masonry walls providing a large thermal mass. This mass can be ventilated during cooler nights to store the "coolth," which can then be utilized during the day by circulating air into the growing area. This approach, known as "decoupled thermal mass," allows for precise control of cooling, similar to how termites regulate temperature by opening and closing vents. To control solar gain, a deployable sunshade was also implemented.

The Davis Alpine House successfully maintains the ideal conditions for the plants with minimal energy input, as the thermal labyrinth proves highly efficient. In fact, the relatively short payback period of nine years for the cost of the thermal labyrinth, compared to traditional cooling methods, has decreased further due to rising energy costs. The design takes inspiration from nature, where many animals simply seek cooler environments and utilize convective heat transfer.

In a similar vein, the Mountain Data Centre by Exploration tackles the challenge of cooling data centres, known for their high energy consumption. Rather than relying on energy-intensive cooling systems, the data centre is located in a naturally cold mountainous region with a steady temperature of approximately 5°C. The team implemented a circular layout for the data blocks and designed the ductwork to emulate branching systems found in biology, inspired by Murray's law. This combination of efficient airflow and free cooling is anticipated to make the Mountain Data Centre one of the most energy-efficient data centres globally. (23)

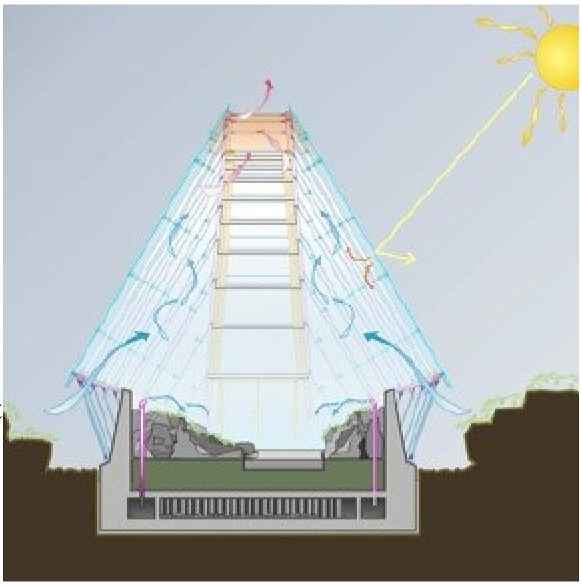


Fig. 25. Ventilation diagram

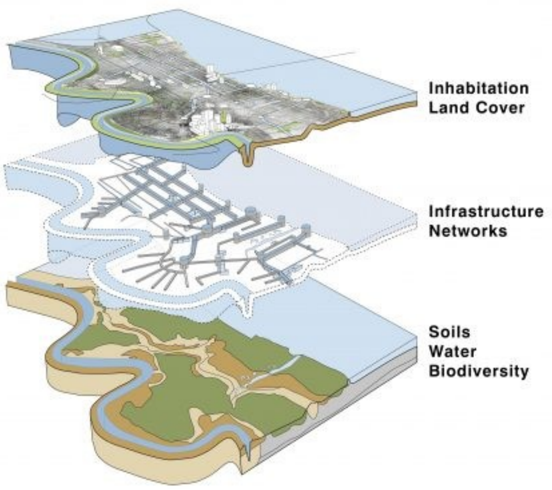
C. Biomimicry in urban and landscape design

Is important to look at cities as ecosystems. Although, there are no cities that are completely biomimicry yet, there are examples of urban projects.

The "Living with Water" approach to resilience aims to reduce the strain on the cities' stormwater system by implementing green infrastructure practices and strategic storage solutions. This involves the creation of vegetated systems that effectively manage stormwater runoff, utilizing natural elements to enhance resilience. Two examples of green infrastructure, stormwater bump outs and rain gardens, mimic natural environments, effectively slowing down stormwater runoff and facilitating its absorption back into the ground.

In addition to these efforts, the project incorporates the concept of Complete Streets, which prioritizes safety, comfort, and accessibility for all users of the streets, including pedestrians, cyclists, runners, and vehicles. By adopting this holistic and community-focused perspective, the project fosters resilience on multiple levels, ensuring the well-being and sustainability of the community.(24)

Fig. 26. Living with Water, Scenario Journal, New Orleans, LA
Firm: Waggonner & Ball (lead)



V. Case study

A. Comparison of a traditional project with a biomimicry project

Sant Cugat Residential Building

This project is a multi-family building located at Carrer de Jeroni Pujades, 1, 08173 Sant Cugat del Vallès, Barcelona. It is a compact construction, seeking to expose the minimum possible envelope, which is centered on the triangular-shaped plot. The access is on the north side and on the first floor there are two houses on the east side because it is where the lowest levels are. From the second floor there are four dwellings that are repeated on the different floors and on the top floor the community space program is incorporated.

This project was designed from the structure, imagining boxes that make up the different spaces. For this purpose 20 cm reinforced concrete walls were used. The rooms were placed in the corners, in this way all the dwellings follow the same pattern and being surrounded by structure allowed a good stability of the building. In this way the houses had an entrance next to a set of wet areas (bathrooms and kitchens) and together with the rooms gave an "L" shape to the living-dining room, allowing to play with double visuals.

The foundation is made of reinforced concrete spread footings, the floor is a system of igloos and the slabs are recticular, bidirectional concrete with lightened.

Prototype Sant Cugat Residential Building

I call this project a prototype because it is quite simple, it is more hypothetical and not as developed as the previous project. It is just a case of reflection as a personal challenge and to be able to open my mind about my own work that I did at the time of which I am proud, but it is a unique version of the thousands of possibilities to be done.

Reinforced concrete is also used. In fact, reinforced concrete is an answer to a problem solved by biomimicry. Joseph Monier was a gardener who designed his pots with concrete incorporating a metal mesh inspired by the fibers of the sclerenchyma of some plants (supporting tissue formed by dead cells), then this system evolved into reinforced concrete.

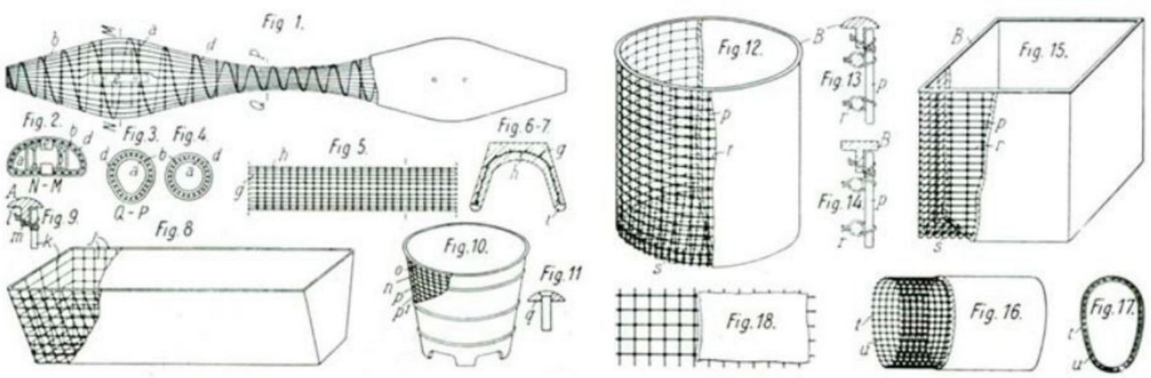
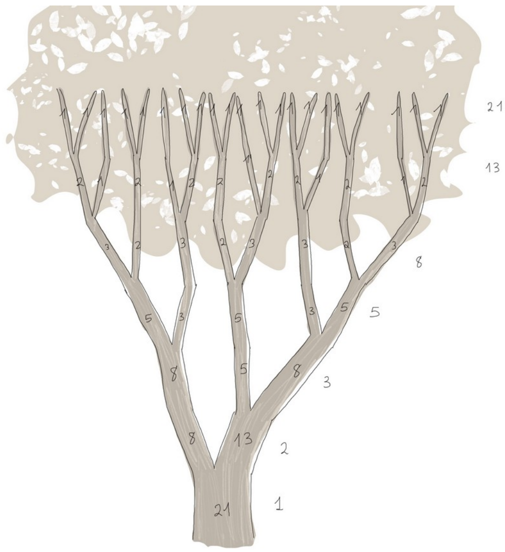


Fig. 27. A. Monier, Joseph. (1884), Bocetos de las primeras macetas de hormigón y acero.

To design this prototype, I first based myself on the growth of trees. As mentioned in the theoretical part trees grow following Ludwig's law. Therefore the structure will be made of reinforced concrete pillars, these will be inclined and will start from a central pillar. As the plot is triangular and it is of interest to have three buildings that when going up in height the platforms can be joined and intertwined. This will create an open first floor open to the public with three pillars of cylindrical section of 1.5m in diameter that as the floors go up will be divided and therefore decreasing in section.

The section of the pillars will be cylindrical like the trees, this shape is very resistant, easy to form for its construction and also behaves better against the wind, since a cylinder, unlike a rectangular shape, has no direction and therefore can not exert as much wind pressure.

Concrete slab, slab with ribs at the maximum stresses, as in the example explained above by architect Nervi. This results in a thinner slab that can support more spans between columns and is prepared to receive stresses from different directions.

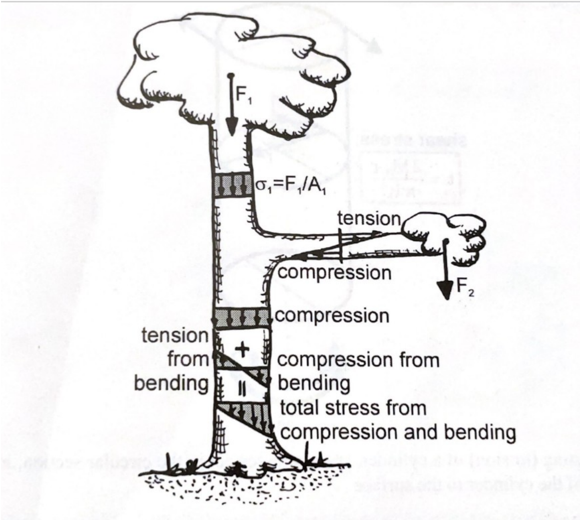


The large pillars on the first floor will have a foundation with micropiles, which allow a great grip to the ground with minimal stresses, imitating the roots of trees. This distribution also allows the columns to grow at different ground levels, avoiding the creation of retaining walls.

Figure Combined axial and bending load induced by the two crown wights F1 i F2. Source: Claus Mattheck, (1998) Design in Nature, Learning from trees.

We see how both projects use the same materiality but have totally different aspects. One seeks stability with vertical walls and horizontal slabs and closes in on itself, while the other extends much more over the plot and seeks little orthogonality, the pillars are inclined and are decreasing in section and multiplying as it rises in height.

Fig. 28. Combined axial and bending load induced by the two crown wights F1 i F2. Source: Claus Mattheck, (1998) *Design in Nature, Learning from trees.*



VI. Conclusions and recommendations

After writing this dissertation, I have been able to reach a better understanding of Biomimicry and its application to architectural designs.

During the research of Biomimicry, I have observed that architecture can benefit from taking structural models of different plant or animal organisms from nature. It is essential before designing to ask yourself what nature would do.

And thus achieve in its design an optimal development from a sustainable point of view.

The main idea of my work was to learn from natural structures in order to apply them in architectural designs.

Although this type of nature-inspired architecture is known, it does not have a wider scope even though it could bring innovation, sustainability and resilience. As it is still considered a recent term within the architectural world, it still has many challenges to overcome such as regulations or construction methods. However, I believe it is the architectural style that will be very important in the future.

Through this work, I have achieved my main objective of learning in more detail about this type of architecture and understanding its applicability.

Going forward with this knowledge, I will be able to investigate architects who utilize designs inspired by nature and thus be able to continue studying its applicability in sustainable buildings and spaces.

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Fig. 20. Bridge Kintai-Kyo (1673), Japan

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Fig. 21.Giants causeway in Ireland Source: wikimedia commons.

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