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جامعة محمد خيضر بسكرة
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Biomimicry, towards a living Architecture in hot and arid regions

Defended by:

Sara KHELIL

Examiners' Committee

Dr. Benabbas Moussadek	**M C A**	**President**	**University of Biskra**
Pr. Zemmouri Nourdinne	**Professor**	**Advisor**	**University of Biskra**
Pr. Boucheham Yasmina	**Professor**	**Examiner**	**University of Constantine**
Pr. Kazar Okba	**Professor**	**Examiner**	**University of Biskra**

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CHAPTER 1

INTRODUCTION

"Bomimicry is a vision of a world that works"
- janine Benyus

Contents

1.1 MOTIVATION

Among the most significant environment challenges, of our time, are the global climate change, excessive fossil fuel dependency and our growing cities demand for energy, all likely to be major challenges of the twenty first century and some of the greatest problems facing humanity [Gut 1993].
By looking at the community today, it's hard not to ask, "how this will end "? The earliest known writings of environment challenges were written between the 9th and the 13th centuries, but were not really thought of until after the World War II. After the Great Smog in London in 1952, that killed at least 4000 people, the first major modern environmental legislation was set in 1956, The Clean Air Act. In the United States, the Congress passed the Clean Air act, the Clean Water Act and the National Environmental Policy Act between the mid-1950s and early 1970s [OmAmarson 2011].
Rachel Carson's published her book "Silent Spring" in 1962. It generated a storm of controversy over the use of chemical pesticides. She is recognized by many, as the pioneer of modern environmental awareness. Baker Randall said that "The controversy sparked by Silent Spring led to the enactment of environmental legislation and the establishment of government agencies to better regulate the use of these chemicals.[Baker 1996]. In this context, the Intergovernmental Panel on Climate Change (IPCC) represented in 2007, the work of 2,500 scientists from more than 130 countries, which claim that humans have been the primary cause of global warming since 1950. In order for mankind to stop affecting the climate , it has to move away from fossil fuels like coal and oil, within few decades.

There is ample evidence to suggest that the narrow band of climatic conditions that supports the on-going survival of the human species is changing. This affects not only humans but also many, if not most of the other species that inhabit the planet as well as the complex web of relationships between them.
The on-going existence of human civilization, in its current form, is potentially in danger not only due to climate change but also because of ecosystem degradation and the loss of biodiversity. Because these two problems are caused mostly by humans, it is apparent that the way many humans currently live, particularly in industrialized countries is not conducive to the long term continuation of human civilization [Zari 2012], (Figure 1.1) clarifies this. It illustrates that humans exist within ecosystems, rather than as separate from them. Ecosystems in turn exist within and influence the greater global climatic system. Humans impacts on climate change and biodiversity are represented by the red arrows in Figure 1.1.

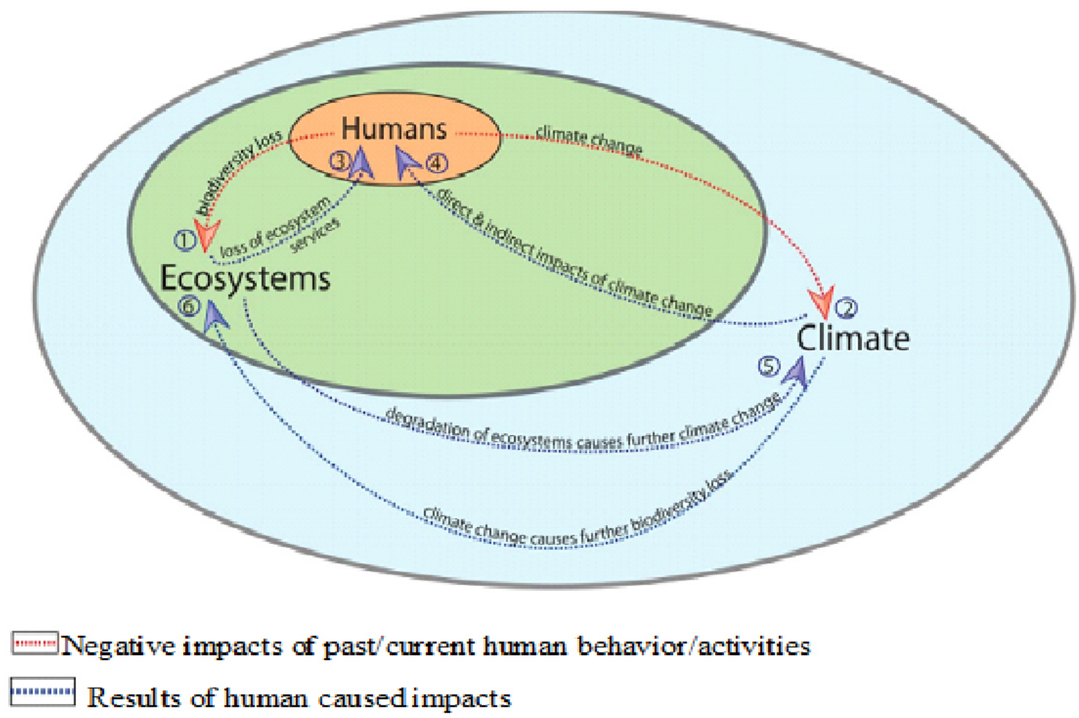


Figure 1.1: Drivers and results of change. Source: [Zari 2012]

Human activities and behaviors have impacted negatively on the climate and on ecosystems (represented by the red arrows). Changes in climate are known to be largely anthropogenic in origin, and stem from many different kinds of human activities. This means direct and indirect impacts of climate change on human societies are occurring (represented by blue arrow 4). The degradation of ecosystems and

loss of biodiversity are also caused by numerous human activities. This results in the loss of ecosystem services,in terms of both quality and quantity (represented by blue arrow 3). The feedback caused by human induced drivers of change between the climate and ecosystems amplifies in many instances the speed and scale of both climate change and biodiversity loss (illustrated by blue arrows 5 and 6) creating a self-reinforcing feedback loop [Zari 2012].
In front of the global climate's dilemma, scientists and decision makers are conscious about the importance of improving and adapting it, and they adopted the basic principles of sustainable development. As quoted in [Benyus 2002], the significant problems we face cannot be solved by the same level of thinking that created them, it is time to both acknowledge the difficult issues that face the integrity of ecosystem health, as we know it and venture whole-heartedly to find solutions.
Globally, buildings account for around one third of energy use and are responsible for over half of total greenhouse gas emissions. Studies show that the efficiency improvement capacity of buildings is significant; researchers have estimated that the current energy consumption of buildings could be cut by 30 to 35 per cent simply by using energy more efficiently. Another 25 per cent could be gained by transforming the existing building stock through retrofitting it into energy-efficient buildings [Krigger 2004].
One of the most important design challenges in architecture is designing ecological buildings located in hot and arid region. This region is situated in two belts at latitudes between approximately 15^0 and 30^0 North and South of the equator. Its main characteristics are the very hot summer season and a cooler winter season, and the great temperature difference between day and night (see Figure 1.2).
In this region, scientists recommend the use of the principles of the sustainable design that are based mainly on reducing the energy consumption of the building and the achievement of eco-efficiency of buildings.

We have a specific interest to a sustainable approach in the design because we have a strong feeling that it is time to act, especially to introduce new reflection's methods, new ways of thinking and find a new way to approach the architecture and urbanism in Sahara.
A new approach is emerging attracted our attention since we started looking more closely to sustainable design, an approach that not only reverses degeneration of the earth's natural systems, but creates systems that can co-evolve with us, in a way that generates mutual benefits and creates an overall expression of life and resilience. This ideology is called biomimicry that refers to sustainability by looking to nature for solutions. More precisely, it is a process that involves artificially reproduce natural properties from biological systems [Yurtkuran 2013].
Biomimicry is the science of copying natural systems and designs, in order to create new industrial products. It is based on what we can learn from the nature, not on what we can extract from it [Vincent 2002]. It is defined by Benyus as the technical term used in biochemistry, biology, pharmaceuticals, engineering, and by material scientists in their quest for properties in living organisms and natural systems that

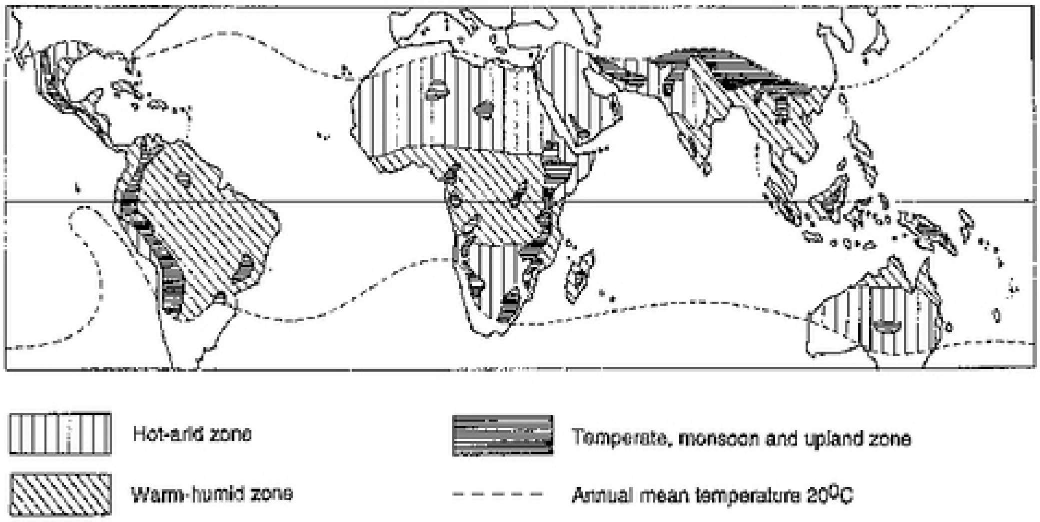


Figure 1.2: World climatic zones

can be extrapolated from observation and scientific analysis, in order to apply them in industry, medicine as well as other disciplines [Elghawaby 2010].
As seen in [Bahamon 2007], [Gauthier 2011], [Baumeister 2012], Biomimicry provides an example that can serve as a model, a conceptual framework that permits and enhances the exploration of our world. Instead of having to do cost benefit analysis of human health and the environment and working to clean up our messes we could instead model our systems after nature so that there are no messes to begin with.
Letting nature take a role as teacher has a logic that crosses academic barriers and suggests that the study of natural processes is a valuable component and potentially an equal partner with traditional biological disciplines researching nature.
Biomimicry presents a very promising solution to this issue. This is due to both the fact that it is an inspirational source of possible innovation and because of the potential, it offers as a way to create a more regenerative built environment.
According to Benyus [Benyus 2002], the Biomimics are discovering what works in the natural world, and more important, what lasts. After 3.8 billion years of research and development, what surrounds us is the secret of to survival. The more our world looks and functions like this natural world, the more likely we are to be accepted on this home that is ours, but not ours alone.
The principle of Biomimetics strives to learn what can nature learn us and to not necessarily imitate it but distil from nature the qualities and characteristics of natural form and systems that may be applicable to our interpretation of architecture.

1.2 RESEARCH QUESTIONS

The nature gives us several examples and solutions of adaptation to hot climate. These living biological systems do not only offer special physical characteristics but also functional systems. In this context, a number of questions are addressed in this dissertation:

- Could the lessons learned from living natural systems be applied to architecture to lessen its environmental impact?
- Can the combination of the biological characteristics of life and the built environment offer new solutions for more appropriate, more sustainable architectural designs in hot and arid regions?
- Can we use and explore the potential of biomimicry in developing a more sustainable reflection's methods towards a living architecture in hot and arid regions?

1.3 HYPOTHESIS

In the light of various readings, we think that answers to the questions posed previously, may be summarized in the following hypothesis:

1. The biomimetic ideology offers to the designers the opportunity to develop a more sustainable reflection's methods towards a living architecture in hot and arid regions.
2. Biomimicry offers to the designers the opportunity to design better buildings, which are located in hot and arid regions by emulating the very natural systems and processes in ecosystems and translating them into human designs.

The scope of this research is the study and analysis of biomimicry as an important tool for architectural design and sustainable construction, focusing on the possibility of applying biomimetic principles selected in the design process, describing their potential for future sustainable design in hot and arid regions.

1.4 OBJECTIVES OF THE RESEARCH

The main objective of this research is to link the two emerging sciences, Biomimicry and architectural design, exploring their potential in developing a more sustainable reflectionâs methods towards a living architecture in hot and arid regions. To reach this objective we are aiming to:

- Imitate such living biological systems of adaptation found in flora and fauna of the desert biome (living in hot and arid climates) in order to transform them into architectural design principles.

- Investigate new strategies for sustainable design in hot and arid climates, which are derived from the natural designs, living systems and processes, from their material, properties and from their adaptive response to changes in their environment.

The current work attempts to investigate new strategies for sustainable design in hot and arid climates, which are derived from the natural designs, living systems and processes, from their material, properties and from their adaptive response to changes in their environment.
Simultaneously, the nature gives us several examples and solutions of adaptation to hot climate. These living biological systems do not only offer special physical characteristics but also functional systems. In this research, we try to imitate such living biological systems of adaptation found in flora and fauna of the desert biome (living in hot and arid climates) in order to transform them into architectural design principles aiming to prove that the human reasoning is illogical and we can rectify it using the nature's genius.

1.5 STRUCTURE & METHODOLOGY

Through an exploratory and analytical research, this work is an attempt to establish a link between biomimicry and architectural design. It starts by the exploration of the influence of biomimicry on architecture, resulting in a set of selected principles that could be applied in the design in hot and arid climate. These principles are then abstracted in order to use them as specific architectural design concepts.
Architectural design and natural sciences are both vast and complex fields. To avoid creating a superficial relation between the two disciplines, a comprehensive and careful examination are necessary. Methods used for this investigation are diverse. Literature research, expert interviews and analyze of natural mechanisms and systems are carried out.
To achieve the main objective of this research, the following steps are carried out:

- Investigate adaptation strategies and mechanisms found in nature.

- Explain the basics of biomimicry.

- Analyze design methods existing in literature and summarize their merits and limitations.

- Introduce and investigate some case studies that have been built or that are in developing stage. These cases will aim to explain three main aspects of nature's mentoring approaches, which are natural forms, processes and systems.

- We will look at some precedent built examples that have been inspired from natural forms.
- We will look at theoretical examples that have been developed from the understanding of natural processes.
- We will look at natural systems that act as mentor to inform architectural design solution in the desert biome.

- Explore the potential of biomimicry on architecture.

- Explore the possibility of implementing and correlating selected biological principles with architectural design.

The outline of this thesis is as follows: this thesis contains two parts; theoretical and practical part:

1. The theoretical part:" Biomimicry, innovation inspired by nature". This part contains two chapters (chapter 2, chapter 3) reviewing, respectively, the natural world and theoretical framework on biomimicry . The contents of chapter 2 tell how is nature is a living laboratory, how it can be a model, measure and mentor by having the best solutions for nowadays problems. Chapter3 introduces the biomimetic approach and deals with the analysis of the different design methods and approaches of Biomimicry found in literature and summarizes their merits, and how we can explore them in the design.

2. The practical part:
"Towards a living architecture" contains three chapters (chapter 4; chapter 5, chapter 6). In chapter 4, an overview of Biomimicry and its influence on architectural design, we will explore its potential in architecture and the possibility of implementing biological principles with architectural design. This chapter deals with the analysis of some applications of Biomimicry in architecture to find out the advantages and the spaces that exist in this approach of design. In chapter 5, we present the case of the study and the Biobrainstorming methodology, a useful bio-key tool based on biomimetic principles to find new methods and systems for renewable energy in hot and arid regions. This methodology is relevant to various disciplines as a problem solver to optimize the energy use; this is due to the generality of the strategy tools. Chapter 6 includes the simulation, the main highlights, results and final remarks. Finnaly, chapter 7 contains the research contributions, recommendations and the perspectives.

Part I

BIOMIMICRY, INNOVATION INSPIRED BY NATURE

Chapter 2

NATURE: A LIVING LABORATORY

"Look deep into nature, and then you will understand everything better."
- Albert Einstein

Contents

2.1 Introduction

After 3.8 billion years of evolution, nature has "learned" what works, what is appropriate, what lasts, and what survives. Nature is a model of efficiency, where virtually nothing is wasted, and where natural systems work in harmony with each other, in communities. The “model of nature” has been used as a source of inspiration for design of the human environment for millennia. The forms, structures and organizing principles found in nature have inspired countless concepts, processes and products in art, design and architecture. In this chapter, we will show what we could from nature, studying the science of nature and by exploring native organisms and ecosystems.

Figure 2.1: MonarchButterfly (Source: http://biomimicryqi.org/biomimetisme/)

2.2 DEFINITION OF NATURE AND SIGNIFICATIONS

It will be attempted to discover what exactly it is meant when someone refers to nature, what is the meaning of the world nature and which elements belong in the physical planet.Nature is the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations. Based on this definition, nature is the natural world without any change that people made, thanks to the development of this civilization. The nature includes all the elements of the natural world, for instance, mountains, trees, animals, or lakes [Tselas 2013].
Macnab [Macnab 2012] has mentioned some facts about the direct connection of nature with architecture. That is explained by the fact that there are so many different kinds of architecture that are connected with nature. Some examples of these kinds of architecture are: organic, biomimicry, vernacular and landscape architecture. All of these different categories use nature as inspiration for the form of building, the functions that could be applied or the way that a building could be combined with the natural environment. According to Alvaro Siza, “ What is made by man is not natural. More and more think that there must be a certain distance between the natural and the manmade. However, there must be also a dialogue between the two. Architecture comes from nature forms but it also transforms nature...” [Finsterwalder 2011].
Nature is a great source of inspiration. Inspiration is the process of being mentally stimulated to do or feel something, especially to do something creative. When a project started architects, start to look around in hope to find inspiration in order

to design their idea. This idea after many changes and a lot of development will take the final shape. Inspiration could be almost anything for the architects. For instance, inspiration for an architect could be a painting that they saw, the shape of the site for which they have to design the building or the functionality of the building . There are many common sources of inspiration, which are used very often and other sources of inspiration that could be extraordinary. One of the most used sources of inspiration is nature because it offers many ideas that an architect can use for a design. Like said Feuerstein in [Feuerstein 2002]) "the variety of forms in nature seems endless. Out of a limited quantity of mathematical rules, a seemingly endless quantity of forms and patterns arise. The beauty of patterns and forms in nature based on mathematical rules, the regularity and uniformity, and symmetry are what man feels as harmonious."
Nature is the grand experimentalist, and bio-inspiration looks at naturel's successful experiments and attempts to apply their solutions to present-day human problems.

2.3 LIFE, BIOLOGY

The discussion of the natural world requires a discussion of living systems and life itself. What is life? There is no universal agreement on the definition of life.
Life is a characteristic distinguishing physical entities having biological processes (such as signaling and self-sustaining processes) from those that do not, either because such functions have ceased (death), or because they lack such functions and are classified as inanimate. Various forms of life exist such as plants, animals, fungi, protists, archaea, and bacteria. The criteria can at times be ambiguous and may or may not define viruses, viroids or potential artificial life as living. Biology is the primary science concerned with the study of life, although many other sciences are involved [Koshland 2002].
The smallest contiguous unit of life is called an organism. Organisms are composed of one, or more, cells, undergo metabolism, maintain homeostasis, can grow, respond to stimuli, reproduce and, through evolution, adapt to their environment in successive generations, [Koshland 2002]. A diverse array of living organisms can be found in the biosphere of Earth, and the properties common to these organisms plants, animals, fungi, protists, archaea, and bacteria are a carbon and water-based cellular form with complex organization and heritable genetic information.
Simple creatures like bacteria and algae are systems of enormous complexity, which offer many different fields of research. Even our best technical achievements are still far away from this complexity [Gruber 2011].

2.3.1 GENERAL CHARACTERISTICS OF LIFE

Different approaches to a definition of life have been taken over the past hundred years. The interpretation of life is influenced by the respective technological level of a certain time. Starting with a mere listing of criteria, we have now moved on towards a systemic view of this phenomenon. Nonetheless, According to Petra Gruber [Gruber 2011], important characteristics of life serve as criteria for a comparison with architecture and will be presented in the following.

1. **Individual forms**.
   The necessity of thermodynamically isolating a subsystem is an irreducible condition of life. The partial separation of living entities from their environment by means of membranes is crucial for the processing of matter and energy.
   There is an obvious tendency to diversification and differentiation, so that life exists in an abundant diversity of individual forms. Five big kingdoms of organisms have been agreed upon:protoctista, bacteria, fungi, plants and animals [Margulis 2000].

2. **Entropy**.
   The first law of thermodynamics says that during any transformation the total energy of any system and its environment is constant: energy is neither lost nor gained. Energy - whether as light, movement, radiation, heat, radioactivity, chemical or other -is conserved.
   The second law says that in any moving or energy-using system entropy increases. Other forms of energy tend to convert to heat, and heat tends to disorganize matter. There is low entropy and a high degree of order in organisms. This is only achieved through permanent processing of solar and chemical energy.
   As Gruber said, order is based on a hierarchy of structural levels, every level based on the one beneath it. Depending on the scale, different phenomena become important. Order is a fundamental characteristic of any architectural creation. Organisms have found two different ways to get round the laws of thermodynamics: autotrophic organisms use solar energy to establish and maintain order; heterotrophic organisms use chemical energy by degrading high-molecular nutrition.

3. **Living systems are open systems**
   Because metabolism requires exchange of matter and energy with the environment, living systems are open systems. Consisting of proteins and nucleic acids, they are able to synthesize these substances. Supply of energy and emission of positive entropy in the form of disoriented substance or thermal energy is necessary to keep entropy low.

4. **Emergence**
   With a growing level of order, new characteristics evolve which did not exist on the level beneath. These characteristics are called emergent characteristics and result from the interaction between the components (synergism). Emergence occurs on all levels: with growing complexity, for instance, communication and sensing organs have to be used.

5. **Life is based on hierarchical levels of structure**
Life is organized on hierarchical structural levels. Most processes in living systems take place on more than one level (Chemical level, Cells, Organs and tissues, Population, Community, ecosystem). The hierarchical structuring of matter is one of the most important characteristics of materials in biology.

6. **Limitation**
In nature, the size of constructions is limited through the size of elementary particles and the size of the universe.

2.3.2 CLASSICAL CRITERIA OF LIFE

A literature review and examination of criteria of life was conducted by Petra Gruber in 2011. The so-called criteria of life are defined as follows: order, propagation, growth and development, energy use, sensing and reacting, homeostasis and evolutionary development. These criteria substitute a definition. Living systems are supposed to display all of these criteria.

1. **Order, or negative entropy**
All characteristics of life develop out of the complex organisation of the organism itself. The existence of life depends on a specific level of complexity. The processes in living organisms take place in dynamic structures. Differentiation and change of structure and form are possible. All organisms exist in some kind of chemical order. Order often takes the form of ("natural") patterns.
As mentioned before, the order of living systems is not consistent with the second law of thermodynamics saying that with every transformation of matter and energy the universal entropy increases. Living systems use a trick to fulfil this physical condition: autotrophic organisms use sunlight as an energy source and create complex molecular material to store energy.

2. **Propagation**
Organisms are capable of reproducing themselves through passing on genetic information.

3. **Development and growth**
Inherited programs in the form of DNA together with RNA control growth and development processes and thus generate an organism typically representing a species.

4. **Growth**
Growth in nature relies on cell division and differentiation. Cells divide, assembling and building material for the living organism.

5. **Use of energy**
Organisms absorb energy and transform it into other forms. They use solar energy or nutrients to perform different kinds of activities.

6. **Reactions to environment**
   Sensing and reacting are vital for the survival of organisms and their species. All organisms have to adapt to their environment, therefore they have to be sensitive to external stimuli and process them. ”All living beings, not just animals but also plants and microorganisms, perceive.” [Margulis 2000].

7. **Homoeostasis**
   The internal environment of an organism is kept constant within certain limits by regulating mechanisms, in spite of variations in the environment. This regulation is called homoeostasis and is characterized by complex interwoven control cycles.

8. **Evolutionary adaptation**
   As organisms and their environment interact, life develops. As a consequence of evolution and natural selection organisms, become more and more well-adapted to the environment, while at the same time shaping it.

2.4 NATURE AS MODEL, MEASURE AND MENTOR

”Doing it nature’s way” has the potential to change the way we make materials, harness energy, heal ourselves, store information, and conduct business . . . In each case, nature would be model, measure, and mentor.

- Nature as model. We would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics, and chemicals. Our farms, modeled on prairies, would be self-fertilizing and pest-resistant. To find new drugs or crops, we would consult animals and insects that have used plants for millions of years to keep themselves healthy and nourished. Even computing would take its cue from nature, with software that “evolves” solutions, and hardware that uses the lock-and-key paradigm to compute by touch.
  In each case, nature would provide the models: solar cells copied from leaves, steely fibers woven spider-style, shatterproof ceramics drawn from mother-of-pearl, cancer cures compliments of chimpanzees, perennial grains inspired by tallgrass, computers that signal like cells, and a closed-loop economy. It means emulating nature’s forms, processes and systems to solve human problems; this is the act of biomimicry.

- Nature as measure. Beside providing the model, nature would also provide the measure, we would look to nature as a standard against which to judge the “rightness” of our innovations. Are they life promoting? Do they fit in? Will they last?

- Nature as mentor. Finally, our relationship with nature would also change. Instead of seeing nature as a source of raw materials, we would see nature as a

> source of ideas, as a mentor. This would change everything, ushering in a new era based not on what we can extract from nature, but on what we can learn from her.

When we view nature as a source of ideas instead of goods, the rationale for protecting wild species and their habitats becomes self-evident. To have more people realize this is my fondest hope.
Instead of acting as we are separate from nature, we need to accept that we are part of it and we should be behaving accordingly. By changing our perspective on nature, we can improve our world through designs that take advantage of nature's ingenuity. These designs can do this on a number of levels.

Figure 2.2: Kingfisher (Source: http://biomimicryqi.org/biomimetisme/)

2.5 NATURE AS INSPIRATION DURING THE HISTORY OF ARCHITECTURE

The design and therefore architecture have a tight connection with nature. This connection started when people started to build the first buildings [Gans 2003]. For centuries, nature has been used to explain the origins of architecture.
The examples of architecture inspired by nature during the period that the first buildings were erected are countless. This was absolutely normal as the first shelter-like residences that were ever built had nature as their only source of inspiration. One every characteristic example is that the form of bird's nest inspired the shelters that were built. Apart from the natural inspired form of the buildings that the people design, they were using the functions of nature in their buildings in order to make them more functional.
Separately from that first period that people used nature as inspiration, they continued to use it during the history of architecture. The development of civilization helped the progress of the architecture too. Many ideas from nature were applied in architecture in order to achieve the best results for the designing and the construction of the buildings. Architecture and its relationship with nature can be either be distinguished as metaphorical, architecture whichis like nature or literal, architecture that imitates natures laws and systems.
The introduction of technology added multiple complexities to otherwise simple designs, thus increasing its impact on the surrounding ecology. It is through the return to nature that this simplicity and elegance can once again be achieved.
Initial concepts of architectural mimesis (imitation) of nature began with the arts. Sculptures and painters were among the first to both, metaphorically and literally imitate nature. Architecture, was not initially associated as a representational art as it neither reproduced natural objects, nor, like poetry, human moods and emotions. It took centuries for the discourse between the relationship of nature and architecture to be clarified. It was argued in the 18th century that: while architecture did not represent the superficial appearances of nature, it could and did represent the principles inherent in nature, and provided a more profound form of mimesis than that found in the other arts whose representation of nature was direct and literal.
Observations and analysis of historical architecture can behold many connections with nature through its proportional systems.The most prominent proportional system to be found in nature, that since it's discovery has been applied to architectural design in variety of ways, is the Golden Section (Figure 2.3) [Finsterwalder 2011]. The Golden Section's use in architectural design has subsequently been analyzed as both deliberate and accidental. The latter reinforcing the previous observation regarding our tendency to design natural forms intuitively.
The Golden Rectangle (the Golden Section), is an illustrative representation of the Golden Ratio. The golden ratio = 1.61803,is known to scientists and mathematicians, as phi . This number has been generatedusing a mathematical algorithm. The algorithm is based upon the Fibonacci sequence '1, 1, 2, 3, 5, 8, 13, 21...' As numer-

ical values, they're purely mathematical, however, when arranged illustratively as the Golden Section it becomes apparent that the Golden Ratio links directly with nature.
If we connect the successive points where these "whirling squares" divide the " sides of the Golden Ratios, you obtain a " logarithmic Spiral that coils inward toward the pole (Figure 2.3).

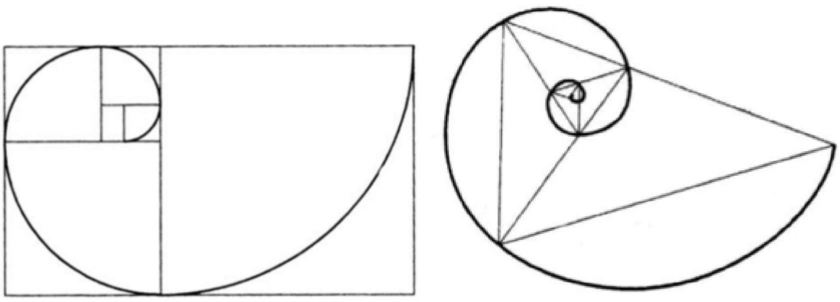


Figure 2.3: Left:Golden Section / Right: Logarithmic spiral

The logarithmic spiral and the golden section can be seen throughout nature, from the spiralling form of a sunflower head (Figure) to the movement of a Peregrine Falcon while it attacks its prey (Figure 2.4).

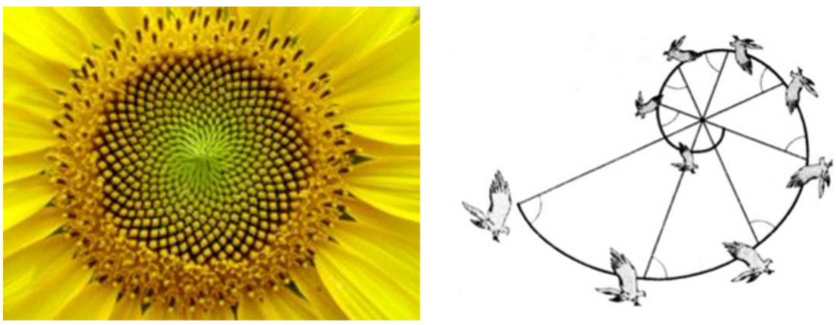


Figure 2.4: Left: Sunflower Head / Right: Peregrin Falcon flight path

In recent decades there has been a move toward a "re-invented nature" to replace the high modernism of the mid-late 20th century. High modernism disregarded the principles of nature that had been used for centuries and instead, replaced it with 'technology'.
The re-invented nature has focused design to incorporate environmental and ecological 21st century concerns as principle factors in architectural design. The advocators for sustainable design see that architecture needs to minimize its confrontation with nature. To do that it must respect nature's laws. Working our buildings into the cycle of nature will return architecture to its very roots.
During the mid-late 20th century there was emphasizes that nature (the world in

which we exist), and culture (the world man created), were part of the same single system. Consequently, humanity began to consider their impact on nature and its eco-systems, through the continuous use of unsustainable construction.
There have been several groups within architecture that have considered the importance of nature and its relevance to architecture either through using its forms or systems, to create sustainable dynamic buildings.The limitations of material science in the mid-20th century meant architecture wasn't able to evolve into what some were envisaging as being an organic architecture, based on both metaphorical and more significantly, literal imitations of nature. With recent advancements in material science and construction techniques, it has been possible to advance both into the way in which buildings are composed and constructed.
Nature has evolved over millions of years, therefore it has formulated the most efficient composition and methods of achieving an end result. Architecture is beginning to mimic this efficiency more readily allowingit to embrace more natural forms and systems.

2.6 NATURAL FORM BECOMES FORM OF A BUILDING

During the history of architecture, there have been many buildings inspired by nature. It is obvious that in some of them is easy to understand, that their shape and form was inspired by the natural environment but in some others is not that easy.
Nature has long been a source of inspiration for designers, engineers and architects for their building projects. This is because these designs are not just aesthetically pleasing but are also practical and innovative as some of them also take on the adaptive features of the things they were based on.

2.6.1 TAIPEI 101

Taipei 101 is located in the Xinyi District in Taiwan's capital city- Taipei. It was formerly known as the Taipei World Financial center and was ranked as the tallest building in the world from 2004 to 2009. The building was designed by C.Y. Lee Partners and was inspired by the indigenous slender bamboo that the country sees as an icon of learning and growth. The building is also considered as one of the greenest in the world when it was awarded the Leadership in Energy and Environmental Design (LEED) platinum certification in July 2011.

Figure 2.5: Left: Bamboo Plant / Right: Taipei 101

2.6.2 BIRD's NEST STADIUM

The Beijing National Stadium or better known as the Bird's Nest Stadium was designed by Swiss architecture firm Herzog de Meuron for the 2008 Summer Olympics and Paralympics in Beijing, China. As the name implies, the stadium looks like a giant bird's nest. The infrastructure was also built using advanced energy-saving

Figure 2.6: Left: Bird's Nest / Right: Beijing National Stadium

design and environment friendly features such as natural ventilation lighting, a recycling system for rainwater, use of renewable geothermal energy sources and utilization of photovoltaic power technologies.

2.6.3 LOTUS TEMPLE

The Lotus temple in New Delhi, India was designed by Iranian architect Fariborz Sahba who took the lotus flower as his inspiration for the project. The temple is the site of worship for followers of the Baha'i Faith.
The temple's design is composed of 27 free-standing marble clad petals that are group in clusters of three in order to form nine sides (a stipulation of the religion).

Figure 2.7: Left: Lotus Flower / Right: Lotus Temple in India

2.6.4 PALM ISLANDS

The Palm Islands are an artificial archipelago in Dubai, UAE that is shaped like a palm tree, topped with a crescent. The archipelago will be made from sand dredged from the Persian Gulf and will house both residential and commercial establishments such as hotels, residential beach side villas and apartments, theme parks and restaurants.

The Palm Islands are being constructed by a local property developer in UAE-Nakheel Properties. The Belgian and Dutch land reclamation experts Jan De Nul and Van Oordwere hired for the dredging operations.


Figure 2.8: Left: Palm Tree / Right: Palm Islands in Dubai

2.6.5 CENTER FOR DISEASE CONTROL COMPLEX

This design by Manfredi and Luca Nicoletti was an entry for a design challenge for Taiwana's new Center for Disease Control BioLab. The two buildings nicknamed as the Biolab Squadron were inspired by the shell of a nautilus and features interlacing geometric incisions in its outer skin. The pattern in its outer skin reproduces the


Figure 2.9: Left: Nautilus Shell / Right: Center for Disease Control Complex

four conventional symbols attributed to the DNA sequence of the bacteria that is to be studied in the building. The result of this design is a seemingly homogenous surface that is engraved with by symbols not known to common people.

2.6.6 CHICAGO SPIRE

The Chicago Spire is a skyscraper in Chicago, Illinois that was inspired by a seashell. Designed by Spanish architect Santiago Calatrava and was developed by Shelbourne Development. Although the project was supported by a lot of people in Chicago, the developer faced numerous financial difficulties and design revisions which eventually caused the project's end. The building's construction efforts were officially

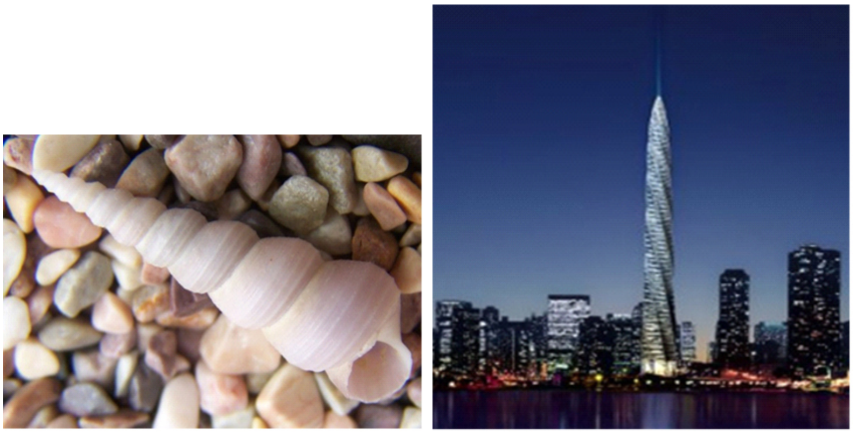


Figure 2.10: Left: Seashell / Right: Chicago Spire

abandoned in 2008 with only the foundation work completed and with a USD77 Million lawsuit filed against its Irish developer.

2.6.7 REDWOODS TREEHOUSE

The Redwoods Treehouse is a pod-shaped structure that sits 10 meters high in a redwood tree. The treehouse, which draws inspiration from insect cocoons, can accommodate up to 30 guests and serve as a restaurant in which special occasions can be held.

Figure 2.11: Left: Cocoon / Right: Redwoods Tree House

2.6.8 ALDARHEADQUARTERS BUILDING

The Aldar Headquarters Building in Abu Dhabi is one of the most unique and striking infrastructures in the city's skyline. It was voted as the Best Futuristic Design of 2008 and was inspired by a seashell. It is the first circular building in the

Figure 2.12: Left: Seashell / Right: Aldar Headquarters Building

Middle East which uses grids of steel for maintaining its shape. The building also features international Grade A specification which includes floor to ceiling glazing, an impressive double height dual entrance lobby and of course, amazing views of the entire city of Abu Dhabi and the nearby Al Raha beach.

2.6.9 MMAA BUILDING

This design is from the Aesthetics Architects Go Group from Bangkok. Their design for the Office of the Minister of Municipal Affairs and Agriculture in Doha, Qatar is inspired by a plant commonly found in the desert-the cactus. Just like a real

Figure 2.13: Left: Cactus plant / Right: MMAA Building

cacti thriving in the arid desert environment, the designers of the building hopes to make the infrastructure a comfortable haven in the middle of the desert with energy efficient features such as sunshade panels that open and close depending on the sunâs intensity. There is also a botanic dome at the base of the building that houses a botanic garden.

2.6.10 BEIJING WATER CUBE

The Beijing National Aquatics Center otherwise known as the Water Cube is another infrastructure commissioned by the Chinese Government for the 2008 Summer Olympics in Beijing, China. At first glance, the entire building looks like a cube of water and bubbles, but a closer look reveals that the infrastructure is made from a steel space frame clad with ETFE, a fluorine based plastic. The water cube hosted

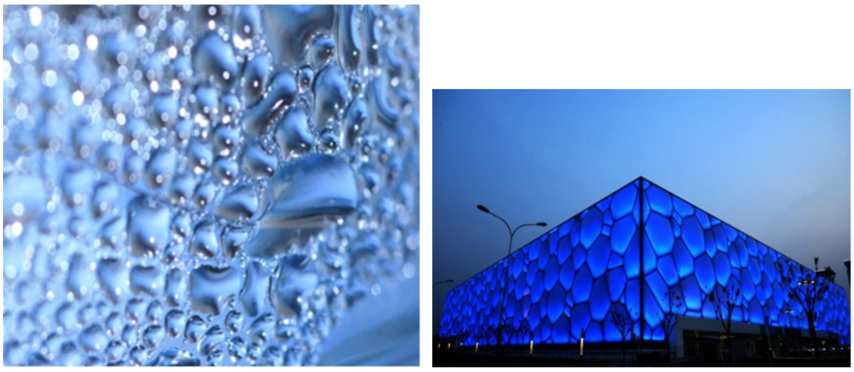


Figure 2.14: Left: Bubbles / Right: Beijing National Aquatics Center

the swimming, diving and synchronized swimming events in the 2008 Olympics and was able to accommodate 7,000-17,000 people. The infrastructure is also a green building with its ETFE cladding that allows more light and heat penetration, which in turn reduces energy costs.

2.7 CONCLUSION

In this chapter, we have shown that the natural world is resilient, resourceful, opportunistic, and utilizes existing relationships for symbiotic advantage , then ,in a given location and climate, it may provide a model or a set of performance targets, for architecture in the same location and climate. Some sustainable design literature implies that understanding the living world could be an important part of design approaches. The emulation of strategies, seen in the living world as a basis for human design, is known as biomimicry which is the context of the following chapter.

CHAPTER 3

THEORETICAL FRAMEWORK OF BIOMIMICRY

"The more our world functions like the natural world, the more likely we are to endure on this home that is ours, but not ours alone."
- Janine Benyus

Contents

3.1 INTRODUCTION

Designers and engineers are always searching for inspiration to solve their problems. They used nature for centuries as source of inspiration through biological forms, mechanisms, systems, and analogies, this practice is often referred to biomimicry.

This chapter reviews existing literature and explores biomimetic information relevant for architectural design. It also seeks to provide a starting point for architectural designers and students to work with this subject, as a literature base to help architectural designers to know the biomimetic approach.

3.2 UNDERSTANDING BIOMIMICRY

To solve problems humans have always looked to nature for inspiration. By studying the history, we find that Leonardo da Vinci applied biomimicry to the study of birds in the hope of enabling human flight. He studied the anatomy and flight of birds,and made several notes and sketches of his observations and many sketches of planned flying machines. His ideas lived on and were the source of inspiration for the Wright Brothers, who were also inspired by their observations of pigeons in flight. They finally did succeed in creating and flying the first airplane in 1903.

Figure 3.1: Left: Leonardo's design for a flying machine, c. 1488, inspired by birds in flight. Middle and right: Pigeons also influenced the Wright Brothers' design for the first airplane

3.2.1 DEFINITION OF BIOMIMICRY

Biomimicry means the imitation of life, the word coming from a combination of the Greek roots bios (life) and mimikos (imitation).
According to Benyus's definition [Benyus 2002] Biomimicry is the study of nature's most successful developments and then imitating these designs and processes to solve human problems. The idea is that, during its 3.8 billion years of research and development, nature has evolved highly efficient systems and processes that can inform solutions to many of the waste, resource efficiency and management problems that we now grapple with today.
Biomimetics, a name coined by Otto Schmitt in the 1950s for the transfer of ideas and analogues from biology to technology, has produced some significant and successful devices and concepts, but it is still in its infancy and still needs time to

become fully integrated into popular thinking and popular design. The biologist Julien Vincent describes it as "*The abstraction of good design from nature*". [Vincent 2006]. The architect Michel Pawlin defines Biomimicry as "*mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions*" [Pawlyn 2011].
The Biomimicry institute posit that Biomimicry is the science and art of emulating nature's best biological ideas to solve human problems.
In 1997 Janine M. Benyus published a book about biomimicry, that book popularized this concept and made it well known. Benyus is the founder and the Board President of the Biomimicry Institute, and also a co-founder of Biomimicry Guild. She is also a Natural Sciences writer, innovation consultant, author as wellas teacher and lecturer at the Universityof Montana. She has degrees both in Natural Resource Management and in English Literature/Writing from Rutgers University where she graduated with highest honors. In 1997 Benuys was awarded the Rachel Carson Environmental Ethics Award and in 2007 she was honored by the Time magazine as "Heroes of the Environment" where the most innovative and influential protectors of the planet are honored
Due to the fact that biomimicry is an inspirational source of possible new innovation and because of the potential it offers as a way to create a more sustainable and even regenerative built environment.Biomimicry, where flora, fauna or entire ecosystems are emulated as a basis for design, is a growing area of research in the fields of architecture and engineering.

3.2.2 BIOMIMICRY MOTIVATIONS

Nowadays, humans can explore and investigate the living world and all the natural phenomena more precisely thanks to the technological advancements. The Biomimetic investigation and the emergence of Biomimicry as research area increase human capacity to understand and mimic nature.
Maibritt Pedersen Zari said that *"Mimicking organisms or ecosystems is an expanding field of research in both academic and design discourse"* [Zari 2012]. According to her, there are three main motivations behind investigating Biomimicry:

1. Biomimicry for innovation
   Biomimicry can be seen as a source of innovation in the creation of new materials and technologies. Most biomimetic investigationrelate to this reason and they are not necessarily aiming to improve the ecological performance of human technology. Rather, they are about novel approaches to technical problems, increased performance capabilities. This brand of research is related particularly to robotics, computing and materials technologies that have no focus on sustainability issues.

2. Biomimicry for sustainability
   There is a rise in interest in the potential of biomimicry as a way to create more sustainable materials, products, built environments, and engineering

solutions.Biomimicry can improve the environmental performance of human technologies and the built environment [Pawlyn 2011]. The act of mimicking an organism in design is in itself a means to achieve greater sustainability. One of the crucial dissimilarities between biomimicry-for-sustainability and biomimicry-for-innovation, is that biomimicry-for-sustainability have a tendency to recognize the importance of mimicking not just organisms but also the underlying processes, strategies and systems of ecosystems, to lead to more sustainable outcomes. Biomimicry-for-sustainability is not focused exclusively on the creation of new and novel technologies, but on the altering of the underlying foundations of design.

3. Biomimicry for human well-being.
   The third motivation for exploring biomimicry comes from examining whether design based on an understanding of the living world could contribute to increasing human psychological wellbeing, due to its inherent relationship to the concept of Biophilia [Zari 2012].

3.2.3 BIOMIMICRY: TERMS, DEFINITIONS AND RELATED FIELDS (BIONICS, BIONIK AND BIOMIMETICS)

Biomimicry is a scientific discipline, but also a new philosophy, or rather rediscovered philosophy that is returned to a lost balance, balance of man and nature, a posture that opens up new horizons. Analogies between ecosystems, living organisms, and architectural design, mentioned to here as bio-inspired design, are investigated in many diverse ways [Zari 2012], [Gruber 2011]. It is one aspect of bio-inspired design. (Figure 3.3) shows different types of bio-inspired design that have significance in an architectural framework. It maps elements of bio-inspired design onto the three drivers for biomimicry described earlier; and increased human well-being. This figure exposes possible fundamental significances and motivations behind the several terms used.
According to Werner Nachtigall, 2002, at the conference entitled "Bionics Symposium: Living prototypes – the key to new technology" in 1960, the US Air Force Major J.E. Steele coined the German-language term Bionik originally comes from the English word "bionics"as a combination of the words "biology" and "technics" or "electronics".
In German, the term "Bionik" has found a very expressive reinterpretation in the first and last syllables of the words Biologie [biology] and Technik [technology]. It is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology.
The term bionics [Bionik]: a combination of two terms:

- Biology, the science of life.
- Technology, the constructive creation of products, devices and processes by using the materials and forces of nature, taking into account the laws of nature.

Below the diagram explains the relationship between nature and technology. Where technical biology means 'understanding nature with the help of technology'. Bionics means 'learning from nature for the sake of technology'.

According to Gruber [Gruber 2011], there is three specific subfields of the field

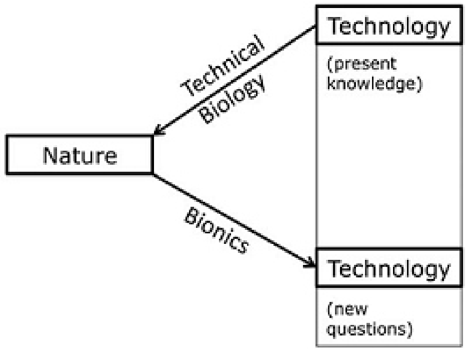


Figure 3.2: Diagram explaining the relationship between bionik (bionics) and technical biology, nature (left) and technology (right) [Gruber 2011]

Bionics:

- Structural bionics: Nature's constructions, structures, materials.
- Procedural bionics: Nature's procedures or processes
- Informational bionics: Principles of development, evolution and information transfer

Detailed subfields:

- Structures bionics [Strukturbionik] (material bionics): Biological structural elements, materials and surfaces.
- Device bionics: Development of usable overall constructions.
- Structural bionics [Konstruktionsbionik]: Biological constructions, closely related to above structural and device bionics.
- Anthropobionics (bionic robotics, bionic prosthetics): Issues of human/machine interaction, ergonomics.
- Construction bionics [Baubionik]: Light constructions occurring in nature, cable constructions, membranes and shells, transformable constructions, leaf overlays, use of surfaces, etc.
- Climate bionics (energy bionics): Passive ventilation concepts, cooling and heating.

- Sensory bionics: Detection and processing of physical and chemical stimulation, location and orientation within an environment.
- Locomotion bionics (bionic kinematics and dynamics): Walking, swimming and flying as primary forms of movement. Interaction with the surrounding medium.
- Neurobionics: Data analysis and information processing.
- Evolutionary bionics: Evolution techniques and evolution strategies, made useful for technology.
- Process bionics: Photosynthesis, hydrogen technology, recycling.
- Organizational bionics: Complex relationships of biological systems Some of the subfields are especially interesting for architecture: structural, climate, construction, locomotion and evolutionary bionics are promising fields.
- Other terms occurring in combination with bionics:
- Bio-inspiration: more general term indicating the fact to be inspired from the living world to create new objects or processes that do not occur naturally. We often talk about bio-inspired design,architecture and material science.
- Bio-morphology: Is the science of construction and of the organization of living things and their components – organs, tissue and cells.
- Structural morphology: Refers to functional design in technology and functional anatomy in biology.
- Micromorphology: Examines and describes the form of microscopic objects and represents a treasure trove of functional forms.
- Biomechanics: is the study of the structure and function of biological systems such as humans, animals, plants, organs, and cells by means of the methods of mechanics. It is closely related to engineering, because it often uses traditional engineering sciences to analyze biological systems. Biophysics: Examines and describes biological objects with the terms and methods of physics.
- Biotechnology: Explores biological objects using technical methods. Recently the notion has shifted towards technologies using organisms for production purposes in biochemistry, e.g. enzymes, drugs and pharmaceuticals. Biotechnology is also related to genetically modified organisms.
- Bio-assistance: it consists of using biological molecules or whole organisms to mimic the functions observed in nature, or divert to meet the technological challenges.
- Eco-mimicry: imitation of a set of interactions present in an ecosystem. It will also say Ecosystemic biomimicry or procedural or processual.

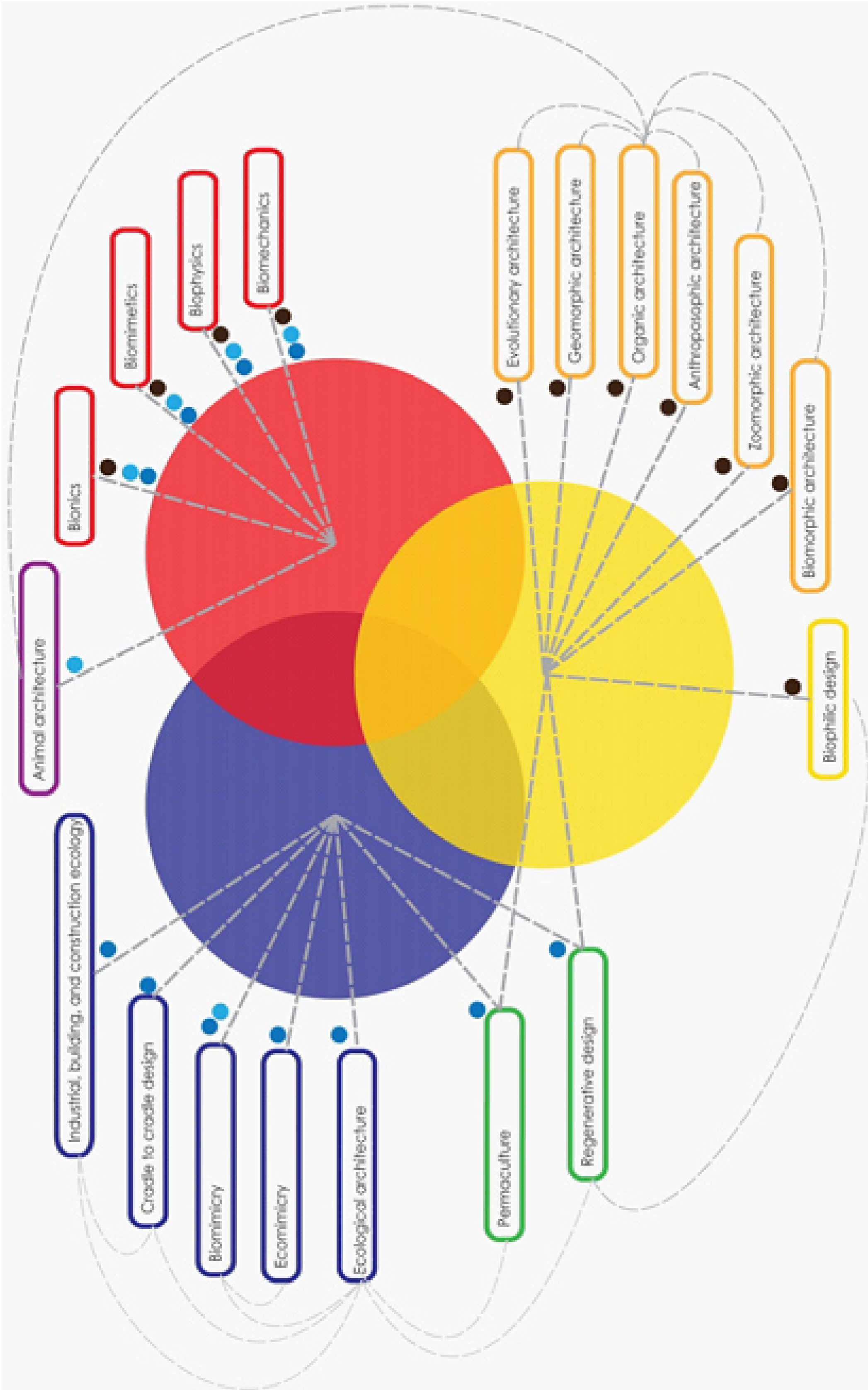


Figure 3.3: terms to describe design approaches that mimic aspects of nature [Zari 2012]

3.3 HISTORICAL BACKGROUND AND DEVELOPMENT OF BIOMIMICRY

A good example is the historical development of human flight, a challenge that had occupied researchers and inventors for centuries.

1. Leonardo da Vinci (1452-1519) : Italy
   In 1505 Leonardo da Vinci compiled a book on the fiiight of birds, "Sulvoldegliuccelli".
   Leonardo has drawn numerous ideas and observations from nature, which were not taken up during his lifetime, but have influenced countless inventors ever since.

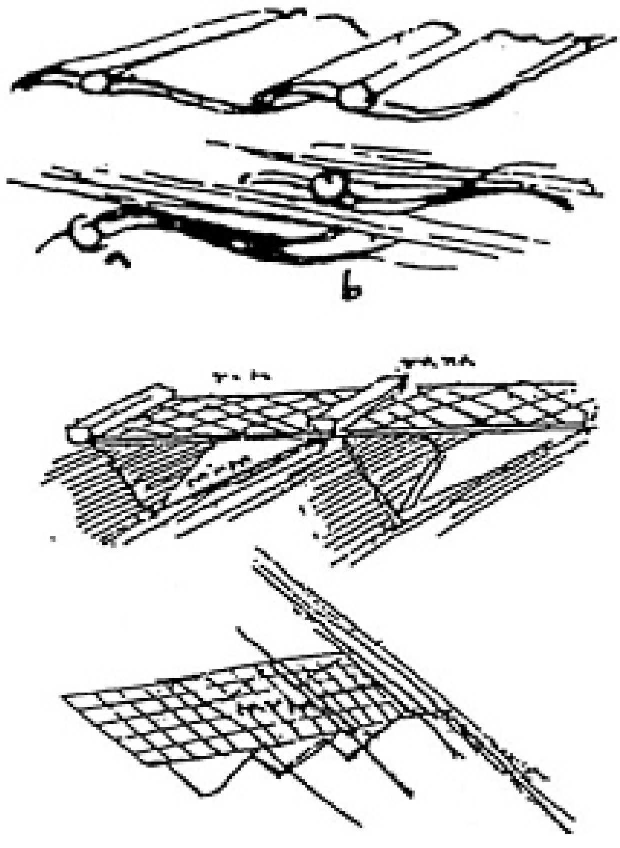


Figure 3.4: Leonardo da Vinci: sketches investigating the overlapping of the feathers and flow through the bird's and the technical wing [Gruber 2011]

2. Alfonso Borelli (1608-1679) : Italy
   A professor of mathematics in Florence and Pisa,he explained the flight of birds by means of the physical impact of a wing as wedge-shaped displacement of air in "De motuanimalum" (about the locomotion of animals).

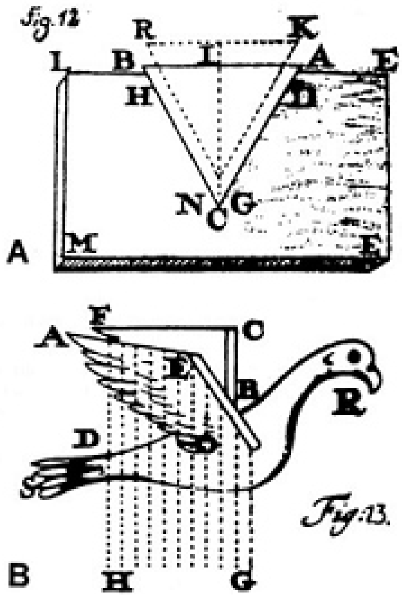


Figure 3.5: Alfonso Borelli: about the impact of wedges and the flapping wing [Gruber 2011]

3. Sir George Cayley (1773-1857): England
   He analysed the forms of a dolphin by cutting its frozen body into slices. In 1816, he designed a balloon with allegedly very low air resistance.
   Manned flight remained a challenge until the end of the 19 th century, when Otto Lilienthal, IgoEtrich and the Wright brothers made their contributions to progress.

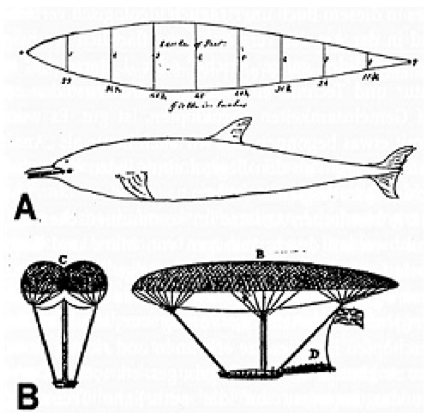


Figure 3.6: Sir George Cayley's Studies on form and design of a balloon flapping wing [Gruber 2011]

4. Otto Lilienthal (1848-1896), Germany.
   Otto Lilienthal was one of the most famous pioneers in human flight. His drawings show perfectly how a living creature can be described by means of engineering drawings.
   Plants have been used as role models ever since man began to use technology. For architecture, plants are especially important as they share some common problems with houses: most of them stay at one place and are dependent on local environmental conditions. Trees and houses are of a similar size, and subjected to similar influences of natural forces.

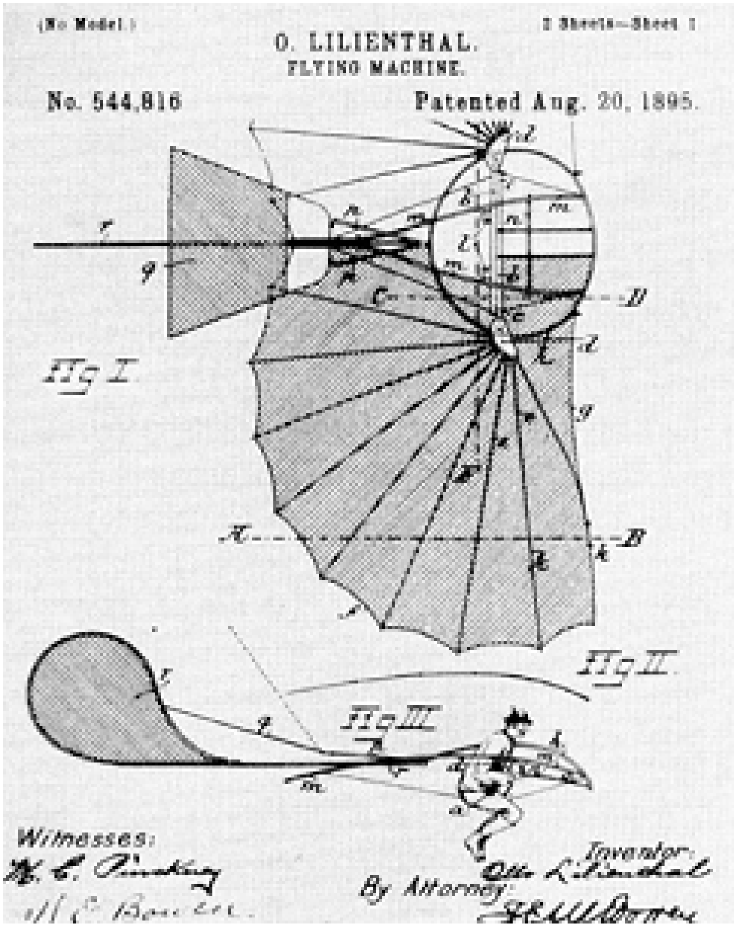


Figure 3.7: Patent of Lilienthal'sglider, 1895 [Gruber 2011]

5. Schwendener, Austria.
   "*Without any doubt plants construct using the same principles as engineers, but their technology is much finer and more perfect.*" [Gruber 2011]
   Schwendener found out that in corn stalks load bearing capacity and bending resistance is achieved with similar elements as in buildings.

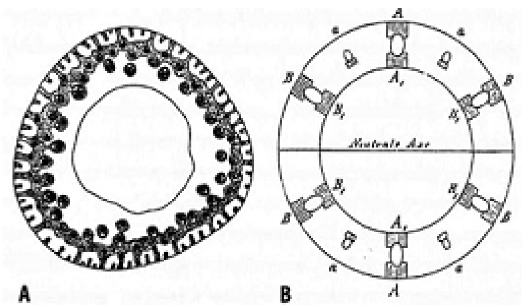


Figure 3.8: Cross-section of Cladiummariscus and structural interpretation by Schwendener [Gruber 2011]

6. J. Monier, 1867
   A gardener is inspired by the structure the sclerenchymatic fibre structure of decaying parts of opuntia and the problem of breaking garden pots. The solution was a system of wire mesh and concrete that was later recognized as reinforced concrete that is used now in construction

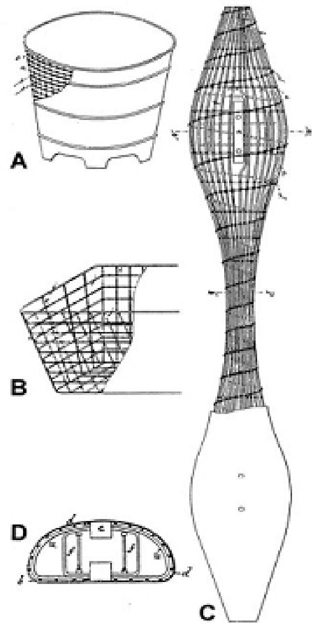


Figure 3.9: Drawings of Monier's patent specifications: containers for plants, railway sleeper [Gruber 2011]

7. Ernst Haeckel, 1866
   Artist and biologist who drew marine organisms and then published a book on the morphology of organisms. His interpretations of drawings inspired forms

for various architects and designers.

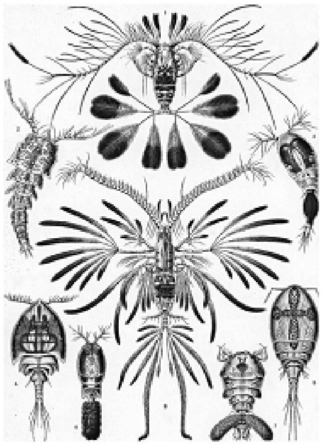


Figure 3.10: Ernst Haeckel's tables of marine organisms, here copepoda, small crustaceans [Gruber 2011]

8. Raoul H. Francé, 1919
   Raoul Francé published a large number of articles and books, continuing with both research on and the development of structures, and mechanisms of plants, under the term "biomechanics". Although his numerous ideas for using natural role models in technology are often too direct and uncritical, he is a protagonist of a "biological technology" and his research is exemplary.

Figure 3.11: Front page of "Die Pflanze als Erfinder" of Raoul France, 1920 [Gruber 2011]

9. Alf Geissler.
   Basing his work on Francé's findings, Geissler looked for role models from nature in many fields of technology, and developed analogies. His book "Biotechnik", published in 1939, contained ideological sections.

10. Velcro, 1940.
    In the 1940s, Swiss inventor George deMestral found that, upon returning home fora walk with his dog one day, his pants andthe canine's fur were covered with cockle-burs. He studied the burs under a microscope, observing their natural hook-likeshape, which ultimately led to the design ofthe popular adhesive material, Velcro.

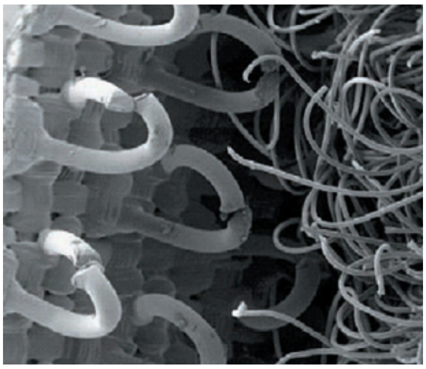


Figure 3.12: A scanning electron microscope image of Velcro's hooks and loops (370 micron view)

11. Biomimicry, 1950.
    The term Biomimicry was coined by the American biophysicist Otto Schmitt. Then it was popularized in 1997 by the American scientist and author Janine Benyus.

3.4 GENIUS OF BIOME

3.4.1 DEFINITION OF A BIOME

Biomes are very large ecological areas on the earth's surface, with fauna and flora (animals and plants) adapting to their environment. Biomes are often defined by abiotic factors such as climate, relief, geology, soils and vegetation. A biome is not an ecosystem, although in a way it can look like a massive ecosystem. If we take a closer look, we will notice that plants or animals in any of the biomes have special adaptations that make it possible for them to exist in that area. We may find many units of ecosystems within one biome.
A biome describes a type of climate, fauna and flora that exists in specific regions throughout the world. A fundamental classification of biomes are:

1. Terrestrial (land) biomes which includes grassland, tropical rainforest, temperate and tundra
2. Aquatic biomes (including freshwater biomes and marine biomes)

Climate is a major factor determining the distribution of terrestrial biomes. Among the important climatic factors are:

- Latitude: Arctic, boreal, temperate, subtropical, tropical
- Humidity: humid, semi-humid, semi-arid, and arid
  - ☐ Seasonal variation: Rainfall may be distributed evenly throughout the year or be marked by seasonal variations.
  - ☐ Dry summer, wet winter: Most regions of the earth receive most of their rainfall during the summer months; Mediterranean climate regions receive their rainfall during the winter months.

There are many classification systems. All are similar yet different in how they divide climatic and ecological conditions. We select the best classification system that provides a commonly used map that fits our needs. The classification system is a derivative of the World Wildlife Fund classification of terrestrial ecosystems that describes 18 biomes.

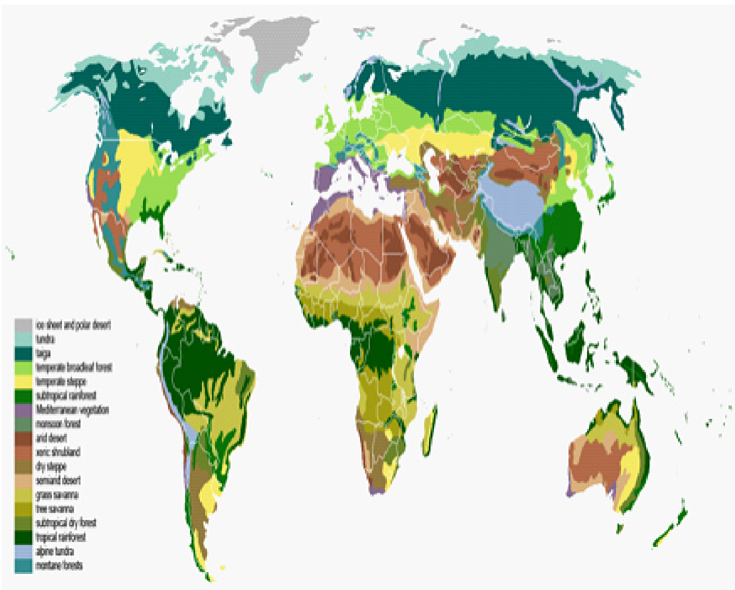


Figure 3.13: Main biomes in the world.

3.4.2 WORLD BIOMES

There are five major categories of biomes on earth. In these five, there are many sub-biomes, under which are many more well defined ecosystems.

- Aquatic Biomes: Aquatic biomes are grouped into two, Freshwater Biomes (lakes and ponds, rivers and streams, wetlands) and Marine Biomes (oceans, coral reefs and estuaries).
- Forest Biomes:There are three main biomes that make up Forest Biomes. These are the Tropical Rainforest, Temperate and Boreal Forests (also called the Taiga)
- Grassland Biomes: There are two main types of grassland biomes: the Savanna Grasslands and the Temperate Grasslands.
- Tundra Biomes: There are two major tundra biomes—The Artic Tundra and the Alpine Tundra.
- Desert Biomes: They are the Hot and Dry Deserts, Semi Arid Deserts, Coastal Deserts and Cold Deserts.

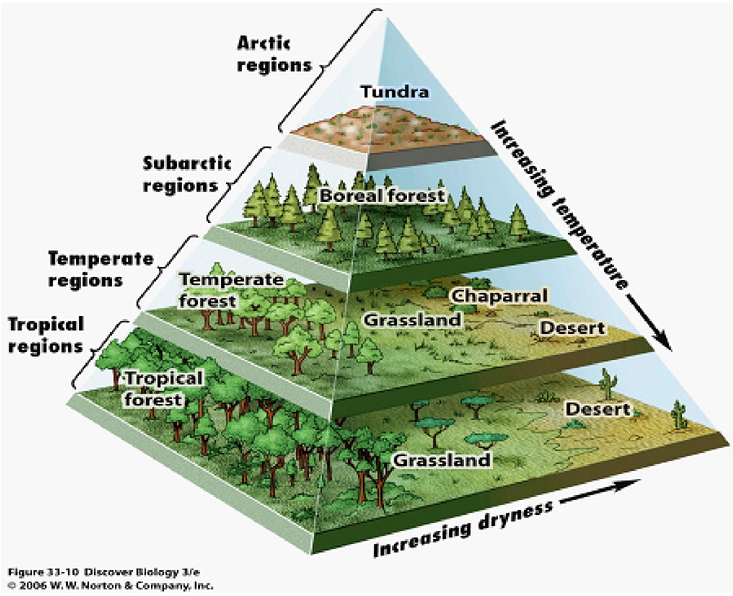


Figure 3.14: Different categories of biomes on earth

1. **Aquatic Biome**
   This includes all water bodies on the earth's surface. Aquatic biomes are grouped into two, Freshwater Biomes (lakes and ponds, rivers and streams, wetlands) and Marine Biomes(oceans, coral reefs and estuaries). These biomes make up about 73% of the total earth's surface.
   Life forms in these waters depend on the abiotic factors such as sunlight entering the waters,temperature, pressure, salt content and so on. Water biomes with lots of light tend to have more flora (plant) diversity, and the growth of

algae and plankton is more. Small water bodies that freeze during the cold seasons, or dry out in the dry and hot seasons tend to have less diversity.
Examples of animals found in marine biomes include star fishes, sharks and

Figure 3.15: Aquatic Biome

tuna and sea birds. Examples of animals in freshwater biomes include salmon, tilapia worms, water-surface insects and crabs.
Aquatic biomes are very important because apart from being home to millions of water animals, they also form the basis of the water cycle and help with atmospheric moisture, cloud formation and precipitation. One example of a marine biome is the Great Barrier Reef (a coral reef system) of Australia. An example of a fresh water biome is the Amazon river in Brazil.

2. **Forest Biome**
Forests make up about 30% of the total land cover on earth, and are of incredible value to life on earth. They are a store of carbon and play a very important role in climate control. They have a watershed role, and are a source of many raw materials that humans depend on. It is believed that forests have the most bio-diversity. A small portion of the Rainforests, for example, may be hometo millions of insects, birds, animals and plants. There are three main biomes that make up Forest Biomes. These are the Tropical Rainforest, Temperate and Boreal Forests (also called the Taiga).
Temperatures of forests biomes (especially the tropical rainforest) are generally high all year though, but a lot cooler at the surface. This is because there is very little sunlight reaching the forest floors as a result of the heavy vegetative cover. Humidity is extremely high with lots of rainfall,exceeding 200cm all year though. Soils are loose and very airy, with high acidity and decaying organic matter.
Plant types of the Tropical Rainforests are usually huge trees with buttress roots, lots of large green leaves and shallow roots. Ferns and palms are also common. Plants in the temperate forests are less dense with a bit of sunlight reaching the floors. Tree types include the willow, basswood and elm. Plants of the Boreal are mostly conifers with needle-like leaves. There is very little

Figure 3.16: Forest Biome

under story and lots of light at the floors. Trees like fir and spruce are common.
Small mammals, birds, insects and bats are common in the tropical rainforests, as they either can fly up for sunlight or do not need sunlight. An example of the Tropical Rainforest is the Amazon.

3. **Grassland biome**
   As the name suggests, these are massive areas dominated by one or a few species of grass, with a few sparsely distributed trees. There are two main types of grassland biomes : the Savanna Grasslands and the Temperate Grasslands. One major savanna is located in Africa, and takes up more than a third of the continents land area. Others can be found in India, South America and Australia. Temperate grasslands can be found in South Africa, Argentina, and some plains in Central North America.
   If the grassland is prevented to develop into a forest by climatic conditions such as rainfall, it is termed as 'climatic savannas'. If their characteristics are kept by soils, they are termed as 'edaphic savannas'. Sometimes, large animals such as elephants can constantly disturb young trees from taking over grasslands. Human causes like farming or bush fires can also prevent grasslands from developing into forests. Such grasslands are termed 'derived savannas'.
   Soils in savanna are thin layered and do not hold water. The soils contain some organic matter from dead grass, which is the main source of nutrients for plants. Rainfall is moderate, and not enough to cause major floods. Animals in the savannas include large mammals such as lions, hyenas, snakes, giraffes, buffaloes with lots of insects.
   Temperatures in the temperate grasslands are extreme, with high summer and freezing winter temperatures. Animals here include hawks, owls, deer, mice, foxes, rabbits and spiders. Temperate grasslands with short grasses are called 'steppes' and those with tall grasses are called 'prairies'.

Figure 3.17: Grassland Biome

4. **Tundra Biome**
This is known to be the coldest of all the terrestrial (land) biomes, with the least bio-diversity capacity. Tundra got its name from '*Tunturia*' a Finnish word that means ' barren land'. This biome has very little rain and extremely freezing temperatures, and covers about a fifth of the earth's land surface.
There are two major tundra biomes: The Artic Tundra and the Alpine Tundra. The Artic tundra is located around the north-pole in the northern hemisphere. This biome has temperatures of about $2-3\ C$ in the summer and about $-35\ C$ in the winter. Bogs and ponds are common as a result of constantly frozen surface moisture and melted permafrost.
Plants in the Arctic Tundra are short and grow closely to each other. Exam-

Figure 3.18: Tundra Biome

ples include mosses, heaths and lichen. They are adapted to perform photosynthesis even in the freezing conditions.Animals here include herbivores like hares and squirrels. Carnivores include polar bears and artic foxes. It also has lots of birds, insets and fish like cod and salmon.
The Alpine Tundra is very cold, located on top of high mountains, often with very few trees and very little vegetative cover. They are icy for a larger part of the year. Animals in this biome include some birds, mountains goats and marmots. There are also beetles and butterflies.

5. **Desert Biome**
   The desert biome has the lightest cover of plants of any biome. Lack of moisture prevents plants from establishing themselves in this harsh climate. Many unique adaptations to the extreme heat and lack of moisture enable some plants to survive. Plants adapted to drought are called xerophytes.
   The desert biome is one that is very hot and dry. They are found at the lower latitudes, between the Tropic of Cancer and the Tropic of Capricorn. Light winds occur often which evaporates any type of moisture that is typically going to develop in them. The heat is very dry and that makes it hard for too many types of plants or animals to be able to survive in such biomes. Approximately 20% of the Earth falls into this category.
   Some of the desert biomes are extremely large. For example, the Sahara desert in Africa is more than 3.5 million square miles in size. Others are extremely dry. The desert biome has two extremes that make it difficult to survive. First, it is extremely hot and second, it is extremely dry. Most people do not realize though that it can be come cold as the sun goes down in the desert. This is because there are very few trees or other elements there to retain any heat. The changes in the temperatures can be very harsh for a human, which is why it can be so dangerous to be exploring in the desert on your own.

Climate	From 32 °F at night and 113 °F at day
Plants	Cactus, shrubs, Cardón, Camel Thorn Tree, Prickly pear, Saguaro.
Animals	Snakes, lizards, tarantulas, dingo, porcupines, coyotes.
Location	North and South America, Africa, Asia and Australia.

Table 3.1: Desert biome characteristics

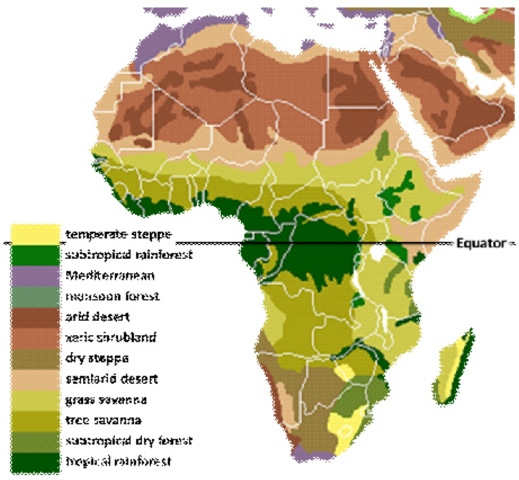


Figure 3.19: Main biomes in Africa

- **Desert Biome Fauna**
  There is very limited types of plant and animal life that are able to live in the desert biome. Those that do live in the desert biome have learned to adapt to the temperatures. They have also learned to survive with very little water and very little food. The majority of the animals living in the desert biome are nocturnal. This means they sleep during the heat of the day and they are active at night when the sun goes down.
  Desert animals do not need to feed very often, which is why almost all of them are very small. They also do not need to find water independently. They get the water they need from their sources of food. Ants are quite plentiful in the desert biome. They create underground tunnels where they are able to stay out of the heat.
  A variety of rodents including mice and the shrew live in these conditions as well. The desert biome is also where you will find the tarantula. These spiders are very dangerous and they don't seem to mind the harsh conditions either. Medium sized animals found living in the desert biome include rabbits, rattlesnakes, and porcupines.
  There are larger animals in the desert biome as they are able to feed on the small ones. Don't be surprised if you find the puma, bobcat or dingo around. In various areas of the desert biome there are deer living there that they will find upon. In certain desert locations, you will also find camels.
  One of the living creatures in the desert biome that thrives with these harsh conditions is the Gila Monster. It is a very aggressive type of retile. It feeds on eggs and on small mammals. This creature needs the heat for its body to stay regulated. It can be active during both the day and the night. They are very dangerous to humans due to the toxic venom that is produced when they bite.

- **Desert Biome Flora**
  In order for any plants to survive in the desert biome, they have to be able to collect and store what water is present. They also have to be able to reduce the water evaporating from them. The cactus is the number one plant you will find living in a desert biome. The design of this plant makes it possible for them to hold onto the moisture they have.
  The hard leaves make it possible for them to handle the extreme changes in temperature from day to night that occur in a desert biome. The cactus also has a hairy texture that helps the plants to reflect the heat from the sun. This is why they are able to withstand that high level of heat without suffering.
  The future for the desert biome is one that many worry about. Issues including global warming continue to cause changes to the natural pattern of weather behaviors. The desert is already extremely dry and hot.

Should those temperatures continue to increase then there could be problems for the plants and animals that live there.
When you combine that with the possibility of additional heat is going to reduce the already low amount of rainfall, it could spell out disaster. These plants and animals are already surviving with so little. It would be next to impossible for them to be able to continue to thrive in such an environment with even less. There are all ready projections that claim the diversity of plants and animals in the desert biome will decrease by at least 15% over the next 50 years.

Figure 3.20: Desert Biome

3.4.3 GENIUS OF A BIOME

Drawing inspiration from natural systems provides a fresh opportunity to rethink and reimagine how to solve human design challenges. The genius of Biome offers designers, architects, and planners, examples of how organisms and ecosystems have adapted to Biome challenges of climate, energy, materials, nutrients and communication.
By looking at the genius of Biome, we can learn the strategies and designs adopted by living organisms found in the nature; further, it highlights strategies and designs at the ecosystem level. Ecosystems are made up of living entities along with their abiotic conditions (climate, temperature, soil types, and topography). In a biome, abiotic conditions are just as important as they are to architects, designers, and planners.
Ecology offers an additional lens through which we can view nature's genius and learn design principles that adapt to a biome's abiotic and biotic conditions.
Once describing the biological principles and patterns common to organisms and ecosystems within biology, this biology is then translated into design principles that can be used to inspire design innovations to mimic the successful designs, processes, and patterns found in the larger scale of the natural world ecosystems. An important part of understanding these biological and design principles and how to mimic them is to know the history of these biomes.

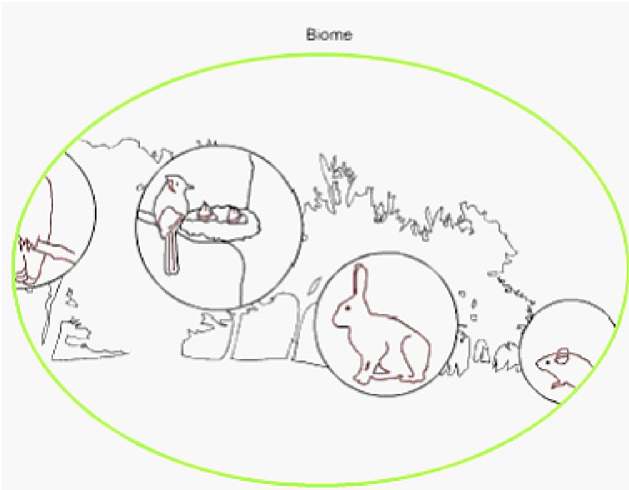


Figure 3.21: Genius of a biome

3.5 BIOMIMETIC DESIGN STRATEGIES

No general approach has been developed for Biomimetics, although a number of people are at this time developing methods for searching biological literature for functional analogies to implement. Although it is well known that design and engineering are rendered much easier with use of the biomimetic theory, every time we need to design a new technical system we have to start afresh, trying and testing several biological systems as potential prototypes and striving to make some adapted engineered version of the biomimetic device. Moreover, the transfer of a concept or mechanism from living to non-living systems is not trivial. A simple and direct replica of the biological prototype is rarely successful, even if it is possible with current technology. Some form or procedure of interpretation or translation from biology to technology is required. More often than not, the technical abstraction is possible only because a biologist has pointed out an interesting or unusual phenomenon and has uncovered the general principles behind its functioning. Only then does the biological principle become available outside biology f or biomimetic use. The result is often unexpected and the final product seldom resembles the biological prototype [Vincent 2006].
We present here a logical framework that we believe exposes some important underlying methods and approaches to Biomimicry.

3.5.1 BIOMIMICRY 3.8 LIFE'S PRINCIPLES

The Biomimicry Institute and the Biomimicry Guild, along with many partners, have distilled a collection of scientific research to create a summary of the most fundamental principles conductive to life [Stokoe 2013].

Life's Principles are design lessons from nature. Based on the recognition that Life on Earth is interconnected and interdependent, and subject to the same set of operating conditions, Life has evolved a set of strategies that have sustained over 3.8 billion years. Life's Principles represent these overarching patterns found amongst the species surviving and thriving on Earth.

Life integrates and optimizes these strategies to create conditions conducive to

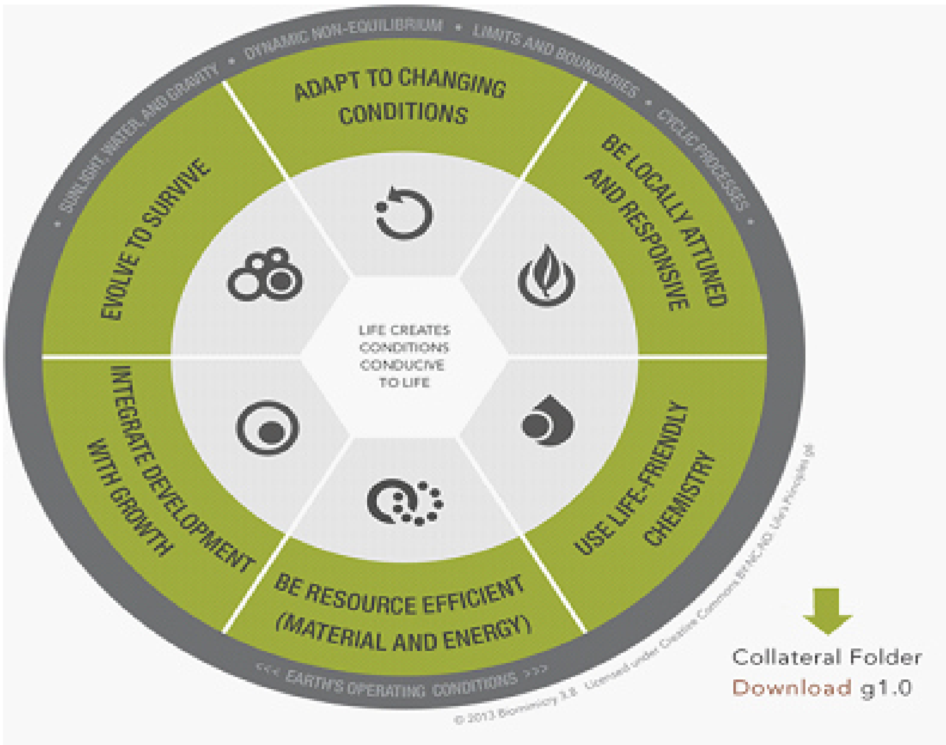


Figure 3.22: Fundamental principles conductive to life (Source: ©2014 Biomimicry Group)

life. By learning from these deep design lessons, we can model innovative strategies, measure our designs against these sustainable benchmarks, and allow ourselves to be mentored by nature's genius using Life's Principles as our aspirational ideals.
Life's principles Sustainability Wheel Figure 3.23 illustrates the holistic overriding principles, patterns and solutions utilized by nature to create highly sustainable, non-intrusive environments. The aim of life's principles is to create products, processes, and policies inspired by nature to create a new way of living **(Biomimicry 3.8, 2011)**. This method helps to identify a problem, to explain it, to find a suitable solution and concludes with a Biomimetic design.

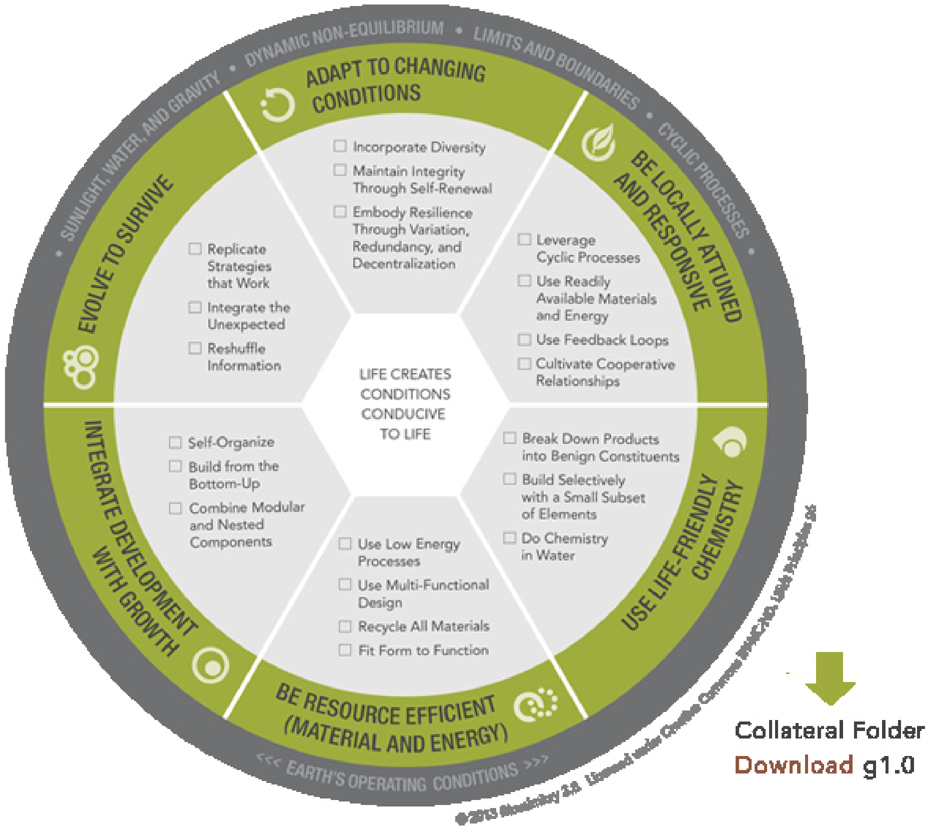


Figure 3.23: Life's principles Sustainability Wheel (Source: ©2014 Biomimicry Group)

3.5.2 THE BIOMIMICRY DESIGN SPIRAL: A TOOL FOR INNOVATION

The Biomimicry Institute has provided a tool aiding innovative design using the Biomimicry process -The Biomimicry Design Spiral provides a clear process to follow in order to produce a design inspired by nature that utilizes solutions found in nature to solve problems in innovative ways. The seven-step guide helps to ensure a deep consideration for biological problem solving, rather than a superficial replication of nature.

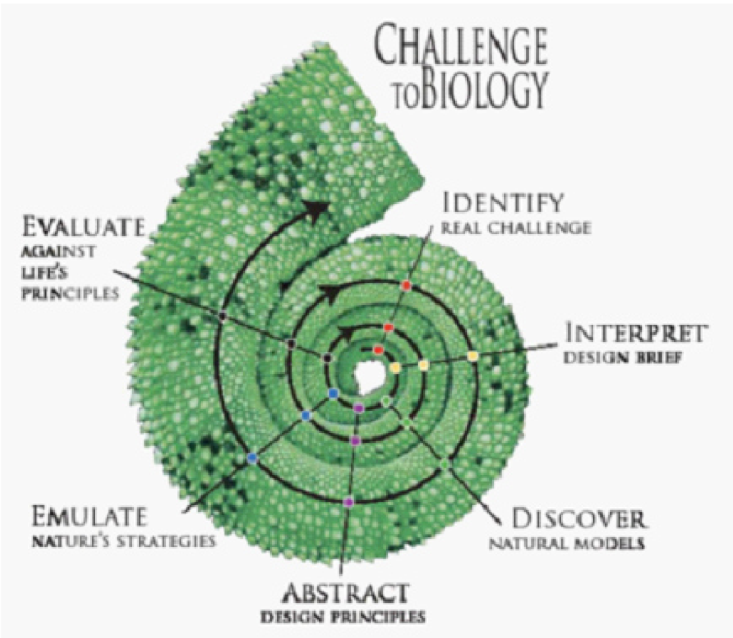


Figure 3.24: Biomimicry design spiral developed by the Biomimicry Institute (Source: ©2014 Biomimicry Group)

Details of the design spiral <u>Step 1: Identify.</u> **Find the core of the problem and the design specification by asking "what do you want your design to do?" rather than "what do you want to design?"**
This step involves developing a design brief that clarifies the specific problem to be solved. This is done by identifying the core function that the design is intended to accomplish (asking "what do you want your design to do"), rather than immediately implying a design solution ("what do you want to design"). This is attempting to avoid the traditional 'top down' approach that enforces a preconceived concept of a solution (a design) onto the problem.
<u>Step 2: Interpret</u>- **Biologize the question, as "how does nature do this function or solve this problem?" and "how does nature NOT do this function?" Define the habitat/location more specifically.**

This step involves 'biologizing' the question, the most distinctive feature of this problem solving tool. It requires the designer to look at the various outcomes of 3.8 billion years of environmental research and development which has occurred in nature to produce complex sustainable systems, to reconceive the problem from this basis.
By defining the specific conditions under which the function is achieved in nature, such as the climate, nutrient, social and temporal conditions, the focus will become more specialised and reduce the quantity of possibilities. This biologising of the question instils a greater chance for the outcome to be ecologically sustainable.
Step 3: Discover- Find the best natural models to answer/solve your challenges, find champion adapter by asking "whose survival depends on this?" consider literal and metaphorical models.
This step involves finding specific examples and models of solutions to the biologized problem as established in the previous step. Seeking in particular organisms who are champions in this area and those whose survival depends on their means to solve this design challenge. Collaboration with a biologist is recommended at this stage to provide in depth biological knowledge.
Step 4: Abstract- Find the repeating patterns and processes within nature that achieve success.
This step involves the process of abstraction, which can clarify the essence of the subject without forfeiting its complexity. It allows concepts and solutions to be communicated without specific details which may convolute them and therefore be transferred multi-disciplinarily.
Step 5: Emulate- develop solutions that apply these lessons from nature as deeply as possible in your design, mimicking form, mimicking function, mimicking ecosystem.
This step involves developing practical solutions to the design challenge based on the natural models identified in the previous step. This is where the scale of the solution must be carefully considered and it's interconnectedness with the surrounding environment analysed to ensure ecological sustainable outcomes.
Step 6: Evaluate- how do your ideas compare to life's principles (sustainability imperative imbued).
This step involves evaluating the product of the process so far against 'Life's Principles' by asking questions such as whether it produces 'conditions conducive to life?', 'can the design adapt and evolve?' or 'is it closed loop'? This is the point at which to critically review the solution to ensure the outcome is sustainable.
Step 7: Identify- develop and refine design briefs based on lessons learned from the evaluation section, repeat the process.
This additional step is the point at which the process begins again from the beginning 'identify' step and repeating all the stages of the process with a now deeper understanding of the problem and considering the issues identified in the previous 'evaluate' step. This aspect of the tool is what makes it an iterative process, cycling continuously through the stages, but also spiralling down to a more specific and refined outcome. This process is itself mimicking nature and the process of learning

and adaption which occurs through small reiterative feedback loops.
In the process that assists innovators to respond to design challenges by thinking in biological terms, there is two design spirals: Biology to Design and Challenge to Biology. The outcomes of which are then evaluated against their set of "life's principles".
The Biology to Design Spiral, is reductive to be useful to the design of a landscape, would work better for product design. Challenge to Biology Spiral provides a basic framework for landscape architecture as both function and context serve as primary starting points for the design process.

1. Biology to Design
   Biology to Design is a specific path through Biomimicry Thinking. This path is most appropriate when your process initiates with an inspirational biological insight (including a Life's Principle) that you want to manifest as a design. Those who might follow this path include inventors and entrepreneurs, students who do not yet have their own design process, those interested in discovering strategies that might inform new innovations, and educators interested in sharing biology in ways that generate interest with non-biologists.

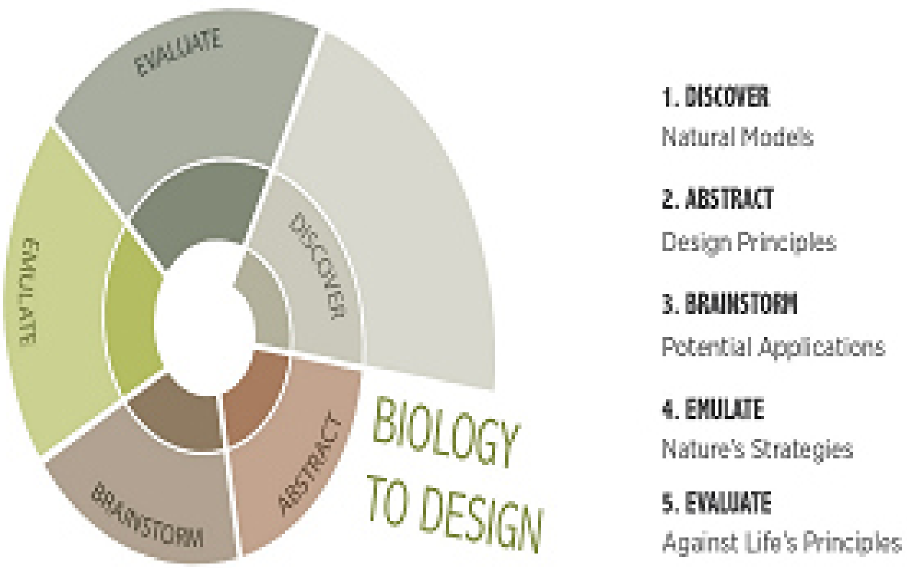


Figure 3.25: Biology to Design spiral

2. Challenge to Biology
   Challenge to Biology is a specific path through Biomimicry Thinking. This is useful for scenarios when a specific problem is at hand and you are seeking biological insights for the solution. It is particularly useful for a "controlled" setting, such as a classroom, or for creating an iterative design process. Not

surprisingly, the best outcomes occur when you navigate the path multiple times.

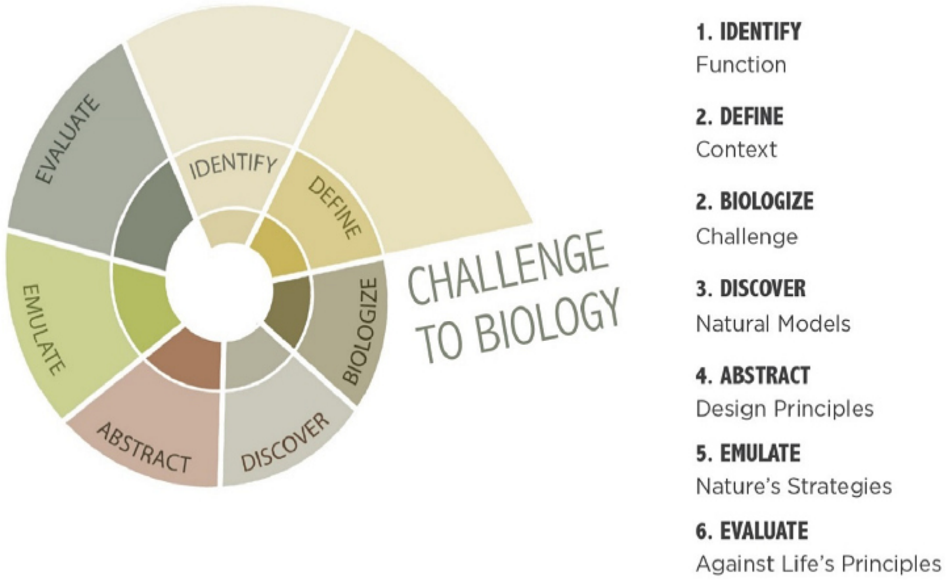


Figure 3.26: Challenge to Biology spiral

3.5.3 THE BIOMIMICRY TAXONOMY

AskNature is an online inspiration source for the biomimicry community set up by the biomimicry institute. Nature's most elegant ideas organized by design and engineering function.
Information organized on AskNature uses a classification system known as the Biomimicry Taxonomy: in order to organize how organisms meet different challenges.
How Do You Use the Biomimicry Taxonomy?
The Biomimicry Taxonomy provides a novel way to approach our next innovation challenge sustainably. We have to look to the taxonomy as a tool when we first approach our design challenge, using its framework to ask questions of nature. For example, if we are trying to make less toxic pigments, "ask" a Morpho butterfly how it creates its color. If we want to manufacture tough, lightweight building materials without unsustainable high pressures and temperatures, "ask" a toucan how it manages impact with its strong and light beak.
An Example:
Here is an example of how we could use the Biomimicry Taxonomy to solve our next innovation challenge. We have Use one or, better yet, all of these approaches to find inspiration from nature.
The Innovation Challenge: we are designing a building in an area of low rainfall.

To ensure an adequate water supply, we want our building to capture rainwater and store it for future use.
Approach #1.
Identify verbs that directly define the challenge. Use the Biomimicry Taxonomy for ideas that shift from predetermined thoughts of *how* or *what* we will design to *why* we are designing (in other words, your design's purpose or the outcomes it must accomplish).

Use verbs that describe functions (such as move, break down, distribute, etc.). In this example, the questions we pose might be: How does nature...

- Capture water?
- Store water?

Approach #2.
Consider concepts that go beyond the exact challenge but are related enough to why we are designing that they may have similar solutions. In this example, we may consider that some organisms (like the Namibian beetle) live in areas that experience little to no rain, yet they still get all of the water they need.
Use the Biomimicry Taxonomy to spark ideas of new verbs, and think about different nouns. In this example, questions to pose might include: How does nature...

- Absorb water?
- Capture fog?
- Manage humidity?
- Move water?

Approach #3.
Turn the question completely around. Instead of asking how nature stores water, think about how it protects against excess water or keeps water out. The Biomimicry Taxonomy is a great resource for ideas of verbs that represent opposites. In this example, we might ask: How does nature...

- Remove water?
- Stay dry?

Using the Biomimicry Taxonomy in AskNature
AskNature offers two ways for us to ask questions of nature: Search and Explore. Explore enables us to quickly find strategies by function using a table of contents organized by the Biomimicry Taxonomy. With Search, we can ask questions like those posed above - for example, "How does nature stay dry?".

Figure 3.27: The biomimicry Taxonomy (Source: The Biomimicry institute)

3.5.4 TYPOLOGICAL ANNALYSIS (TA)

TA examines nature at three levels of mimicry: the organism, the behavioral and the ecosystem [Stokoe 2013].

- ORGANISM: specific flora or fauna, mimicking either the whole organism, or a particular feature.
- BEHAVIOUR: translation of an aspect of how an organism relates to its environment, or larger context.
- ECOSYSTEM: emulating or recreating the common principles that allow an ecosystem to successfully function.

Each of these three levels is further categorized into five dimensions to consider different aspects of design that may be emulated in an organism or a system [Zari 2007].

- Form: shape
- Material: properties
- Construction: arrangement or composition
- Process: mechanism
- Function: application

According to Gamage and Hyde [Gammage 2012] TA is a framework to explain the application of Biomimicry at these different levels, and attempts to clarify the potential of using Biomimicry as a tool to increase the regenerative capacity of the built environment. This can be used by designers to utilize Biomimicry as a methodology for improving the sustainability of the environment as an effective approach
Table 3.2 shows a framework for the application of biomimicry using TA. This example looks at the beaver emulating [Stokoe 2013].

ORGANISM	FORM	The site is shaped like a beaver.
	MATERIAL	The site is made from a material that mimics a beaver skin or hair.
	CONSTRUCTION	The site is constructed in the same way as a beaver, ie; it goes through various growth cycles
	PROCESS	The site works in the same way as an individual beaver, ie it is semi-aquatic and functions in both dry and aquatic environments
	FUNCTION	The site functions like a beaver in a larger context; their excrement is re-introduced to the environment providing nutrients for plant life.
BEHAVIOUR	FORM	The site looks like it was made by a beaver: a replica of the beavers dam.
	MATERIAL	The site is made from the same materials that a beaver builds with, using twigs and mud as the primary material
	CONSTRUCTION	The site is made in the same way a beaver would build his lodge or dam, working at night and self-built
	PROCESS	The site works in the same way as a beavers dam would; covering their lodges with fresh mud, when frozen in winter it becomes hardened.
	FUNCTION	The site functions In the same way that it would if made by beavers; providing both protection against predators and access to food in winter.
ECOSYSTEM	FORM	The site looks like an ecosystem that a termite would live in ie. a riparian zone with stream bed.
	MATERIAL	The site is made from the same kind of materials found in a riparian ecosystems;woodland and water
	CONSTRUCTION	The site is resembled in the same way as a (beaver's) ecosystem;principles of succession and increasing complexity over time.
	PROCESS	The site works in the same way as a (beaver's) ecosystem; it captures and converts energy from the sun, and stores water
	FUNCTION	The site is able to function in the same way that a (beaver's) ecosystem would and forms part of a complex system by utilizing the relationships between processes; it is able to participate in the hydrological, carbon, Nitrogen cycles.

Table 3.2: Example: a landscape that emulates a beaver [Stokoe 2013]

3.5.5 BIOTRIZ APPROACH

Biotriz uses the methodology of TRIZ to abstract design information from natural systems and gives designers a tool that allows that knowledge to be applied to engineering design without requiring that designers possess extensive knowledge of biological systems. The development of BioTRIZwas led by Dr. Vincent of the University at Bath. Like TRIZ, BioTRIZ condenses design information into a contradiction matrix that lists inventive principles(IPs) used to solve conflicts between system parameters.

TRIZ is a Russian collection of tools and techniques of engineering problem solving, developed by GenrichAltshuller and Rafik Shapiro [Altshuller 1999] that ensures accurate definition of a problem at a functional level and then provides strong indicators towards successful and often highly innovative solutions. It was named TRIZ, the acronym of TeorijaReshenijaIzobretatel'skihZadach. The acronym is usually translated into Theory of Inventive Problem Solving [Vincent 2002]. One of the most popular tools is a look-up table made up of 39 opposing features (parameters, variables) of engineering systems such as strength, weight, speed, volume, temperature, ease of manufacture and versatility. The claim is that if you define your problem in its terms, the TRIZ contradiction matrix will point you to a handful of principles that have been found to resolve the trade-off. Altshuller and his colleagues reportedly found 40 such inventive principles from the study of 3 million patents.

TRIZ identifies 39 system parameters that designers may wish to optimize as well as forty inventive principles (IPs) that can be used to resolve design challenges. The setof conflicts and solutions is presented as a 39 by 39 "contradictions matrix" in which each row and column corresponds to a system parameter and each cell lists the IPs that other designs have used to solve the conflicting parameters of the cell's row and column.

However, while TRIZ shows designers how design problems have been solved in technical and engineering designs, BioTRIZ shows how those problems are solved by natural systems. BioTRIZ is based on the analysis of approximately 500 biological phenomena with over 270 functions and 2500 contradictions. One other important difference between TRIZ and BioTRIZ is that BioTRIZ groups the 39 system parameters of TRIZ into six fields of operation: substance, structure, space, time, energy, and information. Consequently, the conflict matrix for BioTRIZ is only a 6 by 6 matrix. However, BioTRIZ does retain the 40 IPs used in TRIZ. The procedures used to apply BioTRIZ to a design problem are identical to those used for TRIZ.

To make the best use of BIOTRIZ, Vincent proposed the following five-step methodology.

- Define the problem in the most general way
- List both desirable and undesirable properties and functions.
- Analyze and understand the problem and so uncover the main conflicts or contradictions.

- Find the functional analogy in biology.

- Bridge from natural to technical design.

3.6 CONCLUSION

In this chapter we have presented, in one hand, a framework for understanding biomimicry and how it can be applied to design and what sustainability outcomes could be predicted from their application. In the other hand distinct strategies to biomimetic design have been presented with their distinct advantages and disadvantages inherent in each as a design methodology. We have also introduced the various distinctions between different types of biomimicry, that commonly exist or could be explored in the future, and their potential sustainability outcomes. We will focus in the second part of the dissertation on the applicability of biomimicry on architectural design in order to reach the concept of living architecture in hot and arid regions.

Part II

TOWARDS A LIVING ARCHITECTURE

CHAPTER 4

INFLUENCE OF BIOMIMICRY ON ARCHITECTURAL DESIGN

"It is clear that industrial systems and biological systems are deeply similar. Indeed it is clear that both are complex systems, and that in general, they evolve to maintain themselves over time without discontinuous change...."
- Allenby and Cooper, 1994

Contents

4.1 INTRODUCTION

The growing interest in biomimicry suggests that architects must become more aware that nature has much to offer in order to improve the way our designs and buildings

function. Biomimicry already achieved and realized some of the advanced and efficient technologies in materials and products, however, it is still largely unrealized in the architectural design...
This chapter aims to examine Biomimicry's potential effectiveness on architectural design. This research focuses mainly on applying biomimicry in the architectural design in order to outline concepts, systems and strategies for the architectural design.

4.2 DESIGN APPROACHES TO BIOMIMICRY IN ARCHITECTURE

Through a comparative literature review, and an examination of existing biomimetic technologies we can define distinct approaches to biomimetic design, each with inherent advantages and disadvantages.
Approaches to biomimicry as a design process typically fall into two sets.

1. Design referencing biology: first, we define the human need or the design problem, and then we explore the ways other organisms or ecosystems solve this.
2. Biology influencing design: we identify a particular characteristic or function in an organism or ecosystem and then we translate it into a human design context.

4.2.1 DESIGN REFERENCING BIOLOGY

Throughout literature review, this approach was found to have different designation, such as

- Design looking to biology [Zari 2007];
- Up-down Approach [Knippers 2009] and
- Problem-Driven Biologically Inspired Design [Goel 2009] all referring to the same meaning. It is the most common approach to biomimicry.

When designers look to organisms or ecosystems for solutions they are first required to identify problems and then to match these problems to organisms that have solved similar issues. Generally, to access to this immense encyclopedia of biological and ecological knowledge, we have to consult scientists in the field of biomechanics or biology like biologists, zoologists, ecologists... However, this approach must be led by designers who must identify initial aims and parameters for the design.
Daimler Chrysler's 2005 prototype Bionic Car (figure 4.1), is an industrial design example of this approach, characterized by The large volume, small wheel, which is the concept of Bionic cars. It was based on the hydrodynamic and the strength features of the box fish (Ostracion meleagris). It had also a biomimetic chassis and

structure, which have been designed using a computer modelling method designed by Claus Mattheck that mimics how trees are able to grow in a way that minimizes stress concentrations [Pawlyn 2011]. Total car weight was reduced by at least a third, because material was allocated only to the places where it is most needed [Vincent 2006].

The body of the car is aerodynamic due to the mimicking of the box fish, which

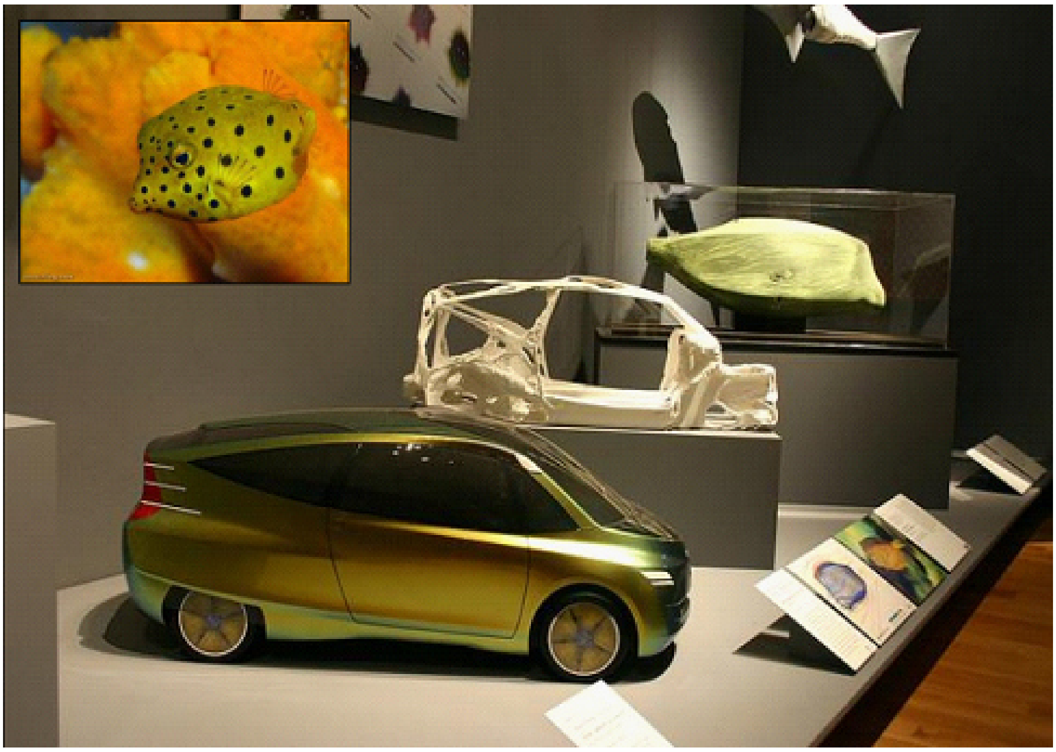


Figure 4.1: daimlercrysler's bionic car inspired by the boxfish and tree growth patterns (car: photo by ryan somma. boxfish insert: photo by richard ling

makes this Bionic car is more efficient in terms of fuel. The structure of the car has the minimum amount of material, which are efficient materials due to the mimicking of tree growth patterns. They made small improvements to existing technology [Saad 2011].

Despite of this approach's disadvantages by imposing the formation of multidisciplinary teams that contain biologists, engineers, ecologists…It might be a way to begin transitioning the built environment from an unsustainable to efficient to effective paradigm.

The Biomimicry Institute has referred to this design approach and explained it through the "Challenge to Biology Design Spiral" as illustrated in (figure 4.2).

Research held in Georgia Institute of Technology by Michael Helms, Swaroop S. Vattam and Ashok K. Goel, at the Design Intelligence Lab in 2006, also defined

Figure 4.2: Design Spiral by the Biomimicry Institute

this approach through 6 definite steps, which are very similar to those defined by the Biomimicry Institute:

Step 1: problem definition

Step 2: reframe the problem

Step 3: biological solution search

Step 4: define the biological solution

Step 5: principle extraction

Step 6: principle application

Figure 4.3: top-down design approach: design referencing biology [Ahmar 2011]

4.2.2 BIOLOGY INFLUENCING DESIGN

When biological knowledge influences human design, the collaborative design process is initially dependent on people having knowledge of relevant biological or ecological research, rather than on determined human design problems. The translation from a biological context can be intentional or accidental. This approach also have different naming such as Biology Influencing Design, Bottom-Up Approach and Solution-Driven Biologically Inspired Design [Zari 2007].
As an example of this kind of accidental biomimicry is the development of Velcro by Swiss engineer George de Mestral in 1948. Upon returning home for a walk with his dog one day, his pants and the canine's fur were covered with cockle-burs. He studied the burs under a microscope (figure 4.4), observing their natural hook-like shape, which ultimately led to the design of the popular adhesive material, Velcro. Velcro is a two-sided fastener one side with stiff 'hooks' like the burrs and the other side with the soft 'loops' like the fabric of his pants. The result was VELCRO.

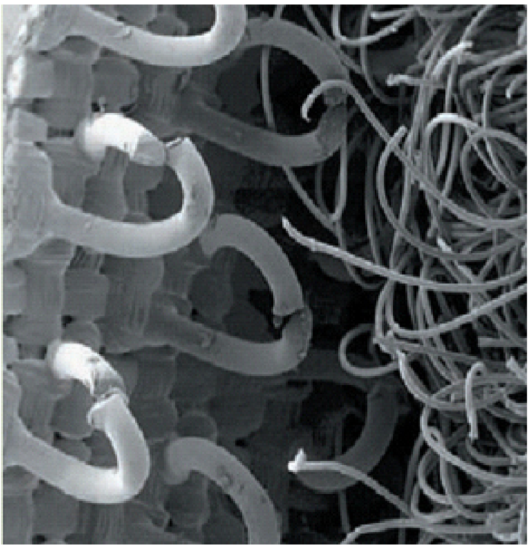


Figure 4.4: A scanning electron microscope image of Velcro's hooks and loops

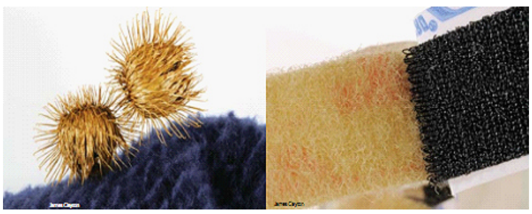


Figure 4.5: Velcro, adhesive material

Scientists at the University of Manchester have developed a new type of adhesive, which mimics the mechanism employed by the gecko lizard to walk on surfaces, including glass ceilings, which is an example of a more intentional study of biology for human application. This study has led to experiments aiming to create strong dry adhesion tapes that are reusable, referred to as 'Gecko Tape'.

Figure 4.6: Geckos' feet pads have given up their secret

Another example is the scientific analysis of the lotus flower emerging clean from swampy waters, which led to many design innovations as detailed by Baumeister [Baumeister 2012] , including Sto's Lotusan paint which enables buildings to be self cleaning.

Figure 4.7: Lotus effect.

One of the advantages of this approach is that biology may influence humans even if there is no predetermined design problem resulting in previously unthought-of technologies or systems or even approaches to design solutions. The potential for true shifts in the way humans design and what is focused on, as a solution to a problem, exists with such an approach to biomimetic design. As a disadvantage for this approach is that biological research must be conducted and then identified as relevant to a design context. Biologists and ecologists must therefore be able to

Figure 4.8: Sto's Lotusan paint

recognize the potential of their research in the creation of novel applications. Research held in Georgia Institute of Technology by Michael Helms, Swaroop S. Vattam and Ashok K. Goel, at the Design Intelligence Lab in 2006, also defined this approach through 7 definite steps:

Step 1: biological solution identification. Here, designers start with a particular biological solution in mind.

Step 2: define the biological solution

Step 3: principle extraction

Step 4: reframe the solution. In this case, reframing forces designers to think in terms of how humans might view the usefulness of the biological function being achieved.

Step 5: problem search. Whereas search in the biological domain includes search through some finite space of documented biological solutions, problem search may include defining entirely new problems. This is much different from the solution search step in the problem-driven process.

Step 6: problem definition

Step 7: principle application

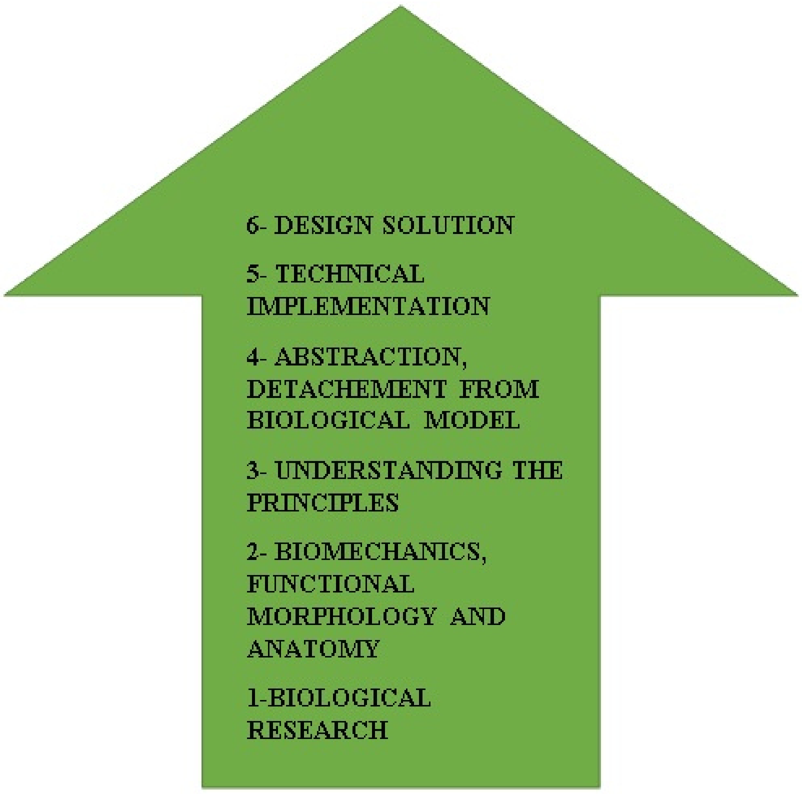


Figure 4.9: Bottom-up approach: biology influencing design [Ahmar 2011]

4.3 LEVELS OF BIOMIMICRY

The information embedded in each organism can be found in many levels, which is summarized in Figure 4.10, possible features that can be concluded from an organism and its biomimicry are analyzed using three levels. Each level is concerned with a layer of the design of an organism. The first includes aspects and properties of a creature as a whole unit. The second includes other features that focus on the relationships between an organism and its living community. The third level highlights systems and eco-solutions that can be concluded from relationships between an organism and its context/environment. Within each of these levels, a further five possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function). M.

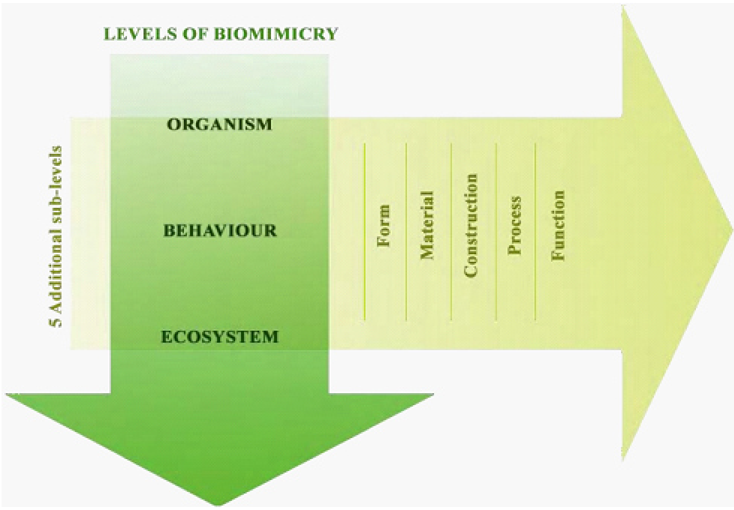


Figure 4.10: Levels of Biomimicry

Pedersen Zari attempted to clarify the various levels and dimensions of biomimicry and proposed a framework for understanding its application. This is applicable to both approaches (design looking to biology, and biology influencing design).

Levels of Biomimicry	Aspects of the levels
Organism features (Features of the organism itself	Formal attributes include shape, color, volumetric treatment, transparency, rhythm.
	Organization and hierarchy of parts and systems.
	Structure, stability and gravity resistance.
	Construction materials and process.
	Mutation, growth and lifecycle.
	Function and behavior.
	Motion and aerodynamics.
	Morphology, anatomy, modularity and patterns.
	Probability and mobility.
	Self-assembly.
	Healing, recovery, survival and maintenance.
	Homeostasis the balances internal systems while external forces change.
	Systems that include organ, digestive, circulatory, respiratory, skeletal, muscular, nervous, excretory, sensory and locomotive systems.
Organism- community relationship (The organism's relationship to its community of similar organisms as well as other creatures that it may deal with).	Survival techniques.
	Interaction with other creatures.
	Transgeneration knowledge transfer and training.
	Hierarchy of community members.
	Group management and coordination.
	Communication.
	Collaboration and teamwork.
	Self- protection.
	Sensing, responding and interaction.
	Risk management.
Organism-environment relationship (How an organism fits in its biome and environment).	The contextual fit.
	Adjustment to change.
	Response to climate by cooling, heating and ventilation solutions.
	Response to context by, for example, camouflage, self-protection and self-cleaning.
	Adaptation to ecosystems includes adjustment to various light or sound levels, shading, and self-illumination.
	Shelter building.
	Limited resource management such as adaptation to lack of water, light or food.
	Waste management. Input/ output/ process cycling.

Table 4.1: A Framework for the Application of Biomimicry adapted from [Zari 2007]

4.3.1 ORGANISM LEVEL

Humans have a wide pool of examples to draw on to solve problems experienced by society that organisms may have already addressed, usually in energy and materials effective ways. Species of living organisms have typically been evolving for millions of years. Those organisms that remain on Earth now have the survival mechanisms that have withstood and adapted to constant changes over time.

As an example, the mimicking of the Namibian desert beetle. The beetle lives in a desert with negligible rainfall. It is able to capture moisture however from the swift moving fog that moves over the desert by tilting its body into the wind. Droplets form on the alternating hydrophilic hydrophobic rough surface of the beetle's back and wings and roll down into its mouth.

Matthew Parkes of KSS Architects proposed fog-catcher design for the Hydrological Center for the University of Namibia, which is inspired by the beetle, and demonstrates the process biomimicry at the organism level. A more specific material biomimicry at the organism level were discussed, where the surface of the beetle has been studied and mimicked to be used for other potential applications such as to clear fog from airport runways and improve dehumidification equipment for example.

Mimicking an organism alone however without also mimicking how it is able to participate in and contribute to the larger context of the ecosystem it is in, has the potential to produce designs that remain conventional or even below average in terms of environmental impact. Because mimicking of organisms tends to be of a specific feature, rather than a whole system, the potential also remains that biomimicry becomes technology that is added onto buildings rather than being integral to them, particularly if designers have little biological knowledge and no not collaborate with biologists or ecologists during the early design stages. While this method may result in new and innovative building technologies or materials, methods to increase sustainability are not necessarily explored [Zari 2007].

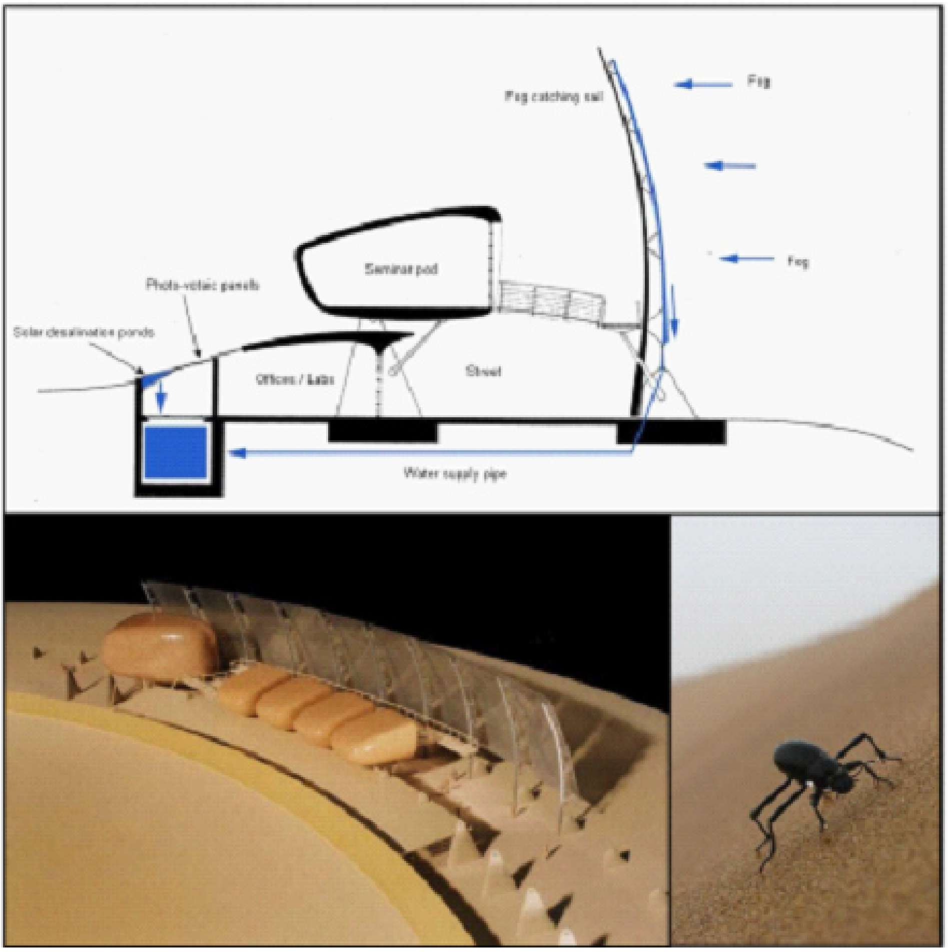


Figure 4.11: Matthew Parkes' Hydrological Center for the University of Namibia and the stenocara beetle [Zari 2007]

4.3.2 BEHAVIOUR LEVEL

A great number of organisms encounter the same environmental conditions that humans do and need to solve similar issues that humans face. As discussed, these organisms tend to operate within environmental carrying capacity of a specific place and within limits of energy and material availability. These limits as well as pressures that create ecological niche adaptations in ecosystems mean not only well-adapted organisms continue to evolve, but also well-adapted organism behaviours and relationship patterns between organisms or species [Reap 2005].
Organisms that are able to directly or indirectly control the flow of resources to other species and who may cause changes in biotic or abiotic (non living) materials or systems and therefore habitats are called ecosystem engineers. Ecosystem engineers alter habitat either through their own structure (such as coral) or by mechanical or other means (such as beavers and woodpeckers). Humans are undoubtedly effective ecosystem engineers, but may gain valuable insights by looking at how other species are able to change their environments while creating more capacity for life in that system.
The example of the North American beaver (castor canadensis) demonstrates how through it is altering of the landscape, wetlands are created and nutrient retention and plant and animal diversity is increased, helping in part to make the ecosystem more resilient to disturbance.
In behaviour level biomimicry, it is not the organism itself that is mimicked, but its behaviour. It may be possible to mimic the relationships between organisms or species in a similar way.

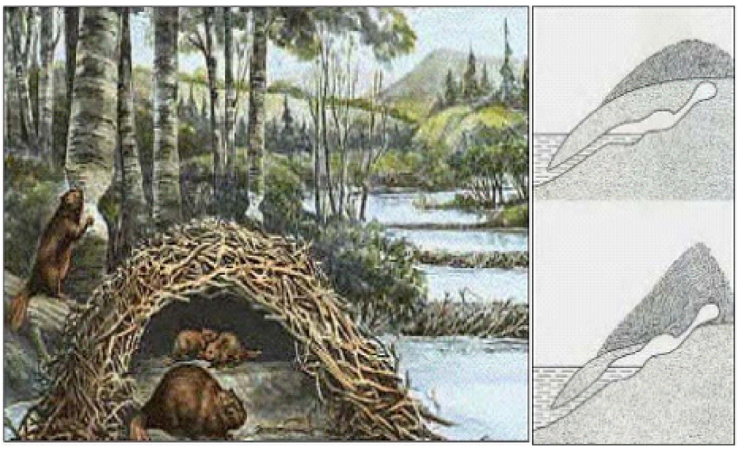


Figure 4.12: North American beaver [Zari 2007]

4.3.3 ECOSYSTEM LEVEL

The mimicking of ecosystems is an integral part of biomimicry as described in [Benyus 2002] and [Vincent 2007]. The term Ecomimicry has also been used to describe the mimicking of ecosystems in design. Proponents of industrial, construction and building ecology advocate mimicking of ecosystems and the importance of architectural design based on an understanding of ecology is also discussed by researchers advocating a shift to regenerative design [Saad 2011].

We can use the design at this level of biomimicry in combination with other levels of biomimicry (organism and behavior). It is also possible to integrate existing established sustainable building methods that are not specifically biomimetic.

The most important advantage of such an approach to biomimetic design however may be the potential positive effects on overall environmental performance. Ecosystem based biomimicry can operate at both a metaphoric level and at a practical functional level.

At a metaphoric level, general ecosystem principles (based on how most ecosystems work) are able to be applied by designers with little specific ecological knowledge. Benyus [Benyus 2002] has offered such general principles. A set of ecosystem principles derived from comparing these cross disciplinary understandings of how ecosystems function is detailed by Pedersen Zari [Zari 2007]. If the built environment was designed to be a system and was expected to behave like an ecosystem even if only at the level of metaphor, the environmental performance of the built environment may increase.

On a functional level, ecosystem mimicry could mean that an in-depth understanding of ecology drives the design of a built environment that is able to participate in the major biogeochemical material cycles of the planet (hydrological, carbon, nitrogen etc) in a reinforcing rather than damaging way [Saad 2011]. That a greater understanding of ecology and systems design is required on the part of the design team is implicit. Also required would be increased collaboration between disciplines that traditionally seldom work together such as architecture, biology and ecology. Such an approach challenges conventional architectural design thinking, particularly the typical boundaries of a building site and time scales a design may operate in [Zari 2007].

Pedersen Zari suggested that if biomimicry is to be conceived as a way to increase sustainability of an architectural project, mimicking of general ecosystem principles should be incorporated into the design at the earliest stage and used as an evaluative tool throughout the design process.

As an example for the functional biomimicry at an ecosystem level; Mithûn Architects and Green Works Landscape Architecture Consultants' proposed Lloyd Crossing project for Portland. The project began with a detailed study of how the ecosystem had functioned on the site before development, termed by them 'Pre-development Metrics'. This was used to set goals for the ecological performance of the project over a 46 year time span and gave them a proven working model of a system that had worked in a highly refined and successful way on the same site

[Zari 2012].

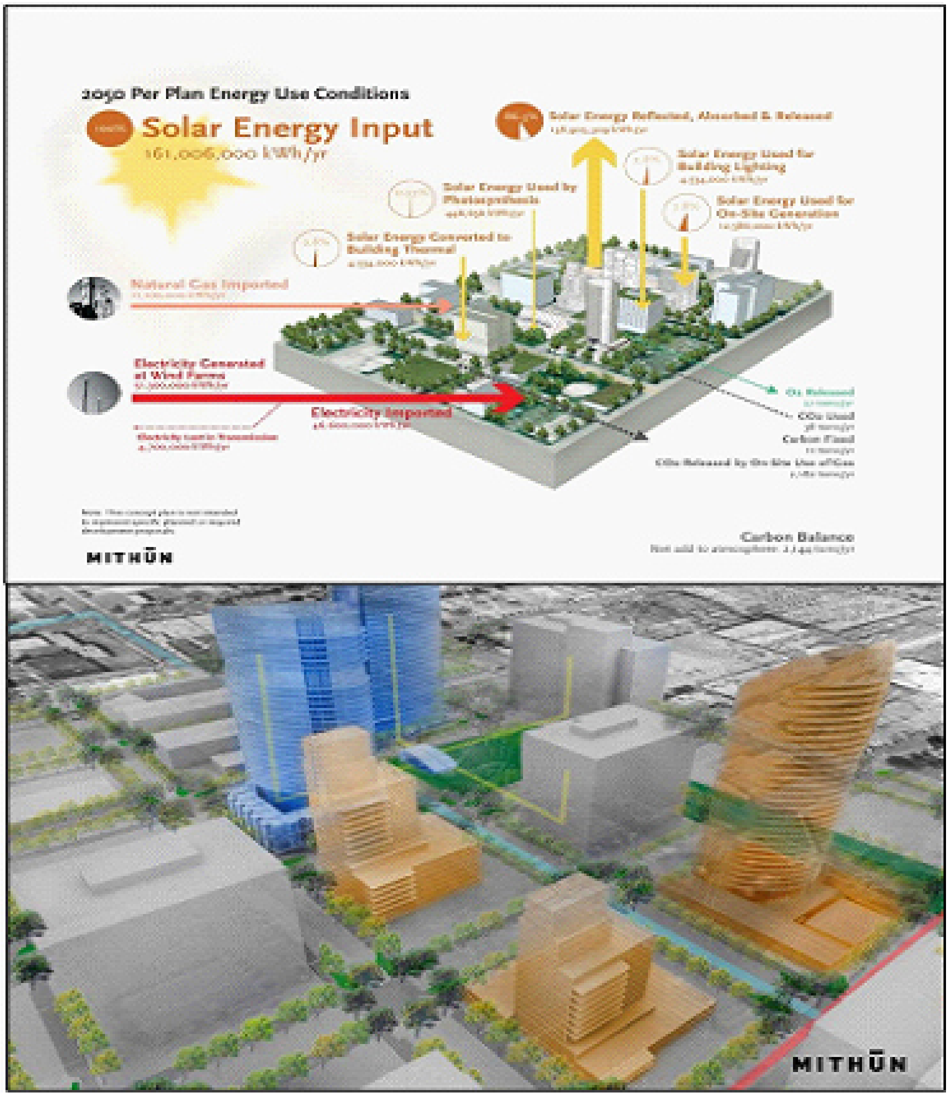


Figure 4.13: LLOYD CROSSING PROJECT, PORTLAND, USA [Zari 2007]

4.4 PRINCIPLES OF BIOMIMICRY IN ECOSYSTEM

Within all of these levels, the possibility of the biomimetic design may be based on certain aspects which are: what it looks like in forms, what materials it is made out of, how it is made in construction, how the process of the works or what it is able to do in functioning. Somehow, there is an overlapping between different existing biomimicry levels. For example, the system that is able to react and interact like an ecosystem would be functioning at the level of ecosystem of biomimicry process. Pederson Zari [Zari 2007] have clarified a set of ecosystem principles that are derived from disciplinary understandings of the ecosystem functions by doing a cross comparison between the principles in biomimicry to formulate the functions and analysis the system of ecology, biology, industrial ecological and biomimicry. It can be comply by the designers such as architects and engineers in that field to aid in the evolution of the methodologies in enable a creation to make a sustainable built environment that will affect the entire world. The research conducted by [Zari 2012] explains that ecosystem principles are depending on the complexities of certain aspects of ecosystems with number of controversial theories in ecology such as exact process and mechanism in the process of ecological principles succession. According to previous research, the ecosystem principles are:

1. Ecosystems are dependant on contemporary sunlight.
   - Energy is sourced from contemporary sunlight.
   - The sun acts as a spatial and time organizing mechanism.
2. Ecosystems optimize the system rather than its components.
   - Matter is cycled and energy is transformed effectively.
   - Materials and energy are used for multiple functions.
   - Form tends to be determined by function.
3. Ecosystems are attuned to and dependant on local conditions..
   - Materials tend to be sourced and used locally.
   - Local abundances become opportunities.
4. Ecosystems are diverse in components, relationships and information.
   - Diversity is related to resilience.
   - Relationships are complex and operate in various hierarchies.
   - Ecosystems are made up of interdependent cooperative and competitive relationships.
   - Emergent effects tend to occur.
   - Complex systems tend to be self organising and distributed.
5. Ecosystems create conditions favorable to sustained life.
   - Production and functioning is environmentally benign.
   - Ecosystems enhance the biosphere as they function.
6. Ecosystems adapt and evolve at different levels and at different rates.
   - Constant flux achieves a balance of non-equilibrium

- Limits, tend to be creative mechanisms

In the ecosystem principles, dependent on contemporary sunlight is defined as the energy sourced that comes from contemporary sunlight and the sun will acts as a spatial and time organizing mechanism in the ecosystem process. The other principles of ecosystem, optimize system rather than components is to make the cycled of energy to transformed effectively and used for multiple functions by creating form as determined the function. The principles to attune and dependent on local conditions aspects will concern on source of materials that used locally and local abundance will become the opportunities to the context of ecosystem. The next ecosystem principle is diverse in components, relationship and information that related to resilience, which would come in various hierarchies that make relationship complex and operate among each other. It also emergent effects tend to occur by creating complex systems that tends to be self-organizing and distributed. The principles of ecosystem in create conditions favorable to sustain life is by making production and functions where the environmental begin and the ecosystem will enhance the biosphere as to make it functional. The ecosystem principles could be applied in the design process and to be applying to every stage in design by transforming them into a set of design principles that required in a project.

4.5 PRINCIPLES OF BIOMIMICRY IN DESIGN

The previously topics explained the principles of biomimicry in the ecosystem. From that, a set of specific principles were selected as there are providing a basis for further study in designing purpose and method within the limitations of available technology and knowledge. The approaches of biomimicry as a design process generally fall into two categories as seen before.In the view of [Mazzoleni 2013], [Elnokali 2012] the designers will look to the living world solutions as the methods to identify problems and match these to organisms that have similar issues in their design. Based on that, there are several principles of biomimicry that will inspire the designer in the process of design by getting the inspiration from nature and making it better to the surroundings and also as the interaction between human and living organism.

The selected principles of biomimicry in design are:

√ Adaptation

√ Material as system

√ Evolution

√ Emergence

√ Form and behavior

The five principles are generated from the previous principles of biomimicry in ecosystem. The first principle is adaptation, the ecosystem can adapt and evolve at different levels and rates, so we can change environments by behavioral adjustments. Basically, adaptation is the evolutionary process that makes a population feels comfort and better suited with its habitat. It also can be referred to a feature process which includes the organism to survival by accepting naturally the current situations that to get involved in successfully. The next principle in design is material as systems that comes from ecosystems optimize the system rather than its components. The biological material systems are self-assembled that makes weak materials become strong structure and the used properties are totally different from the classical engineering of traditional man-made structures. The other principle of design in biomimicry is evolution, which comes from the ecosystem principle that adapts and evolves at different levels too. The adaptation and evolution will allow the whole ecosystem and organism to continue constantly dynamic in cyclic environment that they existed in it. The variety and perfection of natural forms will produce the result of relentless in experimentation of evolution. Moreover, the analogy of evolutionary architecture does not mean to be taken without imply the development of natural selection. In addition of that, the grows of living form is a complex process that contributes in the genotype with variables contribution in environmental dependencies that also comprises the genetic constitution of an individual and the interaction between the genotype and the environment is the product that is evolutionary formed.

As have been discussed in the ecosystem principle that ecosystems are diverse in components, relationship and information, emergence is a principle in the design that is complex and works in various hierarchies, the emergent will effects the tendencies to occur in that design process. All multiples variations of biological form is a form of evolution that should not be thought separately from the structure and materials. The emergent performance comes from complex hierarchies of material within natural structures.

The last principle biomimicry in design is form and behavior that is generated from the ecosystem principle, ecosystem that optimize the system rather than its components. It explains the emphasized call between functions and form that produce the result of equally important between form and behavior. It emerges from the process that produces, elaborates and maintains the structure forms of biological organism and the complex process consist of the exchange between the organism and ecosystem. The choice of these principles is done due to literature review of previous studies on biomimicry in attempt to link them with current research in the design part.

4.6 LIVING ARCHITECTURE

Architecture, by its nature, is part of inanimate nature and is subjected to the same physical principles and processes. Architecture is not alive, but it has a life cycle. Even if some of life's criteria exist in individual projects, technology is still far from creating artificial life. In the table 4.6 below, we compare the life cycle of a building and that of an individual organism.

Architecture	**Organism**
Idea, project development, planning	Evolutionary, development of species
Production	Conception, creation of egg cell
Implementation, building	Birth, aliveness, growth
Operation	Normal life, propagation
Damage, abrasion	Injury, illness
Repair, renovation	Recovery (self-healing), medical treatment
change	Metamorphosis
Vacancy, abandonment	No analogy in nature
Decay, dismantling	Death
Recycling	Recycling

Table 4.2: Comparison of the lifecycles of architecture and organisms [Gruber 2011]

The usage of architecture is the significant parameter for "aliveness". Artificial life is a tempting issue in the discussion of life sciences and architecture. In spite of the presence of some already existing criteria of life in architecture, the whole range of these criteria has not been found in one single architectural project.
On the other hand the expression of "architecture being alive" is commonly used for life in architecture, assuming architecture being used and valued highly by the occupants. Life in architecture is a sign of high quality, and can be stated by:

1. Occupant satisfaction
2. Use of space, frequency of activity (also constant over time - as against shopping zones that are "dead" in the evening)
3. Integration of architecture in the social and cultural lives of people

4. Exchange of matter and energy with its environment

5. Slow increase of entropy - good maintenance: energy/material input by maintenance measures to stop normal decay

6. Added value for the environment, design of the environment

The expressions ”aliveness of architecture” and ”life in architecture” have different meanings. The discussion of life of, and life in, architecture, can deliver the means to talk about the quality of architecture beyond flows of energy and material. There is no single measurable parameter, which indicates architectural quality, but the values mentioned above are investigated when we are sufficiently interested in the quality of our built environment [Gruber 2011].

4.7 EMERGING ADVANCEMENTS IN THE DOMAIN OF BIOMIMETIC ARCHITECTURE

4.7.1 BREATHING WALLS TO ENHANCE THE EFFICIENCY OF NATURAL VENTILATION SYSTEMS, ELGHAWABY Mahmoud

The researcher Elghawaby Mahmoud (PhD Student, ABC Research Laboratory, Marseille School of Architecture, France) has introduced the concept of ”Breathing walls” (Figure 4.14) which is inspired by human skin to create a thermally active facade. This model is able to control the flow of air over the entire surface and functions as a layer suitable for buildings It consists of three layers that aim to minimize the solar energy received directly from the sun allowing the airflow exceed and to cool and then be diffused inside the building. Each layer has specific characteristics:

- External layer is capable of preventing or minimizing direct sun light. It can be simple layer made of material that has the ability to absorb the moisture such as natural textile, clay, wood or reeds. This layer can be more sophisticated layer consisting of openable slots capable of controlling the intensity of sunlight according to a preprogrammed needed orders or according to the occupancy desire.

- Middle layer resembles the “epidermis” layer in human skin, it contains controlled airflow entrances, water sprayed system and airflow duct network. This layer aims at achieving three tasks; thermal insulation, cooling airflow by evaporative cooling then receiving and controlling airflow by duct network. Controlled airflow can be re-cooled by convection with earth deepness or other natural resources like underground water or sea water.

- Internal layer contains controlled ventilation outlets managed by both building management system and occupancy desire. This phase could contain a condensation process for obtaining potable water. This process can mimic camel's nose, which is capable of extract water vapor from exhaust air.

This research suggests that this concept could be applied whether with traditional simple elements or with advanced technologies; such as nanotechnology, artificial intelligence and telecommunications systems. These sciences help building facade to breathe in order to cool the interior spaces, which mean converting the entire façades to work as thermal adaptive layers.

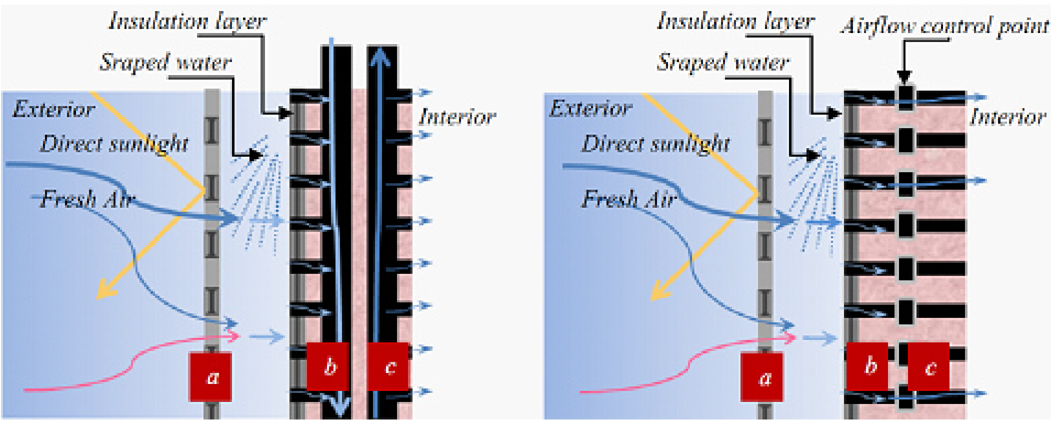


Figure 4.14: Conceptual model of breathing wall; (a) exterior layer capable of preventing or filtering direct sunlight while allowing airflow to pass, (b) Middle layer acts as thermal insulation layer, then it cools air temperature by evaporative cooling and receives air flow, (c) Internal layer aims at controlling airflow

4.7.2 BIOMIMICRY FOR ADAPTIVE BUILDING ENVELOPES, LIDIA BADARNAH KADRI

The researcher proposes the BIOGEN methodology as a strategic methodology, referred to as the living envelope methodology. The methodology assists channeling the way from technical challenges, defined by the demands on the building envelope, through functional aspects and various strategies found in nature.
Ongoing exploration:

1. **An adaptive shading system**
   As a result of the transformation of principles and methods used in plants for reacting to sun radiation, a shading system is being explored. The system has the ability to track the range of sun radiation throughout a day, and to adjust for different inclinations and distances from the envelope.

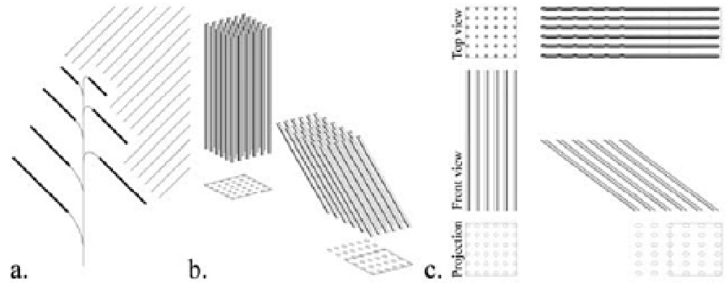


Figure 4.15: The angle of incidence determines energy density. (a) Leaves normal to sun radiation for maximum energy gain. (b) The effect of different inclination on the projection. (c) Top, front and projection view [Badarnah 2008]

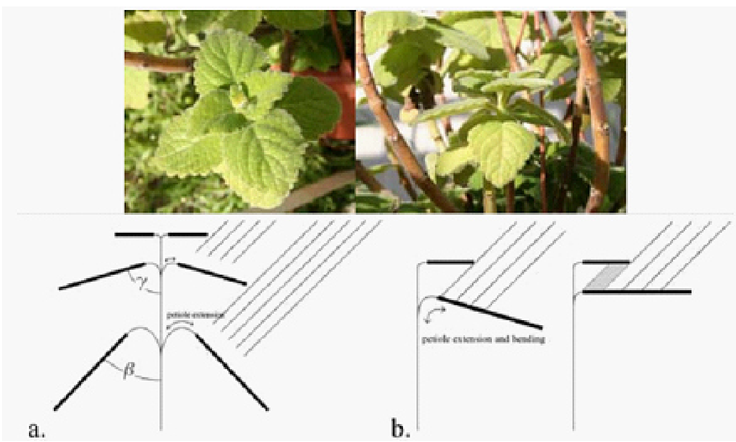


Figure 4.16: Lower layers of leaves bend for maximum light perception. (a) Lower leaves get bigger with smaller inclination ($\beta < \gamma$). Alternation of 90 degrees is adopted in this plant for more space between the layers in order to catch more sun light. (b) The effect of the inclination, preventing self shading [Badarnah 2008]

	Distribution/ position	Orientation/inclination	Dynamics
Minimum light exposure	• dense distribution at multi-layer • loose distribution at mono-layer • minimum projected area	• parallel to sun-rays (Paraheliotropic) • facing east for minimum exposure at noon • high leaf angles (more vertical) for minimum exposure at noon • facing south/north for gradual exposure during morning • leaflet folding • low leaf angles	• parallel to sun-rays (Paraheliotropic) • folding / rolling • bending • buckling • vascular bundles • concave surface shape
Maximum light exposure	• loose distribution at multi-layer • dense distribution at mono-layer • maximum projected area • Fibonacci series for compact pattern packing • extending stem • horizontal expansion	• perpendicular to sun-rays (Diaheliotropic) • facing east for maximum exposure at morning and afternoon • facing south/north for maximum exposure at winter noon's	• increasing internode and petiole length • increasing leaf area combined with reducing mass per unit • plasticity, nastic structure • different flexibilities of the sides of a blade • special surface properties- uncoated cell clusters (for flexibility) • convex surface shape

Figure 4.17: Summary of main organizational features in leaves for minimum and maximum light exposure [Badarnah 2008]

. The new shading technologies for building envelopes inspired from plants.

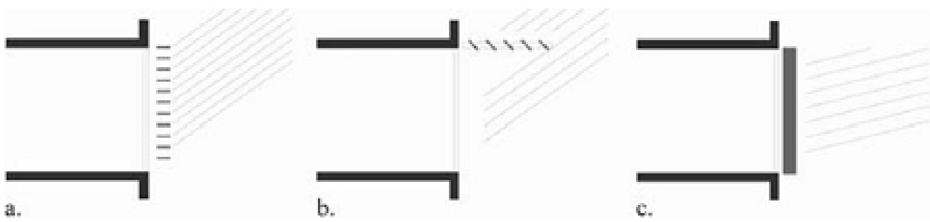


Figure 4.18: Simplified version of current shade devices. (a & b) horizontal shade devices for high angles of radiation. (c) Vertical shade devices for low angles of radiation (morning and evening) [Badarnah 2008]

Figure 4.19: All shade blades have the same angle of inclination (α) when flipped. Light gray indicates the old position and dark gray the new position [Badarnah 2008]

2. **A breathing envelope**
   The Asconoide sponge, respiration systems, blood veins, and the skeleton and surface of a sea sponge are investigated for this case. We have designed a skin that reacts to changing conditions and influences the air pressure on the surface to perform a process of inhaling and exhaling. Such a system is an integral part of the building envelope, which functions as a protective layer too.

3. **Light regulating envelope**
   Based on light managing methods found in nature, a light regulating envelope is being investigated to improve visual comfort of the occupied spaces.

4. **A thermo regulating envelope**
   Organisms based on their habitats and physiological characteristics adopt different strategies (active or passive), they perform thermoregulation by physiological, behavioral, or morphological means. Organisms succeed to maintain an adequate balance between heat gain and heat loss without seeking air-tightness and water-tightness. Such adaptation solutions by organisms could be applied in buildings with similar challenges.

The building envelope has to maintain a thermal comfort for the occupant Current technologies for buildings consider the envelope as a thermal barrier or a shield that has to be insulated to prevent heat loss and allow it to be open to dissipate heat if necessary. Since we can found more efficient thermoregulation solutions in nature.
As an outcome of this research, the author provides performance taxonomy of organisms that facilitate thermoregulation in nature, and discuss their possible application in building envelopes. Moreover, they present an application case of such taxonomy for an evaporative cooling system (Stoma Brick) for building envelopes.
An evaporative cooling system (Stoma Brick - SB) for building envelopes was designed based on principles of several natural systems. These include stoma of a plant, pine cones, hair protecting eyes in the desert, and human skin.
The cooling system consists of four integrated parts (figure 4.20) :

1. The Stoma brick – SB (figure 4.21)
   made of porous material, which is the functional part for thermoregulation. It has an outer layer of hairy structure to filter the air passing through the envelope. A veneer shutter to control opening/closing in accordance to humidity gradient. The most inner layer is spongy to hold moisture for evaporation.

2. The mono-brick
   it includes an irrigation cycle that irrigates through holes the SB's (figure 4.22), which are inserted into the mono-brick to allow a continuous performance vertically. Two configurations of mono-bricks sexist for this envelope, 3 SB's and 9 SB's, depend on their position in the specific envelope design.

3. The steal framing
   it's the load bearing structure of the cooling system.

4. The inner layer
   HEPA filter for air cleaning or a double acrylic glass for lightening and visual contact with the exterior environment.

Naturel system	Deep principel
Stona of plants	Osmotic pressure changes control openings for evaporation
Pine cone	Relative humidity changes cause material deformation
Hair around eyes	Protection against smal particles (e.g. dust and sand)
Humain skin	Latent heat transfer-Cooling trough evaporation

Table 4.3: Summary of the deep principles used for the SB design [Badarnah 2010]

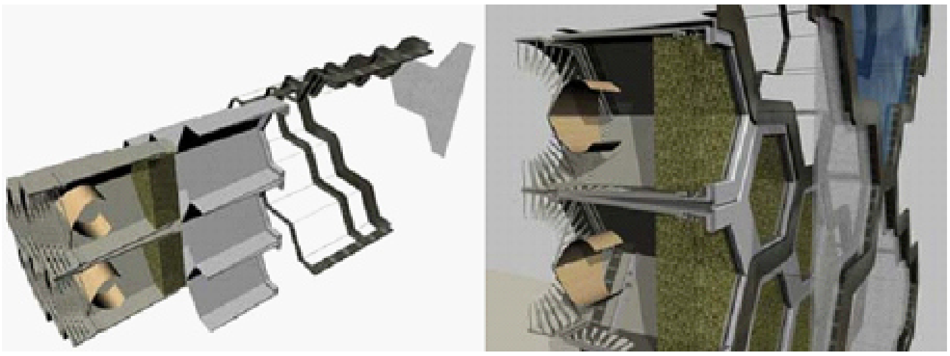


Figure 4.20: Left: the four integrated parts shown separately. Right: the parts are attached to each other creating one system [Badarnah 2010]

The system operates at hot and humid weather: the veneer shutter deforms when humidified, this allows the air to get inside passing through the spongy structure. At hot and dry weather the system functions differently: the irrigating cycles are activated letting water droplets to fall on the veneer shutter in order to cause a deformation and open it allowing the air to enter and pass through the humidified spongy structure. As a result, the dry air that entered is humid when it reaches the inner space.
In cold and dry weather, the spongy structure acts as an insulating layer reducing heat loss. Hot and exhausted air is driven outside by upper blocks close to the ceiling.

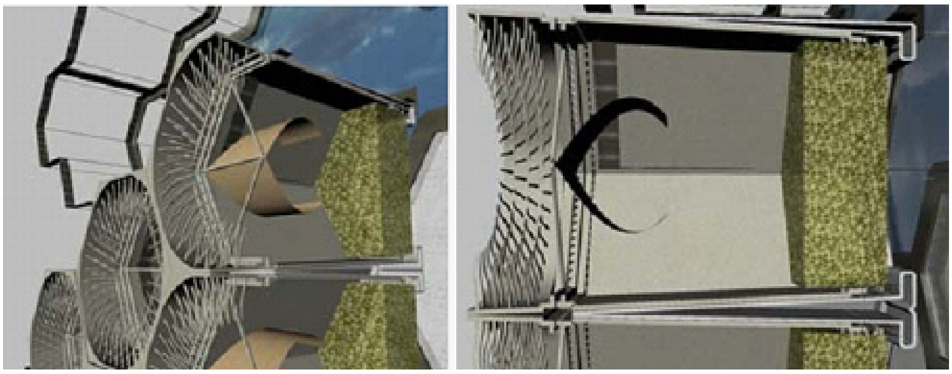


Figure 4.21: A cross section through the SB showing the deformed veneer (as a reaction to humid environment) allowing the air to enter and ventilate the inner space [Badarnah 2010]

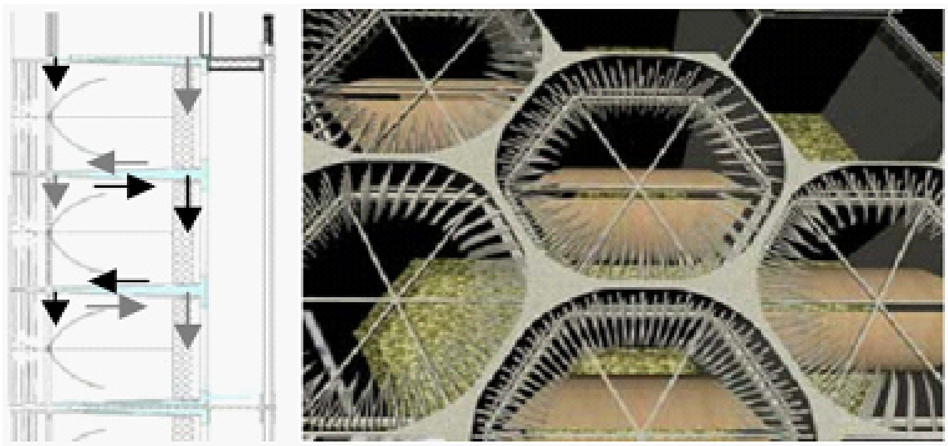


Figure 4.22: An integrated irrigation system to supply moisture. Two irrigating cycles (black and gray arrows) are active when operated [Badarnah 2010]

4.8 CONCLUSION

From the discussion on the above study, it can be concluded that the nature also can give an impact to the world of architecture. This chapter has presented two main approaches in biomimetic design (Problem based and Solution based) and discussed a framework for understanding the different levels of biomimicry; organism, behavior and ecosystem levels. Advantages and disadvantages of each level were presented, highlighting the different potentials of each level in architectural design.
A focus has been made on a group of more specialized or specific researches, that serve as examples for the application of the biomimetic approach on architectural design aiming to reach the concept of living architecture. This study will be used for developping a new methodology in order to generate biomimetic design concepts, which will be the subject of the following chapter.

CHAPTER 5

BIOBRAINSTORMING METHODOLOGY

" We're awake now, and the question is how do we stay awake to the living world? How do we make the act of asking nature's advice a normal part of everyday inventing ? "
- - Janine Benyus

Contents

5.1 INTRODUCTION

In this chapter, we propose a useful bio-key tool based on biomimetic principles to find new methods and systems for living architecture and to optimize a selected challenge in hot and arid regions. This methodology is relevant to various disciplines as a problem solver to optimize the energy use; this is due to the generality of the strategy tools.

Figure 5.1: Natural world's processes

5.2 BIO-PROBLEM SOLVER FOR SUPPORTING THE ARCHITECTURAL DESIGN

Approaches to biomimicry as presented in Chapter 4 typically fall into two categories. The 'design referencing biology' and 'biology influencing design'. The current work follows the first approach which is mimicking the nature by looking to its systems and process in order to learn how natural systems can overcome the same design problem. One of the most important design challenges in architecture is designing natural ventilation systems in buildings located in hot and arid regions as in Biskra, Algeria. Actually, ventilation and cooling purposes are consuming the highest amount between building sections. In hot climate, this is due to using mechanical air-conditions, and ignoring the natural ventilation in our modern buildings.

5.2.1 DESCRIPTION OF THE METHODOLOGY

The current research is based on a strategic methodology for the generation of biomimetic design concepts and to facilitate the implementation of the biomimetic approach. This strategy is inspired by Sherry Ritter' strategy to find inspirations from the natural world; and based mainly on the BioGen strategy. This methodology is a selective tool to identify the relevant systems and strategies in nature, in order to find new alternatives for the energy optimization and saving. The aim of this methodology is to explore and extract mechanisms found in nature, for potential application in innovations.
In the aim of developing a Biobrainstorming tool and for developing a living building' ventilation; an amount of steps must to be carried out: definition of the challenge and its functions, explore biological challenges similar to the identified technical challenge, discover creatures and natural organisms, Select the pinnacles that do the needed roles for extracting the main principles and processes, build Taxonomies

to obtain Brainstorm ideas, evaluate the ideas, transform the best ideas into designs, build physical models, evaluate and validate them. These steps and phases are presented in tables, and figures that provide a selective tool, which leads to a concept design of the living building. This methodology is basically dealing with the exploration process and organisms' investigation, and the results in leading architects to a concept design [Khelil 2015].

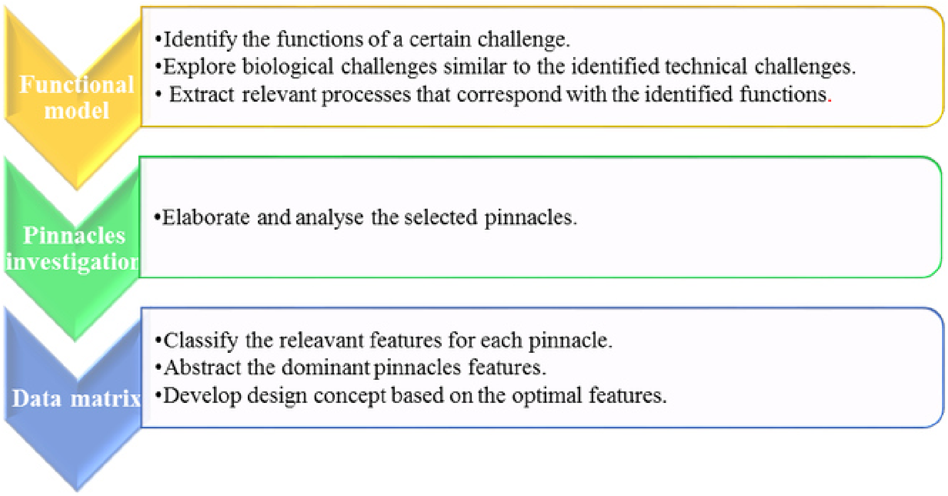


Figure 5.2: Flow chart of the design methodology showing the several phases

Initially, we define a design challenge that we are wondering to resolve. This methodology contains three levels of abstraction, the functional model, pinnacles investigation, Data matrix.

1. The functional model
   It offers numerous scenarios leading to diverse significant pinnacles. It consists of several information units, classified at four hierarchical levels (Figures 5.5, 5.6). Every unit comprises a head keyword that is located at one of the four levels and related to other units. The different levels of the functional model:

   - At the first level we find function data units,
   - The second level contains relevant processes,
   - The third level is about influencing factors,
   - The fourth level presents the pinnacles.

   The identified challenge defines particular functions, and the detail level of definition can define additional levels of the functional model (i.e., processes). We have the liberty to select correlated factors and pinnacles at the descending levels of the functional model.

2. Pinnacles investigation:
   As we see, in the previous level of the methodology, we have numerous pinnacles. As a result, we distinguish numerous strategies, mechanisms, principles and features, thus the difficulty of solutions increases with the amount of pinnacles and their several features. For minimizing this difficulty, additional investigation is carried out to define taxonomy groups where the challenging transformation, from the biological field to the engineering field, can be analyzed. The optimal choice of the significant groups is influenced by the design discipline and the challenges involved.

3. Data matrix:
   In this level of the methodology, we are aiming to outline the design concept with the optimal features, it contains two steps;

   - The pinnacle analyzing matrix
   - The design path matrix.

In the first step, numerous categories must be defined (e.g. environmental conditions and adaptation solutions...) in order to classify each function and selected pinnacles, and detect the key feature of each group. In this research, the imaginary pinnacle denote the collection of key features, where a specific function is represented. Each group of the imaginary pinnacle contains a key feature between features of the selected pinnacles at the same group. Therefore, the imaginary pinnacle has the same function as the selected pinnacles, and it must have features that are all well-matched with the challenge.
The summary of the investigation of the extracted pinnacles from the functional model may derive multiple imaginary pinnacles, that's why we use the Design path matrix tool, as a second step, to indicate the successful features to be applied in the design concept, which is based on the predefined groups for pinnacle investigation. In this tool, we superpose the imaginary pinnacles in order to define the dominant aspects to be addressed in the integrated design concept.

5.2.2 DEFINITION OF THE DESIGN CHALLENGE

Here in the city of Biskra, a hot and arid region, we are facing the problem of sick building syndrome, which is the combination of discomfort experienced by building occupants due to poor conditions of air quality and other aspects related to indoor climate. To solve this syndrome of air quality, ventilation is provided with minimal energy use.
Natural ventilation is a passive cooling strategy that consists of using natural forces, such as wind and buoyancy to drive cool outdoor air through a space. If well implemented, it can considerably contribute to reducing the cooling energy consumption of a building. Moreover, natural ventilation is not only beneficial to reducing energy consumption in a building; its high flowrates also lead to higher levels of indoor air quality than mechanically cooled buildings.

Natural ventilation was one of the only methods available to keep spaces at comfortable temperatures, even in extremely hot climates. It is still widely used in residential settings, particularly in the developing world. For example, wind catchers are still commonly used in the Middle East to take advantage of the wind blowing in any direction to ventilate multi-story houses.
The two main goals of natural ventilation are to improve the indoor air quality (IAQ) and to reduce the cooling/ventilation energy consumption of a building. Both of these goals must be fulfilled by guaranteeing that the indoor thermal comfort conditions are acceptable. If this condition is not met, the natural ventilation system will most likely be replaced by an air conditioning system by the building occupants or owner.
Despite all of the advantages of using natural ventilation, the strategy is rarely used to cool buildings because the performance of naturally ventilated systems is highly dependent on the building geometry and the weather conditions, forcing the designer to account for several additional factors very early in the building design to guarantee occupant comfort.
Generally, Natural ventilation is used for two purposes: natural ventilation to control the indoor air quality IAQ, and for summertime cooling.

- The use of natural ventilation to control IAQ is of particular interest during the winter time. At this time of year, windows are opened such that the minimum required airflow rate is met, and not more. The physical framework to model natural ventilation to control IAQ in the wintertime is slightly different than that to provide cooling in the summertime for two reasons: the indoor temperature –if controlled by a heater with a set point thermostat– does not depend on the airflow through the space, and physics of the airflow through cracks (or very small openings) varies slightly from that of flow through large openings (windows).

- Using natural ventilation to prevent overheating within a building presents a very different challenge to maintaining acceptable IAQ standards. For summertime cooling, important considerations are internal heat loads and external solar gains, as well as building characteristics, such as thermal mass and insulation level, and the overall building floor and site layout. The higher the airflow availability, the greater the cooling effect.

It has been found, that the comfort levels occupants of naturally ventilated buildings do vary with outdoor temperature. This is because people naturally adapt their clothing levels from season to season, and will increasingly wear warmer clothes when the air is colder, and wear lighter garments when temperatures are higher. They will even adapt to hourly changes in weather conditions: they will open and close the windows depending on the amount of draft desired.
This human adaptation to outdoor conditions widens the traditional thermal comfort ranges, with occupants feeling comfortable at temperatures lower than the minimum and higher than the maximum acceptable conditions in a mechanically ven-

tilated space. This provides an even greater advantage to using natural ventilation, and can lead to larger energy savings if the adaptive comfort range is considered in the building controls, rather than the traditional range.
Despite of all of its advantages, NV is rarely considered as a cooling strategy in new buildings. In this research, we try to develop a biomimetic design tool that can help the architect implementing this strategy properly during the building design.
In this context, after approaching our challenge, we have to define it in functional terms, so that we can find many models in nature for adequate strategies to choose among. The current research explores and analyzes air regulation and thermoregulation strategies found in nature to apply them in ventilation and thermal comfort systems.
Air exchange and movement, Heat retention and dissipation are significant functions in nature, as organisms need oxygen and thermal comfort to survive. The efficient solutions in nature might promote the design of innovative ventilation and thermal comfort systems for buildings located in hot and arid regions. A brief background on some selected air regulation and thermoregulation strategies in nature is presented. The investigated functions, processes, factors and pinnacles are summarized in the functional model.

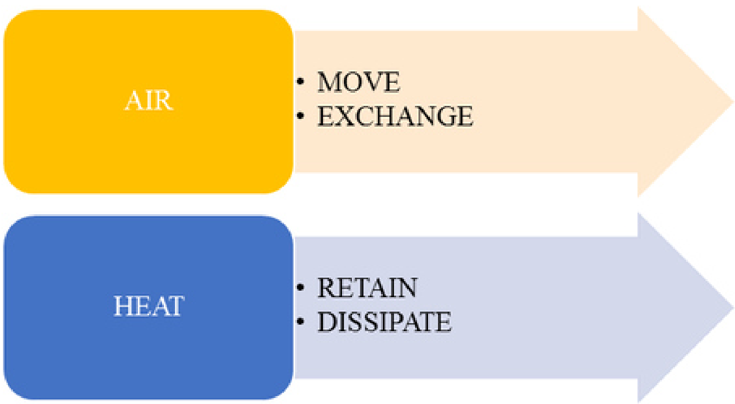


Figure 5.3: Proposed key Functions

5.3 CONSTRUCTION OF THE FUNCTIONAL MODEL

5.3.1 AIR REGULATION IN NATURE

For the most organisms, one of the main objectives of Air regulation is oxygen uptake and Carbon dioxide release (or vice versa) [Badarnah 2012]. Organisms have developed several mechanisms and strategies to maintain the required gas concentration levels whether in their bodies or their immediate surrounding environment. Generally, animals construct their structures for protection against extremes of cli-

mates. Gas exchange is related to the complexity of the structure's functional design. As such, the nature's architecture provides ways to maintain environmental homeostasis. Velocity gradients generated across surfaces provide potential source of work that might be used by burrowing animals to solve the ventilation problem in their narrow burrow.
The air regulation in organisms has several mechanisms of gas movement. In our work, we limit ourselves only on two mechanisms: pressure differences and diffusion.

1. Air exchange via diffusion: is the substance flow from higher to lower concentration, it is an important gas exchange process, animals have evolved several mechanisms and systems to increase the rate of diffusion and facilitate the exchange of gases. For example, we have the gas exchange in the lungs that occurs in the alveoli, gases move from higher concentration to lower concentration.

2. Pressure differences is generally generated by velocity or volume variations. In this work, we are interested by the velocity. Fluids move from regions of higher pressures to regions of lower pressures. Consequently, the lowest pressures occur at the highest velocities, and the highest pressures occur at the lowest velocities.

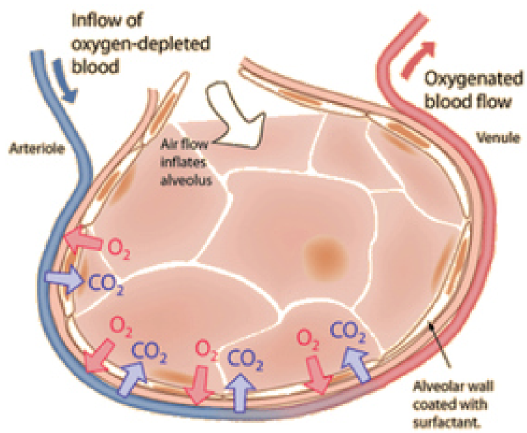


Figure 5.4: Gases move by diffusion from high to low concentration.

◇ FUNCTIONAL MODEL FOR AIR REGULATION

Previously we defined the various entities of the functional model. The investigation and exploration of air regulation in nature is based on two initial functions: movement and exchange, each function contains several processes, but we indicate some of them in the exploration model for air regulation depending on our initial goals. The exploration model contains four scales: Functional aspects, processes, influential factors, pinnacles that are defined by Badarnah Kadri [Badarnah 2012] as the representative organism or system from nature for a particular adaptation strategy.

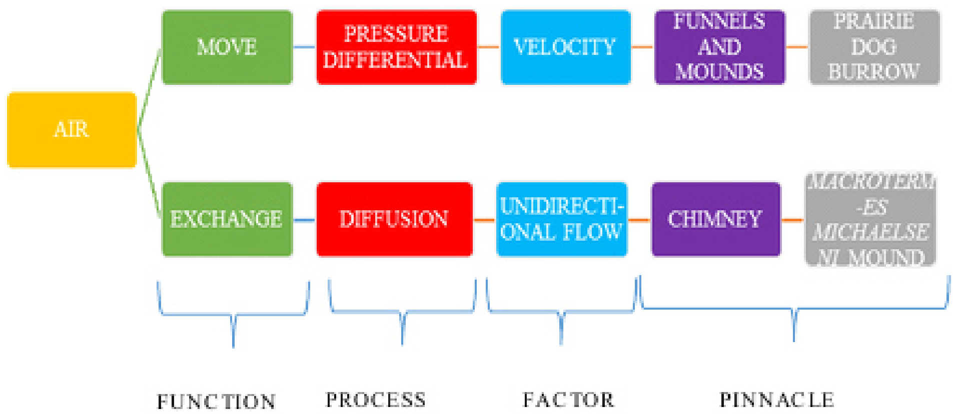


Figure 5.5: Extracted functional model for air regulation

5.3.2 THERMOREGULATION IN NATURE

Thermoregulation is the ability of an organism to keep its body and environmental temperature within certain boundaries, even when the surrounding temperature is very different. Efficient thermoregulation solutions can be extracted from thermoregulation strategies found in nature, or carried out by living organisms. Living organisms maintain the thermal comfort of their habitats narrow ranges in order to survive. The aim of this section is to explore and extract thermoregulation mechanisms found in nature, for potential application in buildings.
The thermoregulation in organisms has several mechanisms and strategies. In our work, we limit ourselves only on two mechanisms: heat retention and dissipation. The outcome of the investigation is classified in exploration model.

◇ FUNCTIONAL MODEL FOR THERMOREGULATION

According to Badarnah Kadri Lydia, the investigation and exploration of heat regulation in nature is based on four initial functions: gain, retain, dissipate, and prevent. Each function incorporates different processes. In our work, we focus mainly on two functions of heat regulation: retention and dissipation. The functional model is classified on four scales: function, processes, factors, pinnacles. The content of the presented model is a representative state for the current exploration.

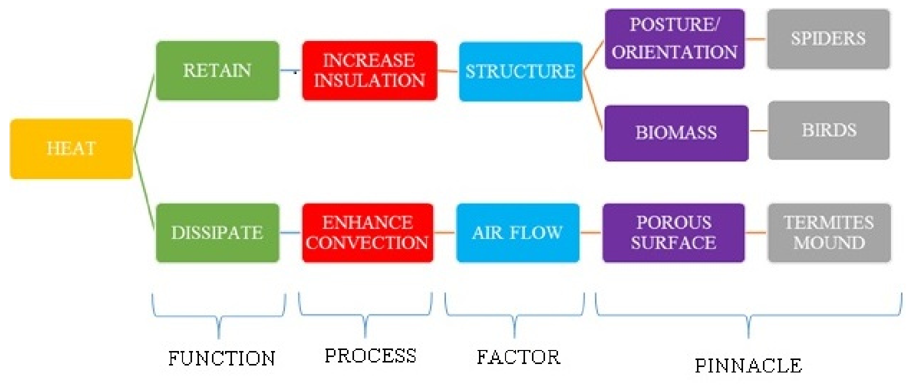


Figure 5.6: Extracted functional model for heat regulation

5.3.3 ANALYSE OF THE SELECTED PINNACLES

In this level of abstraction, we investigate, analyze and summarize the air and thermal regulation strategies. In this research, we want to say by pinnacle: a representative organism or system from nature for a particular adaptation strategy.
In each selected pinnacle, we are interested in:

- The strategy of performance.
- The relevant mechanism.
- We extract the key principle.
- We indicate the key feature of the performance.

√ Pinnacle .1: Galinaceous Birds

Gallinaceous birds is a name given to members of the order Gallinae. Members of this order are chicken-like in appearance and live on the ground. This kind of birds build Mounds for auto-egg warming.

These birds have found a way to warm their eggs without having to sit around all day. Biomass does the trick for them instead.
The male parent build a mound of 1.5 m tall and of 3-4 m diameter, from dead leaf which produces heat while fermenting, if the desired temperature 33^0 is exceeded the male parent drills holes in the mound, also to reduce CO2 levels inside it. In early spring when the fermentation rate declines, the mound can be opened up at the top to let sun heat the mound.

Design tips from birds

Figure 5.7: Galinaceous Bird

1. Rotting biomass could be a cheap means of heating, especially in winter time.
2. In autumn and winter a building has to be as closed as possible to retain the inside heat.
3. In spring and summer, consider opening up the top of your building, to collect as much heat as possible.
4. In spaces with danger of excessive heat and /or CO2 concentration, openings are necessary.

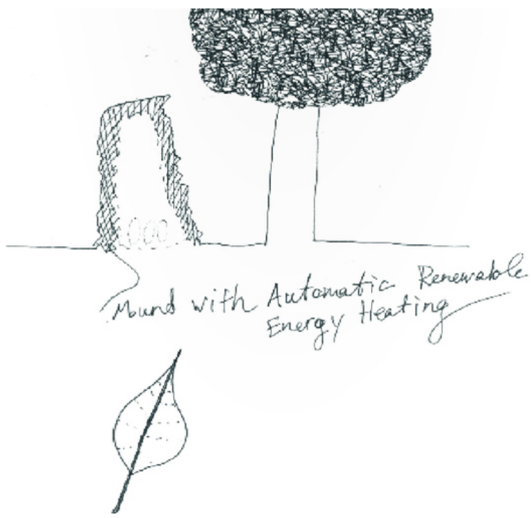


Figure 5.8: Galinaceous Birds' mound with automatic renewable energy heating

√ Pinnacle.2: Spiders (Micrathena gracilis)

Micrathena gracilis is a spider in the family Araneidae (orb-weavers), commonly known as the Spined Micrathena. This spider spins a moderately large (can be 30 cm or more across), very tightly coiled web.
This spider has a very interesting temperature control strategies: They use the orientation of the web to keep the web's user cooler, in open spaces with lot of light and warmer in shady places. This strategy is achieved by north-south web orientation in shaded places and east-west orientation in well illuminated places. This strategy affect the body temperature of the spiders. Spiders' webs are also examples of tensile architecture in nature.

Design tips from spiders

1. Proper orientation depends to the amount of shade or light in the area.
2. In the shady area we need maximum surface towards the East and West, so a North-South orientation to absorb heat if needed.

In a well illuminated hot area it might be best to have an East-West orientation to avoid the heat from the East and West wall surfaces.

Figure 5.9: Spiders' web (Micrathena gracilis)

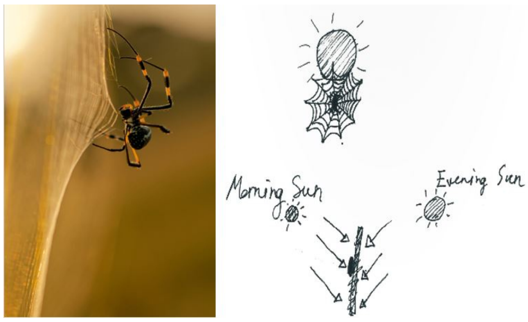


Figure 5.10: Spiders web's temperature control strategies

√ Pinnacle .3: Termite mound of the savannah biome

While some termites live in the wood of our homes, others build their own houses, some of the most impressive structures in the animal world. Their mounds are forever-evolving cities, made from the simplest materials. Working independently, without any coordinator or blueprint to reference, they construct temperature-controlled environments that include ventilation and cooling/heating systems, and specialized chambers that store food, contain fungal gardens, hold eggs, and house the egg-producing queen. As a colony, they are able to create worlds that far exceed their individual capabilities.
Termites probably deserve nature's bioclimatic architecture prize. Termites build mounds up to 3.7 m high, 1m thick and 3m wide that have their long axis aligned north to south, to present a large surface in morning and evening sun and a small surface at midday sun (Figure 5.11).

The Termites usually congregate in the shaded west side of the mound in the morning and on the shaded east side in the evening. The slim shape of the mound allows sufficient air ventilation through the pores of the surfaces.
This mound can maintain a steady internal temperature of around 30^0 C despite the temperature variations occurring throughout the day.
The structural features of the mounds allow heat dissipation and retention, for example: variation in wall thicknesses, mound surface design or projecting structures, and orientation.
This model for termite mound function was Martin Lüscher's thermosiphon mechanism, in which the mound is a venue for metabolism-driven circulation of air. Here, the colony's production of heat (roughly 100 watts) imparts sufficient buoyancy to the nest air to loft it up into the mound and to drive it eventually to the mound's porous surface. There, the spent air is refreshed as heat, water vapor and respiratory gases exchange with the atmosphere across the porous walls. The higher density of the refreshed air then forces it downward into open spaces below the nest and eventually through the nest again. This mechanism was thought to operate in mounds with capped chimneys, those that have no obvious vents.

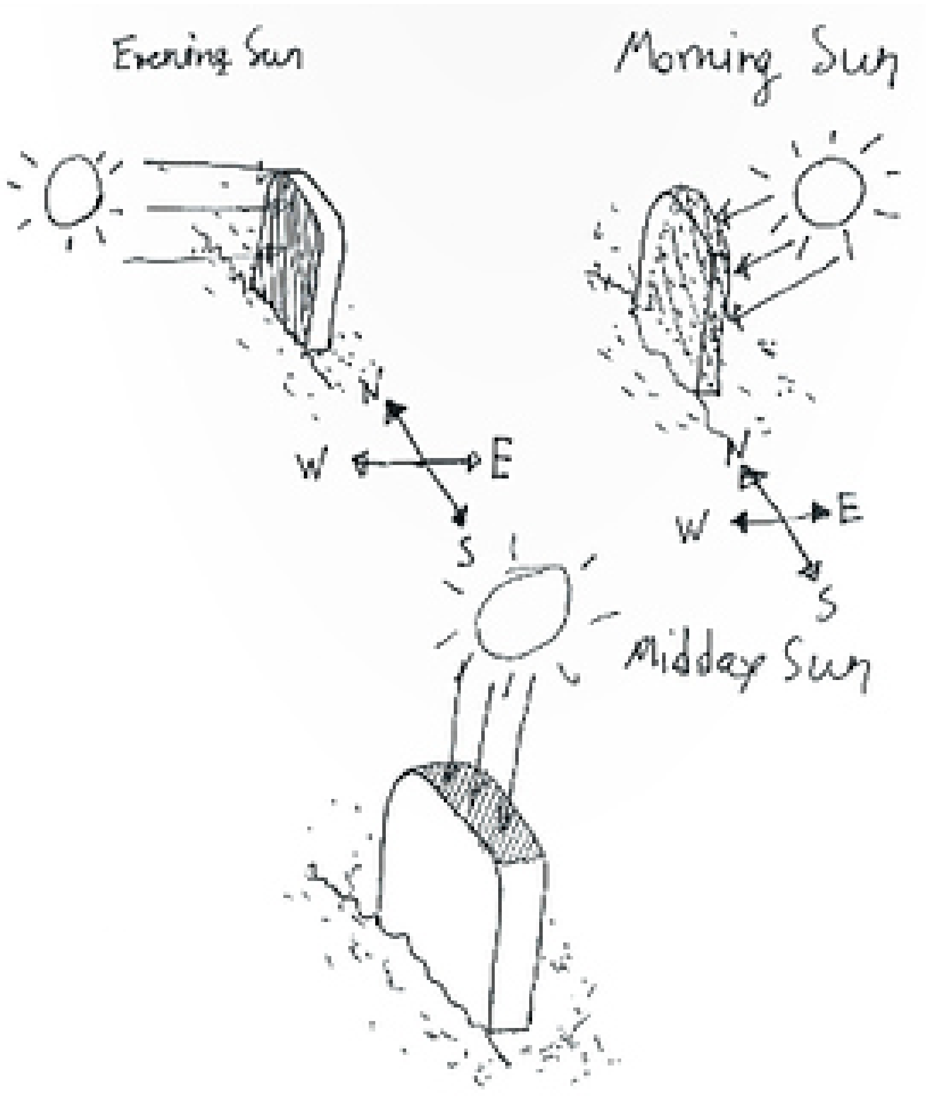


Figure 5.11: Termite mound orientation

This termite mound have thin walls with numerous ridges and turrets, which results in more heat dissipation. They have air passages close to the surface without chimneys that ventilate through natural convection. Thus, the mound balances between temperature regulation and ventilation. The gas exchange occurs through holes all over the surfaces of the mound.

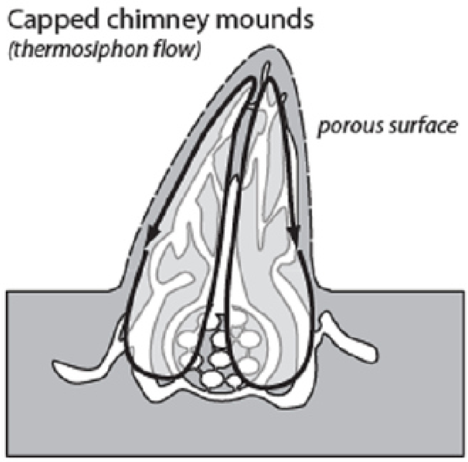


Figure 5.12: Thermosipheon flow mound

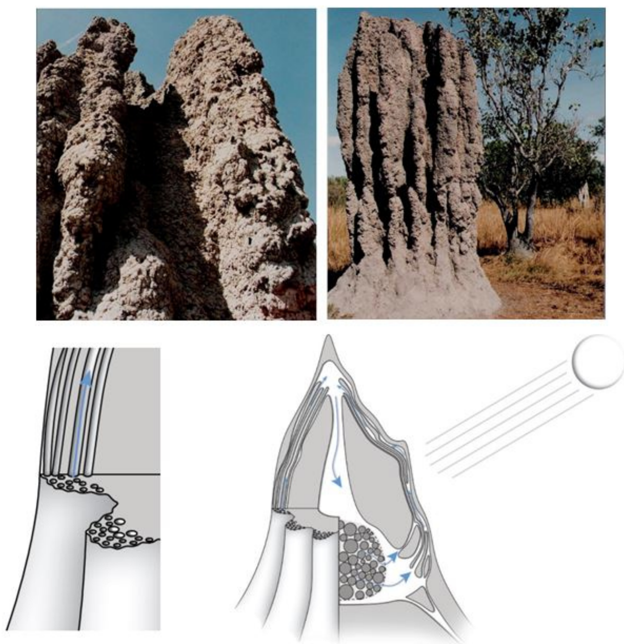


Figure 5.13: Porous surface of the capped chimney mound

Bioclimatic design tips from termites

1. A clever shape and positioning on a building allows us to use the heat from the sun when we need it, and avoid it when there is a danger of overheating.
2. A big (external surfaces) / (built mass) ratio means that more spaces are close to the outer environment and can be ventilates through openings.
3. The design of the building should vary according to the local climatic situation.
4. During daytime, different spaces of the building might be more pleasant, which can be used to wisely distribute functions of the building in the floor plan.

√ Pinnacle .4: Macrotermes michaelseni mound

The fungus cultivating termites, Macrotermes, develop mounds that are among the most spectacular architectures created in nature. They are found in the tropical and sub-tropical regions of Africa, South East Asia and Australia. Termites of the order 10 mm in length can build structures over a thousand times their own size. Biologists know this model as induced flow, but it is probably better known to architects and engineers as the stack effect. This mechanism was thought to occur in open-chimney mounds. Because the mound extends upward through the surface boundary layer, the large chimney vent is exposed to higher wind velocities. A Venturi flow then draws fresh air into the mound through the ground-level openings, then through the nest and finally out through the chimney. Unlike the thermosiphon model's circulatory flow, induced flow is unidirectional.

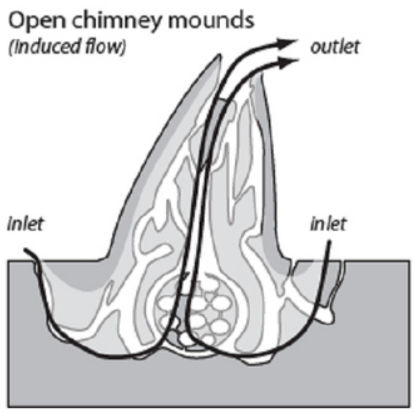


Figure 5.14: Induced flow mound [Turner 2008]

Outwardly, the mound consists of three parts (figure 5.15) :

- A columnar spire atop a conical base. The spire reaches on average about three meters high, but it can reach as high as 9 meters.
- A conical base, roughly 4-5 meters in diameter and roughly 1.5 meters tall
- A broad outwash pediment, roughly 10-20 meters in diameter, consisting of soil eroded from the mound.

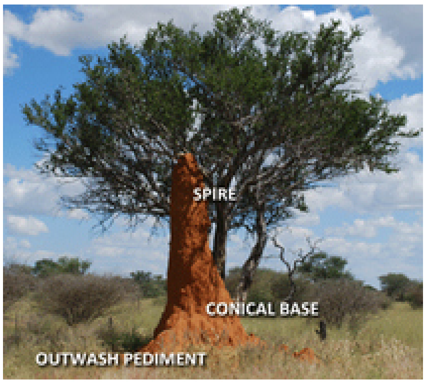


Figure 5.15: Elements of external Macrotermes michaelseni mound structure

The relatively simple external architecture masks one of the most sophisticated animal-built structures on the planet. Inside the mound is an extensive reticulum of tunnels and conduits, which reveals its function: the mound is an organ of physiology for the termite colony super-organism, which is centered on the underground nest(Figure 5.16). As mentioned in figure which represents an experience done by the researcher turner which show the internal structure of a Macrotermes michaelseni mound, where we found:

a Plaster cast of a portion of the superficial tunnel network showing egress tunnels and surface conduits. The mound surface has been partially washed away.

b Plaster cast of the deep tunnel reticulum in a mound of Macrotermes michaelseni.

c Plaster cast of the subterranean reticulum that envelops the nest. The nest is just visible behind the reticulum.

d A horizontal slice at roughly 1 m above ground level through a plaster filled mound. The reticulum and surface conduits are indicated.

e Cross section through the subterranean nest, showing the galleries (the fungus combs are the yellowish masses inside the galleries) and the base of the chimney opening into the nest

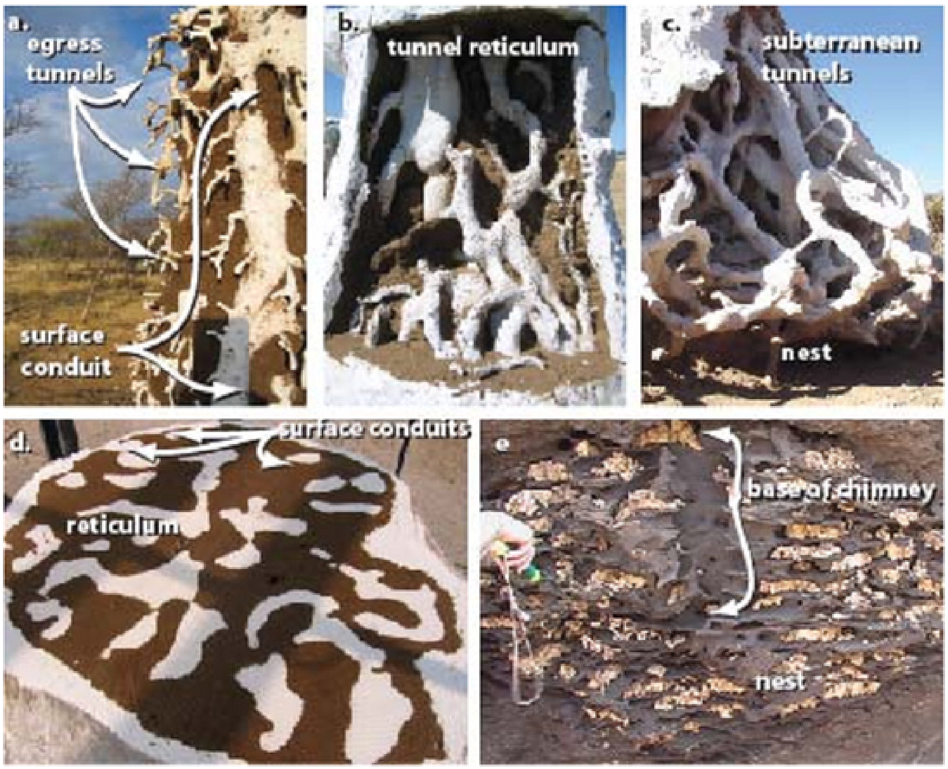


Figure 5.16: Internal structure of a Macrotermes michaelseni mound [Turner 2008]

The mound (Figure 5.17). is constructed out of a mixture of soil, termite saliva and dung. Although the mound appears solid, the structure is incredibly porous. Its walls are filled with tiny holes that allow outside air to enter and permeate the entire structure. The top of the mound consists of a central chimney surrounded by an intricate network of tunnels and passages. Air travels through the porous walls into a series of small tunnels until it reaches the central chimney and rises up. When fresh air mixes with this warm air, the air cools and sinks down into the nest. This ventilation system constantly circulates the air and ensures that oxygen reaches the lower areas of the mound and keeps the nest from overheating.
Termites do not live throughout the mound but spend most of their time in a nest located at or below ground level. It is comprised of numerous galleries separated by thin walls. Workers are constantly repairing areas that require maintenance and adding new tunnels and corridors to the nest.
At the base of the mound are several openings that the termites use to enter and exit the nest. Termites make forays out to collect food at night, when temperatures are cooler. Six feet below ground level is the cellar. It is the coolest part of the structure. Its ceiling is comprised of a series of thin plates that absorb moisture from the colony above and provide another ingenious cooling mechanism. As the moisture evaporates, the temperature falls, cooling the air around the nest.

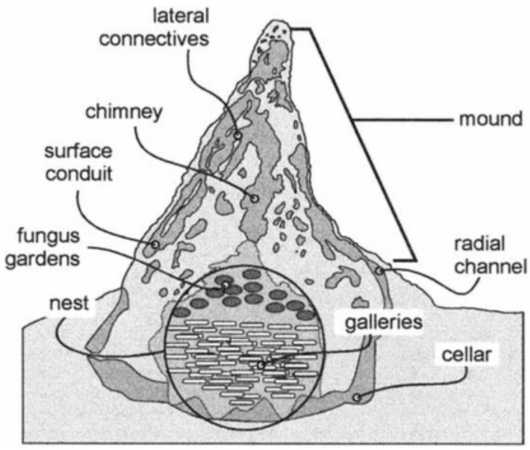


Figure 5.17: Diagram of termite mound structure [Turner 2001]

- Ventilation and gas exchange of termite mounds

The nest is out of equilibrium due to the driving flux of the metabolic demand from the termites and the fungus and so homeostasis is achieved by balancing the metabolic demand with the ventilatory flux [Turner 2008] due to complex boundary layer pressure gradients across the surface of the mound due to flow of wind. The disequilibrium between the nest and the outside air is the partial pressure of O2 below atmospheric, the partial pressure of CO2 above atmospheric and a high relative humidity close to saturation compared with a low to medium relative humidity typical of the locations where the nests are found.
Turner [Turner 2001] investigated Macrotermes michealseni. The proposed new model describes the mound as an organ for the exchange of respiratory gases. Gas exchange is driven by the interaction of the mound, the nest, the wind and the buoyancy due to the metabolic output of the termites and the fungi.
Ventilation of the nest and mound is driven by temporal variations in wind and so is 'tidal not circulatory'. The action of the wind sets up complex fluctuating pressure fields across the mound surface and induces mixing in the surface conduits. The temporal variations in wind velocity are the transients and can vary considerably in frequency and amplitude, so the mound may act as a low-pass filter to block the high-frequency, fluctuating components to leave a steady, reliable component [Turner 2008]. Tracer gas measurements have shown that the central chimney acts as a space for respiratory gas exchange rather than a conduit for ventilation and so suggests that the simple thermosiphon model does not adequately describe the processes involved.
A hole in the top of the building along with a vertical corridor (chimney) leading to it allows hot air to escape the building naturally.

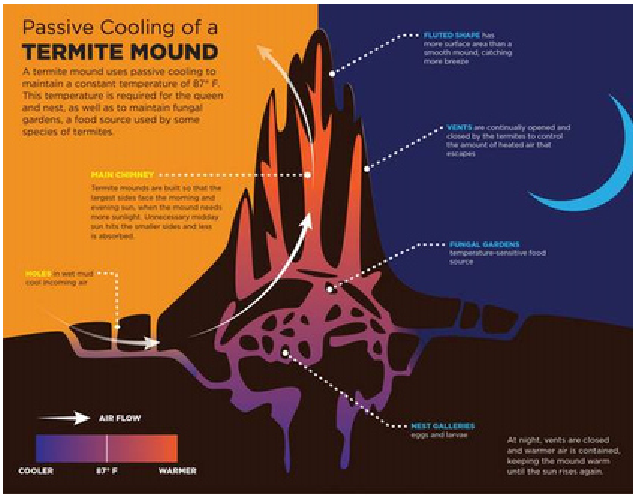


Figure 5.18: Passive cooling of a termite mound

√ Pinnacle.5: The burrow of the prairie dog

The prairie dog is a rodent of the family Sciuridae. They occupy arid environments, and prefer areas without vegetation and wind barriers. They live in long and narrow burrows about 12cm in diameter, 10-30 m long, and 1-5m deep, with 2-3 m entrances [Badarnah 2012].

The burrow systems of prairie dogs are usually complex underground corridor systems that need to be ventilated to import the O2 needed and keep CO2 in low levels.

Figure 5.19: Black tailed prairie dog

On both sides of long corridors, the prairie dog builds mounds for wind entrance and wind exit. The mechanism to achieve this ventilation is based on Bernoulli's principle: the pressure over the exits is lower than pressure over the entrances and this causes an air flow from the entrances to the exists. The entrances are wider and on a lower mound (half the height of the exit mound), and thus the air speed over the exits is bigger than over the entrance.

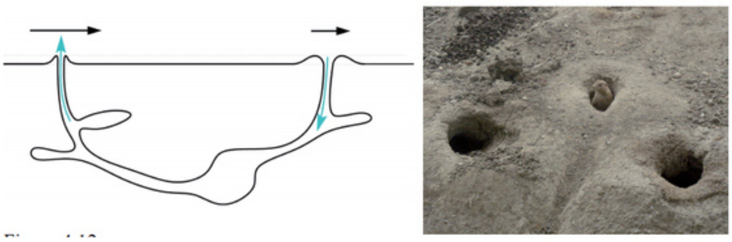


Figure 5.20: Prairie dog's burrow

Design tips by prairie dogs

1. Air flow parallel to the surfaces of the building can be used to motivate ventilation inside the building.
2. The opening designed to be the entrance of the incoming air should be lower than the opening designed to be the exit.
3. Air streams inside the building decrease humidity.
4. The route of the ventilation stream should be carefully designed.

Figure 5.21 presents the summary of the analysis of the five pinnacles, taken from the functional model of air and thermal regulation; this table offers us a reference and functional recommendations to apply them in the design process.

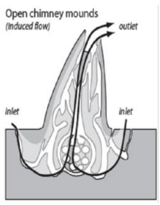
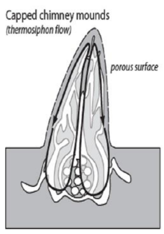
	The pinnacle	Strategy	Mechanism	Main principle	Main feature
AIR	Macrotermes michaelseni mound 		A Venturi flow draws fresh air into the mound through the ground level openings, than through the nest and finally out through the chimney, which is exposed to higher wind velocities.	Induced flow	Chimneys and air passages.
	The Burrow of the prairie dog 	Special architectural features to ventilate their long and narrow Burrows.	Induce the air flow by creating velocity gradients on the ground surface through building mounds for wind entrance and wind exit.	Bernoulli's principle	The entrance openings should be lower than the exit openings.
HEAT	Galinaceous Birds 	They build mounds to warm their eggs without having to sit around all day.	The mound from dead leaf produces heat; in cold weather it has to be as close as possible to retain the inside heat, in hot weather openings are necessary.	Biomass	Rotting biomass could be a cheap way of heating especially in cold time.
	Spiders (Micrathena gracilis) 	They have an interesting temperature control strategy in different spaces.	The structural feature of the spider's web keeps the web's user cooler.	orientation	Proper orientation depends on the amount of shade or light in the area.
	Termite mound of the Savannah biome 	The inhabitants construct temperature controlled environments that include ventilation and cooling/heating systems and they modify it in accordance to the environment changes.	The structural features of the mound allow heat dissipation and retention: wall's thickness, orientation, porosity…	Natural convection	Pores , air passages.

Figure 5.21: Summary of pinnacles analyses

5.4 DATA MATRIX

After analyzing the selected pinnacles, we apply the Data matrix because we need one imaginary pinnacle for each challenge to lead the transition phase from biology to design. In figure 5.22 we indicate that in the shaded line the dominant features that correspond to the different categories for each individual challenge.
We need another level of abstraction because the preceding phase may give us several imaginary pinnacles. In order to identify the dominant features to be addressed in the integrated design concept, we use the design path matrix, where we superpose the imaginary pinnacles (from preceding phase: pinnacle analyzing matrix).

	Process				Flow		Scale		Environmental context				Structural features					Other features	
Challenges	Pressure difference	Diffusion	Insulation	Convection	Active	Passive	Micro	Macro	Arid	Tropical	Moderate	Continental	Chimney	Pores	Air passages	Orientation	Biomass	Peripheral flow	Unidirectional flow
Exchange -Macrotermes michaelseni mound	X	X				X		X	X	X			X		X		X		X
Movement -prairie dog Burrow	X					X		X	X		X	X			X				X
Imaginary pinnacle for Air regulation	X	X				X		X	X				X		X				X
Retention -Galinaceous Birds			X			X		X	X		X	X		X		X	X		
-Spiders			X			X		X	X										
Dissipation -Termite mound of the Savannah biome				X		X		X	X	X				X	X	X	X	X	X
Imaginary pinnacle for Thermoregulation			X	X		X		X	X					X	X	X	X	X	X

Figure 5.22: Pinnacle analyzing matrix [Khelil 2015]

The previous step may derive multiple imaginary pinnacles; we need another level of abstraction. The design path matrix represents the superposition of the imaginary pinnacles (from previous step) and determines the dominant features to be addressed in the integrated design concept (in the next step). In the design path matrix tool (Figure 5.23) we find the dominant features (dashed forms) are the features that have the larger number of links from the different imaginary pinnacles, where the larger number of links (counting line styles) the more dominant the feature becomes. Numerous pertinent features from the several categories for the design concept are indicated in the design path matrix.

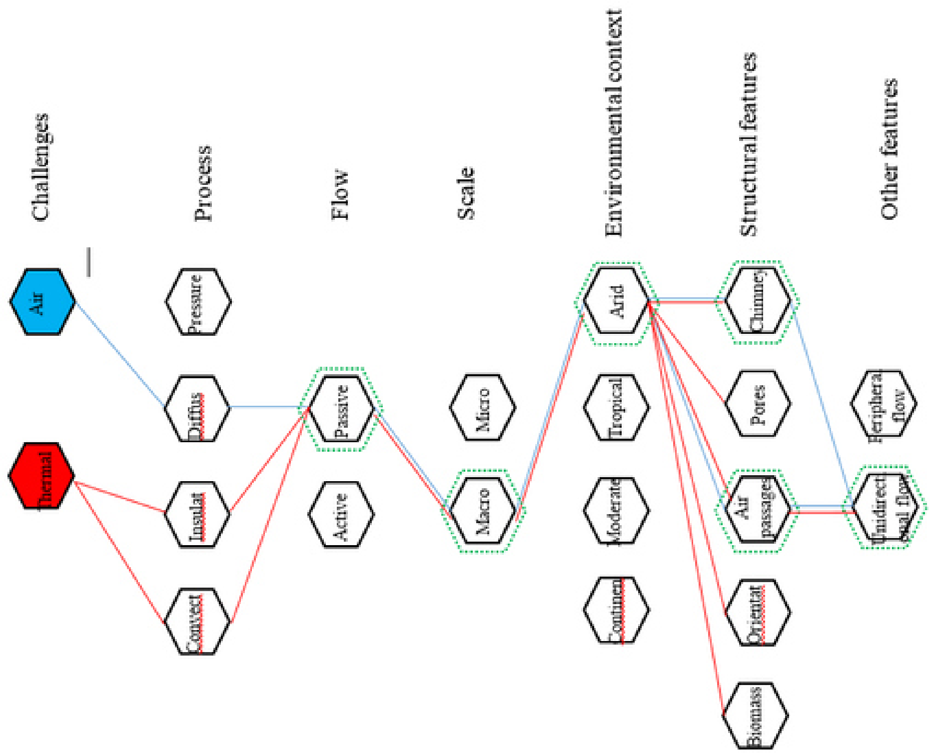


Figure 5.23: Design path matrix [Khelil 2015]

Each vertical column represents a category and its various features. Red lines denote the path of thermoregulation, the blue lines denote the path of air regulation, and the green nodes denote the dominant features, which represents the design path. The derived dominant features from the design path matrix are:

- The flow is passive for all functions.
- The macro scale is the relevant scale for all functions.
- The imaginary pinnacles share arid environmental context.
- The morphological features are independent for each specific function.
- The structural features are Chimneys for air regulation and air passages for thermoregulation.

After outlining the dominant features, in order to achieve the design concept proposal; we have to transform the design path matrix into a design concept for natural ventilated building located in Biskra, a hot and arid region, and then we have to estimate and evaluate its performance by making a comparison of this model with the existing state of the building.

5.5 PRESENTATION OF THE CASE OF THE STUDY

The city of Biskra, located in Algeria, is chosen for its representativeness of the hot and arid environments in the country. It has a rigorous climate characterized by very hot, dry summer and cold winter. Meteorological data of Biskra shows that The average temperature ranges from a maximum of $44,9^0$ C and a minimum value of -2.1^0C with high insolation, exceeding 3500 h / year and intense direct sunlight which can reach 900 to 1100 W / m2 on a horizontal plane, with rare and irregular rainfall. In addition to these unfavorable characteristics, this city is characterized by violent sandstorms. Its characteristics are unfavorable to achieving thermal comfort. More climatic details about this region will be provided in chapter 6.

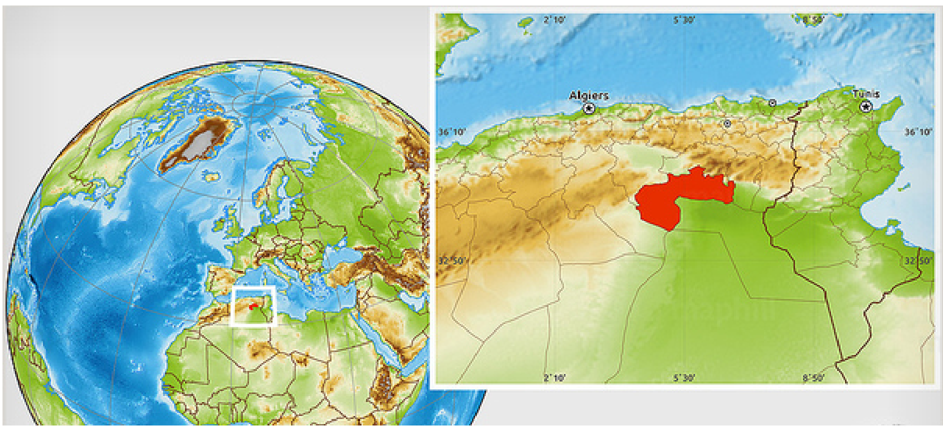


Figure 5.24: location of Biskra

We will apply the Biobrainstorming methodology proposed before to prove that we can learn from nature to better design our buildings. So to achieve our goal a collective building was chosen as the climatic conditions of the city of Biskra in order to control the summer and winter comfort in addition to considerably reduce costs for air conditioning and heating which characterizes the sick building syndrome.

Our study focuses on the typology of the most common habitat in this town. Indeed, collective buildings, contemporary architectural style, allows a study of the comparative analysis of the type and number of samples initially having the same characteristics, some of which have undergone transformations from their acquisition by the inhabitants.

Those residential buildings (Figure 5.27) have a built environment marked by:

- An arbitrary location,

- An architypique form, dispersed and fragmented,

- Similar facades exposing their windows to weather conditions, so that these conditions can be moderated by creating pleasant microclimates.

- With an arbitrary orientation of the facades where the prototype can be subjected to various directions, without considering neither the amounts of energy consuming or thermal comfort inside the group housing, not to mention the use of materials non-adapted to the climatic requirements while it increases losses including the important need for air conditioning and heating.

These constructions are done in ignorance of the knowledge related to climatology, comfort and thermal behavior of building materials. The selected building to do the experiments is a part from "la cité des 500 logements " in Biskra.

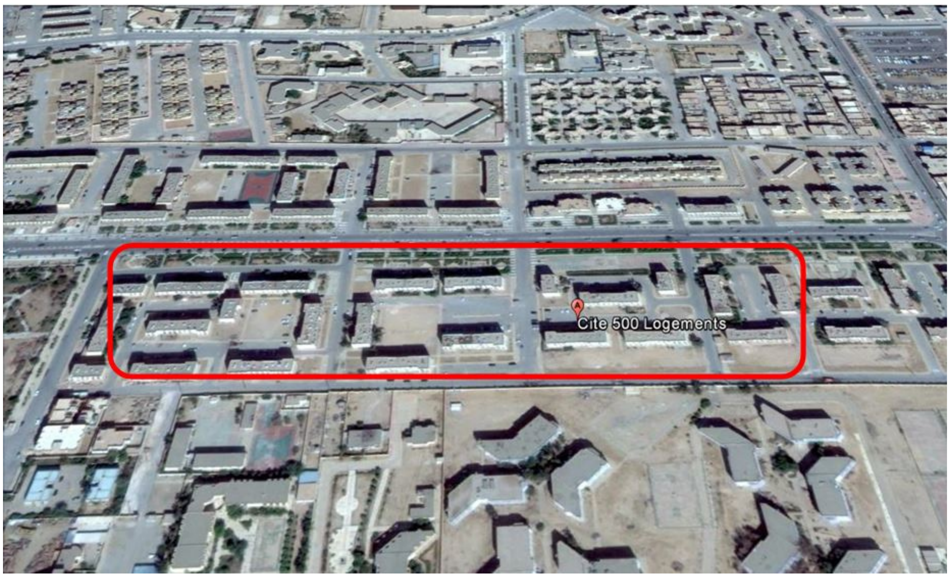


Figure 5.25: situation of the case of the study

Figure 5.26: Situation of the selected building

Figure 5.27: Selected building

5.6 PRESENTATION OF THE OUTLINED DESIGN MODEL

Considering the climate of the region, passive ventilation aim represents a major challenge for us architects that is why we propose, as an architect, a design model inspired by different pinnacles analyzed before and systems perfected that keep an indoor environment in a moderate level of comfort.
In order to reach our aim, we have to apply the outlined features from the Bio-brainstorming methodology by transforming them into a design concept: ”A breath of fresh air”, which is a design concept for natural ventilated building located in Biskra, a hot and arid region. We propose for this design concept ”A breath of fresh air” (Figure 5.28), an induced or stack effect ventilation process.

Figure 5.28: Outlined model ”a breath of fresh air”

5.6.1 CONFIGURATION OF THE DESIGN CONCEPT "A BREATH OF FRESH AIR"

We tried to incorporate both the thermosiphon and induced flow principle into our design. The building has an extensive tube system within the floors that move air through the building. Heat generated within the building, along with stored heat within the structure, creates a thermosiphon-effect that draws air up and through the rooftops where chimney stacks are located. These tall stacks are essential for creating an induced flow.
The design model have chimneys at the top that opens to the outside. This arrangement creates induced flow, also called the stack effect. The chimneys break the surface boundary layer and is exposed to higher wind speeds compared to inlets on the ground. The unidirectional flow draws fresh air from near the ground into the basement, where it passes on through the chimney and ultimately to the outside.
For certain, the building works on the termite mound and the other pinnacles principles but we cannot ignore the fact that the building uses fans during the day, and during the night to keep the air from being too stagnant (Figures 5.29, 5.31, 5.32).

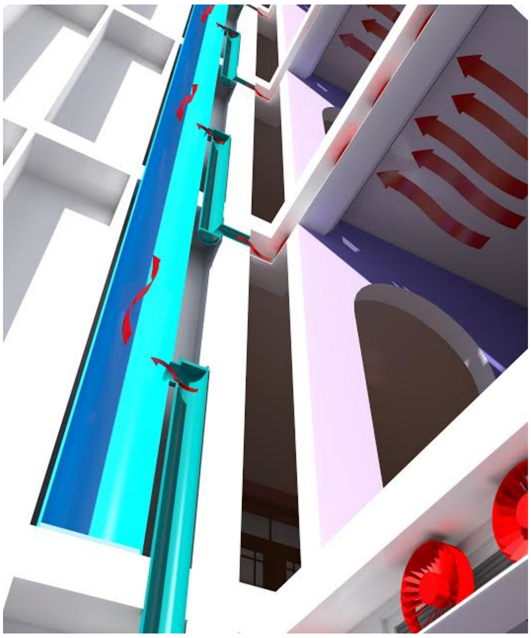


Figure 5.29: Use of fans in the heat accumulation box

The use of fans for keeping the environment within the building comfortable and push the heat out through the ducting in the ceiling.

5.6.2 HOW DOES THE NEW MODEL WORK?

The structure of our new design model based on the use of stack ventilation, fans, thermal mass and buoyant air all mimic the relevant features of the analyzed pinnacles (Figure 5.28).
It is built around a heat core (Figure 5.30) which contains chimneys, where the hot air generated by its occupants being naturally drawn through convection out of the chimneys, and the radiant heat being transmitted into the thermal mass, which further enhances the convection. Fans suck in cold air, which passes through the building, cooling the thermal mass.

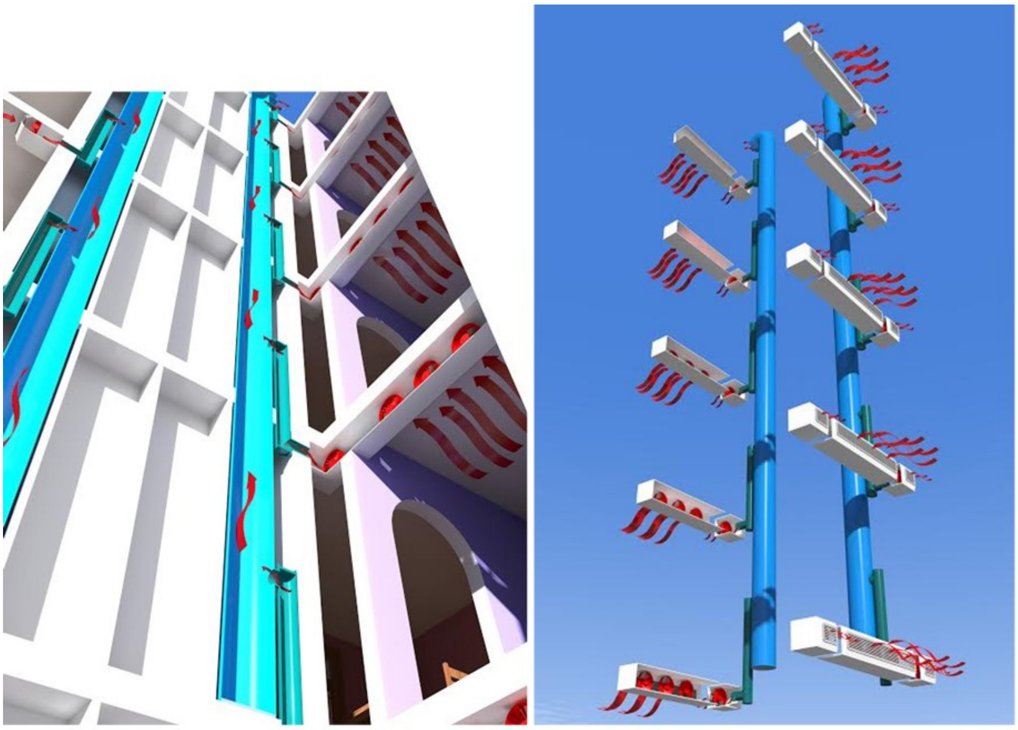


Figure 5.30: Heat core

Outside air that is drawn in is either warmed or cooled by the building mass depending on which is hotter, the building concrete or the air. It is then vented into the buildingâs floors via the fresh air box (Figure 5.33) before exiting via chimneys at the top.

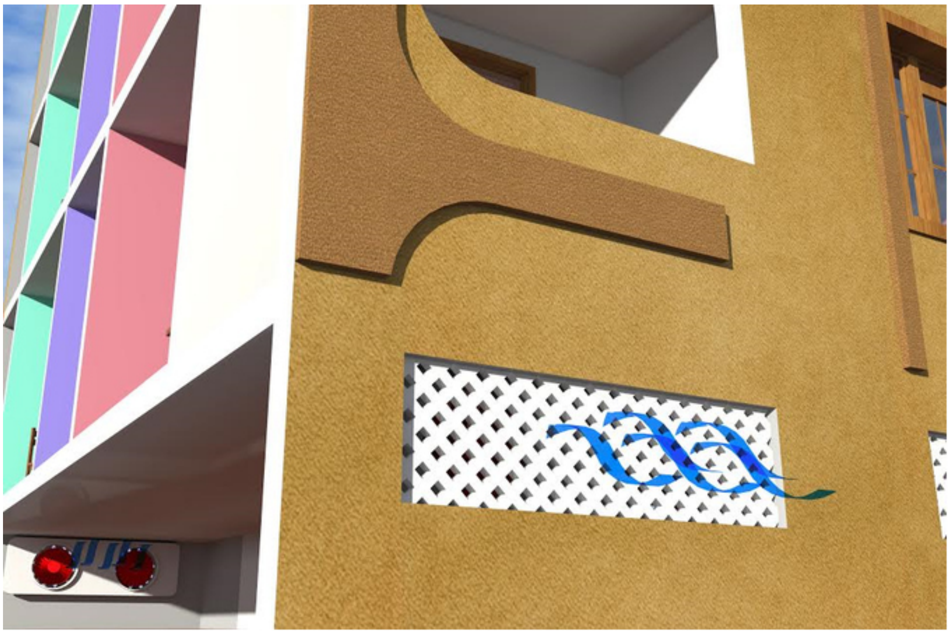


Figure 5.31: Basement's openings

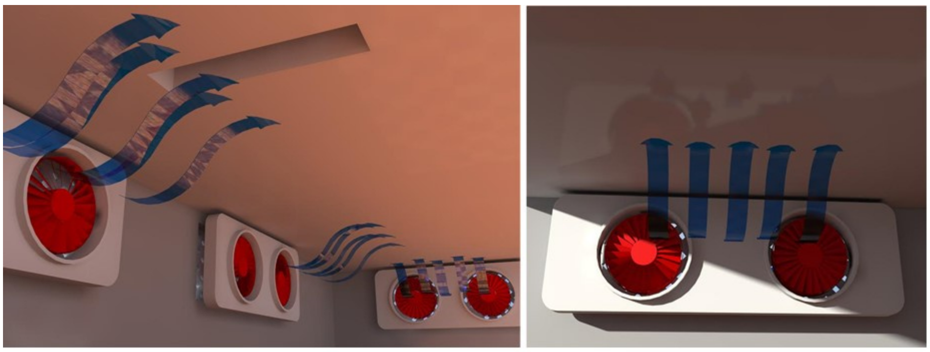


Figure 5.32: Use of Fans in the basement

Air is continuously drawn from this open space by fans on the basement. It is then pushed up vertical supply sections of ducts that are located in the central spine.

The fresh air replaces stale air that rises and exits through exhaust ports in the

Figure 5.33: Fresh air box

ceilings of each floor. Ultimately it enters the exhaust section of the vertical ducts before it is flushed out of the building through chimneys.

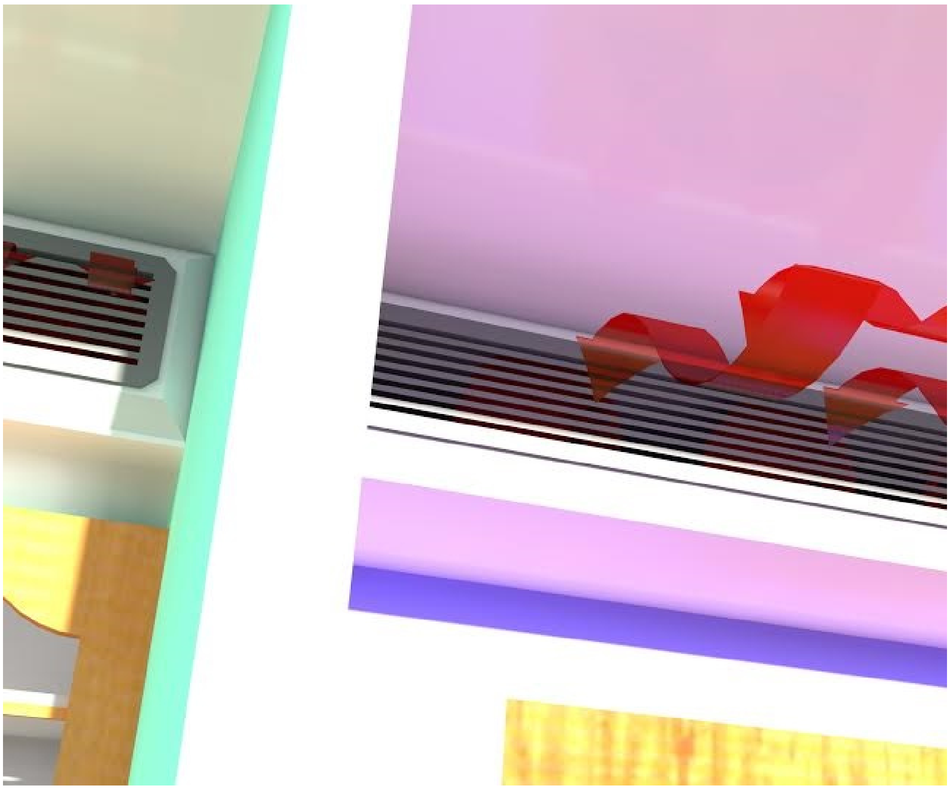


Figure 5.34: Heat accumulation box

Figure 5.35: Connections to the heat core

The hot air is drawn into the top of the building, and then it is discharged through the chimneys. This phenomenon causes a flow of air in the lower parts of the building: the air is sucked through these inner parts thanks to small openings all around the building in the basement (Figure 5.31). This fresh air backs into the staircase and then it will be distributed in the apartments for refreshing them. When heating, it is then attracted by the top of the building, and so on (Figure 5.28).

5.7 CONCLUSION

In this chapter, we have developed a new systematic methodology to prove that we can learn from nature in order to better design our buildings, which is called the Bio-Brainstorming methodology. The main principle of this methodology is to identify the relevant systems and strategies in nature to find new alternatives for the energy optimization and saving.
An implementation of the Bio-Brainstorming methodology, which creates an investigation platform for the architects, is demonstrated to solve a particular architectural challenge of a hot and arid region: the buildingâs ventilation. We have chosen a collective building located in the 500 housing units in Biskra as a case of the study, where we have applied the outlined features from the Bio-brainstorming methodology by transforming them into a design concept: ”A breath of fresh air”. The configuration of our new design model based on the use of stack ventilation, fans, which all mimic the relevant features of the analyzed pinnacles. To validate this configuration we will proceed, in the next chapter, to the simulation using Computational Fluid Dynamics methods using the design day of the region of Biskra.

Chapter 6

SIMULATION, RESULTS DISCUSSION

" You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete."
- - Buckminster Fuller

Contents

6.1 INTRODUCTION

Natural ventilation is a main sustainable strategy in building designs, and it has considerable interests from designers, because it may provide occupants with good indoor air quality and a high level of thermal comfort, and reduce energy costs. There are three approaches available to study natural ventilation: empirical models, experimental measurements, and computational fluid dynamics (CFD) simulations. CFD is becoming popular due to its informative results, low labor costs, and little equipment requirement. In our research, we use CFD simulations (Phoenics code) to study the air flow in the building [Evola 2005]. In this chapter we will present, in one hand, the notion of the design day and ,in the other hand, we will develop a new method for selecting Biskra's design day in the aim to use it in the simulation of the outlined model to prove that we can reach the vitality of the architecture.

6.2 FUNDAMENTALS OF COMPUTATIONAL FLUID DYNAMICS (CFD)

6.2.1 INTRODUCTION OF CFD

Computational Fluid Dynamics (CFD) is becoming available as a tool to assist with modeling the airflow and dispersion of pollutants among complex urban geometries on the scale of a section of a building exterior up to several city blocks. This tool allows more accurate predictions of impacts over a range of meteorological scenarios and alternative building designs and placements relative to roadways and other pollutant sources. Examples of its uses have been shown in Figure6.1 and Figure 6.2

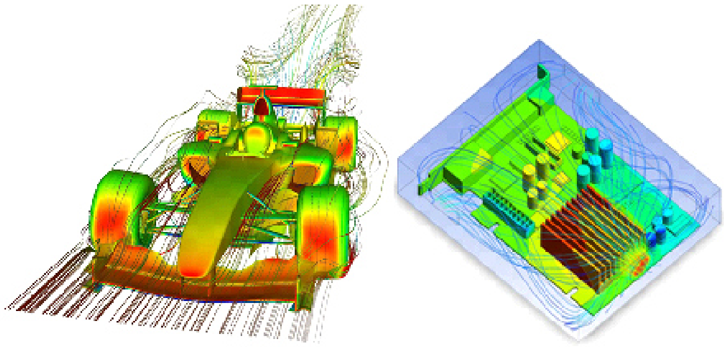


Figure 6.1: Different experimental observations based on CFD

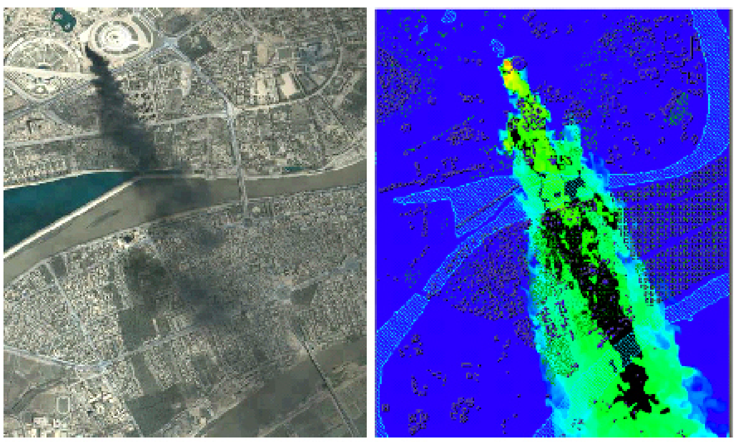


Figure 6.2: CFD Simulation of Smoke plume from an oil fire in Baghdad

Computational Fluid Dynamics, more commonly known as its acronym CFD, is a branch of fluid mechanics that uses numerical methods and mathematical algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform calculations required to simulate liquids or gases interaction with surfaces defined by boundary conditions. To do that, specialized and high technology software are needed, to perform such complex calculations [Houda 2011] CFD allows building a virtual prototype of a product or process to simulate actual conditions of functioning. CFD is a complement to other modeling and experimental techniques to get an accurate description of fluid flow problems. CFD also allows us to ask questions like "What will happen if ...?", To examine the consequences of certain technological choices and validate a design.

6.2.2 AVAILABLE CFD SIMULATION CODES

CFD codes are widely used in the study of global warming, urban climate, microclimate, building ventilation, indoor air quality, indoor and outdoor thermal comfort, fire safety, and smoke extraction. Building simulation using CFD software is gaining popularity due mainly to new standards on health and comfort in the built environment and the need to design internal spaces and HVAC systems that meet the required standards criteria [Versteeg 2007].

In the CFD domain, the most common commercial codes include OpenFoam, OpenFlower, FLASH, ANSYS CFX, ANSIS ICEM CFD, FLOW3D, PHOENICS, FIDAP, FLOVENT, FLUENT, and STA RCD$\cdots$

a- OpenFOAM

OpenFOAM is a free, open source CFD software package produced by a commercial company, OpenCFD Ltd. It has a large user base across most areas of engineering and science, from both commercial and academic organisations. OpenFOAM has an extensive range of features to solve anything from complex fluid flows involving chemical reactions, turbulence and heat transfer, to solid dynamics and electromagnetics.

b- OpenFlower

OpenFlower is a free and open source CFD code (for Linux and Windows) mainly intended to solve the turbulent incompressible Navier-Stokes equations with a LES approach. It can deal with arbitrary complex 3D geometries with its finite volume approach.

c- FLASH

A modular, parallel adaptive-mesh code initially designed for thermonuclear runaway problems but now capable of a wide variety of astrophysical problems. Includes modules for MHD, nuclear burning, radiative cooling, self-gravity, particle dynamics, and cosmological expansion.

d- ANSYS CFX

ANSYS CFX computational fluid dynamics (CFD) software, it delivers the ability to apply the most powerful and precise CFD technology to virtually every fluid engineering problem. Explore in depth the technology and advantages of ANSYS CFX using the chart below or menu on the left.

e- ANSYS ICEM CFD

ANSYS ICEM CFD is the only Universal pre-processor for analysis including FEA, CFD and other CAE applications such as particle transport and computational electro-magnetics. Used for engineering applications such as computational fluid dynamics and structural analysis, ANSYS ICEM CFDs mesh generation tools offer the capability to parametrically create grids from geometry in multi-block structured, unstructured hexahedral, tetrahedral, hybrid grids consisting of hexahedral, tetrahedral, pyramidal and prismatic cells; and Cartesian grid formats combined with boundary conditions.

f- FLUENT

It is a computer code for simulating fluid flows with and without heat transfer in simple and complex geometries. It can solve flow problems with structured and unstructured meshes, produced with complex geometries easily.

g- COMSOL Multiphysics

COMSOL Multiphysics is a modeling package for the simulation of any physical process with partial differential equations (PDEs). It features state-of-the-art solvers that address complex problems quickly and accurately, while its intuitive structure is designed to provide ease of use and flexibility. Fast results and unprecedented flexibility make COMSOL Multiphysics the ideal modeling and simulation software for research, product development, and education.

h- CFDRC

CFDRC offers unique capabilities for Multiphysics, Multiscale, and Coupled Simulations of fluid, thermal, chemical, biological, electrical, and mechanical phenomena for real-world applications. CFDRCs technologies, products, and services enable better understanding of complex problems, and lead to better decisions resulting in better concepts, designs, products and systems.

i- STAR-CD

The STAR-CD solver provides one of the most effective numerical methodologies available in an industrial CFD code with the high level of accuracy needed for complex unstructured meshes. This is delivered with the speed, efficiency and robustness demanded by engineering design and development cycles. STAR-CD uses state-of-the-art, proprietary numerical schemes to achieve the highest levels of accuracy in both steady and transient simulations, making this solver one of the least sensitive to mesh type and quality, including distorted tetrahedral meshes. Remarkably, this has been achieved without sacrificing efficiency or robustness. Therefore, whatever the choice of mesh or engineering application, the STAR solver will provide the best solution in the shortest time.

j- FLOW3D

FLOW-3D is a powerful modeling tool that gives engineers valuable insight into many physical flow processes. With special capabilities for accurately predicting free surface flows. FLOW-3D is an all-inclusive package. No special additional modules for meshing or post-processing are needed. An integrated graphical user interface ties everything together, from problem setup to post-processing.

K- FIDAP

It is the CFD solver of choice for a wide variety of laminar and turbulent flows. Based on the finite element method, FIDAP delivers accurate and efficient solutions for problems involving fluid flow, heat transfer, mass transfer, dispersed phase flow; free surfaces, solid/ liquid phase change and fluid-structure interaction.

L- PHOENICS

A CFD code "Phoenics" is used in this study to simulate the airflow in the existing case of the building and the new design model; we provide more details about this code.

6.2.3 OVERVIEW OF THE PHOENICS CODE

PHOENICS (Parabolic Hyperbolic or Elliptic Numerical Integration Code Series) is a sophisticated code that utilizes Computational Fluid Dynamics (CFD) to numerically simulate different types of engineering problems, such as flow and reaction problems, using a highly accurate set of flow and reaction. CFD is the mathematical simulation of fluid dynamics problems using the physical and mathematical formulas and equations that govern the flow problems. Combustion, reaction, heat and mass transfer models implemented in PHOENICS can range from simple to sophisticated. PHOENICS allows the user to choose among several models based upon the nature of the problem, time available, and accuracy needed [Evola 2005].
PHOENICS is indeed employed primarily by:

- Scientists for interpreting their experimental observations;
- Engineers for the design of aircraft and other vehicles, and of equipment which produces power or which processes materials;
- architects for the design of buildings;
- Environmental specialists for the prediction, and if possible control, of environmental impact and hazards; and
- Teachers and students for the study of fluid dynamics, heat transfer, combustion and related disciplines.

PHOENICS is a "CFD code", i.e. a member, indeed the founding member, of that family of software packages, which embody the techniques of **C**omputational **F**luid **D**ynamics.
PHOENICS is developed by the British company CHAM, and it has been vastly used for different kinds of simulations that involve multi-phase flows, heat transfer, process with chemical reactions, particle tracking, smoke dispersion, aerodynamics, equipment efficiency analysis, ventilation and acclimatization and others. Its friendly interface, the possibility of load CAD files to the object geometries, an open-source routine for user-coding and its exclusive physical models are some of the important advantages of using PHOENICS on CFD simulations. The main features of PHOENICS are listed above:

- 2-D and 3-D geometries;
- Cartesian, Polar, Body-Fitted Coordinates, and Unstructured;
- Local multi-level fine-grid embedding;
- "PARSOL" Cut-cell technique for complex geometry;
- "INFORM" Input of user-defined Formula;
- Conjugate Heat Transfer;
- Single or Multi-Phase Flow;
- Particle Tracking;
- Chemical reaction;
- Radiation;
- Non-Newtonian Flow;
- Choice of equation solvers and differencing schemes;
- Automatic generation of user code;
- Open-source routine for user-coding;
- Automatic convergence control.

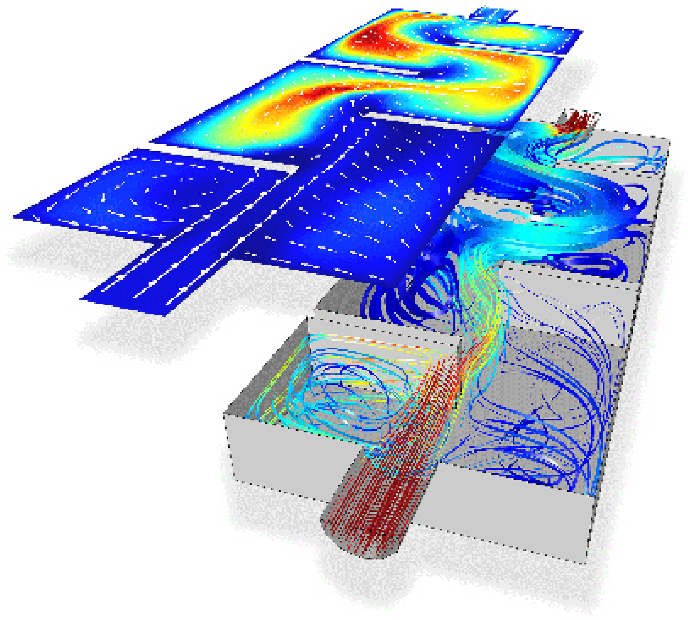


Figure 6.3: Study of fluid dynamics using PHOENICS.

6.3 BISKRA'S DESIGN DAY

Assuring interior comfort in the attempt to realize an energy economy is a task, without which, the design of a new modern building is not even conceivable. The climate factors have a big influence on the energy consumptions of buildings. The annual variations have determined the necessity, in our goal, to know how is the building's energetic behavior through a whole year, it provides an important basis for the design. However in this case we have to do a lot of simulations, which is a time consuming process, and in the other hand annual weather data are not easily available. This is why we have to choose a single day to represent the variations of meteorological parameters in our region; this day is called the Design Day. In this section, we will present an overview on this notion of the design day and how will be the procedure of its selection. This study concentrated on the selection of Biskra's Design Day, which could be used in our simulation.

6.3.1 DESIGN DAY OVERVIEW

6.3.1.1 Definition of the design day and its characteristics

The building's ventilation and energetic behavior simulation is an important phase in the design. the ventilation behavior of the building depends on the values of yearly meteorological parameters variations, which is a time consuming process, The difficulty is aggravated by the fact that annual weather data are not easily available and building designers involved in performance simulations are not the ones responsible for weather information gathering and recording. Consequently, we need an alternative reduced weather data as the design day, extracted from yearly weather information that can ensure shorter time and less complex simulation.

The design day is a real historical day, which reflects the natural hourly variations of meteorological parameters. We select it from a complete set of weather data for a single day chosen from the meteorological year. Theoretically, the design day is to be the day having the most adverse set of weather conditions to enable the design to meet the indoor comfort criterion all over the year when performing at their maximum capacity [Tianzhen 1999].

An important characteristic of a worst case meteorological period is that it can be representative of a class of meteorological conditions that occur in a region and can effect human comfort. This kind of days are known as prototype days.

The design day consists of 24 hourly values of climatic criteria parameters. Because of the significant thermal inertia of a building and its internal structure, the effects of the hour-by-hour fluctuation of the weather are not immediately felt but are distributed over several hours of the day. It is important that a better understanding of a region's meteorological conditions is established to aid in the design of building's ventilation and energy systems [COLDA 2008].

6.3.1.2 Simulations weather data

Over the past 20 years, several organizations have developed weather data sets specifically designed for use in building energy simulations, including EWY, TRY-US, TRY-ROW, TMY, TMY2, TMY3, IWEC, WYEC2, CWEC, and AMY, which are typically single year compilations for specific locations. Each year is compiled from 8,760 hourly records for the desired data parameters [Piotr 2013].

There are three general approaches to selecting weather years.

- The first approach selects a contiguous year where the monthly means and standard deviations for that year match the means and standard deviations for a longer period of record – often 15 to 30 years. Examples of this approach include EWY and TRY-US.

- The second approach involves creating composite years using representative months from different years. Examples of this approach include TRY-ROW, TMY, TMY2, TMY3, CWEC, WYEC2, and IWEC. Data selection therefore emphasized 'typical' years that are representative of these longer-term durations (e.g. 30 years).

- The third approach includes Actual Meteorological Years (AMYs), which represent hourly weather data from a single contiguous year that is not necessarily representative of a greater span of time. This approach is favored when examining a typical or extreme years.

Below we describe some of the major types of climate datasets used in energy modeling. The developers used standard methodologies to determine which data would be used from the actual weather data period of record. The methods were virtually the same; the true differences are related to the different weights applied to weather variables in the selection process.

- **TRY (TRY-US)-Test Reference Years** The TRY datasets were first created in 1976 by NOAA's National Climatic Data Center. They entail hourly data from 60 locations in the United States. The data include dry bulb temperature, wet bulb temperature, dew point temperature, wind direction, wind speed, barometric pressure, relative humidity, cloud cover, and cloud type. However, no measured or calculated solar data are included. When used for building energy simulations, the simulation program must calculate the solar radiation based on the cloud cover and cloud type information available in the TRY data. The representative year is obtained by eliminating years that contained months having high and low temperature means. This process continues until a single reference year remains. The elimination of extremes results in datasets, which are significantly more moderate than other contiguous years for the period of record. The TRY data therefore represent a poor choice when evaluating atypical or extreme conditions.

- **EWY - Example Weather Years** Example Weather Year datasets in the United Kingdom were also developed in the 1970s using methodologies similar to those used for TRY-US. These data were compiled using a representative contiguous year from a 20-year period of record.

- **TRY (TRY-ROW)-Test Reference Years** TRY datasets created in Europe and other parts of the world employed methods and data elements similar to those used in TMY datasets. Therefore, TRY-US and TRY-ROW are not interchangeable.

- **TMY-Typical Meteorological Year** A typical meteorological year (TMY) is a collation of selected weather data for a specific location, generated from a data bank much longer than a year in duration. It is specially selected so that it presents the range of weather phenomena for the location in question, while still giving annual averages that are consistent with the long-term averages for the location in question.
  TMY data is frequently used in building simulation, in order to assess the expected heating and cooling costs for the design of the building. It is also used by designers of solar energy systems including solar domestic hot water systems and large scale solar thermal power plants.
  To construct a TMY, we have to choose the main characteristics that can

be followed through hour values at least for 10 years (temperature, humidity, solar radiation, pressure, wind speed etc). The TMY files do a good job capturing typical conditions but (by design) do not show the extremes, which becomes increasingly important as the movement toward energy efficient design [ISHINO 2005]

The construction is done in two stages [COLDA 2008]:

A- In the first stage, a typical month is chosen based on meteorological data, recorded in several real years. For example, a typical January will be a real January from the observation years taken into account.

B- In the second stage, the data between two typical months (which can be from two different years) are adjusted, in order to do a smooth transition between months. There are a lot of smoothing variants, like, for an example, a local mediation with Gaussian variables or interpolation with cubic spline functions.

Two primary types of TMY files subsequently replaced the initial TMY file:

- TMY2 files that use 30 years of data replaced the initial TMY file in about 1990, with an enhanced weighted average selection method.
- TMY3 files that use 15 years of data were introduced in 2005 with a higher emphasis on solar radiation variables and also included precipitation as a variable. While statistically stable files require 30 years of data, the TMY3 utilized only 15 because that is the period where adequate satellite input was available.

- **WYEC – Weather Year for Energy Calculations** In 1983, ASHRAE created WYEC datasets as another means for simulating 'typical' weather patterns. This database was built on the TRY format utilizing solar data that was either measured or estimated from cloud cover and type.

- **CWEC – Canadian Weather for Energy Calculations** The CWEC datasets represent typical year data based on the WYEC2/TMY methodologies.

- **IWEC – International Weather Year for Energy Calculation** ASHRAE released IWEC weather files in 2000. These datasets contain 'typical' weather data based on the TMY format intended for use with building energy simulation programs. The IWEC format utilizes 18 years of hourly data.

- **AMY – Actual Meteorological Year** As the title implies, AMY files represent actual hourly contiguous datasets for a given location and time, where energy use data is available. It is used to manage and confirm the actual performance of a building. The advantage of AMY datasets is their flexibility and customization; however, when creating customized datasets. AMY files are the way to go when seeking customized datasets that account for actual observed conditions and climate extremes. AMY files can be created from a local airport station [Tianzhen 1999].

- **MDRY – Moisture Design Reference Years** In 2011, ASHRAE 1325-RP developed Environmental Weather Loads for Hygrothermal Analysis and Design of Buildings with the purpose of developing representative weather year data for moisture design calculations. This undertaking created a methodology to determine Moisture Design Reference Years (MDRY) from hourly climate records for 100 locations in the United States and 7 locations in Canada.

  There are two primary sources for climate data:

  - Direct Observations: we can have those files from Weather Stations (ground, buoys, and balloons). Generally accurate but measure a limited number of variables (5-10).
  - Modeled data: Reanalysis data, through full or partial atmospheric models run for individual sites.

6.3.2 BISKRA'S DESIGN DAY SELECTION

Since our research require more precision than general design demands, we will use AMY 2011 (Actual Meteorological Year) as weather data, from where we will select our design day.

6.3.2.1 AMY for Biskra

The main features of Biskra's climate are the very cold and dry winters and very hot dry summers. In our study, we will use AMY 2011. The current AMY file for ventilation simulation in Biskra is a set of annual weather data for 2011. The AMY file contains 8760 hours of information on solar insolation, temperatures, humidity and wind speed.
Thereby climate parameters will be defined as follows:

- **Temperature** This variable is characterized by a large seasonal variation between 0^c and 49^c, with an annual temperature difference of 22^0c. In addition, we note the particular feature that the daily temperature range in summer is around 15^c ; compared to that of cities in this kind of climate.

- **The dominant winds** . It is the seasonal winds; the most common are the cold winter winds, which blow from the North West, causing the increasing humidity. In the second position of importance, there are hot winds blowing from South West in spring and autumn, causing sinister in the region; in addition, there are dry winds in summer. Maximum winds frequencies are recorded in February, March and April.

- **Humidity**. The average relative humidity is low; it is around 47%, with a maximum value of 90% in December, and a 10% minimum in July and August. This variable remains one of the lowest that characterize this climate; in addition, this region is experiencing high evaporation.

- **Rainfall** . In this region, rainfall remains low or even very rare. They do not exceed 31 days per year. Thus, the maximum annual total rainfall rarely reaches 200mm.

6.3.2.2 Basis for selecting the design day weather file

We propose a new method, which identifies an equivalent temperature, on a daily basis, and picks out several possible design days from an AMY weather file; in order to run the simulation for a reference building operating on the design days to reach a good rate of ventilation.

a- Key weather parameters

Depending to our research, we have to identify weather parameters, which have an influence on the energy and ventilation performance of a building. Temperature, and wind speed may be regarded as the most significant weather parameters. Besides acting as control parameters in the selection of a design day, these parameters offer clues for interventions to reduce discomfort in occupied zones.

For application in the simulation, the design day is selected from the 365 days in 2011. The selected design day weather file consists of detailed data of 24 hourly values of climatic criteria parameters: temperature, wind velocity.

Table 6.1 lists two weather parameters from the 2011 weather file, such as for each parameter (temperature or wind speed) the annual maximum, minimum and average are described However the annual mean values of temperatures and wind speed are presented in Fig 6.4.

Weather parameter	Annual maximum	Annual minimum	Annual average
Temperature T[°c]	44.9	-2.1	19.87
Wind speed V[m/s]	10.6	0.1	1.87

Table 6.1: Annual statistics of the Biskra 2011 AMY

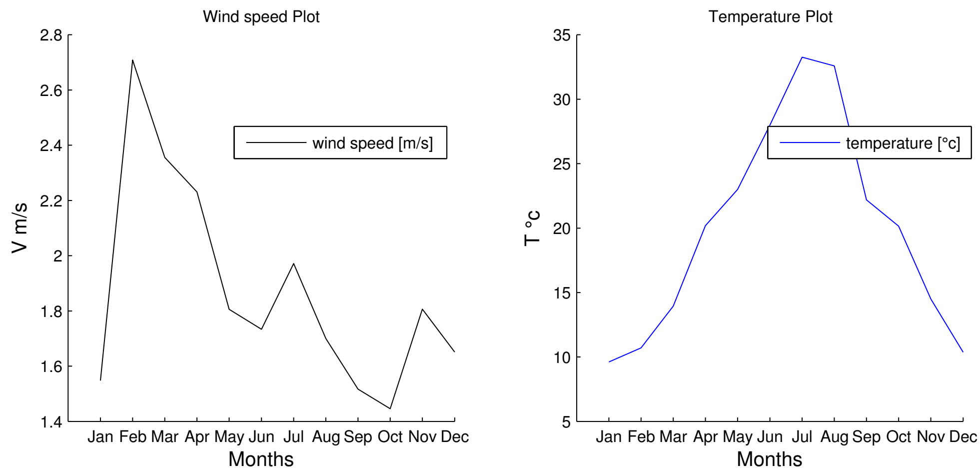


Figure 6.4: Annual mean values of temperatures and wind speed

b- Identify the most representative month of the region

In this level of abstraction, we base on monthly averages for each key parameter to select the most representative months for the investigated region, for example the warmest month, the coldest month...

T[°c]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	9.61	10.70	13.93	20.19	22.99	27.99	33.26	32.59	22.19	20.14	14.50	10.36
Max	20.1	20.9	25.7	32.9	34.9	41.2	44.9	44	40.5	31.9	24	20.9
Min	-2.1	-1.2	1	7.3	12.2	15.7	22.5	22.1	15.6	7.2	5	0.8

Table 6.2: Annual values maximum, minimum, average of temperatures (AMY 2011)

V[m/s]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	1.54	2.70	2.35	2.23	1.80	1.73	1.97	1.51	1.7	1.44	1.80	1.65
Max	7.1	9.9	9.9	10.6	9.6	8.5	7.8	6.7	7.1	7.3	10.5	7.8
Min	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 6.3: Annual values maximum, minimum, average of wind speed (AMY 2011)

Depending on the previous Tables (Table6.2 and Table6.4) and the annual mean values of temperatures and wind speed plot we can conclude that:

- The hottest month: July
- The coldest month: January
- The most windy month: April
- The least windy month: August

c- Identify the most representative day of the region: the design day

In this study, we seek the most unfavorable meteorological conditions for the microclimate of the studied region, so that the designed systems can reach the indoor comfort and the appropriate ventilation criterion throughout the year when performing at their maximum capacity. In this design mode, and according to our objective, we have defined two modes for the design day selection. In the first one, we use two criteria (maximum temperature and maximum wind speed). However, in the second, we use one criterion (maximum wind speed). In this case, we obtain respectively two design days.

c1 Identification of the first Design Day

The most straightforward method to find the first design day (DD1) from the weather data of the hottest month (July) is using a linear combination f of two weather criteria: temperature (T) and wind (V). The weights (w_1 and w_2) are fixed according to the importance attributed to each criterion and they are included between 0 and 1. Then, the problem is defined as research, from a set of possible days d (July days), the design day DD1 that makes the linear combination f maximum. These techniques are normally known as "aggregating criteria", because they combine (or "aggregate") all the criteria of the problem into a single one.

$f(DD1) = maxf(d)$ Where $f(d) = w_1 * T(d) + w_2 * V(d)$ $\mathrm{w}_1 + w_2 \leq 1 and \mathrm{w}_1, w_2 \in [0, 1]$

The design day depends on the weights w_1, w_2, as it is showed in the table below.

w_1	0.4	0.5	0.6	0.2	0.1
w_2	0.6	0.5	0.4	0.8	0.9
d	4	21	21	4	4

Table 6.4: Influence of the weight values on the design day selection

- If we give equal weights to the two weather criteria, the DD1 will be the 21^{st} July.
- If we give a bigger weight to the temperature, the DD1 will be the 21^{st} July.

- If we give a bigger weight to the wind speed, the DD1 will be the 4^{th} July, which is more interesting according to our objective. So we will choose the 4^{th} July as the DD1.

In Figure 6.5, we present Julys daily temperature [°c] and wind speed [m/s] values and their combination with $w_1 = 0.4$ and $w_2 = 0.6$. The Figure 6.6 shows hourly variations of DD1 temperature [°c] and wind speed [m/s].

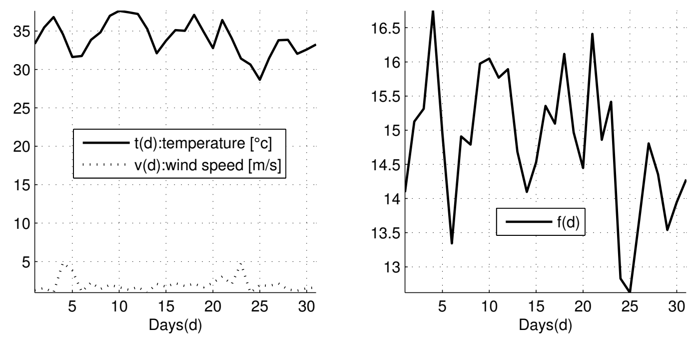


Figure 6.5: July's daily temperature c^0 and wind speed [m/s] values

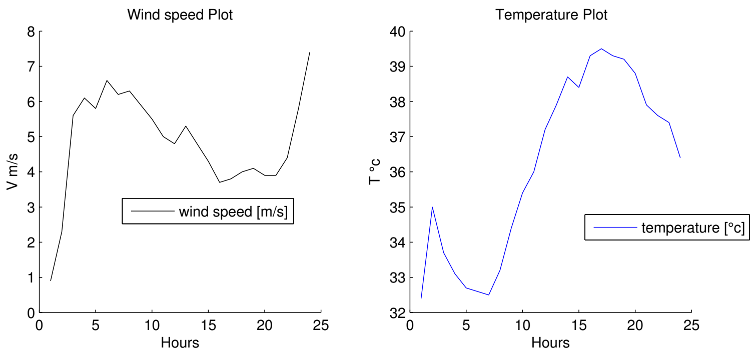


Figure 6.6: DD1 hourly temperature c^0 and wind speed [m/s] values.

c2 Identification of the second Design Day

In the second design mode, the wind speed must be in its maximum value, which is from Table 6.4 V max = 10.6 m/s. We identify the second design day (DD2) from the weather data of AMY 2011, it is found in the windiest month: April. DD2 is the $21^{st} April$.

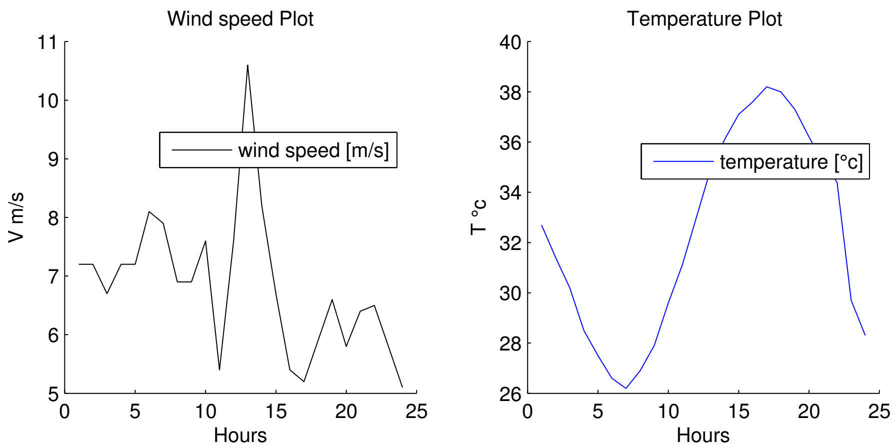


Figure 6.7: DD2 hourly temperature c^0 and wind speed [m/s] values

For each of the Biskras possible design days DD1 and DD2 determined previously, the Phoenics code is used to do the simulation in order to prove our hypothesis defined before that by emulating natures processes, strategies and systems we can improve our buildings reality by achieving a living architecture. Our simulation is done on the existing state of the building and our outlined design concept a breath of fresh air for DD1 and DD2 and then we compare the results for the two cases.

6.4 RESULTS OF THE SIMULATION AND DISCUSSION

A methodology is proposed for the study of natural ventilation of the adopted model (existing case) and the new design model (a breath of fresh air), with input parameters data values of wind velocity and direction, obtained from AMY 2011.
All the objects that will be included in the simulation must be prepared in a step-by-step procedure that defines its attributes. The simulation of the proposed design days is done in two different stages. In the first stage, we incorporate the adopted building and in the second stage, we incorporate the new concept design.

We have employed a Cartesian coordinate system; the size of the domain is a triple of the characteristic height of the building, which is in this case 18 meters. The model was defined by a calculation domain with the size of $70m$, $42m$ and 54 meters in directions x,y and z, respectively, that provides more than $30m$ of open space above the building.

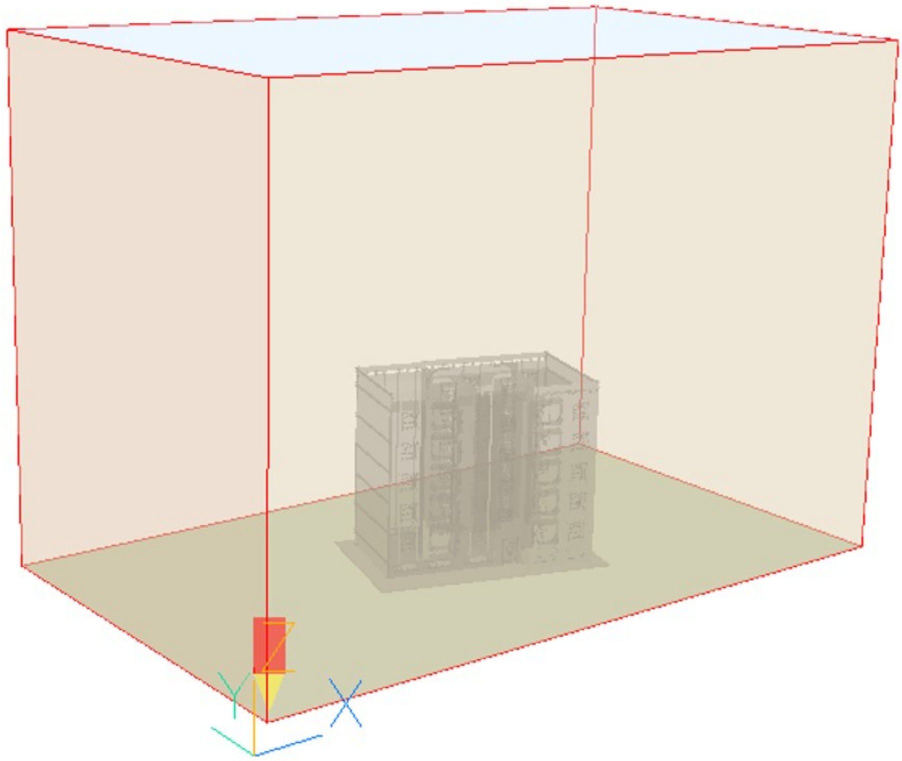


Figure 6.8: Modeling of the 3D building's configuration for simulation under Phoenics.

The mesh contained 73 subdivision in the x direction, 72 in y direction and 45 in z direction, with the smaller spacing is in the regions near the building. The material properties are selected in the ”object” dialog box.

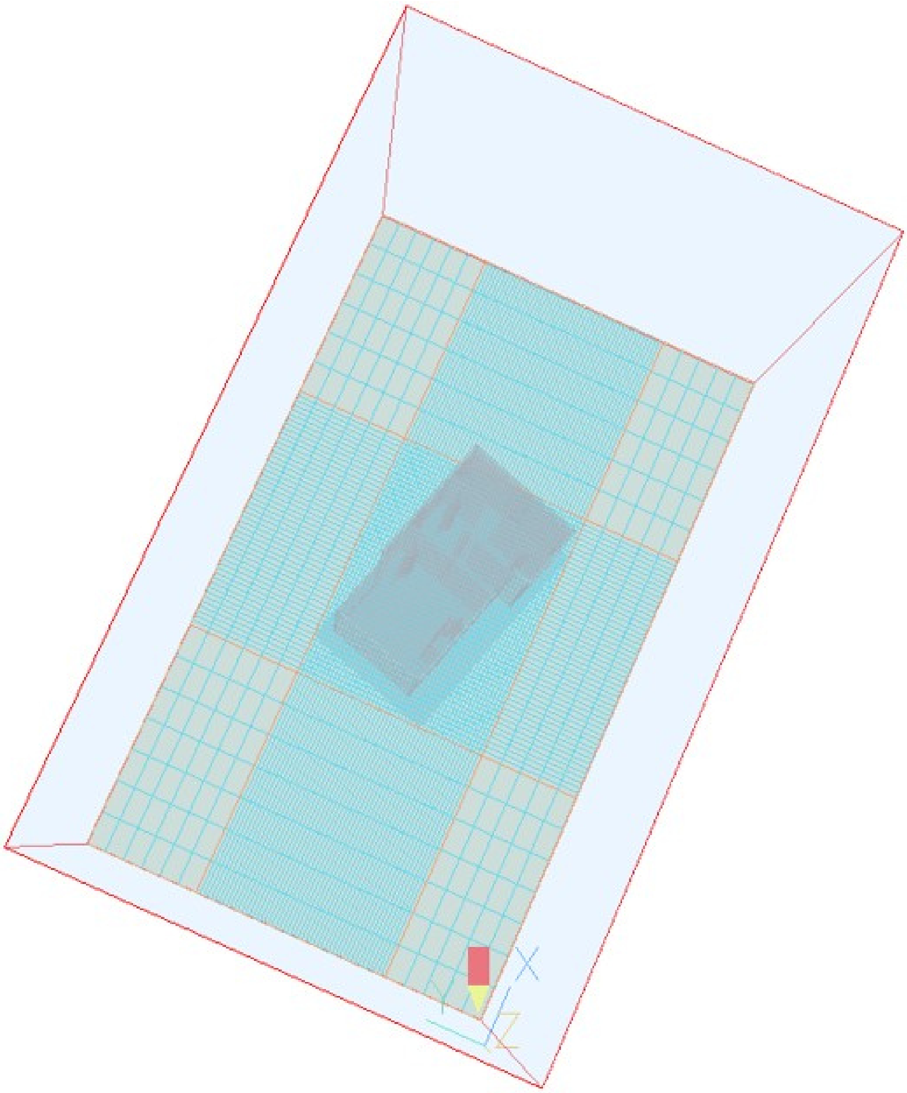


Figure 6.9: Created mesh with the studied building appearing in the Center

An inflow condition was applied at the North West (upwind) side (y-z plane) of the domain, in the case of DD1 with an inlet wind speed of 3.83 m/s, and in the case of DD2 with an inlet wind speed of 10.6 m/s. In addition, the orientation of the building is selected according to the prevailing wind direction.
In order to show the distribution of the airflow in the building, we focus, in our experiment, on horizontal views at different heights (Figure 6.10), which are based on the height of each accumulation heat box and each fresh air box of all the floors.

Figure 6.10: Cross section of the new model design representing the different heights for the simulation

Tables below 6.11, 6.12, 6.13 and 6.14 summarize the results of the simulation of the two models within two design days selected before, DD1 and DD2. Images were generated to show various top views of the velocity fields and the horizontal distribution of airflow at different heights in the sample area.

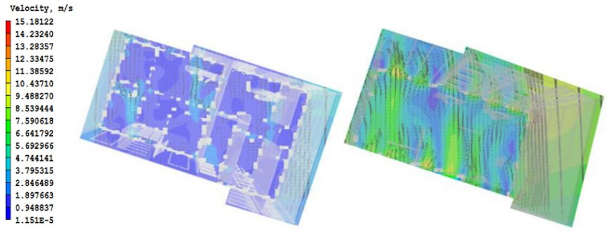
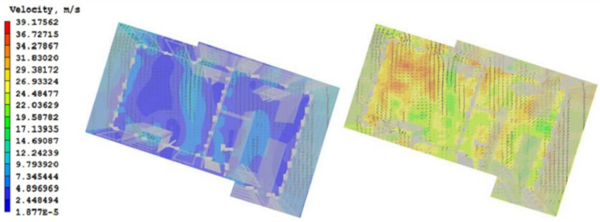
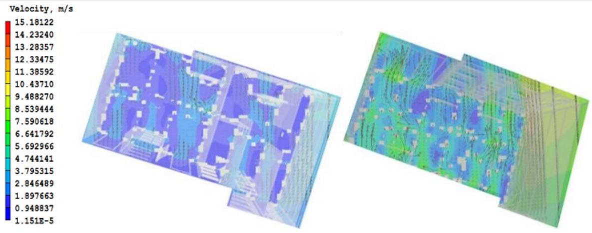
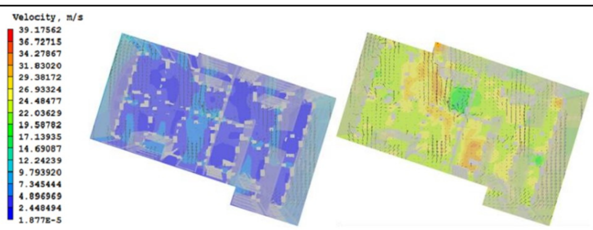
LEVEL	DESIGN DAY	RESULTS	
		EXISTING MODEL	A BREATH OF FRESH AIR MODEL
Z=0.80m	DD1		
	DD2		
Z=3.85m	DD1		
	DD2		

Figure 6.11: Comparison of the horizontal distribution of the airflow results of the two models analyzed in DD1 and DD2 at different heights/part1

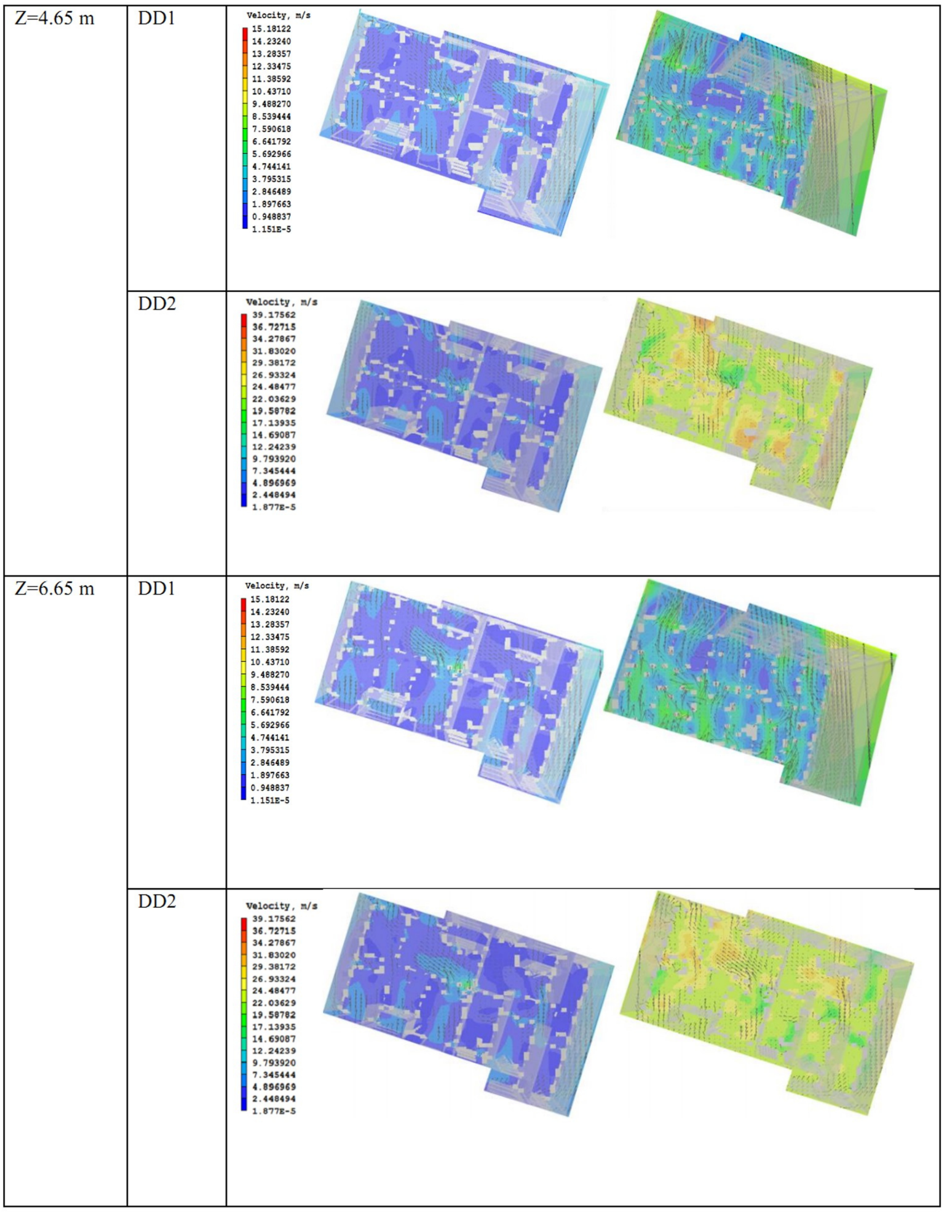
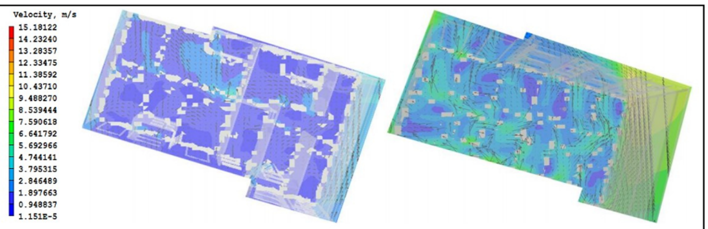


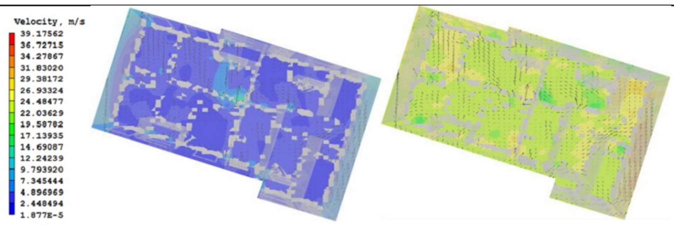
Figure 6.12: Comparison of the horizontal distribution of the airflow results of the two models analyzed in DD1 and DD2 at different heights/part2

Z=7.45 m

DD1

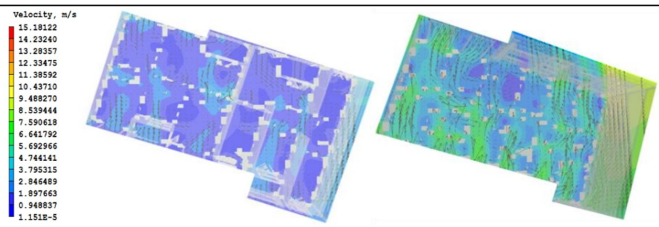


DD2



Z=9.45 m

DD1



DD2

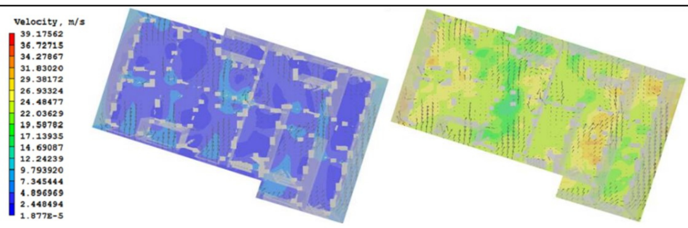
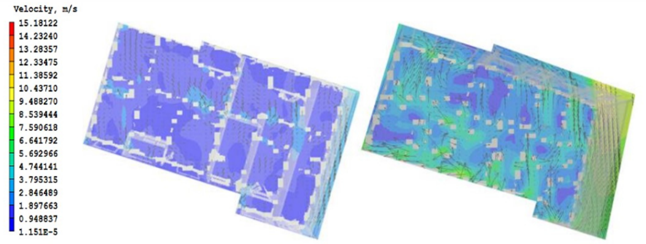
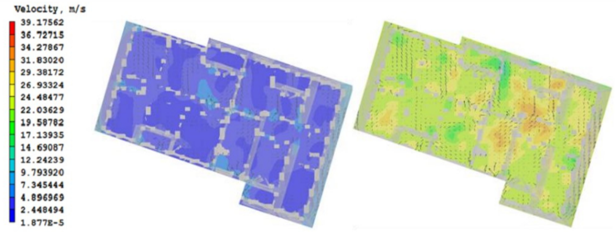
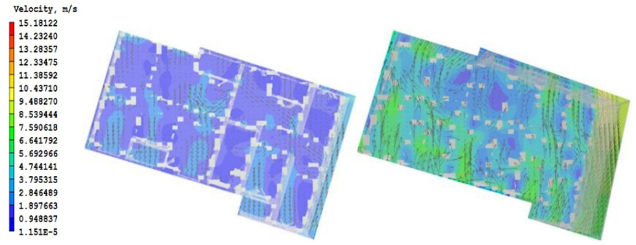
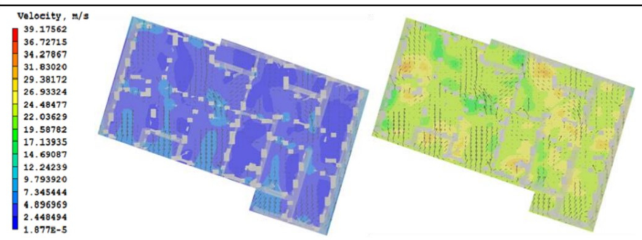


Figure 6.13: Comparison of the horizontal distribution of the airflow results of the two models analyzed in DD1 and DD2 at different heights/part3

<table>
<tr><td rowspan="2">Z=10.25m</td><td>DD1</td><td>
</td></tr>
<tr><td>DD2</td><td>
</td></tr>
<tr><td rowspan="2">Z=12.35 m</td><td>DD1</td><td>
</td></tr>
<tr><td>DD2</td><td>
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</table>

Figure 6.14: Comparison of the horizontal distribution of the airflow results of the two models analyzed in DD1 and DD2 at different heights/part4

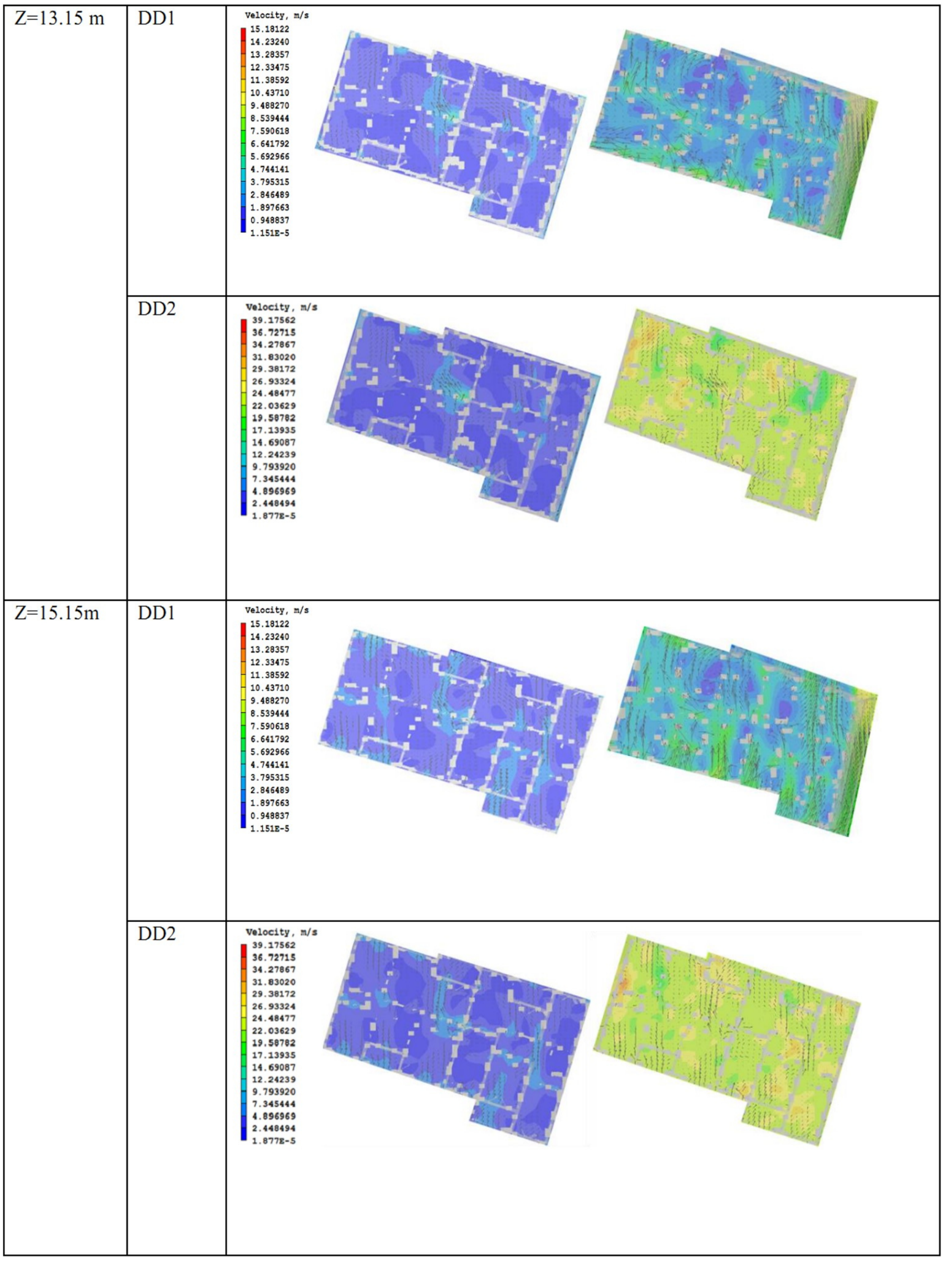

Figure 6.15: Comparison of the horizontal distribution of the airflow results of the two models analyzed in DD1 and DD2 at different heights/part5

Simulations were largely studied so that it could be reached a final result with the best possible exactitude. An analysis of the air flows behavior inside the building is needed. This analysis allowed us to know, understand the behavior of the air flows toward interpreting and theoretically validate the numerical solution of the air velocity at each model.

1. The result of the simulation for each studied model shows clearly the significant difference in the values of the air velocity:
   - Low wind velocities are observed in the different top views of the existing case.
   - High wind velocities are observed in the different top views of the new model.
2. An acceleration in air velocities near to the openings of the two models is produced, as there is a change in direction and diminution in confronted surfaces.
3. The results of the new design model, compared to the existing model results show an rises in the velocities especially near to the basement openings. The fresh air is drawn in the basement through the openings.
4. In the levels (3.85, 6.65, 9.45, 12.35, 15.15), high velocities are spotted in the entrance of each apartments due to the temperature differences, which cause air moving, where hot air rises because of its lower pressure, and it is discharged through the heat accumulation box.
5. In the levels (1.85, 4.65, 7.45, 10.25, 13.15)high velocities are observed near to the fresh air box.
6. The CFD analysis indicated that for the new case configuration the presence of significant flow circulation within the corridor between the heat accumulation box and the fresh air box (as seen in the different top views of the new design model)
7. The Air behavior is similar in all the floors (either in the existing case or in the new design model excepting the basement); we observe only differences in the velocities.

After the observation of the new design model results of each floor, it's clear that the high wind velocities are once in the first height of the floor near to the fresh air box and next height are near to the heat accumulation box; because the density of air decreases as the temperature increases causing warmer air to rise. This system provides an effective ventilation to refresh the air, remove unwanted smells from cooking, and guarantees occupant comfort. The results clearly show that the new system of ventilation improves the flow rates in the building and therefore the ventilation behavior.

6.5 CONCLUSION

In this chapter, we have proposed a method for the selection of the most representative day of the region of Biskra "Biskra's design days". According to our aims of this study, we have selected two designs days DD1 and DD2 for the simulation using the Phoenics code on the existing state of the building and our outlined design concept "a breath of fresh air". By comparing the results of both experiments (existing case and the new design concept), we were able to confirm our main objective highlighted by this study and we can retain the following points :

- It was possible to achieve the living architecture by emulating nature's processes, strategies and systems and at the same time, it was proved that the proposed system improves our living situation and guaranteeing occupant comfort.
- If our new design concept "a breath of fresh air" is well implemented, it can considerably contribute to reducing the cooling energy consumption of a building. Moreover, natural ventilation is not only beneficial to reducing energy consumption in a building; its high flowrates also lead to higher levels of indoor air quality than mechanically cooled buildings, which could be proved in further works.
- The performance of naturally ventilated systems is highly dependent on the building geometry and the weather conditions, forcing the designer to account for several additional factors very early in the building design to reach the comfort.

Chapter 7

GENERAL CONCLUSION

In the framework of climate change, energy efficiency and renewable energy, we are wondering to find new strategies for the energy optimization that leads to identify designs and technologies that minimize the energy use and maximizing energy savings, in hot and arid regions. We have a specific interest to a sustainable approach in the design because we have a strong feeling that it is time to act, especially to introduce new reflection's methods, new ways of thinking and find a new way to approach the architecture and urbanism in Sahara.

This work is an initiative towards the study and analysis of biomimicry as an important tool for architectural design and sustainable construction, focusing on the possibility of applying biomimetic principles in the design process, aiming to reach the concept of living architecture in hot and arid regions. We have investigated new strategies for sustainable design in hot and arid climates, which are derived from the natural designs, systems, and processes, from their material, properties and from their adaptive response to changes in their environment, by linking the two emerging sciences; Biomimicry and architectural design. The main research question addressed in this work, is about the potential of biomimicry in developing a more sustainable reflection's methods and how could the lessons learned from living natural systems be applied to architecture to lessen its environmental impact.

The main objective is to investigate new strategies for sustainable design and to imitate such living biological systems of adaptation found in flora and fauna of the desert biome in order to transform them into architectural design principles aiming to prove that we can rectify the human reasoning using the nature's genius.

Our research is based on exploratory and analytical research, to establish a link between biomimicry and architectural design. Methods used for this investigation are diverse. Literature research, expert interviews and analyze of natural mechanisms and systems are carried out. To achieve the main objective of this research, our manuscript has been divided into two parts: theoretical and practical part.

The first part "Biomimicry, innovation inspired by nature" has been destined to explain the basics of biomimicry and to investigate the adaptation strategies and mechanisms found in nature. It is composed of two chapters: chapter 2 and chapter 3. In chapter two, we have demonstrated how the nature can provide creative and innovative solutions for making life safer, simpler, and healthier for both the environment and us, in addition, how we can translate this natural wonder into a practical use to benefit humanity. Through the presentation of some forms, structures and organizing principles found in nature, we have showing that the nature has long been a source of inspiration for designers, engineers and architects for their

building projects. In chapter 3, a framework for understanding biomimicry have been provided for explaining the concepts and diverse strategies of this emerging approach and to show the different types of bio-inspired design that have significance in an architectural framework.
The second part "Towards a living architecture" focused on the exploration of the influence of biomimicry on architecture, resulting in a set of selected principles that could be applied in the design in hot and arid climate. It contains three chapters: chapter 4, chapter 5, and chapter 6. In the fourth chapter, we examined the existing biomimetic technologies aiming to define distinct approaches to biomimetic design, and we discussed the different levels of Biomimicry (organism, behavior and ecosystem levels) by highlighting the different potentials of each level in architectural design. Different advancements in the world of Biomimetic architecture have been presented, in this chapter, that serve as examples for the application of the biomimetic approach on architectural design aiming to reach the concept of living architecture. In the fifth chapter, we have proposed a new systematic methodology for design in hot and arid regions "the Bio-brainstorming methodology", which is a key tool to find new methods and systems for renewable energy and optimization. This database is based on some existing biomimetic strategies that function simultaneously in nature and inspire us to reduce and control the negative use of our energy resources. An implementation of the Bio-Brainstorming methodology, which creates an investigation platform for the architects, have been demonstrated to solve a particular architectural challenge of a hot and arid region: the building's ventilation. The outlined concept "a breath of fresh air" have been presented as a concept design for living buildings in the city of Biskra.
In the first part of the sixth chapter, we described our proposed method for the selection of the most representative day of the region of Biskra "Biskra's design days". According to our aims of the study, we have selected two design days, DD1 and DD2 from AMY 2011, for the simulation using Computational Fluid Dynamics 'CFD' methods to analyze and study the proposed ventilation system.
In the second part of chapter 6, we have done an experimental study of the natural ventilation of the adopted model (existing case) and the new design model "a breath of fresh air", with input parameters data values of wind velocity and direction, based on the weather data of the selected design days. From the comparison of the experiment's results, we were able to confirm our main objective highlighted by this research; it was proved that the proposed system improves our living situation and guaranteeing occupant comfort and it was possible to achieve the living architecture by emulating nature's processes, strategies and systems.
There are some limitations involved in the application of the strategies outlined in the research. These include conflicts existing between strategies; conflicts can occur when applying two or more of the outlined strategies to a design. As a consequence, all of the strategies may not necessarily be employed in a single building, rather a selection of them. It is for this reason the outlined strategies can be seen as "guides", rather than "rules".
After studying the potential of Biomimicry on architectural design, we can provide

some recommendations:

- Creating a sustainable built environment is not done by integrating just solar panels on every building. Humans need to be more in-tune with nature and look at nature for inspiration. Designs that mimic nature's beauty and elegance should not just be on a material or form basis; it should be from a thorough understanding of the philosophy and principals that make those solutions from nature work successfully.

- We definitely can and should take the philosophy behind natures living organisms and use them to aid in the development of mankind to find a new way to survive that not only benefits humans, but the natural environment as well. Biomimicry can be used as an integrative architectural design component in order to achieve this, and create complete unity between the building, the users, and the environment.

- We have to state our challenge in functional terms, so that we can use the Biomimicry Taxonomy. Through this process, if we have asked the right "How does nature ...? " questions, we should easily come up with 30 to 70 organisms. From there, it is a matter of narrowing down the list and organizing it in a way that we can use to select the best ones for further research.

- Studying adaptation and regulation strategies in nature gave insight into some dominating processes and factors for adaptation and provide a database for biomimetic solutions.

- Other levels of research could be carried out for example available budget, which could be correlated to the exploration model. This type of research needs an intensive investigation of interdisciplinary fields.

- A multidisciplinary platform for biomimetic innovation in architecture, where researchers and industry collaborate is essential for design concept validation.

This research has breached a number of subjects on which careers can and have been built. It has only been possible to scratch the surface of each of these to develop a high-level interdisciplinary knowledge. Further research into multidisciplinarity, interdisciplinarity, transdisciplinarity, biomimicry, bionics, building interactions, and more would ultimately enrich this research further. Ideally, all of this research should be expanded with the help of an interdisciplinary team. With that understanding, there are a number of specific topics of interest for future research. The perspectives of this work are relatively numerous, in both theoretical and practical scale, but we will mention the most essential:

- The biomimetic research still within the context of research and exploration. It would be important for future research projects to fully implement such a design approach within the context of actual building projects.

- Another important line of research is the application of such a design approach on an urban scale in hot and arid regions.
- The elaboration of a database for the adaptation mechanisms and systems found in the desert Biome is a promising field of research that can facilitate the integration of Biomimicry in architectural design.

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Abstract

One of the most important design challenges is designing ecological buildings located in hot and arid regions because of the global climate change. In these regions, scientists recommend the use of the principles of the sustainable design that are based mainly on reducing the energy consumption of the building and the achievement of its eco-efficiency. In this context, developing more energy efficient services and technologies is essential. Biomimetics, as a design approach, provides a huge potential for energy efficiency. Energy saving have become an important part of modern development, which places special emphasis on resource optimization.

Through an exploratory and analytical research, this work is an attempt to establish a link between biomimicry and architectural design. It starts by the exploration of the influence of biomimicry on architecture, resulting in a set of selected principles that could be applied in the design in hot and arid climate. We attempt to reach the concept of living architecture in hot and arid regions by investigating new strategies for sustainable design. These strategies are derived from the natural designs, living systems and processes, from their material, properties and from their adaptive response to changes in their environment, in order to transform them into architectural design principles aiming to prove that the human reasoning is illogical and we can rectify it using the natureâs genius.

We propose a Biobrainstorming methodology as a key tool to find new methods and systems for renewable energy in hot and arid regions. The major benefit of this proposed methodology is its applicability to different disciplines as a problem solver, and not only to architecture and building. This is due to the generality of the design tools.

In Biskra, a hot and arid region, we are facing the problem of sick building syndrome, which is the combination of discomfort experienced by building occupants due to poor conditions of air quality and other aspects related to indoor climate. To solve this syndrome of air quality, ventilation, with minimal energy use, is provided. To achieve our goal, we will take a model of these buildings built by humans as a case study and other models found in nature to be inspired by these models and strategies toward improving our experienced situation and to find new methods and systems for renewable energy in Biskra. We propose a biomimetic design model for a living building that keep the indoor environment in a moderate level of comfort. Finally, we proceed to the simulation using Computational Fluid Dynamics 'CFD' methods, using a Design Day as a representative day of the region of Biskra to test the validity of this theoretical idea.

Keywords: Architectural design, Biomimicry, Bio-inspiration, CFD, Hot and arid regions, Natural world, Problem solver

الملخص

واحدة من أكبر تحديات التصميم هو تصميم المباني الخضراء في المناطق الحارة و الجافة نتيجة لتغير المناخ العالمي . في هده المجالات, يوصي العلماء باستخدام مبادئ التصميم المستدام التي تعتمد في المقام الأول على الحد من استهلاك الطاقة في البناء و تحقيق لها الكفاءة البيئية. في هدا السياق, تطوير التقنيات و الاستغلال العقلاني للطاقة أصبح أمر ضروري. تقليد الطبيعة كنهج تصميم يوفر إمكانيات هائلة لكفاءة الطاقة التي أصبحت جزءا هاما من التنمية الحديثة, التي ترتكز على الاستفادة المثلى لموارد الطبيعة. من خلال البحوث الاستكشافية و التحليلية, هدا العمل هو محاولة منا لدمج مبادئ التصميم المعماري و المحيط الطبيعي. و هي تبدأ من خلال استكشاف تأثير تقليد الطبيعة في الهندسة المعمارية,مما أدى إلى مجموعة من المبادئ المختارة التي يمكن تطبيقها في التصميم في المناخ الحار و الجاف. و نحن نحاول للوصول إلى مفهوم حيوية العمارة في المناطق الجافة و الحارة من خلال دراسة استراتجيات جديدة للتصميم المستدام. و تستمد هده الاستراتجيات من المفاهيم الطبيعية و النظم الحية و تكيفها مع التغيرات في بيئتها من أجل تحويلها إلى مبادئ التصميم المعماري و نحاول من دلك إثبات أن الطرق المستعملة حاليا غير منطقية و يمكننا الاستلهام من عبقرية الطبيعة. و نحن نقدم منهجية " Bio-Brainstorming" كإستراتجية جديدة للاستغلال الأمثل للموارد الطبيعية في المناطق الجافة و الحارة. و الميزة الأساسية للطريقة المقترحة تطبيقها على مختلف التخصصات ليس فقط في العمارة و البناء و يرجع دلك إلى عمومية أدوات تصميمها. في مدينة بسكرة, بظروفها المناخية الحارة و الجافة, نواجه مشكلة ما يسمى بالمباني المريضة, التي هي مزيج من عدم الراحة التي يشعر بها السكان بسبب سوء نوعية الهواء و غيرها من جوانب البناء المتعلقة بالمناخ في الأماكن المنغلقة. من المقترحات الأساسية لعملنا هدا هو الاستغلال الأمثل للطاقة. لتحقيق هدفنا سوف نتخذ نموذج من هده المباني التي بناها البشر كحالة دراسة و نماذج مستوحاة من الطبيعة كمصدر الهام للإستراتجيات لتحسين وضع حياتنا و إيجاد أساليب و نظم جديدة للطاقة المتجددة في بسكرة. في هده الدراسة, نقدم نموذج تصميم بيوميميتيك لمبنى سكني حيث يحافظ على البيئة الداخلية في مستوى معتدل من الراحة. و أخيرا نؤدي المحاكاة باستخدام أساليب " CFD" ديناميات الموائع الحسابية باستخدام "يوم تصميم" كيوم ممثل لمدينة بسكرة من أجل اختبار صحة هده الفكرة النظرية.

الكلمات المفتاحية : تقليد الطبيعة, التصميم المعماري, الاستلهام من الطبيعة, العالم الطبيعي, المناطق الحارة و الجافة, CFD.

RESUME

Un des plus importants défis de conception est la conception de bâtiments écologiques situés dans les régions chaudes et arides en raison du changement climatique mondial. Dans ces régions, les scientifiques recommandent l'utilisation des principes de la conception durable qui sont basés principalement sur la réduction de la consommation énergétique du bâtiment et l'atteinte de son éco-efficacité. Dans ce contexte, le développement des services énergétiques et des technologies efficaces est essentiel. Le Biomimétisme, comme une approche de conception, fournit un potentiel énorme pour l'efficacité énergétique. Les économies d'énergie sont devenues une partie importante du développement moderne, qui met l'accent sur l'optimisation des ressources énergétiques. Grâce à une recherche exploratoire et analytique, ce travail est une tentative d'établir un lien entre le biomimétisme et la conception architecturale. Il commence par l'exploration de l'influence du biomimétisme en architecture, résultant en un ensemble de principes sélectionnés qui pourraient être appliqués dans la conception dans le climat chaud et aride. Nous essayons d'atteindre le concept de la vitalité en architecture dans les régions chaudes et arides en examinant de nouvelles stratégies pour la conception durable. Ces stratégies sont issues des conceptions naturelles, des systèmes et des processus vivants, de leurs matériaux, des propriétés et de leur réponse adaptative aux changements de leur environnement, afin de les transformer en principes de conception architecturale visant à prouver qu'on peut rectifier notre réalité en utilisant le génie de la nature. Nous proposons la Bio-Brainstorming méthodologie comme un outil essentiel pour trouver de nouvelles procédés et systèmes d'énergies renouvelables dans les régions chaudes et arides. L'avantage principal de cette méthode proposée est son application à différentes disciplines non seulement à l'architecture et le bâtiment. Cela est dû à la généralité de ses outils de conception. À Biskra, une région chaude et aride, nous sommes confrontés au problème du syndrome des bâtiments malsains, qui est la combinaison de l'inconfort ressenti par les occupants du bâtiment en raison de mauvaises conditions de qualité de l'air et d'autres aspects liés au climat intérieur. Pour résoudre ce syndrome de qualité de l'air, la ventilation avec une utilisation minimale d'énergie, est prévue. Pour atteindre notre objectif, nous allons prendre un modèle de ces bâtiments construits par les humains comme un cas d'étude et d'autres modèles trouvés dans la nature qui constitue une source d'inspiration par leurs stratégies en vue d'améliorer notre situation vécue et de trouver de nouvelles méthodes et systèmes pour l'énergie renouvelable à Biskra. Nous proposons un modèle de conception biomimétique pour un bâtiment vivant qui garde l'environnement intérieur dans un niveau modéré de confort. Enfin, nous procédons à la simulation en utilisant les méthodes de CFD « Computational Fluid Dynamics » en utilisant un « Design Day » comme un jour représentatif de la région de Biskra pour tester la validité de cette idée théorique.

Mots clés: Biomimétisme, Bio-inspiration, Conception architecturale, CFD, le monde naturel, les regions chaudes et arides.

Biomimicry, towards a living architecture in hot and arid regions