

Biomimicry: A Tool to Achieve Sustainability in Interior Spaces

Ferhat Akçay

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Interior Architecture

Eastern Mediterranean University
September 2023
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Ali Hakan Ulusoy
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Interior Architecture.

Assoc. Prof. Dr. Afet Coşkun
Chair, Department of Interior
Architecture

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Interior Architecture.

Assoc. Prof. Dr. Guita Farivarsadri
Supervisor

Examining Committee

1. Prof. Dr. Nil Paşaoğluları Şahin

2. Assoc. Prof. Dr. Guita Farivarsadri

3. Asst. Prof. Dr. Sevil Aydınlık Başar

ABSTRACT

Nowadays the world is facing serious environmental problems such as global warming, pollution of air, water and soil, floods and droughts. A big part of these problems is caused by unconscious and excessive consumption of world resources by human beings. The building industry in general has a major role in a lot of environmental problems. For this reason, it is very important that the architects and interior architects adopt more environmentally friendly and sustainable design strategies to reduce these problems. Sustainability in general can be described as meeting or satisfying the needs of the current generation without diminishing or compromising the ability of future generations to meet their own needs. The concept of sustainability is very important in interior architecture as well. To ensure sustainability in interior spaces, it is first necessary to know the interiors with all their components, to know the expectation of sustainability in the interiors, and perhaps most importantly, to use a method that can create this. This is where biomimicry comes into play. The biomimicry method offers one of the most effective methods on the path to sustainability. The reason why biomimicry is powerful in terms of sustainability is that it derives its power from nature and the ability of natural organisms to survive for millions of years. This study has two main aims. The first aim is to determine what the environmental sustainability considerations in design of interior components are and to examine how biomimicry can help to achieve sustainability in interiors. As the first step of the study the sustainability requirements for various interior components and biomimicry design examples in the issues related to the interior architecture are searched. Then, a guide has prepared to be used by the interior architects where briefly the requirements to have sustainable interior components and examples of biomimicry

designs that can help to achieve those goals are compiled. The study tends to create a tool to help interested interior designers in achieving more sustainable interior environments and to increase the use of biomimicry in interior architecture.

Keywords: Biomimicry, Interior architecture, Sustainability, Sustainable Design, Interior Components

ÖZ

Günümüzde Dünya küresel ısınma, hava, su ve toprak kirliliği, sel ve kuraklık gibi ciddi çevre sorunlarıyla karşı karşıyadır. Bu sorunların büyük bir kısmı insanoğlunun dünya kaynaklarını bilinçsiz ve aşırı tüketiminden kaynaklanmaktadır. İnşaat sektörü genel olarak birçok çevre sorununda önemli bir role sahiptir. Bu nedenle mimarların ve iç mimarların bu sorunları azaltmak için daha çevre dostu ve sürdürülebilir tasarım stratejileri benimsemeleri oldukça önemlidir. Sürdürülebilirlik genel olarak, gelecek nesillerin kendi ihtiyaçlarını karşılama yeteneklerini azaltmadan veya tehlikeye atmadan, mevcut neslin ihtiyaçlarının karşılanması olarak tanımlanabilir. Sürdürülebilirlik kavramı iç mimaride de çok önemlidir. İç mekanlarda sürdürülebilirliği sağlamak için öncelikle iç mekanları tüm bileşenleriyle tanımak, iç mekanlarda sürdürülebilirlik beklentisini bilmek ve belki de en önemlisi bunu yaratabilecek bir yöntem kullanmak gerekmektedir. Biyomimikrinin devreye girdiği yer burasıdır. Biyomimikri yöntemi sürdürülebilirliğe giden yolda en etkili yöntemlerden birini sunmaktadır. Biyomimikrinin sürdürülebilirlik açısından güçlü olmasının nedeni, gücünü doğadan ve doğal organizmaların milyonlarca yıl hayatta kalma yeteneğinden almasıdır. Bu çalışmanın iki temel amacı vardır. İlk amaç, iç mekan bileşenlerinin tasarımında çevresel sürdürülebilirlik hususlarının neler olduğunu belirlemek ve biyomimikrinin iç mekanlarda sürdürülebilirliğin sağlanmasına nasıl yardımcı olabileceğini incelemektir. Çalışmanın ilk adımı olarak çeşitli iç mekan bileşenleri için sürdürülebilirlik gereklilikleri ve iç mimari ile ilgili konularda biyomimikri tasarım örnekleri araştırılmıştır. Daha sonra iç mimarların kullanımına yönelik olarak sürdürülebilir iç mekan bileşenlerine sahip olmak için gerekenlerin ve bu hedeflere ulaşmaya yardımcı olabilecek biyomimikri tasarım

örneklerinin kısaca derlendiđi bir rehber hazırlanmıřtır. Çalışma, ilgilenen iç mekan tasarımcılarının daha sürdürülebilir iç ortamlar elde etmelerine ve iç mimaride biyomimikrinin kullanımını artırmalarına yardımcı olacak bir araç yaratma eğilimindedir.

Anahtar Kelimeler: Biyomimikri, İç Mimarlık, Sürdürülebilirlik, Sürdürülebilir Tasarım, İç Mekan Bileşenleri

ACKNOWLEDGEMENT

"Behind every successful man there is a woman" I'm not sure if this is a success, but if so, I'm very lucky that there was more than one woman behind me. I would like to thank my beloved İlke Akçay, who supported me in this master's journey that I started at the beginning of the pandemic and the curfew, and who contributed greatly to my completion, and who is the best thing that ever happened to me.

And my endless thanks to my dear supervisor and mentor, Assoc. Prof. Dr. Guita Farivarsadri.

TABLE OF CONTENTS

ABSTRACT	iii
ÖZ	v
ACKNOWLEDGEMENT	vii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF SYMBOLS/ABBREVIATIONS	xv
1 INTRODUCTION	1
1.1 Problem Statement	2
1.2 Aims and Objectives	2
1.3 Methodology of the Study.....	3
1.4 Limitation.....	3
2 COMPONENTS OF INTERIOR SPACES	5
2.1 First Group of Interior Components: Surfaces Defining the Space	8
2.2 Second Group of Interior Components: Furnishings, Furniture and Lighting.	11
2.3 Third Group of Interior Components: HVAC Systems, Natural Air Conditioning Systems and Daylight.....	12
3 ENVIRONMENTAL SUSTAINABILITY IN INTERIOR SPACES.....	17
3.1 Sustainability in Interior Components: Surfaces	23
3.2 Sustainability in Interior Components: Furniture, Furnishing and Lighting ...	24
3.2.1 Interior Lighting Solutions that are Sustainable.....	25
3.3 HVAC Systems, Natural Air Conditioning Methods and Daylight.....	26
3.4 Other Sustainability Concerns in Interior Design	27
3.4.1 Sustainable Materials for Interior Design	27

3.4.2	Water Management Strategies that are Sustainable	28
3.4.3	Options for Interior Construction that are Sustainable	29
3.4.4	Systems for Sustainable and Smart Interior Design.....	29
4	BIOMIMICRY	31
4.1	Origins of Biomimicry	31
4.2	Definition / Concept of Biomimicry	33
4.3	Levels of Biomimicry	34
4.4	The Biomimetic Model: Nature as a Model, Measure and Mentor	40
4.4.1	Nature as Model	40
4.4.2	Nature as Measure.....	41
4.4.3	Nature as a Mentor	44
4.5	Biomimicry Principles	45
4.5.1	Resource (material and energy) Efficient	47
4.5.2	Evolve to Survive.....	47
4.5.3	Adapt to Changing Conditions.....	48
4.5.4	Integrate Development with Growth.....	48
4.5.5	Be Nearby Attuned and Responsive	48
4.5.6	Use life-friendly Chemistry.....	49
4.6	Biomimicry in Design	49
4.6.1	Biomimicry Design Approaches	49
5	BIOMIMICRY IN INTERIOR ARCHITECTURE.....	53
5.1	Flooring	56
5.2	Walls	59
5.3	Windows	65
5.4	Lighting.....	68

5.5 HVAC	71
5.6 Water Management	78
6 CONCLUSION	83
REFERENCES.....	86

LIST OF TABLES

Table 1: What biomimicry provides for interior spaces by considering the expectations of sustainability..... 80

LIST OF FIGURES

Figure 1: Components of Interiors; Floors, Walls, Ceilings, Windows, Doors (Ching & Binggeli, 2018, p. 3)	6
Figure 2: Fundamental Elements of a Building which are Organized in Giving Form to a Building (Ching & Binggeli, 2018, p. 3).	7
Figure 3: Sample Illustration of Furniture and Furnishing (Ching & Binggeli, 2018, p. 333)	11
Figure 4: A Diagram Showing Interior Components that were Examined in this Thesis.	16
Figure 5: Main Dimensions of the Concept ‘Sustainability’, which are Economy, Environment and Equity.	18
Figure 6: Life Cycle of Sustainability. Source: (<i>Golsteijn, 2020</i>)	19
Figure 7: Wing Design by Leonardo da Vinci (<i>Wing Construction with Engineering Design - by Leonardo Da Vinci, 2011</i>)	32
Figure 8: Flight of Wright Brothers in 1903. Source: (National Park Service, 2015).	33
Figure 9: The Nose of the Bullet Train, Inspired from a Kingfisher’s Beak (Primrose, 2020).	37
Figure 10: Pantograph in Conventional Trains (left) and Pantograph in Bullet Trains (right). Source: (Primrose, 2020).	38
Figure 11: Self-Healing Leaf and Self-Repairing Solar Panels. Source: (Graphenea, n.d.)	41
Figure 12: Some Termite Mound Examples and Air Flow in Capped and Open Chimney Mounds. Source: (Yuan et al., 2017).....	42

Figure 13: Eastgate Center Building in Harare, Zimbabwe (Left), Circulation of Heat in a Termite Hill and in a Room (Right). <i>Source: (Jamei & Vrcelj, 2021)</i>	44
Figure 14: Life's Principles by (Biomimicry Group, 2014)	47
Figure 15: Problem Based Approach, adopted from (El-Zeiny, 2012) by (Helms et al., 2009)	50
Figure 16: Solution Based Approach, adopted from (Helms et al., 2009).....	51
Figure 17: A Diagram Showing the Levels and Approaches of Biomimicry	52
Figure 18: Gecko, and Materials inspired by the Feet of them. <i>Source: (Lodson & Jahromi, 2017)</i>	57
Figure 19: Images of Shark Skin and Sharklet AF Material Pattern. <i>Source: (Lodson & Jahromi, 2017)</i>	58
Figure 20: Close-up Picture of a Lotus Leaf (A&B), Water Droplet on Leaf (C), Water Droplet Cleaning the Surface of Lotus Leaf (D).....	59
Figure 21: A Water Droplet on a Lotus Leaf (A), A Water Droplet on a Normal Surface (B), Self-cleaning Effect of a Water Droplet on a Wall Covered with Lotusan Paint (C), Self-cleaning Lotusan Paint (D). <i>Source: (Lodson & Jahromi, 2017)</i>	60
Figure 22: Composition and structure of the plant Selaginella Lepidophylla. <i>Source: (Lodson & Jahromi, 2017)</i>	60
Figure 23: Bionic Car (Daimler Chrysler) inspired by the Boxfish. <i>Source: (Zari, 2007)</i>	62
Figure 24: The Namaqua Chameleon and Standard Fritted Glass. <i>Source: (Yassin et al., 2017)</i>	63
Figure 25: Illustration of How Ornilux Glass is seen by a Bird and seen by a Human. <i>Source: (Lodson & Jahromi, 2017)</i>	65

Figure 26: Constricted (A) and Dilated (B) Blood Vessels, where Heat Conservation and Heat Loss occur Respectively. Schematic of the Composite Window Structure (C) and Artificial Vascular Network Layer (D).	67
Figure 27: Color-Changing Squid (A) and Polymeric Materials inspired from Color-Changing Squid to be Transformed from Transparent to Opaque (B). <i>Source: (Lodson & Jahromi, 2017)</i>	68
Figure 28: Illumination System via Optical Fiber. <i>Source: (Yuan et al., 2017)</i>	70
Figure 29: Sunflower Fiber Optic System in Japan. <i>Source: (Yuan et al., 2017)</i>	70
Figure 30: Singapore Arts Centre. <i>Source: (Atelier One, 2003)</i>	72
Figure 31: Shading Device used in New York State University. <i>Source: (Hoberman, 2010)</i>	73
Figure 32: The Thematic Pavilion in South Korea. <i>Source: (Knippers et al., 2012)</i> . 74	
Figure 33: (A) Front Façade of Melbourne CH2 Building. (B) Using a Microturbine and Solar Panels, CH2 Produces Electricity, Hot Water, and Cooling on its own. (C) CH2 is able to Sustain Thermal Comfort in both the Summer and the Winter thanks to Energy-Efficient Heating and Cooling Technologies. <i>Source: (City of Melbourne, 2006)</i>	75
Figure 34: Ministry of Municipal Affairs and Agriculture Office Building in Qatar, which was inspired from Cactus Spines.	76
Figure 35: Venus' Flower Basket Sponge (A), Gherkin Tower in London (B). <i>Source: (Nkandu & Alibaba, 2018)</i>	77
Figure 36: The Prototype of a Beetle, and the Structure Model (A), Las Palmas Water Theatre (B)	78

LIST OF SYMBOLS/ABBREVIATIONS

°C	Degrees Celsius
°F	Degrees Fahrenheit
3E's	Environment, Economy and Equity
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
dB	Decibel
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
GBRS	Green Building Rating System
HVAC	Heating, Ventilation and Air Conditioning
IWBI	International WELL Building Institute
LED	Light-emitting Diodes
LEED	Leadership in Energy and Environmental Design
PDMS	Polydimethylsiloxane
USGBC	United States Green Building Council
UV	Ultra Violet

Chapter 1

INTRODUCTION

Today's environmental problems (pollution, climate change, energy crisis, resource consumption...) force us/humankind to change our lifestyles. Windmill turbines, solar panels, and green roofing systems are used to get energy from natural resources and absorb heat for our living interior environments. Yet, there is no awareness for the future. For the next generations, we must change our habits. The only way to ensure our future is to include an understanding of sustainability in every aspect of our lives.

Sustainability is transferring the resources we have to the next generations. Foster et al defined sustainability as: "Meeting or satisfying the needs of the current generation without diminishing or compromising the ability of future generations to meet their own needs" (Foster et al., 2012, p. 652). To define it simpler, sustainability is about our children and grandchildren. How do human beings live today so that they can thrive, and future generations can also have a good life? The world has many resources that we depend on for food, and housing, and many of those resources can be replenished. Humans can use natural resources of the world and still there will be some resources if it is only done at a rate that the system of nature can replenish, which is called "the replacement rate". Unfortunately, in the last few decades, people are consuming resources much faster than the replacement rate. And as a result, we consume and lose our resources irreversibly, which is called as environmental degradation (Yusoff, 2020).

Sustainability has three dimensions that are connected with each other, these are: environment, economy, and equity (social equity) (Diesendorf, 2000; Giddings et al., 2002; Ilic-Krstic et al., 2018; Strange & Bayley, 2008). Step by step, humans won't have a long-term economy that is thriving if we solely focus on short-term economic gains. People may not have a thriving society if we solely focus on environmental preservation without considering economics and knowing how people make a living. And if people don't consider equity in society, we can end up with a small number of individuals who control the majority of the resources and a large number of people who are suffering. So, sustainability is basically the connection between these 3E's (environment, economy, and equity).

1.1 Problem Statement

Especially in the last decades, the concept of sustainability appears in all areas of life. But what exactly does this concept is about? Although many designers consider aesthetics and functionality, they do not give much thought to the sustainability of their designs. There are some methods that support the concept of sustainability and play an active role in its implementation. Biomimicry is perhaps the most effective of these. Because it derives its power from imitating the magnificent designs developed by organisms in nature to survive. Despite this fact, there is no study in the literature that focuses on how sustainability can be effectively implemented in Interior Architecture using Biomimicry.

1.2 Aims and Objectives

The main aim of this study is to create a guideline for interior designers in creating sustainable interior spaces with the help of the biomimicry method.

Objectives for reaching the main aim are:

- To review Interior Components, Concept of Sustainability, Sustainability in Interiors, and Biomimicry Method.
- To show how the biomimicry method can be used to obtain sustainable interior spaces.

1.3 Methodology of the Study

This study is based on qualitative research methods and data collection has been done via systematic literature survey as documentary research. The methodology followed in this study has two steps. First of all, information about interior components in general terms, the concept of sustainability, sustainability in interiors, biomimicry method that supports sustainability and the application of biomimicry in interior spaces have been reviewed on the scientific literature and are systematically compiled. At this step, scientific databases, Web of Knowledge and Scopus have been surveyed. As the second step, based on the reviewed sources a guideline has been created for interior architects/designers or anyone who is interested in this topic. The created guideline reveals what should be the characteristics of interior components to obtain a sustainable interior design and how biomimicry method can be used for achieving this goal.

1.4 Limitation

The structure followed by this study proceeds on the examination of interior components in 3 main branches. While doing this, details such as stairs, escalators, elevators and fireplaces, which are interior components, are not included in the study. The focus is instead on main space components which are surfaces creating the boundaries of space, furniture and furnishings, light, HVAC and natural air conditioning systems, and daylight. In addition, although sustainability is accepted to have 3 main dimensions: environmental, social (equity) and economic dimensions, this

study focuses on environmental sustainability, which is most related to the subject of biomimicry.

Chapter 2

COMPONENTS OF INTERIOR SPACES

The second part of this study is on what the interior components are. This section is important in terms of the structure that the thesis follows. We can consider the interior components in three groups under the concept of sustainability. First, the elements defining the space including surfaces such as floors, walls, ceilings, windows and doors were studied. Secondly, furnishing and furniture, including the lighting elements, were examined. Third and lastly, systems related to environmental comfort and daylight were researched and compiled.

In order to understand interior components (Figure 1), first of all, it is necessary to talk about the definition of the interior space. In this context, firstly, definitions of space and interior space will be provided. Then, interior components will be explained based on the three groups explained above.

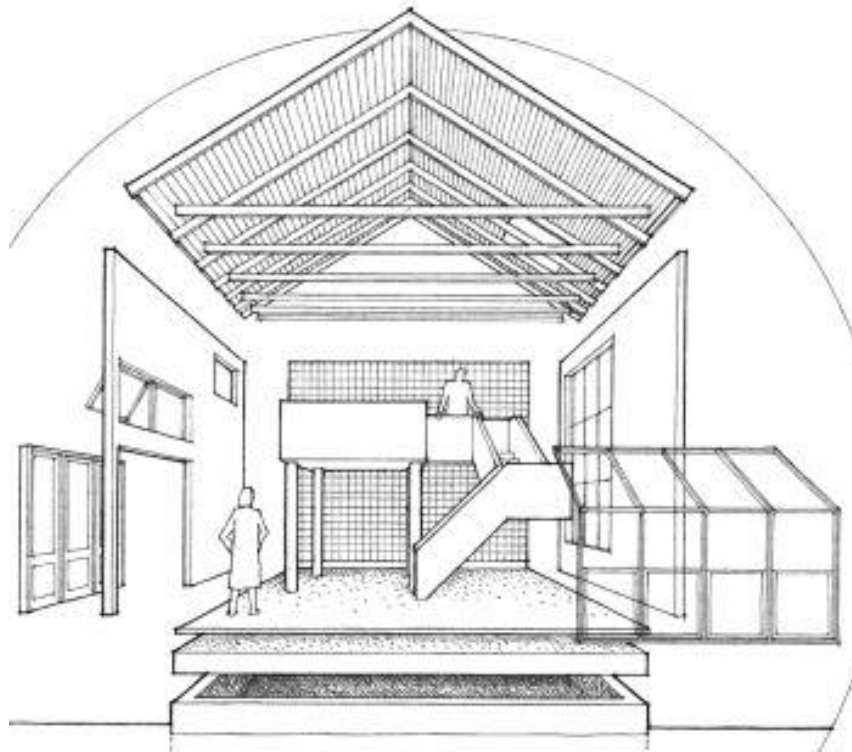


Figure 1: Components of Interiors; Floors, Walls, Ceilings, Windows, Doors (Ching & Binggeli, 2018, p. 3)

Space

We are able to move through the volume of space, but we are also able to see shapes, hear sounds, feel cool breezes and the sun's warmth, as well as smell the fragrant blooms of flowers. The sensuous and aesthetically pleasing traits of the elements in their sphere are inherited by space. Unlike stone and wood, space is not a tangible substance. It lacks structure and is diffused by nature. There are no definite boundaries in the universe. But a visual relationship is created once an element is positioned in its place. Multiple interactions between the space, elements and interactions between the elements themselves, are developed when further items are added to the place. Our perception on these interactions forms the space (Ching & Binggeli, 2018).

Space can be defined and articulated using the geometric forms, line, plane, and volume. These fundamental elements are transformed into linear columns and beams,

as well as planar walls, floors, and roofs, in architecture (Figure 2). They are used in architectural design to provide a building form, distinguish between inside and outside, and specify the limits of interior space.

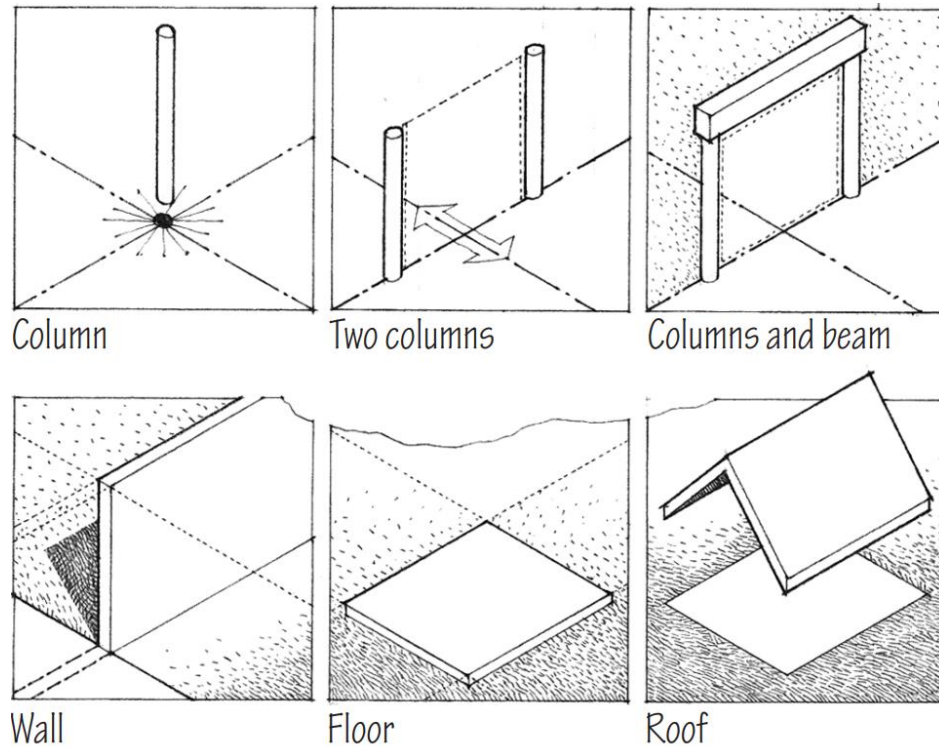


Figure 2: Fundamental Elements of a Building which are Organized in Giving Form to a Building (Ching & Binggeli, 2018, p. 3).

Interior Space

When we enter a building, we sense enclosure and shelter. This impression is brought on by the interior space's defining floors, walls, and ceilings, which are the structural components that specify the physical boundaries of rooms. They define the borders of the area, surround it, and set it apart from other interior spaces and the exterior. Ceilings, floors, and walls signify more than just the size of a room. The designated space is given certain spatial or architectural features by the shape, arrangement, and pattern of the window and door openings. We use terminology like 'grand hall', 'loft space', 'sunroom' and 'alcove' to define a space's size and proportion, as well as its

quality of light, the make-up of its surrounding surfaces, and its relationship to nearby spaces.

2.1 First Group of Interior Components: Surfaces Defining the Space

The basic surfaces of interior space that are level and flat are called floors. They must be designed to safely transport the ensuing loads since they serve as the platforms for furnishings and our interior activities. They should have surfaces that are resilient enough to resist constant use and wear.

A floor might be built from a grid of joists or parallel beams covered with a subfloor, which is a structural material like concrete planks, plywood sheathing, or steel decking that can span the joists or beams. The subfloor and joists or beams are fastened so that they function as a single structural element to withstand stress and transfer loads to their supports (Ching & Binggeli, 2018).

Any building must have walls as key architectural components. They create the building facades. They establish internal spaces that are enclosed, delineated, and safeguarded. The movement of heat, air, moisture, sound and water vapor must be controlled by a building's outer walls. The outside skin, whether it is attached to the wall or is a part of it, must be resistant to the impacts of the sun, wind, and rain. A building's internal spaces are divided by interior walls, which also give these spaces privacy and regulate how sound, heat, and light go from one area to another. A partition is an interior wall that creates divisions between various portions of a room or structure (Ching & Binggeli, 2018; Riggs, 2003).

Floors and walls, just like our own skin, are the biggest organs of the spaces that we constantly touch and come into contact with. And just as it is harmful to touch our eyes with dirty hands, touching dirty surfaces, or being on floors that have not been properly cleaned, or living between unhygienic walls is very dangerous in the long run, and for some sensitive people in the short run. That is why hygiene and cleanability are important factors when deciding about materials and coatings of the interior surfaces.

The ceiling is one of the important architectural components of an interior space. Although frequently out of our reach and not utilized in the same way as floors and walls, the ceiling plays a key aesthetic function in defining interior space and restricting its vertical dimension. It is the component of interior design, which provides people beneath its canopy both physical and psychological safety. Structures on the underside of the floor and roof constitute the ceiling. The physical structure may be directly attached to or suspended from the ceiling material. The above support structure itself can occasionally act as the ceiling if it is left exposed. A ceiling might include the structural pattern of the roof or floor rather than being covered in a smooth, planar material.

Windows provide views of the outside and allow light and air in interior spaces of structures. The amount of partition between an inner space and the outside environment depends on the size and placement of windows in relation to the wall plane in which they are found (Ching & Binggeli, 2018).

While maintaining the containment that the wall provides, windows that are framed inside a wall plane draw our concentration with their intensity and view. In an effort to visually combine interior and outdoor space, large windows and glass walls are

used. Similar to exterior windows, internal windows can visually enlarge a room beyond its actual dimensions and enable it to blend in with the adjacent interior space.

Wall planes that define internal areas and give buildings their structure is broken up by windows and doors. They are transitional features used in both architecture and interior design that connect indoor and outdoor areas visually and physically.

The visual integrity of a wall surface and the feeling of inclusion it creates are influenced by the size, shape, and placement of windows. An entrance framed by a wall, a bright spot inside a wall, a dark plane at night, or a space between two wall planes can all be perceived as windows. It can also be made larger until it reaches the size of the actual wall plane, creating a glass wall that visually connects one internal room to the next or the outside.

According to studies, people who view photographs of natural landscapes exhibit better cognitive function than people who view photographs of urban settings. The shapes and patterns found in nature are also appealing to humans. However, experts caution that goods that resemble nature while also harming nature might be detrimental to holistic approaches to human health.

Along with all this, windows can also play a big role in heating the interior during the day. Windows and glass sliding doors that act as windows help to use daylight as a heat source in winter months if the building is positioned correctly and there is no environmental factor blocking the sun.

Doors provide us with physical access to enter and exit a building as well as to move between rooms. Doors and windows may govern the use of a area, the scenes from one space to another, and the flow of light, sound, warmth, and air by their design, construction, and placement.

2.2 Second Group of Interior Components: Furnishings, Furniture and Lighting

Furnishings and furniture are design elements that make the interior space livable and relieve comfort concerns, which can define space and create a sculptural mass by themselves. The choice and placement of moveable interior aspects, such as furniture, window treatments, and fixtures, are important aspects in interior design. Between humans and architecture, furnishings act as a mediator. They provide a form and size transition between an interior space and the user. By providing comfort and practicality for the duties and actions we engage in, furnishings make spaces habitable (Figure 3).

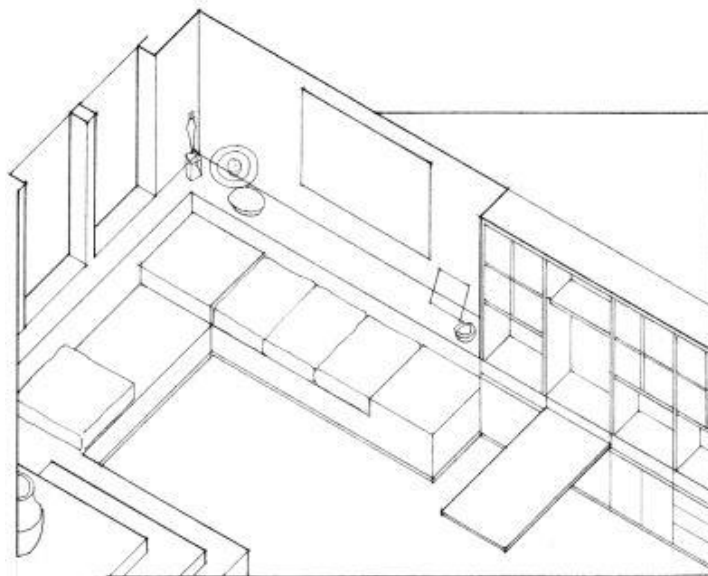


Figure 3: Sample Illustration of Furniture and Furnishing (Ching & Binggeli, 2018, p. 333)

Fire safety regulations are typically stricter in places where the general public can access. The furniture in public areas and places of business is also affected by accessibility requirements. Classrooms, hospitals, and restaurants are just a few examples of spaces that demand extremely robust and well-built furnishings due to their high usage rates (Ching & Binggeli, 2018).

Furniture enhances the aesthetic appeal of interior settings in addition to serving certain functional needs. The expressive qualities of a space are greatly influenced by the color, form, texture, lines, and scale of unique items as well as by their three-dimensional arrangement (Riggs, 2003).

The shapes of furniture parts might be planar, linear, or volumetric; their shapes can be straight or wavy, angular or free flow. They may have mainly vertical or horizontal proportions, can be light and airy, or strong and robust. They can have a soft, plush, warm, slippery, satiny, heavy, or smooth texture. Their hue might be pale or dark in value, cool or warm in temperature, and transparent or natural in quality.

Common materials used to make furniture include wood, metal, plastic, and other synthetic materials. For a piece of furniture to be sturdy, stable, and long-lasting in use, its design and construction should take into account the strengths and limitations of each material.

2.3 Third Group of Interior Components: HVAC Systems, Natural Air Conditioning Systems and Daylight

Systems for controlling the indoor atmosphere are crucial parts of any structure. For the relief and ease of the building's occupants, they deliver the thermal, auditory,

visual, and hygienic situation required. To work well, these systems need to be carefully planned and developed. Additionally, they have to work along with the structural form of a building. Interior designers should be informed of these approaches and understand how they impact the condition of the interior environment. Since each scheme in a building has a distinct lifespan and is intimately integrated with every other system there, upgrading one layer requires manpower for installation and integration with other layers.

Significant amounts of energy are used by internal environmental systems. The majority of this energy—containing electricity—comes from petrol and natural gas, with a smaller amount coming from nuclear energy, coal, and renewable energy fonts such as hydroelectricity, biofuels, wood, geothermal, biomass, wind, and solar energy. HVAC (heating, ventilation, and air conditioning) systems consume energy to keep indoor temperatures comfortable (Ching & Binggeli, 2018). Poor construction allows warm or chilled air to escape from buildings. Typically, hot water used for bathing, cleaning dishes, and clothes is flushed down the toilet. When electrical equipment is not in use, we frequently forget to turn it off, which adds to the energy consumption of buildings. Sustainable design prioritizes reducing this waste.

While the characteristics of a building's physical system can be seen in its internal areas, it is very intricate networks of mechanical and electrical systems that are typically out of sight. However, it is significant for interior architects/designers to be aware of the obvious components that have a direct impact on the interior environment, such as electrical outlets, plumbing fixtures, lighting fixtures, air supply registers, and return grids. The space requirements for air duct runs in both the horizontal and vertical directions, as well as for electrical and plumbing lines, are also of interest. Even though

a structure can last for 40 years or more, the technology inside could need to be upgraded as frequently as every two years. These technical advancements come at a price, both materially and aesthetically. As the various systems become more intertwined over time due to their diverse lifespans and close proximity to one another, personnel costs rise as a result of their intricate linkages (Ching & Binggeli, 2018).

Buildings require a supply of fresh air to replace the oxygen used by the occupants and machinery within and to withdraw wastes like carbon dioxide from the air. The most economical and energy-efficient strategy to improve the air quality inside most buildings is to increase natural ventilation and air dispersion (Attia, 2015). Because air moves from locations of higher pressure to those of lower pressure, air moves through buildings. A source of air with a satisfactory moisture content, temperature, and purity is necessary for natural ventilation. The volume, velocity, and direction of airflow can all be controlled by mechanical systems, which use fans to circulate air into and via structures. Through ductwork, where it is distributed to the rooms of the building, blowers and fans move the air (Ching & Binggeli, 2018). Air into interior rooms is regulated via registers. Return air grilles collect used air so that it can either be cleansed and reused inside the structure or expelled outside.

Typically, a building receives enough energy from sunshine to maintain comfort throughout the year. Solar energy systems are either passive or active systems that transform solar energy into thermal or electrical energy. While active systems need extra mechanisms like circulation pumps, air blowers, automatic systems, etc., passive systems only need sun radiation as their source of energy (Okafor & Akubue, 2012). Most solar heating systems can handle between 40% and 70% of a building's heating load (Ching & Binggeli, 2018). A passive solar-heating system uses little to no pumps

or fans and integrates solar gathering, storage, and distribution into the architectural plan of a structure. The structure is meticulously positioned, the size and kind of windows are designed, as well as the use of huge materials that can store thermal energy, to achieve this. Glare and overheating are prevented by using overhangs and shade structures.

Pumps, fans, heat pumps, and other mechanical devices are used by active solar heating systems to transfer and distribute thermal resources through air or a liquid. They may be fitted to most existing buildings and provide better interior environment management than passive systems. Electricity is used to run the majority of active systems. Many structures use mixture systems, which combine passive solar design elements with electrically powered fans or pumps. By grasping the sun's heat via windows in day time and preventing its egress with thermal window dealings at night, even a space which is not intended for solar heating can benefit from this free heat source in cold weather (Ching & Binggeli, 2018).

Using water that has been heated in a boiler and is then pumped through pipes to radiators or convectors, a heating system known as hot-water or hydronic heating operates (Qi et al., 2012). A boiler generates steam, which is then circulated through piping to radiators for use in steam heating, which operates on a similar principle. For radiating surfaces in radiant heating systems, heated floors, walls, and occasionally ceilings are used. The heat source could be hot water pipes or tubing, electric resistance heating wires installed inside the floor, ceiling, or wall structure, or both.

Typically, a method of supplying cooled air is thought to be an air conditioner. To assure the thermal comfort of a building's occupants, a real air-conditioning system,

on the other hand, offers year-round climate control by handling air in several different ways. Along with controlling air temperature, an air-conditioning system can also control the relative humidity, flow, and cleanliness of the air. The choice of window, wall, and floor covers, as well as the modification of airflow shapes, by the interior designer can influence the outcome of a building's heating or cooling system, which is planned by the architect and engineers during the design of a structure. Since air conditioning consumes a lot of energy, strategies that block out excess heat, like shade, and those that promote air circulation, like thoughtfully placing furniture and installing ceiling fans, support energy conservation (Ching & Binggeli, 2018).

In this section, the interior components are examined in three groups as components including surfaces, furniture, furnishing and lighting, HVAC systems and natural air conditioning systems (Figure 4).

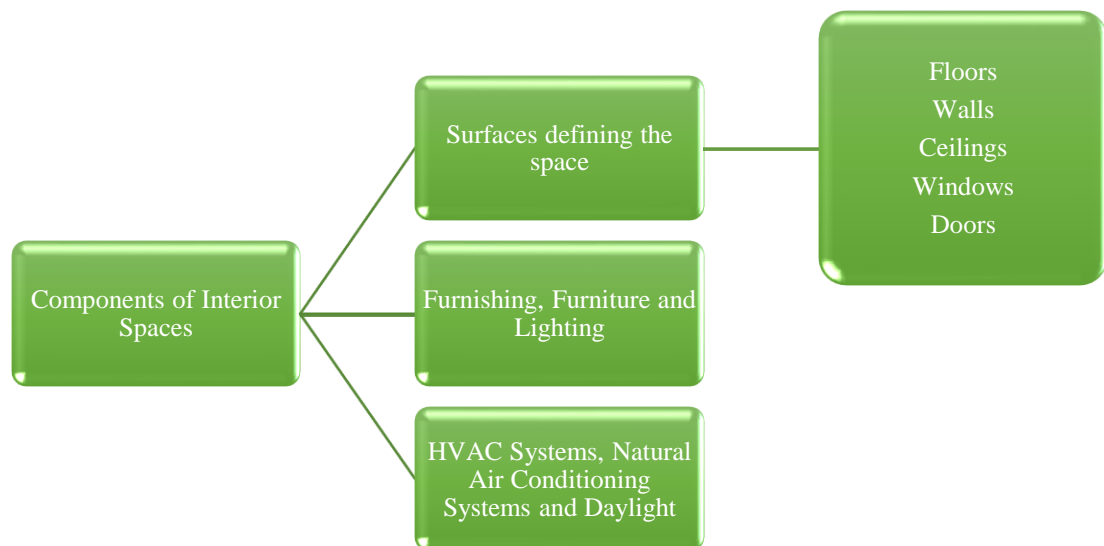


Figure 4: A Diagram Showing Interior Components that were Examined in this Thesis.

Chapter 3

ENVIRONMENTAL SUSTAINABILITY IN INTERIOR SPACES

This chapter examines the general definition of sustainability concept and its different dimensions, and what various sustainability certification programs focus on in relation to environmental sustainability in the interior spaces. In addition, sustainability in Interior spaces has been explained considering the groups of the Interior components mentioned in the previous chapter. By reviewing the key pertinent interior design domains, the next sections discover various possible strategies for sustainable interior design.

As mentioned in the first chapter, the definition of sustainability in the shortest and clearest way is a human and nature-oriented idea that aims to transfer the natural resources we have to the next generations.

The concept of sustainability has many different dimensions, but it is basically named under three main headings in the literature on environment, economy and society (Figure 5). The word equity (Diesendorf, 2000), written instead of society in the first chapter, describes social equality or the equal right of every individual in society and every individual in future generations to natural resources. However, this study focuses on environmental sustainability and how sustainability can be applied to interior space

design and what biomimicry method offers the interior designers in this respect. Thus, this study focuses more on the environmental dimension of sustainability.

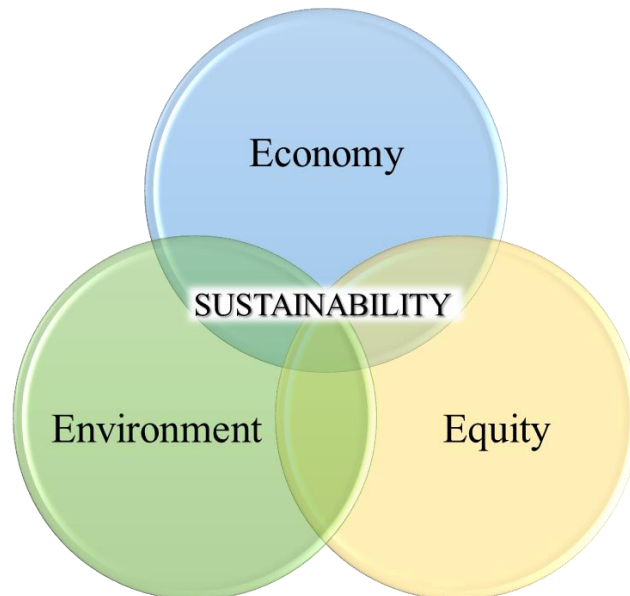


Figure 5: Main Dimensions of the Concept ‘Sustainability’, which are Economy, Environment and Equity.

The work of interior architects who apply sustainability has positive effects on the local and global environment. Ideal interior environment solutions need to take into consideration both people's quality of life and natural ecological systems (Sassi, 2006). The most crucial sustainability objectives in interior design are to reduce harmful construction materials use for the environment, recycle natural resources, increase thermal comfort, decrease indoor contaminants, and improve natural lighting quality inside (Kang & Guerin, 2009). Interior materials should be examined by designers from the point of origin to the point of disposal and aim to minimize environmental harm by utilizing locally produced, long-term, durable, and renewable materials.

Generally, the life of a product carries a linear process. The product is produced, transported, reached to the user and consumed, or over time, it expires and becomes

unusable. However, the understanding of sustainability aims to put this linearity into a circular form in order to create an endless loop. The product is recycled and reused by being put into a process where it can be reused after the consumer's use or at the end of its life. In this way, consumption becomes a part of reproduction and waste of resources is prevented (Figure 6). A product, process, or service's environmental effects throughout the course of its life cycle are measured using a technique known as life cycle assessment (LCA), sometimes known as life cycle analysis. Every stage of a product's life cycle, including the extraction of raw materials from the environment, the manufacturing process, the usage phase, and what happens to the product once it is no longer in use, can have an effect on the environment in different ways. These phases of an item's life cycle are referred to as life cycle stages. With LCA, you may assess the environmental effects of your product or service from the earliest to the last life cycle stage, or at any moment in between.



Figure 6: Life Cycle of Sustainability. Source: (Golsteijn, 2020)

Designers should research the viability of recycling or repurposing procedures and adopt a cradle-to-cradle philosophy that takes environmental effects of a building's whole life cycle into consideration.

When creating recycled or even upcycled products, Cradle to Cradle materials are used with consideration for their inherent merit and long-term utility, which might be higher than that of their original use. As a result, Cradle to Cradle design eliminates waste, shortages, and restrictions, much like in nature. It is a design philosophy based on using renewable energy, encouraging diversity, and reusing raw materials indefinitely. A new industrial revolution must be started in order to guarantee that production and manufacture have a good impact on society, the economy, and the environment.

The Cradle-to-Cradle philosophy significantly contributes to sustainability by completely reusing all materials that have been abandoned in order to eliminate waste. In actuality, every material used in Cradle-to-Cradle certified products has the ability to be completely recycled, either biologically or technically. But among the qualities that Cradle-to-Cradle design looks for in a product, material reutilization is simply one. According to the Cradle-to-Cradle Products innovation institute, Cradle to Cradle looks at a product through five quality categories: material health, material reuse, renewable energy and carbon management, water stewardship, and social fairness (McDonough & Braungart, 2002).

Sustainability Certification Programs

In order to confirm a building as a sustainable design, there are organizations that carry out certification programs on sustainability. Being certified in sustainability verifies a person's expertise in sustainability principles, which enables them to gain knowledge,

establish credibility, reputation and connections, and increase employment possibilities. Many certification programs are being run across different sub-disciplines, such as General Sustainability, Climate and Environment, Construction and Infrastructure, and Energy. The best-known certification program in construction discipline is Leadership in Energy and Environmental Design (LEED) Green Associate Certification and is followed by Building Research Establishment Environmental Assessment Method (BREEAM), Deutsche Gesellschaft für Nachhaltiges Bauen - German Sustainable Building Council (DGNB), Green Star and WELL Building Standard (Zeinal Hamedani & Huber, 2012).

LEED

As an internationally recognized program, LEED Certification was developed by the United States Green Building Council (USGBC). Through the adoption and application of broadly known and accepted techniques and performance criteria, the LEED™ Green Building Rating System™ stimulates and encourages the global adoption of sustainable green-building practices. According to the LEED™ system, points are given for performance in areas such as sustainable site development, energy and atmosphere, water efficiency, indoor environmental quality, materials and resources, regional focus, and design innovation. To obtain a LEED™ rating, designers can choose the points that apply to their projects the most. The possible highest score is 100 plus 10 points. Platinum, Gold, Silver, or Certified ratings are given based on the points (Kubba, 2010).

BREEAM

A widely used certification program BREEAM was created by the Building Research Establishment (BRE) Group in 1990, in the United Kingdom. This program is

considered to be the first Green Building Rating System (GBRS) in the World. It considers factors including energy and water efficiency, ecological effect, waste management, and the materials used in construction while evaluating and rating the sustainability performance of buildings (BreGroup, 1990).

DGNB

German certification program DGNB uses comprehensive evaluations to encourage the use of sustainable construction methods. It evaluates a building's functional, sociocultural, economic, and environmental factors in an effort to achieve overall sustainability. It also includes six different schemes for DGNB Certification: New Construction or Renovation of Buildings, District Development, Buildings in Use, Interior Fittings, Deconstruction of Building Stock and Construction Sites (German Sustainable Building Council, 2020).

Green Star

Australian assessment system Green Star assesses the environmental impact of buildings in a variety of categories. It evaluates materials, indoor environmental quality, water and energy use, and emissions (Green Building Council Australia, 2003).

WELL Building Standard

The WELL Building Standard was launched in 2014 by the International WELL Building Institute (IWBI). It is a performance-based method for evaluating, validating, and tracking aspects of buildings and interiors that have an effect on people's health and wellbeing. To design places that enhance occupant productivity and health, it focuses on ten concepts: air, water, nourishment, light, movement, thermal comfort,

sound, materials, mind and community. Scores earned from each concept are sum up to a highest possible score of 100 (Matos, 2014).

The common point of all certification programs introduced above is an understanding that examines the consumption of natural resources such as efficient water and energy use, correct material selection and quality in interiors, and the selection of the right material. While the list of some programs contains more items, basically each one seeks standards on the economic, environmental and human equality factors of sustainability. The following sections of this study discuss environmental sustainability and sustainability in interior spaces.

3.1 Sustainability in Interior Components: Surfaces

The structural elements that enclose the interior areas, including the walls, ceilings, floors, windows and doors are known as surfaces. The interior space's surface areas add up to more than three times the volume of the room, so a lot of finishing materials are needed. The issue of sustainability in interior components with surfaces such as walls, ceilings, floors, windows and doors is directly related to the naturalness of the materials used, the money spent for the hygiene of the products and the negative effects of these products on nature and human health. In addition, if the materials used in the interiors are not local, the shipping costs and the damage caused by the gases released by the vehicles during the transportation of the materials to the atmosphere are also the issues followed by the concept of sustainability in the interiors (Alfuraty, 2020).

Use of sustainable products significantly reduces the negative environmental impact that surface materials have. Therefore, in order to protect the environment, the choice of surfaces' finishing materials should include sustainability measures by selecting

long-lasting materials that do not deplete natural resources and are not harmful to human health (Alfuraty, 2020). Additionally, designers must use less material by dividing interior areas with fewer dividers, among other creative ideas (Omer & Noguchi, 2020).

3.2 Sustainability in Interior Components: Furniture, Furnishing and Lighting

From the perspective of sustainability; chosen fixtures should be long-lasting, have managed manufacture progressions, and employ sustainable materials meeting the same criteria as those mentioned previously in the beginning of this chapter, particularly that of recyclability (Winchip, 2011). The differences between whether a material is recyclable or not are important in terms of material and health. For example, the difficulty of using wood is that, it is a slow-renewing material that affects natural surroundings over time. In contrast, it is not possible to recycle furnishings made of synthetic or polymer-based materials and hence they release poisonous gases. Natural wood is commonly utilized and considered sustainable.

Reducing the number of materials wasted during production operations are given priority in sustainable furnishing production management. Some experimental home decor items and furniture are constructed solely from scraps. Even though these items satisfy functional needs, they are not necessarily attractive; yet they do help to preserve resources. Innovative design ideas that preserve resources without compromising human requirements include multi-functional furnishings, particularly those that include smart technologies. When possible, interior designers ought promote the use of recycled or refurbished furniture to increase the useful lifespan of the pieces (Spiegel & Meadows, 2010; Winchip, 2011).

3.2.1 Interior Lighting Solutions that are Sustainable

One of the most important aspects of indoor space quality that affects interior design is lighting. Sustainable indoor lighting gives a good answer to two different problems. Firstly, it provides an indoor environment with high-quality by achieving maximum sunlight and the ability to connect to natural surroundings through glass windows as well as the size and settlement of vegetation. One of the substantial factors that have the greatest impact on building users' behavior, efficiency, and wellness is natural light. For instance, retail establishments with more sunlight report higher levels of operative and customer happiness, which in turn boosts sales (Winchip, 2011). Bringing daylight into an internal environment is known as "natural lighting," which produces illumination that is more aesthetically pleasing and superior to that produced by unnatural sources of light (Jones, 2008).

In order to maximize the amount of daylight in a space, architects and interior designers need to evaluate where to place structures and what room sizes and dimensions to use. The light is carried to the deeper interior sections of the structure by innovative technical equipment that captures sunshine and reflects it through tubes. Systems for light piping, laser-cut panels, and vertical and horizontal light pipes are a few examples of such technologies.

Reducing artificial lighting systems' energy use is another concern, as it makes up 40-50% of the power used in buildings (McDonough & Braungart, 2002). Many strategies can be used by designers to decrease energy use and upgrade the value of life for occupants. The use of energy-efficient lighting features, like light-emitting diodes (LEDs), which provide more environmentally friendly lighting options, and compact fluorescent light bulbs are two examples.

3.3 HVAC Systems, Natural Air Conditioning Methods and Daylight

Human health, safety, well-being, and productivity are all addressed in this aspect of sustainable solutions. By being cautious during construction and renovation processes, interior designers can improve indoor air quality. For example, they should provide adequate air ventilation, maintain a comfortable temperature and humidity level, and manage aerial contaminants like toxic gas emissions from furnishings, manufactured materials, equipment and finishes (Spiegel & Meadows, 2010).

In three ways, designers may actively manage air quality. Source control supports nonporous materials and decreases gaps and holes as a starting point to prevent mold from forming and energy leaks. Second, separating and filtering pollutants by using air-lock entrances, air pressure diversities, mechanical filters, and provisional areas (like vestibules) can remove or lessen a range of contaminants. Third, architects and interior architects/designers need to make sure there is an appropriate balance between mechanical and natural air movements. Cross-ventilation and negative air pressure can help with natural ventilation while lowering the energy requirements of a structure. By venting indoor air with the right pressure and humidity controls, mechanical air conditioning systems can maintain a high-quality atmosphere (Jones, 2008).

Natural light is among physical parameters that have the greatest impact on building users' behavior, efficiency, and wellness. Bringing daylight into an internal environment is known as 'natural lighting', which produces illumination that is more aesthetically pleasing and superior to that produced by artificial light sources (Jones, 2008).

3.4 Other Sustainability Concerns in Interior Design

3.4.1 Sustainable Materials for Interior Design

The choice of interior materials can promote hygienic conditions, lower transportation energy consumption, and regulate air quality, thermal performance, toxicity, out-gassing, and mold. Flooring, coatings and paints, sealants and adhesives, wall coverings, furniture, wood artifacts, fabrics, insulation, and cleanup supplies are examples of interior materials (Spiegel & Meadows, 2010).

The choice of interior relevant can be made based on functional characteristics, such as particular requirements for thermal comfort, interior aesthetics, sterility, or strength, together with the time and effort needed for installation. Designers should choose eco-friendly materials that adhere to regional and global sustainability requirements, such as those that are extremely durable, recyclable, reusable, and low emission (Kubba, 2010). Resources that spontaneously replenish themselves or expand at a rate faster than human consumption are referred to as renewable resources (Spiegel & Meadows, 2010). Materials should be chosen carefully to ensure that they have a low environmental impact at every step of their life: extraction, assembly, transportation, use, and post-use.

Designers should also take into account how much energy is used to generate these objects. Natural supplies like wood and stone have lesser embodied energy levels compared to synthetic materials like steel, concrete, and acrylic (Winchip, 2011).

The potential for material reuse or recycling after disposal should also be taken into account. Waste management is an example of recycling since it involves the collection of waste, the separation of waste construction materials, particularly those from

rehabilitation projects, and the transformation and remanufacturing of those waste products in order to create new construction materials. The life cycle of interior materials should reduce the sparing use of natural resources and minimal impact on environmental problems including acidification, global warming, and nutrient improvement (Kang & Guerin, 2009; Osmani et al., 2008).

The quantity of harmful gas emissions, whether they are produced during manufacture or material usage, is another crucial factor to take into account. Due to their extremely low levels of harmful gas emissions, old natural items like mud bricks and hardwood furniture are particularly sustainable (Rashdan, 2015).

3.4.2 Water Management Strategies that are Sustainable

Many sustainable water management solutions have had trouble being implemented because of ignorance. So, by including the usage of water-control systems in the specifications for their finishing solutions, interior designers should promote and advise their clients to do so. The immediate objective is to demonstrate to the client the advantages of these methods for all parties involved in the building. Introduce the reuse and recycling water system to your clients and persuade them of its financial advantages, and you can accomplish this. To avoid any doubt, they should also demonstrate safety precautions. The long-term objective is to modify how building occupants behave with regard to water usage. These techniques' ultimate goal is to increase water management effectiveness within buildings, which will decrease water consumption and allow for wastewater re-use to reduce pollution. Using water-efficient sinks, smart faucets, and other environmentally friendly sanitary fixtures while designing interior spaces. Reusing water systems, like using a sink or washing

machine wastewater for filling the flush, is also something that interior designers may advocate (Rashdan, 2015).

3.4.3 Options for Interior Construction that are Sustainable

Innovation in mechanical technology considerably improves the sustainability of interior architecture finishing construction techniques, which can be summed up in two points. When assembling the interior building components, it first decreases the consumption of infrastructure materials like plaster and cement. These practices reduce the number of resources and energy used in manufacturing. Second, it will make it easier to disassemble the material for replacement during repairs or upgrades. Because the construction can be disintegrated under conditions that allow for material reuse in other places or through other recycling processes, it will reduce material waste as a result (Rashdan, 2015).

3.4.4 Systems for Sustainable and Smart Interior Design

The next language of design is smart interior design. To promote the advancement of sustainability practices, computerized systems and creative material, lighting, and equipment use are essential. By observing and altering lighting, heating systems, and ventilation, computer software manages usage. Particularly with the emergence of nanosystems, which are adaptable and hence responsive to transitory needs, smart systems drastically increase the environmental and financial efficiency of interior materials. Because smart lighting, acoustics, and materials have flexible capabilities in shifting design atmospheres, this trend eliminates the need for various design elements and maintains the interior architecture mood for extensive durations (Rashdan, 2016).

In this chapter of the study, the general definition of the concept of sustainability was reminded again and the subject of "environment", one of the three main topics of economy, environment and equity, was examined. In addition to this, the principles of the worldwide known and certification organizations about the concept of sustainability and indoor sustainability and how they work were mentioned. Afterwards, just as in the second part where interior components are discussed, it is explained how the sustainability principle should be applied in interiors under three main headings (1. Surfaces, 2. Furniture, furnishing and lighting, 3. HVAC systems and natural air conditioning).

Chapter 4

BIOMIMICRY

4.1 Origins of Biomimicry

The practice of observing and imitating nature in order to provide answers to human needs is not a recent one. For ages, humanity has observed what is going on around it and has tried to copy it in its own way for surviving. Early people relied on nature to provide them with food, shelter, and additional necessities for their existence. Numerous developments are well-known in the fields like agriculture, food production, manufacturing processes, weapons and defense, including armor, sensors, and alarm systems, as well as medical and pharmaceutical sciences, shelter and shelter architecture (Murr, 2015). Initial scientists and inventors were able to obtain essential knowledge about the operational and sustainable exploitation of resources through simple observation as well as in-depth study of nature. The natural world undergoes transformations and maintains itself over time thru taking care of its own requirements and offering long-lasting solutions to its problems. This is a result of nature's more than 3.8 billion years of development, which makes it an exceptional example of harmonious balance and proportion, including productivity, cooperation, resource utilization, and longevity (Benyus, 1997). For example, very primitive aircrafts are seen at the beginning of aviation history. Mankind has tried quite different aircrafts, from kites to gliders, until the first successful attempt at powered flight. It can be clearly seen that the early pioneers of aviation were inspired by birds. In some cases, inspiration from nature helps to make innovations on the designs of the current

technology. In addition, humankind is inspired by nature to invent new technology for themselves. This is what Leonardo da Vinci did in the era between 1452-1519 by designing wings called as ‘ornitottero’ in Italian (Figure 7).

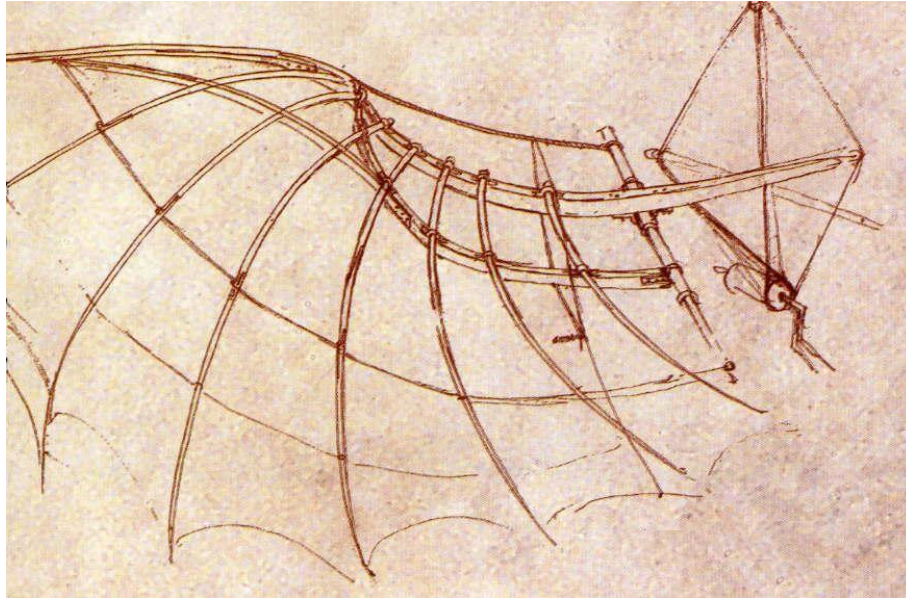


Figure 7: Wing Design by Leonardo da Vinci (Wing Construction with Engineering Design - by Leonardo Da Vinci, 2011)

Although da Vinci could not make his design real or just not practiced it to fly, a man by the name Hezarfen Ahmet Çelebi made da Vinci's dream come true in the 17th century Ottoman Empire. He designed wings to fly by stitching eagle feathers and decided on the latest shape of the wings after nine attempts. He flew from the 183-foot-tall Galata Tower close to the Bosphorus and successfully touched down at Uskudar on the opposite side in 1638 (Edis & Bix, 2012). Then, with Wright brothers Orville & Wilbur Wright, who were American aviation pioneers generally credited with inventing, building, and flying the world's first successful motor-operated airplane (Figure 8); human being took a step into the sky in 1903.



Figure 8: Flight of Wright Brothers in 1903. Source: (National Park Service, 2015).

Da Vinci's design mimicked the wings of bats. In time, development of airplanes has got inspiration from seagulls, hawks, and some other birds. In all these designs that change and facilitate our lives, humankind has found a source of inspiration from nature.

4.2 Definition / Concept of Biomimicry

The term "biomimicry" was made popular by scientist and author "Janine Benyus" in her book *Biomimicry: Innovation Inspired by Nature* which was published in 1997 (Benyus, 1997). Benyus believes that nature has already found solutions to the majority of the problems that have ever occurred. In order to deal with human problems, Benyus advises changing one's perspective from learning about nature to learning from it. One of the challenges that can be resolved by using the biomimicry technique in a project is sustainability issues. Since it is likely that nature already provides a solution to a problem, using an integrated design method can help increase

opportunities to find nature-inspired solutions to creation challenges and incorporate the perspective of nature in the design process.

The words "biomimicry" and "biomimetics" are derived from the Greek words "bios," which means "life," and "mimesis," which means to imitate. Cambridge dictionary (Cambridge Advanced Learner's Dictionary & Thesaurus, 2023) defines biomimicry as: "the practice of making technological and industrial design copy natural processes".

Biomimicry is the imitation of living things. Despite the fact that nature has long been recognized as a source of creative inspiration, there is now an effort to formally define what is referred to as "bio-inspired design". These terms were recently developed by scientists to refer to the unique practice of drawing design inspiration from nature. To create solutions for human problems, comparisons to biological processes are used (Helms et al., 2009). According to Pedersen Zari (Zari, 2007), biomimicry is becoming more significant as a widespread movement in design for environmentally responsible sustainable development.

Janine Benyus' book (Benyus, 1997) is credited with popularizing the term biomimicry and understanding nature as a teacher and role model. Nature has already provided solutions to many of the technological and sustainability issues we face today.

4.3 Levels of Biomimicry

Benyus asserted that there are three ways to get creativity from nature, which are called the levels of biomimicry in literature. The first level, which may also be found in biomimetic technologies and methods, is the organizational level. We may imitate the entire organization or specific components of it at this level. The behavior level makes

up level two. For instance, when it comes to responsive façade design, we may take a cue from how pinecones expand as a result of the shrinkage rate variation. System level comes in third. This level, which focuses on a functionally challenging issue to replicate, is regarded as the most challenging level (Benyus, 1997; Othmani et al., 2018; Zari, 2007).

We are parts of a brilliant planet, we live in a competent universe, and surrounded by genius. The discipline called biomimicry seeks to learn from these geniuses and incorporate their design ideas. The organisms and the total ecosystem are capable of living gracefully on this planet. Biomimics are trying to learn how the living organisms have already solved design problems to survive, as nature's apprentices. Many inventors ask themselves about how nature solves problems in a specific design at the moment of creation. In order to understand what is biomimicry or how it works in design, one of the most popular biomimetic design examples is a train called "the bullet train", which was designed by the Japanese high-speed train system, Shinkansen (Primrose, 2020). The train took its name from its rounded form on front. The name, which in Japanese means "new trunkline" refers to the train line that was built to facilitate faster train travel during the 1964 Tokyo Olympic Games. It is commonly referred to as the "bullet train" outside of Japan. When trains in Europe and the rest of the globe only ever exceeded 161 kilometers per hour, trains on the Shinkansen initially clocked speeds of 217 kilometers per hour. Later, the bullet trains' top speeds significantly increased, and they now travel at 240–320 km/h, with up to 13 trains per hour in each direction (Primrose, 2020).

Despite the clear benefits of bullet trains, their tremendous noise was a significant drawback that had an impact on residents up to 450 meters from the track. This was a

significant problem in a nation as densely populated as Japan, which led to legislation prohibiting trains from making noise levels of higher than 70dB when passing through inhabited areas. All high-speed trains are powered by electricity, therefore noise is produced by three different mechanisms: the wheels' contact with the track, the pantograph's contact with the wires above it, and the sonic booms produced when the train is moving through a small space. The first of these issues can be easily fixed by altering the track bed to absorb the majority of the sound. The other two puzzles have been trickier to solve, but the solutions have been found through research on birds (Primrose, 2020).

At the Japanese rail corporation JR-West, Eiji Nakatsu oversaw technical growth as the general manager. He was aware that making the company's trains quieter was the key to increasing their speed. He attended a presentation on bird flying given by aviation design engineer Seiichi Yajima in 1990, and that is when he experienced his breakthrough. He discovered from Yajima how much research into the anatomy and function of birds has served as the foundation for modern aircraft technology.

A kingfisher can dive quickly from one fluid (air) into another that is 800 times denser (water) with nary a splash, according to Nakatsu, a birdwatcher. He reasoned that the kingfisher's beak form was what allowed it to enter the water so smoothly. To assess the kingfisher's beak's cross-section and length in relation to the bird's size, the JR-West team examined it. Using this knowledge, the design team created a number of nose forms for the bullet trains, testing each one's characteristics in a wind tunnel. These experiments proved that the kingfisher bill was, by a significant margin, the most effective of all those examined. The final version chosen was a 15-meter-long snout that resembled a kingfisher's beak after prototypes were made and tested on

trains (Figure 9). Due to the fact that it has 30% less air resistance than its predecessor, this nose significantly minimizes tunnel boom when in use. As a result, the power consumption has been reduced by 13% while still maintaining the same speed as its predecessor. Additionally, passenger satisfaction rose (Primrose, 2020).



Figure 9: The Nose of the Bullet Train, Inspired from a Kingfisher's Beak (Primrose, 2020).

The noise from the pantographs, however, was mostly to blame for the bullet trains' noise levels going beyond the 70 dB limit. The noise was caused by air rushing over the struts and links, creating a Karman vortex street, which is the name for this phenomenon. Karman vortices develop whenever a single body disrupts the airflow. Karman vortices are produced at all scales, from oceanic islands to automobile aerials, and they are the cause of the "singing" of telephone wires. Nakatsu found the answer to the Karman vortex puzzle by observing owl flight. The majority of birds produce high-frequency sound when flying that can be heard by people and other animals. The one exception are owls. They may fly quite near to their prey undetected because they are silent predators. Due to the design of their wings, owls can fly silently. Typically, as air rushes over a bird's wing, it makes a "gushing" noise due to the buildup of significant air turbulence zones. An owl's wing's leading edge is serrated, which causes

the air flow to be divided into smaller, less turbulent flows. In particular, when the wing is at a sharp angle, as it would be when the owl is approaching to attack its prey, this lessens the noise of the air flowing. In an effort to replicate an owl's wings, Nakatsu's team spent four years redesigning the pantograph. Serrations were eventually engraved on the pantograph's main body, which was successful in lowering the noise level to within the permissible range of 70 dB (Primrose, 2020).

Another change was made that was inspired by birds. The Adelie penguin's spindle-shaped body gives it the ability to travel easily across water while pursuing fish. So, the supporting shaft of the pantograph was reshaped to resemble the body of a penguin (Figure 10). The improvement reduced the vehicle's wind resistance, reduced noise, and resulted in modest energy savings (Primrose, 2020).



Figure 10: Pantograph in Conventional Trains (left) and Pantograph in Bullet Trains (right). Source: (Primrose, 2020).

“Form and function” is the main issue in designers’ world and it is a question that every designer in quite any field probably have heard before: Which one follows which one? Does the form follow function or does the function follows form? How does a designer start to draw some sketches to shape his or her design? Actually, this discussion has been done in the late 19th and early 20th century. But the thing is here;

biomimicry method can work in both ways. As it is mentioned in the samples, in some cases to solve the design problem the way we follow sometimes is just mimicking the shape of an organism. Just like the engineers and the designers copied the form of a kingfisher bird's beak and applied it on the front facade of the Bullet Train. But, unfortunately, in some cases, the situation is more complex. To solve the design problem, the shape of an organism may not be helpful. Because of that, biologists and engineers work together to understand how organisms solve their evolutionary challenges and how we can apply them to our lives for solving our own design problems. As an example of this approach, to create lamps that spend less energy but give more light, biomimics searched about the talent of fireflies and then invented the LED light bulbs. This invention was not about mimicking the form of those insects but, mimicking their complex cell system which creates a big amount of light with less energy (Toufaily, 2021). Mimicking the shape or the complex system of an organism, the aim of biomimicry is to reach smart solutions. So, it should not be confused that biomimicry is not about applying the form of nature or any living thing. *El-Zeiny* states that when an interior designer claims a design was inspired by nature, he or she probably refers to how organic-looking it is (El-Zeiny, 2012). Nature is an excellent instructor in this regard, but simply copying or drawing inspiration from organic-appearing shapes, textures, and hues does not constitute biomimetics. Youssef (2014) mentions three types of biomimicking in his paper (Youssef, 2014), which are: mimicking form, mimicking process and mimicking eco-systems. Youssef also supports that mimicking the form is easy. However, mimicking the process is complicated, since the connection of nature and mimics might need a scientific base. Moreover, Dr. Youssef states that mimicking the eco-system is complex.

Biomimicry is innovation inspired by nature. Chemists, architects, interior architects, material scientists, product designers, industrial designers, and all common professions should ask themselves what the natural world has already solved that humans are trying to solve. This discipline creates designs and strategies that move people toward being better adapted to life on Earth over the long haul.

4.4 The Biomimetic Model: Nature as a Model, Measure and Mentor

The concept of biomimicry has significance and legitimacy in understanding nature together with its living species. Janine Benyus categorized various perspectives that have been expressed in the idea of biomimicry into three categories which are nature as model, nature as measure, and nature as mentor (Benyus, 1997). Nature serves as a model by establishing a direct connection with nature, a measure for sustainability benchmarks by setting up standards, and a mentor for learning by emulating survival techniques from nature.

4.4.1 Nature as Model

While considering Nature as a model, biomimicry seeks to replicate or draw inspiration from natural processes and designs in order to solve human challenges in a sustainable way. Although the term "mimicry" connotes the act of duplicating anything, bio-mimics acknowledges that while they are emulating, they are by no means, under any circumstances, acting imitator (Ferwati et al., 2019).

The solar cells inspired by leaves can be given as an example (Sandru, 2010) (Figure 11). Any leaf under direct sunlight can mend itself after suffering damage via the reassembly of chloroplasts, which include the pigments capturing the energy from sunlight. As a result, they continuously produce new cells to replace the damaged ones. By using microorganisms, proteins and water, scientists have mimicked this system

and replicated the natural processes to create a self-repairing solar panel (Das et al., 2015; Zhang & Park, 2022). This promising start should pave the way for significantly improved synthetic leaf-type sun-oriented solar cells in the future. In addition, we will be able to avoid producing more solar cells, which will bring us closer to the biomimicry goal.

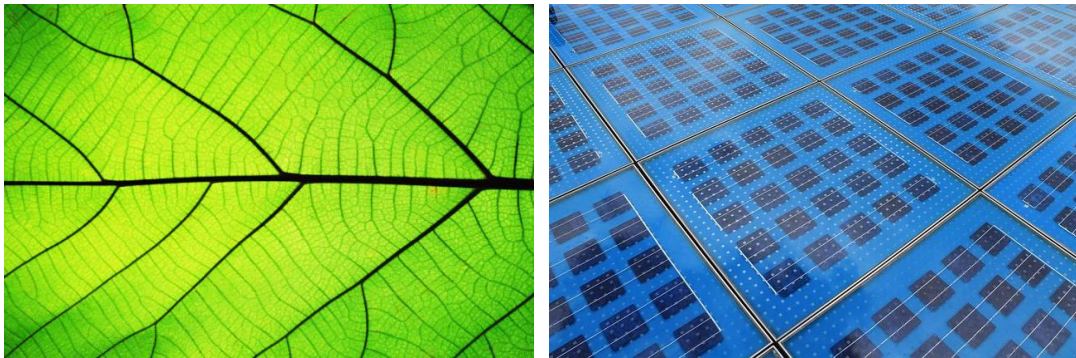


Figure 11: Self-Healing Leaf and Self-Repairing Solar Panels. Source: (Graphenea, n.d.)

4.4.2 Nature as Measure

In biomimicry, the "rightness" of our ideas is assessed by using ecological criteria. The biomimicry concept's strength has been deemed to be measured by nature. Considering nature as a measure focuses on questions like: What is appropriate? What works? What lasts? Can we state a measurable standard from nature?

Biomimicry uses a natural benchmark to assess the sustainability of our technological developments. In addition, nature offers us role models from which we draw inspiration, as well as guidelines that limit what we are or are not allowed to do, and it lends its approval.

When critiquing technical advancements, biomimicry uses ecological norms; for instance, sustainable structures modeled after termite mounds that naturally cool

themselves (Yuan et al., 2017). Natural ventilation technology is now being taken more seriously than in past decades as a passive method of ventilating commercial buildings, hence an impartial evaluation of such systems is needed. Innovative building solutions are inspired by natural models like termite mounds and other passive ventilation systems in nature.

Termite mounds, which can be biggest structures in the world that can be found on the roadways in Australia and Africa, serve as good models for architects (Yuan et al., 2017). These 3-8 meters high mounds can scale up to a 1500 meters tower, which is nearly twice as high as the Burj Khalifa in Dubai, which is currently the tallest structure in the world at 828 meters. They are made of soil and termite saliva, which results in a substance that is even firmer than pitch-covered roadways.

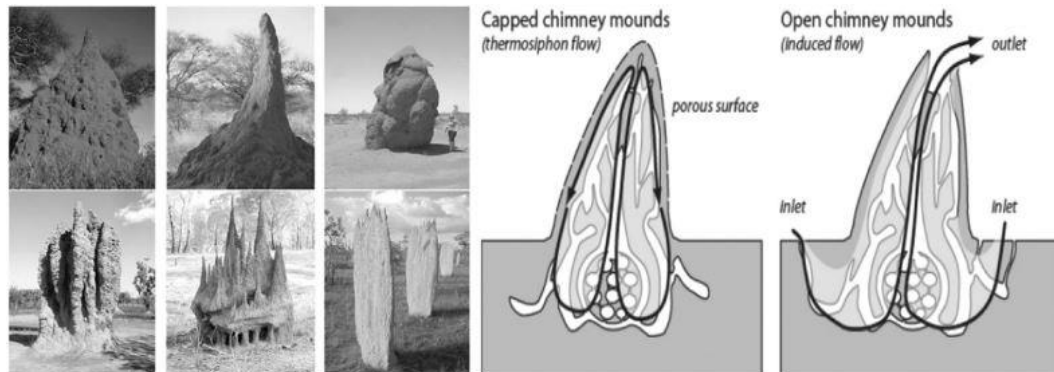


Figure 12: Some Termite Mound Examples and Air Flow in Capped and Open Chimney Mounds. Source: (Yuan et al., 2017)

The average temperature within the mound constantly stays at 28 °C, even when the outside temperature varies by 50 °C from day to night. Fresh air simultaneously enters through the mound's lower portion and stays at the base to chill the mud. The cooled air rises through the middle of the mound and emerges from the top, acting like a ventilation chimney after absorbing the heat within the mounds (Figure 12). The soil,

which has a strong thermal storage capacity, can provide enough heat when it becomes cold at night, and the termites cover up every hole on the surface of the mound except for the ones closest to the bottom to maintain ventilation. By continuously closing or opening the surface and ground vents, the termite adjusts to its changing surroundings and regulates ventilation. The termites' ability to control internal ventilation is substantially improved by this beautiful structure and regulatory system, which also ensures a sufficient supply of oxygen and provides warmth and heat insulation, turning the mound into a fictitious air conditioning tower (Yuan et al., 2017).

The architect Mick Pearce emulated the termite's method of heat acclimatization in the architecture of the Eastgate Center building in Harare, the capital of Zimbabwe (Figure 13). The city's main business and office complex is made up of two slab-style apartment buildings that are connected by an atrium. Double-deck air shafts are installed in the center of the structures, with the inner deck discharging warm air and the outer deck discharging cold air. Green plants are set aside for the footbridge beneath the atrium, where they offer shade and a cooling effect. Additionally, the ventilation system intake is located on the footbridge to capture cold air, allowing it to enter each office first through the skirting board vents and then through the outer-deck air shaft connected to the under-floor cavity. When the air gets warm, it is directed to the double-deck ventilation roof, absorbed into the center inner-deck ventilation shaft, and then eventually released by a carefully placed chimney. The room's temperature and humidity are successfully controlled by the continuous cycle of old and fresh, hot and cold air, and this significantly enhances the room's air quality (Jamei & Vrcelj, 2021).

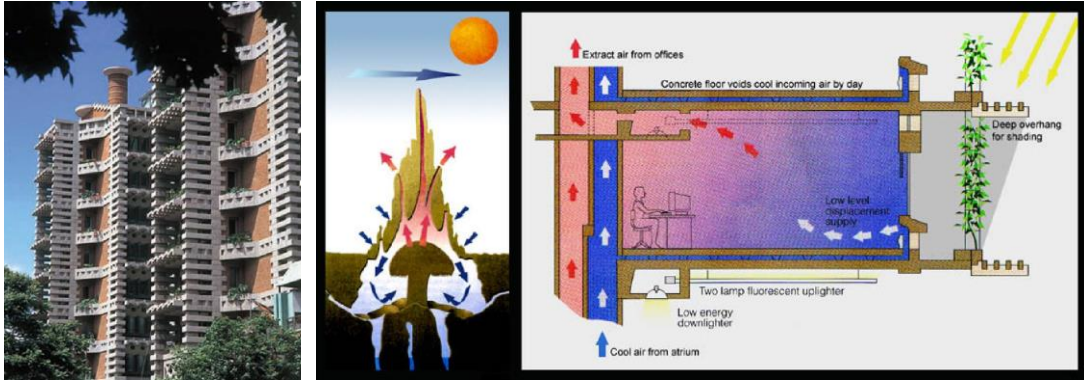


Figure 13: Eastgate Center Building in Harare, Zimbabwe (Left), Circulation of Heat in a Termite Hill and in a Room (Right). Source: (Jamei & Vrcelj, 2021)

4.4.3 Nature as a Mentor

“Biomimicry is a new way of viewing and valuing nature” according to Janine Benyus (Benyus, 1997, p. 2). It illustrates an era in which our priorities are what we can acquire from nature rather than what we can take from it. In order to create our unique arrangements, nature can therefore serve as our guide. It demonstrates that nature may be viewed as an educator in crucial aspects when seeing it as a teacher. Nature ought to be viewed as our teacher and the great philosopher, according to Benyus. Our relationship with the living world transforms as we begin to perceive nature as a mentor. This time, we do not learn about nature so that we can manipulate or avoid her; rather, we learn from nature so that we can finally and permanently blend in on the planet from which we originally came. We have countless inquiries: How ought our food to be raised? How should our materials be created? How should we nourish, heal, and retain what we learn? How can we operate in a way that respects the Earth? We shall keep in mind how it feels to roar like a jaguar—to be a part of, not separate from, the genius that surrounds us—as we learn what nature already understands (Benyus, 1997).

Rolston (1979) investigated the idea that humans and the environment should have an ethical relationship, and also discussed the idea that we should look to nature as a mentor for our personal growth. According to him, the principles of evolution do not entirely apply to how humans live their cultural lives within the context of their nature. But if we look at it from the perspective of nature's law, we can see that humans are definitely subject to the processes of natural laws, even though we sometimes seem to go above them to attain our dependence.

The spiral layout provides a concrete illustration of how nature can serve as a practical guide. This way of organizing development from the bottom up or detailing first has been adopted in nature. For instance, a snail's shell has a logarithmic winding that did not develop because it is attractive, but rather because the snail sees development as continuing without changing shape. When a snail doubles in size, it doesn't need to build walls around its home like most architects would; instead, it just keeps growing more shells in the same shape (Ferwati et al., 2019).

4.5 Biomimicry Principles

In the book *Biomimicry: Innovation by Janine M. Benyus*, nine laws of nature were listed since they were nature's inspiration, and these laws serve as the foundation for the idea of biomimicry (Benyus, 1997, p. 7). Those laws are:

1. Nature runs on sunlight,
2. Nature uses only the energy it needs,
3. Nature fits form to function,
4. Nature recycles everything,
5. Nature rewards cooperation,
6. Nature banks on diversity,

7. Nature demands local expertise,
8. Nature curbs excesses from within,
9. Nature taps the power of limits.

The Biomimicry Institute, however, proposed the biomimicry principles as a more extensive and all-encompassing version of natural laws. These principles are simplified biological techniques, some of which are self-evident and common to most species, that allow life to successfully regenerate itself (Pólit & David, 2014). They are inventive, accessible tools used to assess the sustainability of biomimetic designs, materials, and applications (Kennedy et al., 2015). They are crucial checklists that must be followed to ensure that biomimicry is used in a way that produces sustainable results. The Biomimicry Group (2014) lists the following as twenty-three (23) biomimicry principles that make up its six (6) major concepts (Figure 14) (Biomimicry Group, 2014).

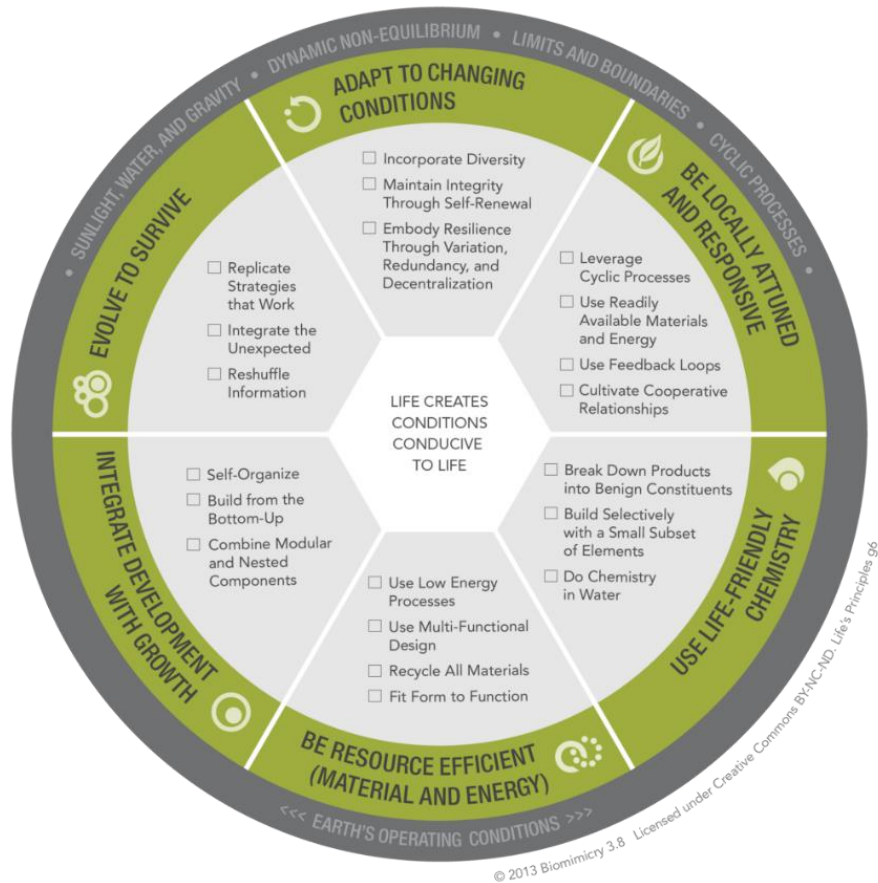


Figure 14: Life's Principles by (Biomimicry Group, 2014)

4.5.1 Resource (material and energy) Efficient

Utilizing resources and opportunities in this manner demonstrates skill and conservatism. Four (4) principles make up this system: using multifunctional design (meeting multiple needs with one elegant solution); using low energy processes (minimizing energy consumption by reducing necessary temperatures, pressures, and/or reaction times); recycling all materials (keeping all materials in a closed loop); and fitting form to function (selecting shape or pattern based on need).

4.5.2 Evolve to Survive.

To ensure long-lasting performance, knowledge is continuously incorporated and embodied. It is based on three (3) principles: repeating successful methods (doing the same thing again), including the unexpected (incorporating failures in ways that can

result in new shapes and functions), and information reorganization (exchange and alter data to generate new selections).

4.5.3 Adapt to Changing Conditions

This is answering active contexts in an acceptable manner. It consists of five (5) principles, including upholding integrity through self-renewal (continually replenishing energy and matter to repair and improve the system), embodying resilience through variation, redundancy, and decentralization (maintaining function after disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together), and upholding diversity (include multiple forms, processes, or systems to meet a functional need).

4.5.4 Integrate Development with Growth

This means making the best possible investments and pursuing activities that foster development and growth. It also includes three (3) principles: constructing from the bottom up (assembling components one at a time); self-organizing; and merging modular and nested components (fitting multiple units within each other gradually from simple to complicated) (create settings to let components to cooperate in concert to move toward an enriched system).

4.5.5 Be Nearby Attuned and Responsive

This blends in with the surroundings and becomes a part of it. It is based on five (5) principles: using readily obtainable resources (build with plentiful, reachable materials); harnessing readily accessible energy (use solar/renewable energy); cultivating cooperative relationships (find worth over win-win interactions); utilizing cyclic progressions (take advantage of phenomena that repeat themselves); and using feedback loops (engage in cyclic data movements to adjust a response properly).

4.5.6 Use life-friendly Chemistry

The utilization of chemistry to support life processes is required for this. Additionally, it consists of three (3) principles, including building selectively with a small subset of elements (assembling relatively few elements in elegant ways), converting products into benign constituents (using chemistry in which decomposition produces no harmful by-products), and performing chemistry in water (use water as solvent).

With the six concepts above, the principles to be followed in the application of biomimicry are mentioned. As mentioned, within these six concepts, 23 principles make up the entire form of the biomimicry method.

4.6 Biomimicry in Design

In order to discover solutions to their professional problems, several disciplines including architecture, sculpture, painting, interior architecture, industrial design, etc., have turned to the centuries-old concept of 'imitating the natural world'. The characteristics of natural materials and forms, such as stability, lightness, resistance to dynamic and static loads, figural and structural properties enabling energy conservation, silence, and self-repairing, have been observed, analyzed, and modeled. This has drawn the attention of many scientists to both living and non-living forms in the natural world. Therefore, if this teaching method becomes commonplace in other fields, according to Benyus, there will be a "biomimetic revolution" in the upcoming years (Benyus, 1997).

4.6.1 Biomimicry Design Approaches

There are two main types of approaches where biomimicry is used in design: problem-based, which is the top-down and solution-based, which is bottom-top approach.

4.6.1.1 Problem-based Approach

This method was proposed by different researchers with different names that all refer to the same idea, including "Top-Down Approach" (Knippers, 2009), "Design looking to biology" (Zari, 2007), and "Problem-Driven Biologically Inspired Design" (Helms et al., 2009).

In Problem-based approach, design professionals first define the challenges they are trying to solve, and then scientists connect those problems to species that have already found solutions in nature. Designers who define a project's aims and parameters effectively lead this approach (Zari, 2007). The problem-based approach pattern consists of a series of steps that, in practice, is nonlinear and dynamic in that the results of later stages commonly affect those of earlier stages, creating iterative feedback and improvement loops (Helms et al., 2009). Additionally, according to McDonough and Braungart (2010), this strategy might be used to start the shift of the built environment from an unsustainable paradigm to a different, more effective one. Problem-based approach in biomimicry was also defined by the research conducted at the Design Intelligence Lab at Georgia Institute of Technology in 2006 by Helms et al (2009) in 6 steps which are shown in Figure 15.

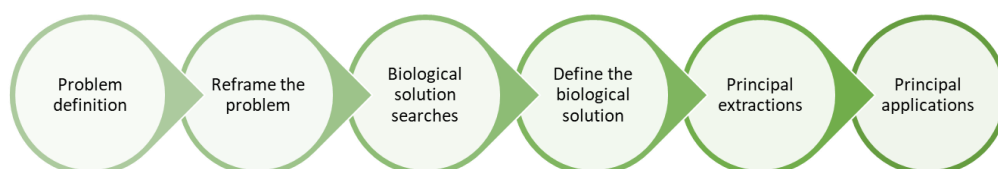


Figure 15: Problem Based Approach, adopted from (El-Zeiny, 2012) by (Helms et al., 2009)

4.6.1.2 Solution-based Approach

The collaborative design approach depends more on individuals being familiar with pertinent biological or ecological research than it does on clearly defined human design issues when biological information affects human design problems. An advantage of this strategy is that biology might have an impact on people in ways that are outside of a planned design issue, leading to technologies or even approaches to design solutions that weren't previously considered. With such a strategy, there is the possibility for a real shift in how humans design and what is prioritized as a problem-solving strategy (Vincent et al., 2005). This approach was further described by Helms et al. (2009) through 7 specific steps (see Figure 16).



Figure 16: Solution Based Approach, adopted from (Helms et al., 2009)

As it was mentioned before, innovation that draws its inspiration from nature is called biomimicry. This respectful mimicry is a completely novel strategy indeed, a revolution in a culture that is used to tame or "fix" nature. In contrast to the Industrial Revolution, the Biomimicry Revolution provides a mindset based on what people can learn from nature rather than what they can extract from it. To develop solutions that are favorable to living things, biomimicry uses an analysis of nature to mimic its deep patterns and functions.

In this fourth chapter of the study, starting from the origins of the biomimicry method, its general definition, levels of biomimicry (nature as model, nature as measure and

nature as mentor), principles of biomimicry and biomimetic design approaches are examined (Figure 17).

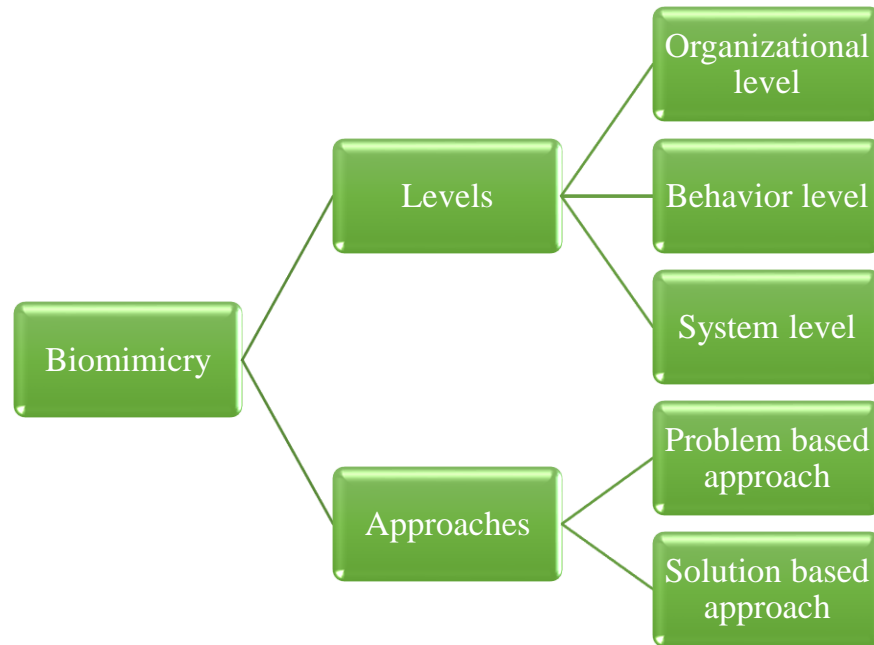


Figure 17: A Diagram Showing the Levels and Approaches of Biomimicry

Chapter 5

BIOMIMICRY IN INTERIOR ARCHITECTURE

Interior architecture or design is among the most exciting and creative professions. A combination of art, science and technology that manipulates space, form, texture, color and light to enhance the quality of human life. Art, science and technology are bolded in the previous sentence, because these three words and also biology are the keywords of biomimicry. Since last decade, the term sustainability has been used in some domains like ecology, economics, politics, culture and design. In these domains, what people do might not be always sustainable, but biomimicry is always a sustainable method since it takes its power from millions of years of evolution process.

It is important to understand how sustainability can be applied in interior environments. Sustainability is a way of life that influences all areas of a person's life, not just a theoretical idea or a field of expertise.

Sustainable design solutions have become a guiding paradigm in order to create a new environment that meets the requirements of the present without threatening those of upcoming generations. The terms "green design" and "sustainable design" are frequently used interchangeably (Rashdan, 2015). Green design denotes an environmental quality which significantly lessens or eliminates the negative effects of buildings on the environment and the health, safety and welfare of occupants. Sustainable design, on the other hand, refers to the preservation of the planet's

environment and future ecosystems. Energy efficiency, alternative construction materials, conservation, and recycling were the key topics of the first wave of experiments in sustainable design. To establish a practical sustainable design theory and practice, the second generation started a synthesis of all the disparate theories and tactics around sustainability (Van der Ryn & Cowan, 2007).

Due to the impact and influence that various interpretations have on the implementation of sustainable design solutions; it is crucial to define sustainability from a variety of perspectives. According to the concepts given above, sustainability is primarily concerned with preserving the environment, minimizing ecological footprints, and promoting economic growth in order to preserve natural resources for humankind. All preceding sustainable issues are significantly impacted by interior design, which is a multifaceted profession. The use of these sustainability concepts will therefore be successful if healthy interior environments are created with little consumption in all design aspects. Therefore, sustainable interior design refers to the creation of places that thoughtfully consider the effects of all of their components, elements, and functions on the environment (Rashdan, 2015). It can also be described as materials and systems that are incorporated into comprehensive design approaches with the aim of minimizing their adverse effects on users and on the environment by maximizing their beneficial effects on social, economic, and environmental systems over the course of a building's life cycle. Sustainable interior design aims to produce aesthetically pleasing and environmentally responsible interiors (IFI, 2011; Kang & Guerin, 2009). Another definition of sustainable interior design is maintaining traditional design aspects while incorporating current technologies (Loftness et al., 2007). In conclusion, responsible environmental solutions relying on sparing use of

local, renewable resources and energy, inspiration from traditional solutions, respect for contemporary trends of design and technologies, and the creation of healthy indoor environments are all characteristics of "sustainable" interior design. Sustainability is integrated into every stage of the design process for a successful sustainable interior project. To do this, flexible spaces must be created that can adapt to shifting activities, residents, and technologies while using fewer resources. They should provide occupants with access to thermal control, outdoor views, daylight, centralized energy management systems, and energy-efficient lighting systems, as well as other amenities. Additionally, they should use efficient building techniques, high-quality supplies, and durable installation systems (Winchip, 2011). Through a variety of channels including conferences, formal education, service learning, potential marketability, books, articles, or coworkers, interior designers might be encouraged to embrace sustainable practices (Rider, 2005). They might be inspired merely by the environmental advantages gained through lessening the effect that building construction and operation have on the air, water, and nonrenewable energy sources. Additionally, enhanced interior environment performance and lower running costs have a positive impact on the economy. Additionally, increased occupant comfort and health have a positive impact on well-being and safety. Communities, therefore, gain when stresses on the neighborhood's infrastructure are reduced as a result of general quality-of-life improvements. Conservation, site, water, energy, indoor environmental quality, material selection, waste, and innovation are the eight categories that sustainable interior design strategies and practices fall under. All of these practices and strategies reduce environmental effects and benefit the Earth, now and in the future (Kang & Guerin, 2009; Loftness et al., 2007; Rashdan, 2015; Rider, 2005).

5.1 Flooring

Effort, time and money

Biomimetic technology, with its inspiration from nature, makes contributions that make life easier at many different points in terms of sustainability. In the products in the examples below, biomimetic products can produce more economical results as it eliminates the need to use products with harmful chemicals such as adhesives that should normally be used in assemblies, thus being more environmental, more practical in terms of reducing the application time and saving it from obligatory products. Biomimetic technology products, from self-cleaning surfaces to bacteria-proof surfaces, provide great benefits for health, especially in environments such as hospitals where the situation is sensitive. In addition, some biomimicry products contribute to decoration, creating amusement, and in many different subjects, which are also indicated in the examples, as shown in the italic titles below.

The capacity of the gecko to grip surfaces with the skin on its feet provides the distinct benefit of being able to cling to different surface types, both smooth and rough, and of being able to release itself at will. This is made possible by incredibly tiny hairs present on its feet. A gecko's foot has roughly 5000 small features (setae of mm^2), allowing it to produce a high adhesive force on areas (Das et al., 2015). The ability of the gecko to curl and flake its toes while adhering and detaching, allows it to move easily, accounts for why the strong bonding force does not restrict its movement. Scientists have worked to create materials with characteristics similar to the gecko's dry stickiness by drawing inspiration from gecko. One such product is the TacTiles, which interface debuted in 2006. One of the earliest biomimetic architectural items to hit the market is possibly this glue-free installation solution for modular carpets. TacTiles'

adaptable backing systems embrace the floor to create dimensional stability without glue, allowing the tiles to be connected without anything adhering to the subfloor. Comparing to other locally available adhesives used in carpets, these solutions have the advantages of being ecologically benign and having a simple application process (Hu, 2015).

An additional item is synthetic "geckskin," a novel super adhesive inspired by gecko feet's mechanism. The University of Massachusetts Amherst scientists and biologists created the Geckskin gadget, which can stick to highly smooth surfaces like glass and has a maximum force of 700 pounds (Das et al., 2015). Everyday items like laptops or televisions may be quickly attached and removed from this synthetic skin (Figure 18). Geckskin, a sustainable material that is reversible, renewable, and biodegradable, is perfect for usage in apparel, home appliances, medical equipment, and other applications (UMassAmherst, 2012).



Figure 18: Gecko, and Materials inspired by the Feet of them. Source: (Lodson & Jahromi, 2017)

Health

How does nature repel bacteria? With remarkably clean skin, sharks are a well-known species of marine fauna. How does this creature keep its body from the bacteria? While chemicals are being used to avoid bacteria formations on the surfaces that people use, sharks turn out with the same denticles on speedo bathing suits that broke all those

records in the Olympics. But its particular kind of pattern on its skin denticles keeps bacteria from being able to land and adhere. Skinny "dermal denticles" or placoid scales, which resemble tiny teeth, make up their skin (Genzer & Marmur, 2008). These minuscule scales benefit the shark in a number of ways, including providing protection from predators, enabling smooth movement through water with little resistance, and preventing the biofouling phenomenon, which occurs when marine organisms attach themselves to an animal's skin.

A group of researchers in University of Florida were motivated to develop a material, named as Sharklet AF (Figure 19), and which similar to the placoids found in shark skin (Genzer & Marmur, 2008) after studying shark skin's capacity to resist biofouling. This artificial surface material prevents the development of pathogenic bacteria. These film-based surface protection products, made possible by Sharklet technology, can be applied to surfaces that may be exposed to bacteria and germs, such as those in hospitals and public bathrooms to keep bacteria from landing, which is better than dousing it with anti-bacterial or harsh cleaners that many organisms are becoming drug resistant. These skins have the potential to be used to make workshop mats, whose surface adhesion qualities can be improved by adding adhesive to the skins' reverse side (Lodson & Jahromi, 2017).

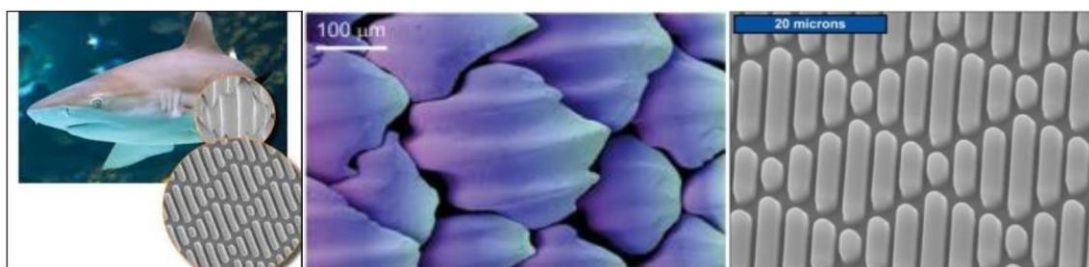


Figure 19: Images of Shark Skin and Sharklet AF Material Pattern. Source: (Lodson & Jahromi, 2017)

5.2 Walls

Effort, money and health

There are some plants that are known to repel water. The lotus plant is a typical illustration. The outside of the lotus flower and leaf is rough and bumpy, which naturally deters dust and debris and produces a clean surface. The slightest wind drafts have the power to slightly alter the plant's tilt, which makes it easier to remove dirt with little effort (Vierra, 2019). Any water droplet that rolls off the leaf is likewise transported by dirt (Figure 20).

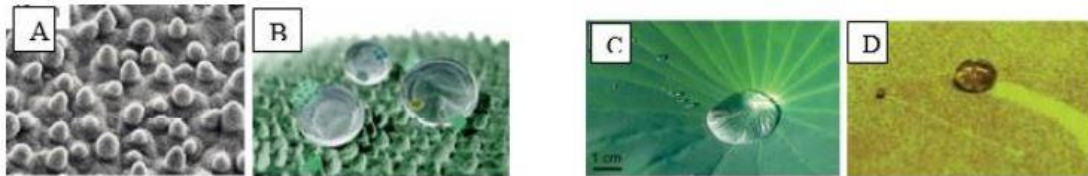


Figure 20: Close-up Picture of a Lotus Leaf (A&B), Water Droplet on Leaf (C), Water Droplet Cleaning the Surface of Lotus Leaf (D).

The German business Ispo decided to focus on this inclination to repel water, and after doing research, they were able to create a paint with comparable capabilities. The paint (Figure 21) makes use of a micro-structure inspired by the hydrophobic leaves of the lotus plant, which reduces the area in contact with water and dirt, making it inherently resistant to the formation of mold, mildew, and algae (Buczynski, 2013). Buczynski claims that this paint is a sustainable product because it is not only economical but also environmentally friendly. Other architectural materials, like paints, tiles, fabrics, and glass, have been developed as a result of the concept and can be utilized with little upkeep and material replacement expenses.

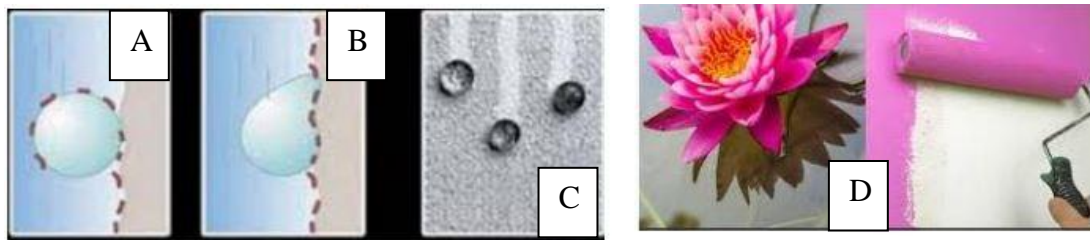


Figure 21: A Water Droplet on a Lotus Leaf (A), A Water Droplet on a Normal Surface (B), Self-cleaning Effect of a Water Droplet on a Wall Covered with Lotusan Paint (C), Self-cleaning Lotusan Paint (D). Source: (Lodson & Jahromi, 2017)

Decorative

An old plant known as *Selaginella Lepidoplylla* has the ability to grow again after the dry season. This plant may last for decades without water (Figure 22). It is renowned for its capacity to withstand almost complete withering; in its native habitat, during dry conditions, its stems curl into a tight ball and only uncurl when exposed to moisture (Lebkuecher & Eickmeier, 1993). The plant's inner stems progressively curl into spirals as a result of the hydro-activated strain differential throughout their length, while the plants outside stems bend into circular rings in a very brief period of dryness. Elaine Ng Yan Ling was able to create interactive textiles (Wooden Skin and Marco Wooden Velcro) inspired by the plant *Selaginella Lepidoplylla*.

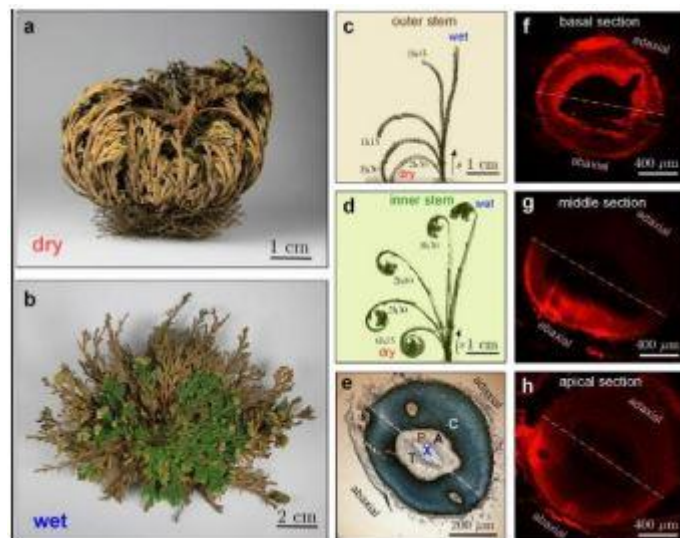


Figure 22: Composition and structure of the plant *Selaginella Lepidoplylla*. Source: (Lodson & Jahromi, 2017)

These textiles are made of layers of veneer combined with fabric, dyes, and reflective surfaces that react to environmental conditions like heat, moisture, light intensity, or mechanical force to create decorative systems that curl and expand or contract. The "macro velcro" tiles have a large-scale interior hook-and-loop pattern and are shaped like flower petals; groups of three of these tiles can be assembled to create floral sculptures with a particularly stunning aesthetic impact (Hu, 2013). They can be used as spatial dividers or put on walls in interior areas.

Weight

Another possibility offered by biomimicry in both architecture and interior architecture and also construction techniques is the idea of lightweight structures. Both internal and exterior loads have varied effects on natural structures. As a result, much as with technologically advanced physical environments, these considerations have an impact on their forms. High levels of insulation and light diffusion are two advantages of employing lightweight materials for building envelopes (Jamei & Vrcelj, 2021). Polar bear fur is a good illustration of these characteristics in nature. In addition to offering effective insulation against the freezing climate of Antarctica, it also permits light to reach the bear's heavily pigmented skin (Aldersey-Williams, 2004). The parallel glass strands that serve as the insulator and light distributor and resemble the hairs also have this property (Pohl & Nachtigall, 2015). It has already been mentioned in the first chapter but there is no harm in remembering it. The Opel company's G.M. model car was designed by mimicking trees and bones to have a lightweight skeleton, which needs less energy for driving the vehicle. Another example and again it is a car skeleton from DaimlerChrysler, "Bionic Car".

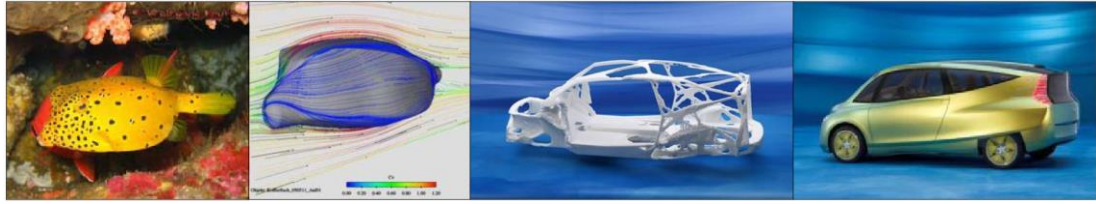


Figure 23: Bionic Car (Daimler Chrysler) inspired by the Boxfish. Source: (Zari, 2007)

Due to the Boxfish's aerodynamic shape, the car's appearance was intended to resemble it. Topological optimization was used to create an optimum, light-weight structure after reaching this form and slightly modifying the "shell" to make it fit to the desired shape of the actual car. It is essential to have some degree of control over the process's limitations. DaimlerChrysler was able to apply the doors in bigger openings as a result. The illustration (Figure 23) shows that the frame has extra material around the engine and wheels (Zari, 2007). This is because the settings that were selected before the final analysis was done to enhance the applicable loads and stresses. By analyzing the Cancellous bone and comparable initiatives like the Bionic automobile, it gave enough knowledge to develop theories about how this process may be imitated to produce a fully optimized structural skin made of concrete for a building. The human body was discovered to be motivating for reasons more than only bone structure, though.

Transparency and temperature

A particularly special adaptation gives the Namaqua Chameleon the ability to endure in a harsh environment. North of South Africa, in the Namib Desert, is where you can find chameleons. Approximately 32.2° Celsius is the typical monthly temperature in Namibia from November to March. But at night, the temperature can go as low as 7.2° Celsius. Numerous creatures have evolved to survive with the intense sun in this region and the abrupt changes in temperature. The Namaqua Chameleon can alter the color

of its skin according to the location of the sun in order to control its body temperature. Wherever the sun is shining, the chameleon changes one side of its skin to a darker hue to absorb heat while changing the other side to a lighter color to reduce heat loss from its body (Singh, 2020). Hoberman Associates' engineers have created a novel technology that works similarly to the skin of the Namaqua Chameleon (Figure 24). The system is known as Adaptive Fritting. Standard fritted glass typically has a pattern or design that is shown as a decorative element or to regulate the transparency through the wall. A cutting-edge technique for giving a fritted glass system operable thermal regulation and total user control is adaptive fritting. Standard fritted glass has a stationary pattern. With adaptive fritting, graphic pattern is employed to manage heat gain in addition to transparency and light entering a space (Singh, 2020).



Figure 24: The Namaqua Chameleon and Standard Fritted Glass. Source: (Yassin et al., 2017)

The question arose as to whether this technology might be advanced further and perhaps integrated into an exterior facade as this fritting is typically utilized on inner walls. Why couldn't the glass gather solar energy and be used as a building's outside skin if it can be used to control the temperature within a structure? Thin film solar panels would be used to control the temperature and gather solar energy in place of a fritted pattern on the glass. The structure would therefore be able to alter its "skin" to

control the internal temperature depending on where the sun is by using the same mechanisms seen in the chameleon.

Perhaps the benefit of "view" is the one that keeps coming up when the advantages of windows are discussed. Human beings frequently express a desire for interaction with the outside world or a view, even in investigations of windowless environments. The term "view" is used here to merely refer to the scene outside the window, despite the fact that it frequently conjures up images of a lovely, pastoral picture. As a result, it can be positive or negative, lovely or ugly, dynamic or stagnant. "The uniquely important characteristics of windows appear to be their provision of a view: people within buildings seem to need some contact with the outside world," (Manning, 1967, p. 3) said in reference to the significance of a view to people in buildings. (Wells, 1965) conducted research to see if office workers could accurately estimate the percentage of daylight in an office that was mostly artificially illuminated, and the results supported this opinion. Even with lots of accessible artificial lighting, he found that 89 percent of those polled thought it was desirable to be able to gaze outside. Only 1% of people said they didn't think it was significant. Furthermore, 69 percent of respondents thought that natural light, as opposed to artificial light, offered a higher level of illumination for office work. Only 3% of people thought artificial light was preferable. (Wells, 1965) came to the conclusion that although those who work far from windows regularly overestimate the amount of sunshine they use, this does not change their conviction that a window view is essential, and that natural light is the best illuminant.

5.3 Windows

Respect to nature

Windows are the iconic components for a building. Windows let us see what is going on outside and also sometimes if there are no closed curtain windows let the surrounding see what is inside that building. It is communication. But, of course, the psychological effect of windows is not the case here. Since we consider sustainability as designers and one of the sustainable issues is being respectful to our surround and nature, we are supposed to deal with some critical issues which may affect other lives. In North America, it has been calculated that collisions with glass on built objects kill a significant number of birds annually (Lodson & Jahromi, 2017). Glass' reflecting and translucent properties, which prevent birds from seeing it, are to blame for this. A technique had to be figured out to make these transparent glasses visible to birds in order to stop this from happening. Researchers looked back at some spiders' webs that have UV-reflective silk strands to do this. Due to their capacity to perceive UV light, birds can avoid flying into the web. Ornilux Glass was built based on web design concepts. With a UV pattern that resembles a spider web yet is still transparent to the human eye, this glass features a spider web-like pattern (Figure 25). The Center for Global Conservation at The Bronx Zoo and a remodeling project at the Great Neck Library both use Ornilux, a double-glazed insulated glass option that is available with either a low-E or solar protection coating (Bonanate, 2015).



Figure 25: Illustration of How Ornilux Glass is seen by a Bird and seen by a Human.
Source: (Lodson & Jahromi, 2017)

Insulation

The biggest organ in the human body is thought to be the skin. 15-20% of the body's weight, according to Rabbani Rankouhi (2012), is made up of it. The skin serves a variety of vital roles in the body, including excretion, protection, and feel of touch experiences. Skin also plays crucial roles in fluid regulation and body temperature regulation. When the temperature of the environment rises, this happens. In response, the blood vessels near the skin's surface dilate, which causes the convective loss of body heat to rise. When the skin is exposed to cold, the opposite occurs. Less heat is lost to the environment because the blood vessels constrict when the body works to preserve its temperature (Rabbani Rankouhi, 2012). In order to address the issue of heat loss in buildings through windows, a team of researchers from the University of Toronto drew on the skin's capacity to regulate temperature (Freeman, 2015). The team used the biological idea described above to reduce heat loss during winter and maintain low temperatures in buildings during summer, taking into account that up to 40% of energy is lost through windows. Their approach entails bonding clear, bendable sheets of elastomer to standard glass windowpanes. Small conduits run the length of the elastomer sheets, which are constructed of polydimethylsiloxane (PDMS), which is a silicone polymer (Figure 26). Similar to how blood capillaries transfer blood, these conduits allow room temperature water to move through. Temperatures can be cooled by up to 7-9 degrees by doing this (Lodson & Jahromi, 2017).

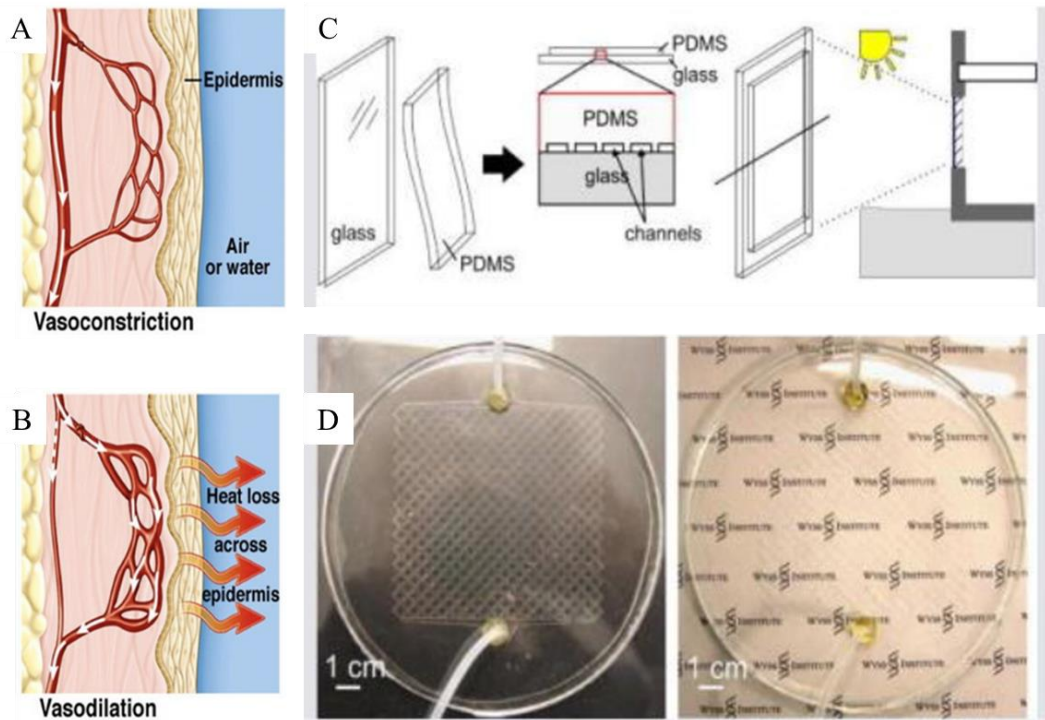


Figure 26: Constricted (A) and Dilated (B) Blood Vessels, where Heat Conservation and Heat Loss occur Respectively. Schematic of the Composite Window Structure (C) and Artificial Vascular Network Layer (D).

Amusement

The family of cephalopods includes the sea animal squid (Figure 27, A). Many cephalopods, including squid and cuttlefish, can quickly adapt to their surroundings by changing their color. The cells known as chromatophores, which have a sac containing pigment, enable this activity. A cell's sac is squeezed to appear larger when the muscles of the squid surrounding it contract, giving the illusion that the squid is changing color (Treacy, 2012).

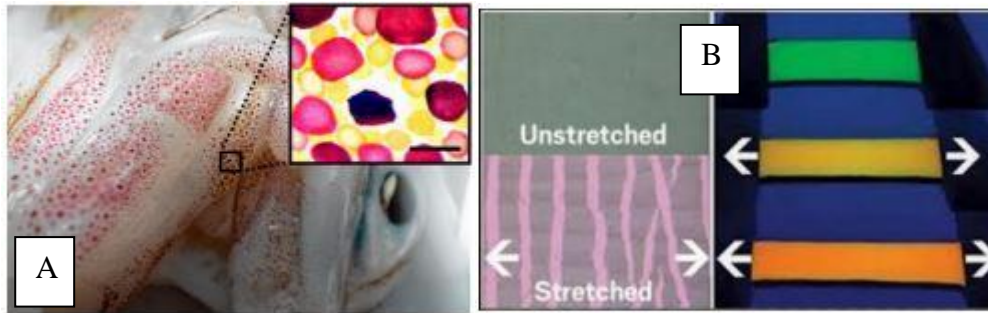


Figure 27: Color-Changing Squid (A) and Polymeric Materials inspired from Color-Changing Squid to be Transformed from Transparent to Opaque (B). Source: (Lodson & Jahromi, 2017)

Researchers have created polymeric materials that change appearance reversibly in response to mechanically induced folds and deformations, taking inspiration from the squid's ability to modify its appearance (Jacoby, 2016). In order to further clarify how this process works, Jacoby claims that stretching this material by 40% causes a transformation on its appearance clearly and irreversibly from transparent to opaque (Figure 27, B). Thus, stretch-induced nanoscale folds and cracks that capture and scatter light are what cause the optical alterations. As mechanical sensors, optical switches, and color-changing smart windows, the material has potential uses.

5.4 Lighting

The demand for artificial lighting is reduced if daylight can be adequately provided in an enclosed area with restricted access. As a result, less heat is produced and less cooling is required, which may lead to a reduction in the size of the cooling apparatus. Overall energy consumption is decreased, and there is less reliance on fossil fuels. This is in addition to the significant aesthetic and health advantages that daylight provides (Zari, 2007). In the wild, cats' pupils react to variations in light intensity. In the glare of direct sunshine, pupils' contract into a vertical line at noon, enlarge to a round shape at night, and stay oval at other times. This is crucial for enabling cats to seek food at night.

Cats' eyes respond to variations in light intensity via dilation of their pupils in the wild. Under the harsh sunlight of noon, pupils narrow into a vertical line; at night, they enlarge to a round form; and the rest of the time, they are oval in shape. For cats to be able to forage for food at night, this is crucial (Hickman, 2021).

Specialized equipment that successfully controls light and the impact of building elevation is present in the Arab World Institute in Paris, which was built by Jean Nouve. This equipment can adjust in accordance with the light intensity outside so that the building's energy consumption is well controlled, and its adaptability is significantly increased (Chen et al., 2012). It mimics the theory that human eyes adjust the intensity of light entering their eyes by constricting their pupils.

Natural illumination can satisfy 25–50% of the working lighting requirements for offices during typical working hours, according to International Commission on Illumination (CIE) (Yuan et al., 2017). Window glass systems, light guide pipe systems, and other bionic energy-saving technologies are examples of natural lighting, which use building elements to bring natural light into the interior. There are several lighting systems that can actively watch the light in order to adjust to changes in sun position and light intensity. These systems are designed to make the best use of available resources while using less energy than conventional lighting systems. An example of an optical fiber illumination system is illustrated in Figure 28, which uses an exterior light collector to gather light that is then transferred by an optical fiber to the interior, where it is uniformly lighted in all four corners of the room (Yuan et al., 2017).

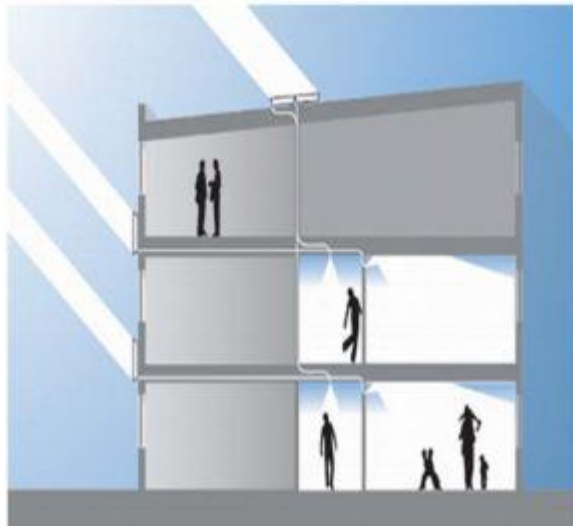


Figure 28: Illumination System via Optical Fiber. Source: (Yuan et al., 2017)

The sunflower fiber optic system in Japan (shown in Figure 29) is one of the most typical examples of an active building lighting device that incorporates light guide series technology. The system is outfitted with an automatic solar tracking system, which satisfies the requirements to obtain the maximum amount of light. According to studies, plant leaves with phototaxis might receive 30–40% more daily direct light than those with fixed blades. Comparing the active solar tracking approach to the passive fixed light collecting method, the performance is improved by 30–36% (Wang, 2011).



Figure 29: Sunflower Fiber Optic System in Japan. Source: (Yuan et al., 2017)

5.5 HVAC

Heating and Insulation

In ecosystems, heat is transmitted through radiation, evaporation, conduction, and convection, just like in developed habitats. In some animals, the body produces heat, which helps to maintain a constant body temperature. While with other types, body temperature varies quite a bit, and heat is primarily absorbed from the environment. Many buildings' heating systems are based on the first kind of animal and the premise that heat is produced by metabolism. By avoiding heat loss, the areas in these kinds of structures are kept warm (Jamei & Vrcelj, 2021).

Direct Heat Gain

Through direct heat-gain from the sun, space can also be kept warm. A notable illustration of this technique is communal nests made of silk layers that are oriented toward the southeast to absorb heat from the sun. The combined effect of insulation and sun direction in this strategy may result in a 4°C increase in temperature (Hansell, 2005).

Consider the way that penguins generate heat. Penguins are social creatures that keep their skin temperature consistent no matter the outside temperature. Penguins cluster together to minimize the exposure of their surfaces to the environment. Similar design principles may be found in vernacular architecture, where buildings are connected to one another, and the sole open area is an opening in the shape of an atrium that is mostly utilized for ventilation (and often closed in winter to decrease heat loss).

Warmer interior temperatures would result from reducing heat loss from structures. This idea, where the heating system primarily relies on internal heat gains obtained

from the metabolisms of the building's occupants and equipment, has been used by a number of passive House projects. The Himalayan rhubarb towers are one of the architectural examples of this biomimetic approach, where a vertical greenhouse of translucent leaves helped to raise indoor temperatures by 10°C above outdoor ambient air temperature (Garfield, 1986) to counteract heat loss through the skin.

Cooling

Some living things that dwell in incredibly hot climates minimize radiative heat gain by keeping out of the sun or mitigate conductive heat gain by reducing their skin's exposure to the sun (skipping across the sand). The fundamental strategy in architecture for cooling buildings has evolved to include this idea (prevent direct heat gain). It appears easy to understand this idea. But it wasn't until the last half of the 20th century that its significance was brought to light. Cabo Llanos Tower by Foreign Office Architects in Santa Cruz de Tenerife, Spain, and the Singapore Arts Centre (Figure 30) by Michael Wilford and Partners with Atelier One and Atelier Ten both use a similar approach to architecture and design (Jamei & Vrcelj, 2021).



Figure 30: Singapore Arts Centre. Source: (Atelier One, 2003)

Chuck Hoberman's work is another example and also one of the pioneers in adaptive sun shading techniques. Hoberman's dynamic windows for the Simon Centre for Geometry and Physics at The State University of New York are one instance of a shading device that is built into the structure (Figure 31), (Hagiwara et al., 2009). The building's windows serve as both a decorative focal point and a practical component for providing shade. Each project panel is made with a unique geometric perforation pattern that corresponds to the building's resident mathematicians' and scientists' areas of research interest.



Figure 31: Shading Device used in New York State University. Source: (Hoberman, 2010)

The patterns differ and vary in line. Circles, hexagons, triangles, and squares are seen growing into an opaque mesh, which results in greater control over the amount of sunlight that is received.

Another illustration of an integrated self-shading device is the Thematic Pavilion in South Korea (Figure 32). It includes a retractable 90-degree flap and was modeled after a South African flower. The major application of the technique is solar shading,

which provides complete sun protection in sunny weather and minimal vision blockage in gloomy conditions (Gruber & Jeronimidis, 2012). *Strelitzia Reginae*'s movements served as the inspiration for The Pavilion. Every time a bird lands on the flower, the petals open and the perch curls, exposing the another to the bird and facilitating pollination. This idea was applied to shading by researchers at the Plant Biomechanics Group at the University of Freiburg. Later, they developed a theory for shading that allows shading to be present when needed and to be moved away when not, preventing vision obstruction. 108 kinetic lamellas are used in the shade system of the Pavilion to reduce the heat radiation from the sun. The lamellas are made of glass-fiber-reinforced polymers, which have great tensile strength and low bending stiffness, allowing for reversible deformations. The bending of the lamellas to regulate solar input required the use of this theory. The actuators are charged by solar panels on the rooftop. The lamellas twist to manage the solar gain, much like an anther moving in and out during avian pollination (Gruber & Jeronimidis, 2012; Jamei & Vrcelj, 2021).



Figure 32: The Thematic Pavilion in South Korea. Source: (Knippers et al., 2012)

For heating and cooling, another good example is Melbourne's Council House 2, which was built with the collaboration of the City of Melbourne and Mick Pearce Inc. (Faragllah, 2021) In this building, a passive cooling system was used that had previously been used in the Eastgate Centre in Harare, and biomimicry had a significant impact on the design of this structure. Passive cooling, heating, and

ventilation system was created according to the tactics termites employed in construction of their mounds (Figure 33).



Figure 33: (A) Front Façade of Melbourne CH2 Building. (B) Using a Microturbine and Solar Panels, CH2 Produces Electricity, Hot Water, and Cooling on its own. (C) CH2 is able to Sustain Thermal Comfort in both the Summer and the Winter thanks to Energy-Efficient Heating and Cooling Technologies. Source: (City of Melbourne, 2006)

The Ministry of Municipal Affairs and Agriculture Office building in Qatar (Figure 34) is designed to mimic the sun-blocking abilities of cacti, which transpire at night rather than during the day. This conserves water by offering shade to the building's facade. Based on how much the cactus transpires, the shade devices open and close in reaction to sun radiation. In order to control the quantity of heat and sunshine that must be transferred into the space, these shades act as filters for the sunlight that enters the rooms and can automatically rise and fall in accordance with the desired interior temperature (Faragllah, 2021).



Figure 34: Ministry of Municipal Affairs and Agriculture Office Building in Qatar, which was inspired from Cactus Spines.

A particular kind of glass sponge called the Venus' flower basket sponge served as the model for The Gherkin's architectural design in creation of the Gherkin Tower in London (Figure 35). Due to its lattice-like exoskeleton and rounded form, which offer stiffness and distribute the forces from powerful currents, the sponge can survive at vast depths. The silica spicule mesh that makes up its body's structural integrity has the ability to bend at its intersections in order to absorb stress. Sea water is filtered for nutrients through the sponge's hollow "basket" made of the silica skeleton. Flagella causes the water to move higher as it passes through the lattice. The Gherkin imitates the sponge's shape and lattice structure to perform the same functions in air as they do in water. As a result of the building's rounded shape, there are less wind deflections and external pressure differentials, which are what power the natural ventilation system (Nkandu & Alibaba, 2018). Compared to the rectilinear design of a conventional office skyscraper, air can flow around the structure more easily. An open floor layout without inside columns is made possible by a lattice-like, diagonally braced structure around the façade. Additionally, the openness allows a lot of natural light to enter.

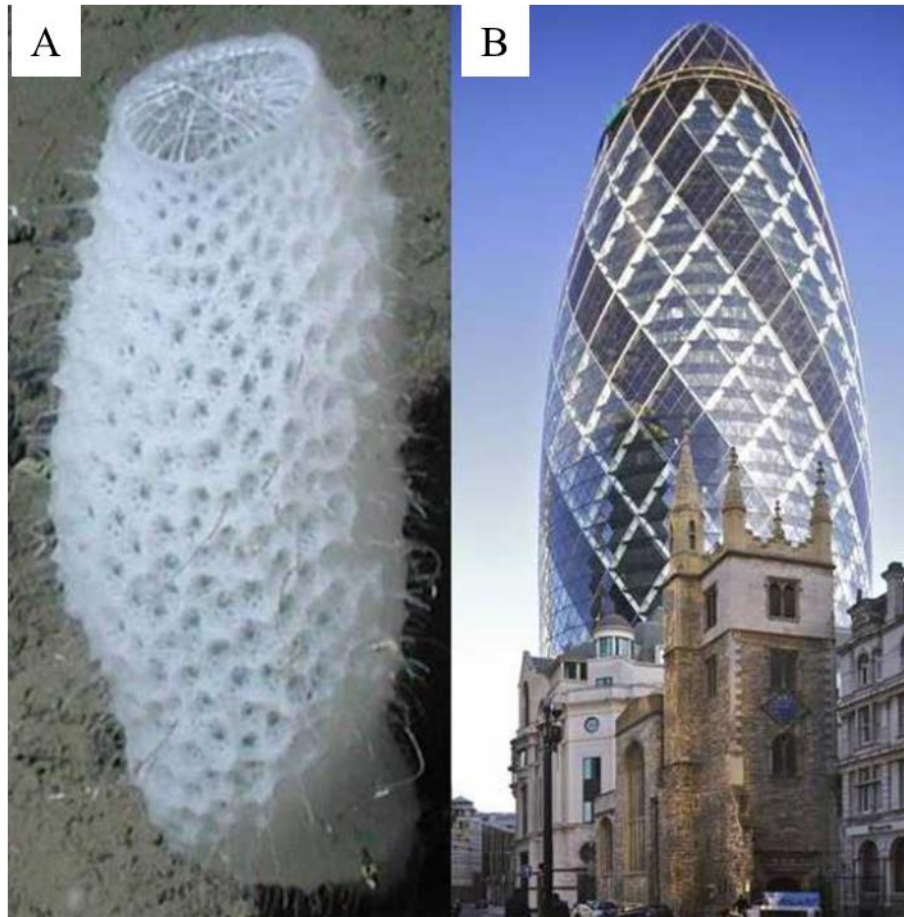


Figure 35: Venus' Flower Basket Sponge (A), Gherkin Tower in London (B). Source: (Nkandu & Alibaba, 2018)

In order to be sustainable, the Gherkin Tower was built with natural ventilation and can "breathe" like a lung. This natural ventilation is produced by air movement between floors caused by gaps in the floorboards. There are six of these atria on each floor, which follow the diagonal lattice construction and span many floors at once. Only firebreaks at every sixth story cause interruptions. The double-skin façade's double-glazing effect, which is produced by the air between an additional set of glass, insulates the office area through passive heating and cooling. By using insulation and natural ventilation, the building can use as little as half the energy that a skyscraper of a same size would.

5.6 Water Management

A little critter that lives in the Namibian Desert has no fresh water to drink in its habitat. However, it can collect the water that it needs to drink out of a fog. The insect has bumps on the back of its wing covers and those bumps act like a magnet for water (Figure 36, A). They have water-loving tips and waxy sides. The fog comes in and it builds up on the tips and it goes down from the sides into the insect's mouth. Scientist Andrew Parker from Oxford University studied this. Kinetic and architectural firms like Grimshaw already started to look at this as a way of coating buildings, so that they can gather water from the fog (Yuan et al., 2017).

The Las Palmas Water Theatre (Figure 36, B) on the Canary Islands in Spain was designed by Grimshaw Architects and Charles Paton using their knowledge of the tenebrionidae method of catching vapor. Its most notable feature is its enormous fresh-water gathering apparatus (Yuan et al., 2017).

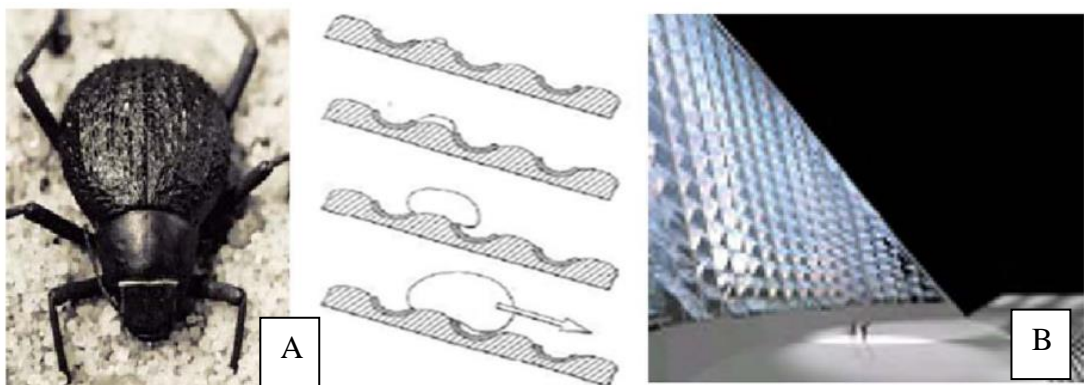


Figure 36: The Prototype of a Beetle, and the Structure Model (A), Las Palmas Water Theatre (B)

Trees and bones are constantly reforming themselves along lines of stress. This algorithm has been put into a software program that's already being used to make bridges lightweight. And also for making building beams lightweight. The automobile

manufacturer Opel used it to create a skeleton for a car model that is called as bionic car. A lightweight skeleton using a minimum amount of material as an organism is a must for the maximum amount of strength. Especially for architecture and interior architecture lightweight is so important. Firstly, light weighted materials in building industry are faster to be produced. And the second advantage is, the logistics of lightweight materials are easier and again faster than heavy ones. All of these actually affect the money a person will spend on that building.

In this last chapter, where the contributions of biomimicry to interior architecture are compiled, reducing the effort spent in the construction or application process, minimizing the time lost, reducing the money spent in the short and long term, the solutions for the concerns in the application process are explained with examples.

Moreover, biomimetic products that respect nature and the life of other living things were mentioned. Finally, information was given on the use of HVAC and water management, which are indoor systems.

The following is a guideline (Table 1) which is created based on all previously mentioned literature searches. In this guideline the properties that interior space components should have to achieve sustainability in interior space, as well as how biomimicry contributes to achieve this is tried to be summarized.

Table 1: What biomimicry provides for interior spaces by considering the expectations of sustainability.

		Expectations of Sustainability in interiors	Biomimicry in interiors
Components of interior spaces	Surfaces: walls, ceilings, floors, windows, doors.	<p><u>Walls</u></p> <ul style="list-style-type: none"> • Hygiene • Long-lasting finishing materials • Light weight • Local materials <p><u>Floors</u></p> <ul style="list-style-type: none"> • Healthy materials • Practical solutions for labor • Long term materials • Reusable materials • Recyclable materials • Local materials <p><u>Windows</u></p> <ul style="list-style-type: none"> • Not giving harm to nature (birds) • Controlling light entering to the space • Helping indoor heating • Aesthetical considerations 	<p><u>Walls</u></p> <p><i>Effort, money & health</i></p> <ul style="list-style-type: none"> • Sharklet AF (anti-bacterial surface) • Self-cleaning Lotusan paint <p><u>Floors</u></p> <p><i>Time, effort, money & health</i></p> <ul style="list-style-type: none"> • Geckskin (for glue-free installations) • Macro velcro" tiles for flexible surface covering. <p><u>Windows</u></p> <p><i>Respect to nature Decorative & shade</i></p> <ul style="list-style-type: none"> • Ornilux Glass (a visible glass for bird to avoid crushes) • Hoberman's dynamic windows (decorative and providing shade).
	Furniture, furnishing & lighting.	<p><u>Furniture and furnishing</u></p> <ul style="list-style-type: none"> • Long-lasting • Healthy • Natural • Energy saver • Sterility • Strength • Lower transportation • Thermal performance • Non-toxic materials • Recyclable materials • Reusable materials 	<p><u>Furniture and furnishing</u></p> <ul style="list-style-type: none"> • Fabrics that do not get dirty (inspired by Lotus flower)

		<p><u>Lighting</u></p> <ul style="list-style-type: none"> • Maximum efficiency • Minimum energy consumption 	<p><u>Lighting</u></p> <ul style="list-style-type: none"> • Sunflower fiber optic system • Illumination system via optical fiber • LED bulbs inspired by fireflies.
	<p>HVAC systems, natural air conditioning systems & daylight.</p>	<p><u>HVAC Systems</u></p> <ul style="list-style-type: none"> • Comfortable temperature • Ideal humidity • Toxic gas emissions <p><u>Natural Air Conditioning</u></p> <ul style="list-style-type: none"> • Cross-ventilation • Negative air pressure. <p><u>Daylight</u></p> <ul style="list-style-type: none"> • Heating indoors 	<p><u>Natural air conditioning</u></p> <ul style="list-style-type: none"> • Eastgate Center Building sample (Circulation of heat in a termite hill and in a room) • The MMAA building, Melbourne. • Qatar Cactus project. • “The Gherkin,” is a commercial skyscraper.
<p>Other elements of Interior spaces</p>	<p>Water Management Strategies.</p>	<ul style="list-style-type: none"> • Water-control systems, • Reuse • Recycling systems • Water-efficient sinks • Smart faucets • Other environmentally friendly sanitary fixtures. 	
	<p>Interior Construction.</p>	<ul style="list-style-type: none"> • Using mechanical technology to avoid material consumption and to alleviate repairs and dismantling. 	

	Smart interior systems.	<ul style="list-style-type: none">• Computer software manages usage for lighting and HVAC systems.• Environmental and financial efficiency of interior materials.	
--	--------------------------------	--	--

Chapter 6

CONCLUSION

The biggest problem of today's time on a global scale is that human beings consume natural resources rapidly, pollute nature and never allow natural resources or nature to recover itself. From the problem of toxic gases released into the atmosphere by the vehicles that people use in transportation, and the chemical products used for the hygienic concerns in the places people live, to the economic problems in transportation and short-term materials, there are serious global problems that have to be solved immediately. The concept of sustainability, with its environmental, economic and equity dimensions is now seen as a must rather than a choice. The concept of sustainability has emerged in all areas of life in recent years. Sustainable politics, a sustainable economy, sustainable energy, sustainable transportation and ultimately sustainable designs. All these concepts are known but how can they really be realized? It is now necessary for designers to prioritize sustainability along with aesthetics and functionality in their projects. Many organizations from different countries express their expectations to achieve sustainability in design through lists they announce with their own certification programs. Although the certification programs have different lists of criteria, the common denominator of all of certification programs is the implementation of methods that prevent pollution, reduce resource consumption and make use of environmentally friendly energy.

In this study, the definition of sustainability was mentioned. In short, the idea of sustainability is to leave a better world to the next generations. It was mentioned about the global problems of the world, what causes those problems and how the principle of sustainability seeks solutions to these problems. In fact, as it is examined the most well-known organizations in the world that have taken steps in this regard. Since this thesis is on interior architecture, the main question was how we can achieve sustainability in interiors. In order to do this, first, it is needed to identify what sustainability is, what it expects from indoors, and most importantly, what method can be used to create sustainability in indoor spaces. In this context, one of the best methods to achieve sustainability can be the biomimicry method, which takes inspiration from the systems and the solutions produced by the nature. Nature allows the most adapted to survive, and many living organisms have been doing this from the very beginning of life. In order to solve human problems in design, biologists, engineers, scientists and designers have been following biomimicry, that is, the method of imitating nature for many years. In this study, the possible contributions of biomimicry to achieve sustainability in interior spaces has been examined and a guide that can help interior architects or anyone who is interested in the subject has been created. The aim has been to raise awareness about how sustainability can be achieved, while designing the interior spaces. In this study it has been realized that studies on creating sustainable building components using biomimicry approach are still very limited and not sufficient. It seems that, more biologists, engineers, scientists and designers need to come together to learn from the nature and to develop biomimicry designs to build a better world. Every research that can encourage the use of biomimicry in interior space is important. Furthermore, detailed studies on biomimicry in specific fields related to interior design such as lighting or air conditioning are

necessary. As well, applying biomimicry design approaches in the design schools in all fields of design and interdisciplinary works with biologists can raise the awareness of the future designers about this issue and increase the possibility of using this approach by them in their future designs.

REFERENCES

- Aldersey-Williams, H. (2004). Towards Biomimetic Architecture. *Nature Materials*, 3(5), 277–279.
- Alfuraty, A. B. (2020). Sustainable Environment in Interior Design: Design by Choosing Sustainable Materials. *IOP Conference Series: Materials Science and Engineering*, 881(1), 0–18. <https://doi.org/10.1088/1757-899X/881/1/012035>
- Atelier One. (2003). *Singapore Art Centre*. <https://www.atelierone.com/singapore-arts-centre>
- Attia, D. I. I. (2015). Biomimicry in Eco-sustainable Interior Design: Natural Ventilation Approach. *International Design Journal*, 5(2), 291–299.
- Benyus, J. M. (1997). *Biomimicry: Innovation Inspired by Nature*. Morrow New York.
- Biomimicry Group. (2014). *Biomimicry 3.8, Life's Principles*. <https://biomimicry.net/the-buzz/resources/designlens-lifes-principles/>
- Bonanate, L. (2015). *Biomimicry: Designs by Nature*. <https://greenhomenyc.org/blog/biomimicry-designs-by-nature/>
- BreGroup. (1990). *BREEAM*. <https://bregroup.com/products/breem/>
- Buczynski, B. (2013). *Eco-Friendly House Paint Inspired By The Self-Cleaning Lotus*

Flower. <http://ecosalon.com/eco-friendly-house-paint-self-cleaning-lotus-flower/>

Cambridge Advanced Learner's Dictionary & Thesaurus. (2023). *Biomimicry*.
<https://dictionary.cambridge.org/dictionary/english/biomimicry>

Chen, P.-Y., McKittrick, J., & Meyers, M. A. (2012). Biological Materials: Functional Adaptations and Bioinspired Designs. *Progress in Materials Science*, 57(8), 1492–1704.

Ching, F. D., & Binggeli, C. (2018). *Interior Design Illustrated* (Fourth). John Wiley & Sons.

City of Melbourne. (2006). *Council House 2*.
<https://www.melbourne.vic.gov.au/building-and-development/sustainable-building/council-house-2/Pages/council-house-2.aspx>

Das, S., Bhowmick, M., Chattopadhyay, S. K., & Basak, S. (2015). Application of Biomimicry in Textiles. *Current Science*, 109(5), 893–901.
<https://doi.org/10.18520/v109/i5/893-901>

Diesendorf, M. (2000). Sustainability and Sustainable Development. In *Sustainability: The corporate challenge of the 21st century* (pp. 19–37).

Edis, T., & Bix, A. S. (2012). Flights of Fancy: The 1001 Inventions Exhibition and Popular Misrepresentations of Medieval Muslim Science and Technology Taking

Flight. *The 1001 Inventions*, 29–303.

El-Zeiny, R. M. A. (2012). Biomimicry as a Problem Solving Methodology in Interior Architecture. *Procedia - Social and Behavioral Sciences*, 50(July), 502–512.
<https://doi.org/10.1016/j.sbspro.2012.08.054>

Faragllah, R. N. (2021). *Biomimetic Approaches for Adaptive Building Envelopes: Applications and Design Considerations*.

Ferwati, M. S., AlSuwaidi, M., Shafaghat, A., & Keyvanfar, A. (2019). *Employing Biomimicry in Urban Metamorphosis Seeking for Sustainability: Case Studies*. 14(40), 133–162. <https://doi.org/10.5821/ace.14.40.6460>

Foster, K., Stelmack, A., & Hindman, D. (2012). *Sustainable Residential Interiors*. John Wiley & Sons.

Freeman, R. (2015). *Geckos, Human Skin and Whale Fins: How Biomimicry Inspires Green Building*. Retrieved 31/12/2016 from <https://www.poplarnetwork.com/news/geckos-human>

Garfield, C. A. (1986). *Peak Performers: The New Heroes of American Business*. (No Title).

Genzer, J., & Marmur, A. (2008). Biological and Synthetic Self- Cleaning Surfaces. *Materials Research Society Bulletin*, 33, 742–746.

- German Sustainable Building Council, D. (2020). *DGNB System: New Construction, Buildings Criteria Set*. <https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/criteria>
- Giddings, B., Hopwood, B., & O'Brien, G. (2002). Environment, Economy and Society: Fitting Them Together Into Sustainable Development. *Sustainable Development, 10*, 187–196. <https://doi.org/10.1002/sd.199>
- Golsteijn, L. (2020). *Life Cycle Assessment (LCA) explained*. <https://pre-sustainability.com/articles/life-cycle-assessment-lca-basics/>
- Graphenea. (n.d.). *Graphene-Perovskite solar cells exceed 18% efficiency*. <https://www.graphenea.com/blogs/graphene-news/graphene-perovskite-solar-cells-exceed-18-efficiency-1>
- Green Building Council Australia, G. (2003). *Green Star Rating System*. <https://new.gbca.org.au/green-star/rating-system/>
- Gruber, P., & Jeronimidis, G. (2012). Has Biomimetics Arrived in Architecture? *Bioinspiration & Biomimetics, 7*(1), 10201.
- Hagiwara, I., Sorguç, A., & Selçuk, S. A. (2009). *Origamics in Architecture: A Medium of Inquiry or Design in Architecture*.
- Hansell, M. H. (2005). *Animal architecture*. Oxford University Press, USA.

Helms, M., Vattam, S. S., & Goel, A. K. (2009). Biologically Inspired Design: Process and Products. *Design Studies*, 30(5), 606–622.
<https://doi.org/10.1016/j.destud.2009.04.003>

Hickman, C. P. (2021). *Integrated Principles of Zoology*. Michael D. Lange.

Hoberman. (2010). *Dynamic Windows*.
<https://www.hoberman.com/portfolio/dynamic-windows/>

Hu, R. (2013). *Beijing Design Week 2013: Wuhao Presents New Work by Mian Wu & Climatology by the Fabrick Lab (a.k.a. Elaine Ng Yanling)*.
<https://www.core77.com/posts/25631/Beijing-Design-Week-2013-Wuhao-Presents-New-Work-by-Mian-Wu-n-Climatology-by-the-Fabrick-Lab-aka-Elaine-Ng-Yanling>

Hu, R. (2015). *Trends in Biomimicry*. <https://interiordesign.net/designwire/3-trends-in-biomimicry/>

IFI, I. F. of I. A. (2011). *IFI Interiors Declaration (online)*. <https://ifiworld.org>

Ilic-Krstic, I., Ilic, A., & Avramović, D. (2018). The Three Dimensions of Sustainable Development: Environment, Economy and Society. *50 Years of Higher Education, Science and Research in Occupational Safety Engineering*, December, 197–202.
https://www.researchgate.net/publication/329611140_THE_THREE_DIMENSIONS_OF_SUSTAINABLE_DEVELOPMENT_ENVIRONMENT_ECONOM

Y_AND_SOCIETY

- Jacoby, M. (2016). MATERIALS Strain-induced Color Changes in Biomimetic Materials. *Chemical & Engineering News*, 94(29), 9.
- Jamei, E., & Vrcelj, Z. (2021). Biomimicry and the Built Environment, Learning from Nature's Solutions. *Applied Sciences (Switzerland)*, 11(16).
<https://doi.org/10.3390/app11167514>
- Jones, L. (2008). *Environmentally Responsible Design: Green and Sustainable Design for Interior Designers*. John Wiley & Sons.
- Kang, M. Y., & Guerin, D. A. (2009). The State of Environmentally Sustainable Interior Design Practice. *American Journal of Environmental Sciences*, 5(2), 179–186.
- Kennedy, E., Fechey-Lippens, D., Hsiung, B.-K., Niewiarowski, P. H., & Kolodziej, M. (2015). Biomimicry: A Path to Sustainable Innovation. *Design Issues*, 31(3), 66–73.
- Knippers, J. (2009). Building and Construction as a Potential Field for the Application of Modern Bio mimetic Principles. *International Biona Symposium*.
- Knippers, J., Scheible, F., Oppe, M., & Jungjohann, H. (2012). Bio-inspired Kinetic GFRP-façade for the Thematic Pavilion of the EXPO 2012 in Yeosu. *International Symposium of Shell and Spatial Structures (IASS 2012)*, 90(6), 341–

347.

Kubba, S. (2010). Basic LEED™ Concepts. *LEED Practices, Certification, and Accreditation Handbook, December 1983*, 19–48. <https://doi.org/10.1016/b978-1-85617-691-0.00002-3>

Lebkuecher, J. G., & Eickmeier, W. G. (1993). Physiological benefits of stem curling for resurrection plants in the field. *Ecology*, *74*(4), 1073–1080.

Lodson, J., & Jahromi, F. S. (2017). Sustainable Innovative Materials for Interior Architecture Using Biomimicry. *Sustainable Structure and Materials*, *1*, 1–11.

Loftness, V., Hakkinen, B., Adan, O., & Nevalainen, A. (2007). Elements that contribute to healthy building design. *Environmental Health Perspectives*, *115*(6), 965–970.

Manning, P. (1967). Windows, Environment and People. *Interbuild/Arena*, *83*(916), 20–25.

Matos, J. (2014). *The International WELL Building Institute launches the WELL Building Standard® version 1.0*. <https://resources.wellcertified.com/articles/the-international-well-building-institute-launches-the-well-building-standard-version-1-0/>

McDonough, W., & Braungart, M. (2002). Design for the Triple Top Line: New Tools for Sustainable Commerce. *Corporate Environmental Strategy*, *9*(3), 251–258.

[https://doi.org/10.1016/S1066-7938\(02\)00069-6](https://doi.org/10.1016/S1066-7938(02)00069-6)

McDonough, W., & Braungart, M. (2010). *Cradle to Cradle: Remaking the Way we Make Things*. North point press.

Murr, L. E. (2015). Biomimetics and Biologically Inspired Materials. In *Handbook of Materials Structures, Properties, Processing and Performance* (pp. 521–552). Springer.

National Park Service. (2015). *1903-The First Flight*. Www.Nps.Gov.
<https://www.nps.gov/wrbr/learn/historyculture/thefirstflight.htm>

Nkandu, M. I., & Alibaba, H. Z. (2018). Biomimicry as an Alternative Approach to Sustainability. *Architecture Research*, 8(1), 1–11.

Okafor, I. F., & Akubue, G. (2012). F-chart Method for Designing Solar Thermal Water Heating Systems. *International Journal of Scientific & Engineering Research*, 3(9), 1–7.

Omer, M. A. B., & Noguchi, T. (2020). A Conceptual Framework for Understanding the Contribution of Building Materials in the Achievement of Sustainable Development Goals (SDGs). *Sustainable Cities and Society*, 52, 101869.

Osmani, M., Glass, J., & Price, A. D. F. (2008). Architects' Perspectives on Construction Waste Reduction by Design. *Waste Management*, 28(7), 1147–1158. <https://doi.org/10.1016/j.wasman.2007.05.011>

- Othmani, N. I., Yunus, M. Y. M., Ismail, N. A., & Rahman, K. (2018). Review on Biomimicry Levels. *American Journal of Humanities and Social Sciences Research (AJHSSR) e-ISSN*, 55–58.
- Pohl, G., & Nachtigall, W. (2015). *Biomimetics for Architecture & Design: Nature-Analogies-Technology*. Springer.
- Pólit, J., & David, C. (2014). *Regreening Nature: Turning Negative Externalities into Opportunities*. Delft University of Technology.
- Primrose, S. B. (2020). *Biomimetics: Nature-Inspired Design and Innovation*. John Wiley & Sons Ltd.
- Qi, H. B., He, F. Y., Wang, Q. S., Li, D., & Lin, L. (2012). Simulation Analysis of Heat Transfer on Low Temperature hot-water Radiant Floor Heating and Electrical Radiant Floor Heating. *Applied Mechanics and Materials*, 204, 4234–4238.
- Rabbani Rankouhi, A. (2012). *Naturally Inspired Design Investigation into the Application of Biomimicry in Architectural Design*.
- Rashdan, W. (2015). Exploring Sustainability Impact on Interior. *Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol. 1: Design for Life, July*, 1–10.
- Rashdan, W. (2016). The Impact of Innovative Smart Design Solutions on Achieving

Sustainable Interior Design. *WIT Transactions on Ecology and the Environment*, 204, 623–634.

Rider, T. (2005). *Education, Environmental Attitudes and the Design Professions: A Masters Thesis*.

Riggs, R. (2003). Materials and Components of Interior Architecture. In *Prentice-Hall: Vol. 6th Editio*.

Rolston, H. (1979). Can and Ought we to Follow Nature? *Environmental Ethics*, 1(1), 7–30.

Sandru, O. (2010). *Self-Repairing, Leaf-Mimicking Solar Cells Invented by MIT Scientists*. The Green Optimistic. <https://www.greenoptimistic.com/self-repairing-solar-cells-mit-20100903/#.Wkh9tCOB0II>

Sassi, P. (2006). *Strategies for Sustainable Architecture*. Taylor & Francis.

Singh, R. (2020). Biomimicry: Learning from nature. *J. Eng. Sci*, 11, 533–547.

Spiegel, R., & Meadows, D. (2010). *Green Building Materials: A Guide to Product Selection and Specification*. John Wiley & Sons.

Strange, T., & Bayley, A. (2008). Sustainable Development - Linking Economy, Society, Environment. In *OECD Publishing*.

Toufaily, N. A. (2021). Informal Interior Architecture: The Inspiration of Light and

Shadow and Biomimetic Methods in Informal Interior Architecture. *Arts and Architecture Journal*, 2(2), 75–95.

Treacy, M. (2012). *Color-Changing Squid Inspire Technology that Could finally get Us That Invisibility Cloak*.

UMassAmherst. (2012). *Geckskin*. <https://geckskin.umass.edu/>

Van der Ryn, S., & Cowan, S. (2007). Ecological Design. In *Environmental Ethics* (Vol. 24, Issue 3).

Vierra, S. (2019). *Biomimicry: Designing to Model Nature*. <https://www.wbdg.org/resources/biomimicry-designing-model-nature>

Vincent, J. F. V., Bogatyreva, O., Pahl, A. K., Bogatyrev, N., & Bowyer, A. (2005). Putting Biology into TRIZ: A Database of Biological Effects. *Creativity and Innovation Management*, 14(1), 66–72. <https://doi.org/10.1111/j.1476-8691.2005.00326.x>

Wang, J. L. (2011). Biomimicry Kinetics Sustainability-Study on Kinetic Building Envelopes based on Biological Acclimatization. *Tianjin University*.

Wells, B. W. P. (1965). Subjective Responses to the Lighting Installation in a Modern Office Building and their Design Implications. *Building Science*, 1(1), 57–68.

Winchip, S. M. (2011). *Sustainable Design for Interior Environments* (Second edi).

A&C Black.

Wing Construction with Engineering Design - by Leonardo da Vinci. (2011).

Www.Leonardodavinci.Net. <https://www.leonardodavinci.net/wing-construction-with-engineering-design.jsp>

Yassin, H. E. A. E., Fathallah, A. M., & Elshapasy, R. A. I. (2017). Biomimicry in Managing Daylighting and Energy Consumption in Office Buildings. *International Journal of Engineering Research & Technology (IJERT)*, 6(02).

Youssef, R. B.-Eld. M. (2014). *Biomimetic Approaches to Sustainability and its Application in Interior Design of the Tourist Buildings.*

Yuan, Y., Yu, X., Yang, X., Xiao, Y., Xiang, B., & Wang, Y. (2017). Bionic Building Energy Efficiency and Bionic Green Architecture: A Review. *Renewable and Sustainable Energy Reviews*, 74(March), 771–787. <https://doi.org/10.1016/j.rser.2017.03.004>

Yusoff, M. M. (2020). Improving the Quality of Life for Sustainable Development. *IOP Conference Series: Earth and Environmental Science*, 561(1). <https://doi.org/10.1088/1755-1315/561/1/012020>

Zari, M. P. (2007). Biomimetic Approaches to Architectural Design for Increased Sustainability. *The SB07 NZ Sustainable Building Conference.*

Zeinal Hamedani, A., & Huber, F. (2012). A Comparative Study of DGNB, LEED and

BREEAM Certificate Systems in Urban Sustainability. *The Sustainable City VII: Urban Regeneration and Sustainability*, 121–132.
<https://doi.org/10.2495/SC120111>

Zhang, H., & Park, N.-G. (2022). Towards Sustainability with Self-healing and Recyclable Perovskite Solar Cells. *EScience*, 2(6), 567–572.