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Architecture Learns from Nature. The Influence of Biomimicry and Biophilic Design in Building

Gastón Sanglier Contreras[1], Roberto A.González Lezcano[1], Eduardo J. López Fernández[1] & María Concepción Pérez Gutiérrez[1]

[1] Universidad San Pablo-CEU, Polytechnic School, Madrid, Spain

Correspondence: Gastón Sanglier Contreras, Universidad San Pablo-CEU, CEU Universities, Polytechnic School, Urbanización Montepríncipe, 28660 Boadilla del Monte, Spain. E-mail: sanglier.eps@ceu.es

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Abstract

Architecture is currently seeking to create new and innovative building forms that are more sustainable and less harmful to the environment. In this pursuit, architects are turning to nature for inspiration, utilizing biomimicry and biophilic design principles to create buildings that are more in harmony with the natural world.

The use of biomimicry and biophilic design has produced encouraging results, as architects are incorporating natural forms and elements into their building projects. This approach has the potential to bring significant advancements in innovation and research, particularly in fields such as green nanotechnology and sustainability.

Moreover, the intentional incorporation of nature in building design can have a positive impact on workers' health, leading to reduced stress levels and greater individual satisfaction with their work or living environment. Thus, biomimicry and biophilic design can play a key role in achieving a more sustainable and healthier built environment.

Keywords: architecture, biomimicry, building, nature, biophilic design

1. Introduction

1.1 Problem Overview

As the climate crisis deepens, especially over the last few years, the most important thing is to focus on building zero-impact buildings and to understand the advantages that biomimicry (designing to mimic nature) and biophilic design (integrating nature into design) can offer (Kshirsagar et al., 2017). The Covid pandemic that has been going on around the world for almost two years has taught us to be prepared to face any new scenario in the near future, where people are forced to remain confined to their homes. The health and safety of homes is the most important thing, and if they are in tune with the natural environment, so much the better.

Architecture has long been influenced by nature, as architects have often looked to the natural world for inspiration in their designs. Recently, two related movements have emerged that are particularly focused on incorporating nature into building design: biomimicry and biophilic design.

Biomimicry is the practice of emulating natural systems and processes to solve human problems. In architecture, this might mean designing a building that is inspired by the shape or structure of a plant or animal, or incorporating natural ventilation or cooling systems that mimic those found in termite mounds or beehives. As Janine Benyus, one of the pioneers of biomimicry, has written, "Life has been engineering for 3.8 billion years, and we have much to learn from its genius."

Biophilic design, on the other hand, is focused on creating buildings and environments that foster a deep connection between humans and nature (Kellert et al., 2008). This might involve incorporating natural materials like wood or stone into a building's design, or creating spaces that offer views of natural landscapes or access to natural light and fresh air. Biophilic design is based on the idea that humans have an innate connection to the natural world, and that this connection can have a positive impact on our health and well-being.

Both biomimicry and biophilic design have gained popularity in recent years, as architects and designers have sought to create buildings that are more sustainable, energy-efficient, and in harmony with the natural world. For example, the Bullitt Center in Seattle, which bills itself as the "greenest commercial building in the world," was

designed with a variety of biophilic features, including a living roof, a rainwater harvesting system, and ample natural light (Benyus, 1997; Wang et al., 2019).

Another notable example is the Eastgate Centre in Zimbabwe, which was inspired by the way that termites regulate the temperature and humidity of their mounds. The building uses a similar ventilation system to cool and circulate air, which has reduced its energy consumption by 90 percent.

As the world faces increasingly urgent environmental challenges, it is likely that the influence of biomimicry and biophilic design will only continue to grow in the field of architecture. By looking to the natural world for inspiration, architects can create buildings that are not only beautiful and functional, but also more sustainable and resilient in the face of a changing climate (Ghirardi, 2021).

1.2 The Term Biomimicry

Where does the term "biomimicry" come from? Janine Benyus in 1997 is known as the founder of the biomimicry movement. She set out all her theories in the book "Biomimicry: Innovations Inspired by Nature". A year later, together with Dayna Baumeister they founded biomimicry, which puts into practice a deep understanding of the biological adaptation of organisms to help architects, engineers and designers solve design and engineering problems in a sustainable way (Elmeligy, 2016). In 2008, the 'biomimicry portal' was developed, which is the first digital database for biological organisms that have strategies to solve problems in line with the humanitarian community (Ibrahim-Anous, 2015). In 2005 together with Bryony Schwan they founded the Biomimicry Institute, two years later Chris Allen joins them to launch "AskNature", the world's first digital library containing a list of natural solutions where designers can search through this collection of natural systems, classified according to their design and engineering (Darwan & Osama, 2016; Button, 2016). Benyus later founded his own world-leading consultancy company, called Biomimetics 3.8. Its mission is to enable the world to be inspired, learn and innovate from nature and the processes within it. It is focused on getting humanity to listen to nature so that they can live together learning from each other towards a more sustainable world. It is about humanity being sensitive in its exploitation and not endangering it (Schreiner, 2020, Hwang et al., 2015). The search for a balance between the two seems difficult, but not unattainable. She frames the concept of biomimicry around the urgent goal of ending environmental destruction. In National Geographic magazine she said that "I wish we had been at the drawing board of the Industrial Revolution" (Scobey, 2014; Biloria, 2012).

In 2006, Richard Bonser published a study in the Journal of Bionic Engineering assessing the growth of biomimetic innovation. Bonser finds that between 1985 and 2005, the number of patents worldwide containing the word biomimetic increased by a factor of 93. (The growth factor for non-biomimetic patents was 2.7) (Scobey, 2014, Bhushan, 2016).

Hansjörg Wyss in 2008 began work to create the Wyss Institute for Engineering based on what Biologics offers and projects to strive to discover the engineering principles that govern living things, using this knowledge and inspiration to address technological solutions to combat the most immediate health and environmental problems facing humanity (Scobey, 2014, Biomimicry Global Design Challenge, 2015).

Michael Pawlyn comments that designers should use nature as a 'sourcebook' for sustainable design and technology (Austin, 2014; Radwan & Nouran, 2016).).

1.3 Biophilic Design

On the other hand, the term "biophilic design" emerged over time. In 1965, the German/American social psychologist Erich Fromm worked with the term "biophilia" and defined it as the "love of life" or "living things". In the 1980s, the American biologist Edward Wilson hypothesised that people have a genetically based need to be in harmony with nature. Stephen R. Kellert, a professor of social ecology, along with a group of academics, took this idea and coined the term "biophilic design": the notion of connecting humans with nature within their built environment.

Why is the integration of biophilic design so good for us?

- Physical health.

Plants inside a room improve air quality by absorbing mould, harmful substances and toxins. They release water vapour into the air and make people less susceptible to allergens and respiratory diseases. They also relax us and lower our blood pressure.

- Mental health.

The biophilic design reduces stress and creates a sense of peace and relaxation.

- Productivity.

Natural light regulates sleep cycles and provides more energy and productivity. The integration of biophilic principles increases creativity, memory performance and the ability to learn. It also provides clarity of thought and mental breaks.

2. Method

Biomimicry and biophilic design are approaches that seek to learn from nature and apply that knowledge in the construction of more sustainable buildings and urban spaces in harmony with the environment. To investigate these approaches, we intend to follow a methodology that includes the following steps, some of which are not yet finalised:

Identification of the problem or research question: Research has been carried out on the origin of the problem to be addressed. For example, how can a building be designed that uses less energy and natural resources, and at the same time provides a healthy and attractive environment for the occupants?.

Literature review: A comprehensive review of the existing literature on biomimicry and biophilic design in construction has been carried out in order to understand the concepts and applications in depth and to know the most relevant examples and case studies.

Defining the research objectives: Once the literature has been reviewed, specific research objectives have been established. For example, to develop a prototype building inspired by nature, to measure the effects of biophilic design on occupants' well-being, or to compare the energy and environmental performance of conventional buildings with buildings designed using biomimetic approaches.

Case study selection: Relevant case studies have been selected for the research to analyse and compare conventional design approaches with those based on biomimicry and biophilic design.

Data collection: Relevant data has been collected for the research, such as measurements of energy consumption, air quality, light and noise levels, occupant surveys on wellbeing and satisfaction, among others.

Data analysis: Data collected has been analysed to determine if there are significant differences between conventional and biomimicry and biophilic design approaches, and to identify best practices and recommendations for future projects.

Conclusions and recommendations: The conclusions of the research should be presented, summarising the findings and answering the initial research question. Recommendations for future construction projects based on biomimicry and biophilic design should also be made (Aminekad, 2018; Benelli, 2020).

The effects or benefits of biophilia on human health have been proven, however, it is unknown how the incorporation of biophilic elements impacts the perception of the space we inhabit. Therefore, the research question would be: How does the use of biophilic elements influence the user's perception of the habitability of the space?

Following this order of ideas, the objective of the research would be to identify and evaluate the influence of biophilic elements on the perception of the habitability of space. To identify in the sense of determining whether or not it has an influence at first, does the user detect it, does the user prefer it, or is the user indifferent to it, or is the user indifferent to it? Or is the user indifferent to this type of design? Afterwards, this influence on the perception of the space would be assessed.

A methodology for the application of biomimetrics has been developed based on the study of the main points associated with the different elements used in the built work, focusing mainly on the influence of nature in space (visual and non-visual connections, sensory stimulation, etc.), natural analogies (biomorphic shapes and patterns) and the nature of the space itself, more related to shelters and risks (Bai et al., 2020; Benyus, 1997).

The incorporation of natural elements into the construction; plants, water, animals, air or breezes, sounds, smells, etc. This is achieved on the basis of three main points:

Table 1. Main points for the incorporation of elements into the building

Nature in Space	Natural Analogies	Nature of Space
Visual connection with nature	Biomorphic shapes and patterns	Perspective
Non-visual connection with nature	Material connection with nature	Refuge
Non-rhythmic sensory stimulation	Complexity and order	Mystery
Variability of temperature and air currents		Risk or danger
Presence of water		
Diffuse and dynamic light		
Connection with natural systems		

According to a study carried out by the architect Alba Beltre Ortega, this provokes sensory experiences with the built environment and its natural elements that we can distinguish in three scenarios:

Table 2. Sensory experiences in the built environment

Indirect experience	Direct experience	Experience of space and place
Light	Images of nature	Perspective and refuge
Air	Natural materials	Organised complexity
Water	Natural colours	Integration of parts
Plants	Mobility and orientation	Transitional spaces
Animals	Cultural and ecological attachment to place	Mobility
Ecosystems and natural landscapes	Naturalistic forms	
Climate	Evocation of nature	
Fire	Richness of information	
Indirect experience	Awareness of the passage of time	
	Natural geometries	
	Biomimetics	
	Simulation of natural air and light	

The basis of the biophilic patterns and design guidelines, although there is a lot of history behind them, are considered to be contributed by Stephen Kellert, to help us understand what is involved in applying biophilic design.

Each of the fourteen patterns based on three main domains shown below, focus on stress reduction, cognitive performance, improving emotions and mood and the human body (Kellert et al., 2008).:

- Nature in space:
    - Visual and non-visual connection with nature.
    - Arrhythmic sensory stimuli
    - Thermal variations of air currents
    - Presence of water
    - Dynamic and diffuse light
- Natural Analogies:
    - Biomorphic shapes and patterns
    - Connection of materials with nature
    - Complexity and order
- Nature over space
    - Panorama
    - Refuge
    - Mystery
    - Risk/Danger

Humans are a kind of full-body sensor, and our sensors are absorbing information from the environment we are in, helping us to understand the places we go. These key points are intended to improve health and wellbeing in a built environment.

Below are some examples of biophilic design in architecture addressing fields such as health, office and public spaces, can be seen in figure 1:

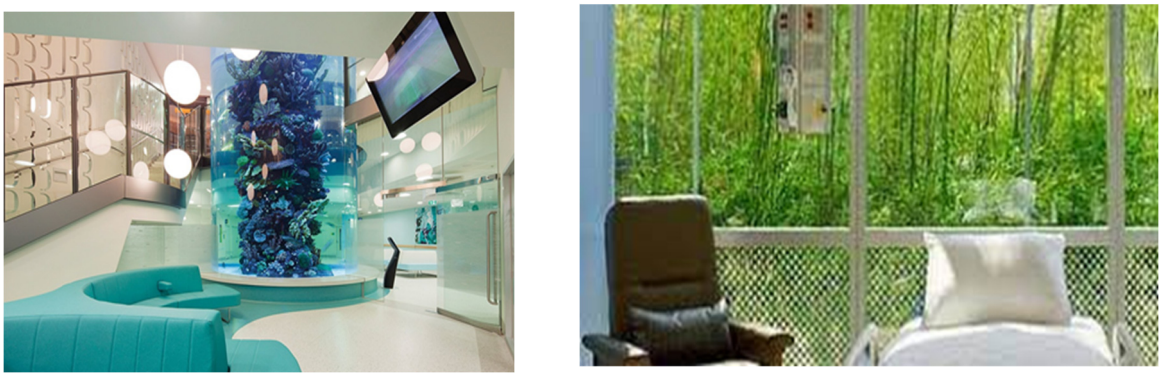

Figure 1. Biophilic health project.

Figure 1 shows two images of part of a hospital project which today is a benchmark in health care for children (The Royal Children's Hospital by Bates Smart - Melbourne, Australia) and in the application of biophilic concepts to improve the wellbeing of patients. The conclusions obtained by different studies are clear: patients who are placed in rooms with views of nature or spacious rooms recover more quickly, obtaining a lower "bed rate" than occupants of other rooms.

Figure 2. University of Oregon office building (woodsbagot.com)

A case study of an administrative office building at the University of Oregon (figure-2) indicated that biophilic architecture directly affects the absenteeism rate of office workers, in this case it was found to be 10 percent.

The two images in Figure 3 provide another of the most emblematic examples that can be identified in New York. The High Line Park, a railway line converted into an open area for visitors with more than 300 species of perennials, grasses, shrubs and trees. More than four million people visit it every year. Biophilic architecture in public spaces that is adapted to urbanism can also help lower urban air temperatures and improve the island effect in urban areas (Elango & Moses, 2017).

Figure 3. High Line Park, converted railway line (glenwoodnyc.com)

3. Results

Humans are a kind of full-body sensor, and our sensors are absorbing information from the environment we are in, helping us to understand the places we go. These key points are intended to improve health and wellbeing in a built environment.

Below are some examples of application to biophilic design in architecture addressing fields such as health, office and public spaces based on the influencing factors mentioned above:

Figure 4. Orquideorama en el jardín Botánico de Medellin (Colombia).

Figure 4 shows the new structure of the Orquideorama as a result of an ideas competition, held by the Botanical Garden of Medellín at the end of 2005. The winning proposal had to resolve a highly flexible space that would not only house the flowers but also all kinds of social and cultural events. A structure in which the limits with the landscape are diluted and its forms are integrated into the surrounding environment.

Figure 5. University of Oregon office building (woodsbagot.com)

Figure 5 shows a case study of an administrative office building at the University of Oregon indicated that biophilic architecture directly affects the absenteeism rate of office workers, in this case it was found to be 10 percent.

The two images in Figure 6 provide another of the most emblematic examples we can identify in New York. The High Line Park, a railway line converted into an open area for visitors with more than 300 species of perennials, grasses, shrubs and trees (Hargroves & Smith, 2006). More than four million people visit it every year. Biophilic architecture in public spaces that is adapted to urbanism can also help lower urban air temperatures and improve the island effect in urban areas.

Figure 6. High Line Park, converted railway line (glenwoodnyc.com)

There are different ways in which architects can help turn these concepts into reality.

3.1 Integrating Nature into Every Project

To get ideas for their work, architects often turn to websites with inspiring photos of new buildings, with other ideas of form and integration aiming for sustainability (Salas-Mirat et al., 2018). It would be better if they took a walk in a forest. As architect James Ingo Freed points out, "The world is fascinating. If we designers opened our eyes, we would find inspiration everywhere - and not in a hippie way, but in a perfectly tangible and practical way". There is a wealth of natural forms to incorporate into a building: modelling columns on trees and their various shapes, applying botanically inspired motifs to fabrics and wall coverings.

Figure 7. Common workspaces at Etsy headquarters. Courtesy of Garrett Rowland/Gensler.

Biophilia, or humans' innate affinity for nature, is reason enough to make this push to incorporate it into buildings. For Etsy's nearly 20,000-square-metre headquarters in Brooklyn, New York, biophilic design was a key component of architecture and design firm Gensler's strategy to promote employee wellness, health and productivity (Van den Berg & Custers, 2011). In this project, the team filled the space with greenery, commissioned botanical-themed artwork, and minimised the use of smooth walls and right angles to emulate the irregularities found in the natural environment. According to Freed, a simple way to incorporate nature into projects is to carefully study the unique properties of each site: the surrounding terrain, the path the sun takes, the climate, the flora and fauna (Tavsan et al., 2015). Some of these elements can be foregrounded in architecture. Freed says that one thing he usually does when he wants to integrate the building into the site is to go and collect samples: leaves, stones, flowers and so on. We document them, scan them, adjust the colour and store them in a repository on the site.

This design strategy echoes nature's own logic. Organisms evolve in response to the conditions of their environment, and so should architecture - this is what Frank Lloyd Wright used to describe as organic architecture. That creative process of 'we don't come with a preconceived form, but we are part of the community and work in harmony with our surroundings'. How can nature in general (and place in particular) inspire us to come up with forms we would never have imagined?

3.2 Becoming A Driver of Biomimetics

Understanding how nature solves problems can help architects create buildings that work in harmony with natural systems, such as the planet's atmosphere and the human body, for example. Over billions of years, nature has been

improving living things to help them function in their environment. The bones of the human body are about four times stronger than concrete (at half the weight); spider silk is five times stronger than steel (Kennedy, 2017). And unlike concrete and steel, bones and silk do not generate pollutant emissions during their production.

Figure 8. Rendering of the interior of a biomimetic office building. Courtesy of Exploration Architecture.

UK-based Exploration Architecture is in the business of translating lessons learned from nature into built form. For a biomimetic office building project, as shown in figure 8, the firm studied how plant and animal biology serve vital needs ranging from structural support to temperature regulation. Drawing ideas from materials such as bird skulls, polar bear skins and mimosa leaves, they created a design with a predicted energy consumption far lower than that of a comparable standard office tower (Yoon et al., 2017**)**. In the Abalone House project, they proposed mimicking the geometry of a mollusc shell (figure 9) to create an undulating roof structure, which halved the amount of building material required. Of course, not every studio has the resources or expertise to jump straight into mollusc-inspired roof design, but Freed believes that architects can still advance the cause, even if they cannot yet mimic nature. He points out that they don't need to become amateur biologists overnight - they just need to be enthusiastic and interested in using this approach to design better buildings. It is important that this approach is transferred to the field of design and architecture with the aim of creating 'different' buildings and aiming for zero impact.

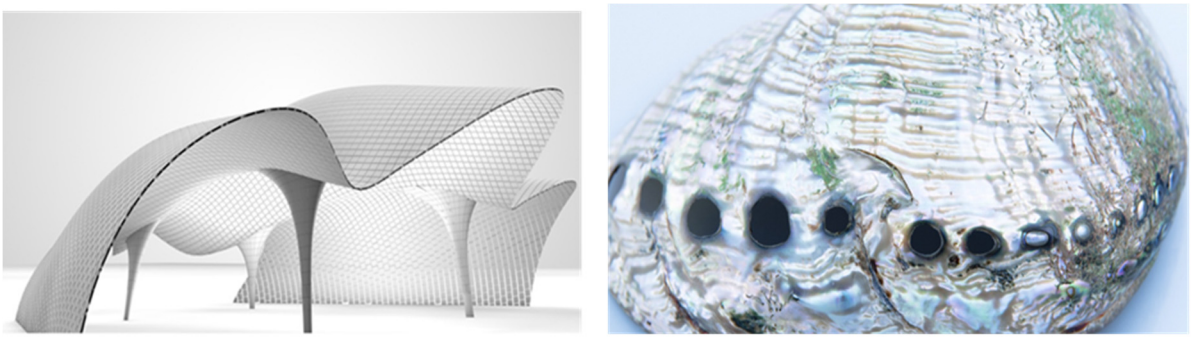

Figure 9. The roof of the Abalone House project mimics the geometry of a mollusc shell. Courtesy of Exploration Architecture.

3.3 Seeking Bio-Based Materials

Manufacturers have increased production of non-toxic and eco-friendly items, and a library of products called mindful MATERIALS is available online and has made it easier to find and evaluate them. Designers can now specify naturally sourced products, such as soy and hemp insulation, alongside more familiar options such as cross-laminated timber or CLT (although there may still be regulatory or supply chain issues). Freed is particularly excited about bio-based materials that can be designed to meet specific needs and produced in the form of crops, rather than through energy-intensive industrial processes (Ferrer-Pla & Gutiérrez, 2019). In addition, DNA can be manipulated to give bricks special properties, such as the ability to absorb carbon dioxide from the air, reflect heat during the summer or glow at night (Almeida et al., 2020).

Figure 10. Image of HempWool plant-based vapour permeable fibre insulation. Courtesy of Hempitecture.

These bricks may not yet be available at the corner building materials shop, but they are more than just a futuristic dream. Fred points out that the DNA map of all these elements has now been sequenced and it is now possible to grow building materials that do the things we want them to do. BioMASON, a North Carolina company that produces bricks using micro-organisms (a process inspired by studies on coral), offers a preview of what the future holds (Vignolini et al., 2012). As Freed points out, most materials contribute to the climate crisis during their manufacture. By growing them ourselves, we can avoid that, and even reverse the process. The use of such materials is a relief in an architecture that demands concrete primarily for the construction of its buildings, and is clearly a material that invites replacement over time by the use of more sustainable materials.

4. Discussion

Biomimicry, also known as biomimetics or biomimicry, tries to observe, understand and apply solutions from nature to human problems, in the form of biological principles, biomaterials of all kinds, trying to improve the sustainability of the planet.

Biomimicry appears as a possible solution to improve energy efficiency by making buildings based on structures of natural organisms, however, it is difficult for users to know that they like the natural world if they cannot experience it, here lies the future of our planet, creating bonds of interest towards nature and caring for it.

One of the great challenges in the different phases of building construction would be to achieve the Sustainable Development Goals (SDGs), trying to minimise the impact and responding to the social and energy challenges facing humanity: building more efficient structures, manufacturing new materials that are more environmentally friendly, creating zero consumption or zero impact systems, managing resources better, controlling thermal comfort or producing energy for buildings are some of the advantages offered by this process.

Together with other areas such as sustainability or green nanotechnology, biomimicry will lead to advances in research and innovation in important fields such as materials, medicine, robotics, energy, biotechnology and artificial intelligence.

Biomimicry finds important partners in parametric design software, 3D printing and laser cutting, which enable designs inspired by nature while minimising waste and reducing environmental impact.

It seems that users prefer places with a large number of biophilic elements (parks, gardens, terraces, biophilically adapted plants in buildings, etc.) to rest, so it is necessary to design work spaces with natural ventilation, natural lighting, vegetation and elements that allow interaction with other living beings and that those who work in large offices can easily access to rest.

Natural (biophilic) elements help to make the workplace more pleasant. This proves the biophilia hypothesis, which stipulates that people prefer the natural world over the urban world, due to the close contact humans have had with nature during their evolution.

4.1 Biomimetic Construction.

Biomimicry and biophilic design are two currents that are having a significant impact on the field of construction. Both are based on the observation and imitation of nature, but while biomimicry focuses on copying biological forms and processes to solve technical problems, biophilic design seeks to create spaces that promote human connection with nature.

In construction, biomimicry is being used to improve energy efficiency, material strength, water management and ventilation, among other aspects. One example is buildings that mimic the shape and functioning of termite nests to

regulate indoor temperature and reduce energy consumption (Hickman, 2018). Another example is façade design inspired by fish scales to improve aerodynamics and corrosion resistance (Nadkarni, 2019; Peattie & Peattie, 2003).

Biophilic design, on the other hand, seeks to incorporate natural elements into the interior and exterior spaces of buildings to improve the health and well-being of their occupants. Studies have shown that exposure to nature reduces stress, improves concentration and increases productivity (Kellert & Calabrese, 2015). Therefore, elements such as natural light, plants, water and natural materials are being used in building construction to create healthier and more attractive spaces.

Evaluations of buildings suggest that biophilic elements do not necessarily influence the physical perception of the space (temperature or lighting), however, they do influence the feelings or sensations generated by the space. In other words, natural lighting and ventilation can be replaced by artificial sources and users will still rate these features highly, but when it comes to evaluating the feelings or sensations generated by the space, it is related to the biophilic elements of the place, from the views, ventilation and natural lighting to the presence of green areas.

In this way, the architect's function is reinforced, not only as a professional in charge of designing according to the norm that allows him to carry out the proposed activity, but also to generate positive sensations in the space and, why not, to make the user leave the space healthier than when he entered it.

It is difficult, due to the situation of current buildings and the urban design of cities, to propose new views or experiences near natural spaces, however, it is possible to bring the natural world (biophilic elements) into the space.

The simplest way to do this is through vegetation inside the building, e.g. plants that do not need sunlight or abundant water. Another means, perhaps less effective than in situ plants, is to place landscape photos in offices, thus providing a visual escape and an information-rich image for workers to access. The way to design buildings in the future (and from now on) should be one that benefits from nature, but not in a parasitic way, but in a symbiotic way. Where vegetation can feed on the nutrients generated from human activities, and in turn, human spaces can benefit from the presence of vegetation (shade or scents from plants within a place).

The ideal would be to work in a tree house or even better to work inside a tree. It is very difficult for this to be the case, but elements of this idea can be brought into the real world. Textures on the walls rich in information and sensations, scents coming from a wooden floor or aromatic flowers, views of different green areas from the workspace, even the possibility of interacting with other living beings such as birds that stop to turn water in a fountain or bees that come to perch on a flower in a pot, could be some examples of where this type of technology is tending towards.

One way of integrating biomimicry and biophilic design into construction is through regenerative architecture, which seeks to create buildings that are not only efficient and healthy, but also have a positive impact on the environment and the community. Regenerative architecture is based on the use of local and renewable materials, the generation of renewable energy and the integration of nature into buildings (Langer, 2020).

Ultimately, biomimicry and biophilic design are two currents that are transforming the way buildings are constructed. Observing and mimicking nature is making it possible to create more efficient, healthy and attractive spaces, and regenerative architecture is taking this approach a step further, promoting environmental and community regeneration. As architect Janine Benyus says, "nature is our teacher, and buildings can be our best students" (Benyus, 2002).

5. Conclusions

In recent decades, there has been a growing interest in the application of nature in architecture, either through the technique of biomimicry or biophilic design. Both approaches are based on the idea that nature is a source of inspiration for architecture, and that imitating natural processes and patterns can lead to the creation of healthier, more efficient and sustainable spaces.

Biomimicry refers to the process of imitating the forms, processes and functions of nature to design buildings and structures that are more efficient, resilient and adaptable. This technique has been used in architecture for a long time, but has gained increased interest in recent years due to the growing concern for sustainability and energy efficiency in construction. Examples of biomimicry in architecture include the design of buildings with shapes inspired by tree leaves to make better use of sunlight and reduce heat load, and the use of materials and construction techniques that mimic nature's processes, such as bio-construction and the use of natural materials.

Biophilic design, on the other hand, refers to the integration of nature into the interior and exterior spaces of

buildings to improve the quality of life and health of the people who live in them. This approach is based on the idea that humans have an innate connection to nature, and that exposure to natural elements such as sunlight, water and vegetation can have a positive impact on their physical and emotional well-being. Examples of biophilic design in architecture include the incorporation of indoor gardens, water features and green walls to improve air quality, reduce stress and increase productivity.

Ultimately, both biomimicry and biophilic design are approaches that seek to integrate nature into architecture to improve people's quality of life and reduce the environmental impact of buildings. Both approaches take into account natural processes and patterns to create more efficient, healthy and sustainable spaces. While there is still much to be done in this field, growing awareness of the importance of sustainability and health in building is driving greater adoption of these approaches in architecture.

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