GAZİ ÜNİVERSİTESİ

1926

A NEW APPROACH FOR BUILDING FACADES FOR DIFFERENT CLIMATE REGIONS: BIOMIMETIC SKIN

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
GAZİ UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ARCHITECTURE

JULY 2018

The thesis study titled " A NEW APPROACH FOR BUILDING FACADES FOR DIFFERENT CLIMATE REGIONS: BIOMIMETIC SKIN " is submitted by Ala’a Al-Deen Khalil Hussein AL JADA’AN in partial fulfillment of the requirements for the degree of Master of Science in the Department of Architecture, Gazi University by the following committee.

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ETHICAL STATEMENT

I hereby declare that in this thesis study I prepared in accordance with thesis writing rules of Gazi University Graduate School of Natural and Applied Sciences;

- All data, information and documents presented in this thesis have been obtained within the scope of academic rules and ethical conduct,
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Ala'a Al-Deen Khalil Hussein AL JADA'AN

11/07/2018

FARKLI İKLİM BÖLGELERİNDEKİ BİNA CEPHE TASARIMLARI İÇİN YENİ BİR YAKLAŞIM: DOĞA ESİNLİ YÜZEYLER

(Yüksek Lisans Tezi)

Ala'a Al-deen Khalil Hussein AL JADA'AN

GAZİ ÜNİVERSİTESİ

FEN BİLİMLERİ ENSTİTÜSÜ

Temmuz 2018

ÖZET

Bina cepheleri, yapılardaki enerji tüketimini düzenlemede önemli bir rol oynamaktadır. Ancak, pek çok cephe tasarımının, iç konfor seviyelerine ulaşmak için çok fazla enerji gerektiren çözümler sunmakta olduğunu söylemek mümkündür. Bununla birlikte, son yıllarda yapılan çalışmalar pek çok disiplinde olduğu gibi mimarlık alanında da biyolojiden esinli adaptasyon çözümlerinin karmaşık, çok fonksiyonlu ve oldukça duyarlı olduğunu göstermektedir. Bu araştırma, ekolojik ortamlar (doğa) ve yapılı çevreler (mimari) ile bina cephelerinin tasarımı için çığır açan çözümler arasında kurulabilecek bağlantının bir değerlendirmesini sunmaktadır. Bu bağlamda tez, bina kabuklarının enerji verimliliğini arttırmak amacıyla bina cephelerinin ön tasarım aşamasında mimarlara farklı bir bakış açısı kazandırabilecek bir kılavuz niteliğinde kurgulanmıştır. Bu çalışma doğal organizmalar içerisinde, çevreye uyum sağlamış ve değişen dış problemler ve farklı çevresel koşullar ile etkileşim ve işbirliği için özel yollar geliştirmiş olan hayvan derilerine odaklanmıştır. Önerilen metodoloji, hayvanların sahip olduğu kabukların/derilerin tasarım prensiplerinin, mimarlıkta bina kabuklarının çevreye uyum sağlayabilmek için nasıl kullanılabileceğini araştırmak için iki aşamalı olarak kurgulanmıştır. İlki, doğada, farklı iklim bölgelerinde yaşamlarını sürdüren hayvanlarda bulunan stratejilerin ve uyum mekanizmalarının nasıl tanımlanabileceğinin araştırılarak ortaya konması ve daha sonra mimari potansiyeli bulunan fikirlerin ve bina kabuklarına/zarflarına uygulanabilecek çözümlerin tespit edilerek tasarıma aktarılmasıdır. İncelenen ve tablolaştırılan 6 örnek ışığında elde edilen sonuçlar, doğa esinli yüzeylerin farklı iklim bölgelerinde tasarlanacak bina cepheleri için etkin sonuçlar elde edebilmek için potansiyeller barındırdığını göstermektedir.

Bilim Kodu	:	80111
Anahtar Kelimeler	:	Doğa esinli yüzeyler, Bina cephesi, Biyo-esinli kabuklar
Sayfa Adedi	:	101
Danışman	:	Doç. Dr. Semra ARSLAN SELÇUK

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(M. Sc. Thesis)

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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

July 2017

ABSTRACT

The building envelopes play a significant role in regulating the waste of energy in constructions in general. But, it is possible to claim that most of them are made to offer solutions requiring more energy to reach internal comfort levels. However, the biological adaptation solutions are complex, multifunctional and highly responsive. The research provides a biomimetic study of the connection that might be settled between biological environments (nature) and constructions (architecture) and ground-breaking solutions for the design of architectural facades. It is guidelines for architects to improve the energy efficiency of buildings skins and to be helpful at the beginning of the design phase of the building facades. This study focuses on animals and wildlife because the animals have adapted to the environment and developed special ways of interacting and cooperating with varying external problems and different environmental conditions. The proposed methodology has been designed in two steps to investigate how the design principles of animals' shells/skins can be used in building shells in architecture to adapt to the environment. The first is to explore the strategies and adaptation mechanisms that are found in animals that survive in different climate regions in the nature and to identify the solutions that can be applied to building shells and envelopes. The results obtained through the six case studies examined and tabulated illustrate that nature-inspired surfaces have potential to achieve effective results for building facades designed in different climate regions.

Science Code	:	80111
Key Words	:	Biomimetic Skin, Building Facades, Bio-inspired Envelopes
Page Number	:	101
Supervisor	:	Assoc. Prof. Dr. Semra ARSLAN SELÇUK

ACKNOWLEDGEMENT

I would first like to thank my thesis advisor Assoc. Prof. Dr. Semra ARSLAN SELÇUK at the department of architecture at Gazi University. The door to Prof. ARSLAN office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this thesis to be my own work and steered me in the right direction whenever she thought I needed it.

I would also like to thank the Turkish Scholarships Team for giving me the amazing opportune to continue my master's degree here in Turkey, it was a great and phenomenal experience.

Finally, I must express my very profound gratitude to my parents and my family for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

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1. INTRODUCTION

Biomimetics means translating the spirit of nature and its intelligence to people to figure out brand new ways to solve the problems we want to solve. In contrast to the historically dominant point of view, biomimetics has introduced a systematic path to transferring knowledge from nature to too many different areas. Nonetheless, a lot of research sees the relationship between nature and architecture in form-based level. In this sense, creating a biomimetic path continues and architects still trying to learn more about nature.

The envelope of a building is the first apparent architectural component from outdoor, cooperates with the environment and interacts with it. The envelope implies covering and it surrounds an area inhabited by humans, and the creatures are also surrounded by the natural skin. The architectural tendencies stated above have carried a novel understanding to the hierarchy of the building system because a strict separation among the roof and the facade is regularly hard to be known. For this reason, the word "envelope" is widely utilized. The envelope contains extra functions, for example, loadbearing, passive ecological regulator or active ecological controller, and personal expression. In contrast to old-style approaches, the architectural envelope is today not considered as a separate element of the building, but as an essential and important part of the building's performance perspective. In addition, with modern technology, building shells can be shaped from a variety of woven surfaces that are imagined on the computer, and machine orders might be sent directly to the factory to provide full-scale production.

A wide application of the skin analogy might be seen through numerous built and undeveloped models of the construction shell, field studies, and experiments. in spite of the increasing influence of biomimetics in architecture, the use of the expression "skin" without a systematic approach to transfer biological information cannot drive beyond a simple metaphor. At this stage, this research wants to use the analogy between the natural skin and the envelope of the building. In addition, it proposes that the envelope design has much in mutual with the natural skin and can derive from them biomimetic information could be useful. Skin can be defined as the external layer of creatures' bodies. In this research, the term "skin" is commonly used for all animal coverages, including exoskeletons, skins, fur, feathers, shells, and scales.

Lately, numerous significant efforts have been completed to improve a biomimetic approach to the construction envelope such as (Mazzoleni, 2013, Gruber 2010, and Badarnah-Kadri, 2012). These studies emphases primarily on learning from nature and trying to copy it to accomplish much more efficiency in the use of resources and energy in architectural envelopes. Meanwhile the skin might be used as a measure for the building envelope design, additional explorations might be debated in this area.

In this thesis, defensive architectural covers, called facades / shells / envelopes /surfaces, should be discussed similarly to skin in nature. To this end, during the research, all the discussions will be conducted, and the skin and its tasks should be taken as a measure. Instead of trying to find specific aesthetic and functional similarities, this research is aimed at focusing on the natural skin and developing a design mapping for creating a high-energy efficient envelope, and it is the main guidelines that will help the designers at the first stages in the design of the building's facade. A biomimetic envelope perspective is needed to copy and study successful adaptation strategies of building envelopes and learn them and thus integrating of natural processes in the entire building.

Problem Statement

From the building systems, the building envelope confronts the varying of the surrounding environmental conditions. So, the building envelope is not just offering a shade and first line of defense from the outside, but also it is offering a number of functions that need to be done and a set of conditions for adaptation and response Nowadays, a lot of architectural systems that react and adjust to any variations in general like adaptive, reactive, dynamic, kinetic, and intelligent systems. these systems call "active systems". In most cases, it is accomplished through changing certain characteristics in the building over a period of time to cope with varying ecological circumstances or user needs (Badarnah-Kadri, 2012). Therefore, in buildings, adaptability and response are generally seen to be the actual time responses to the specified parameters. Although the reaction and adaptation are derived from flora and fauna, their use and implementations in architecture are actual dissimilar from nature. Unlike cases in the architecture field, adaptation means a gradual change in nature. Because of these important variances, buildings are not able to use all the capabilities of adaptive and reactive systems, such as natural creatures.

The adaptation principles transmission process to architectural envelopes concentrates primarily on finding a balance with the imitation of specific natural properties. Meanwhile, the limitations of this specific function do not precisely correspond to the design problem, it is difficult to attain the adaptive quality of the mimicked natural system. For example, while motor-based systems created by nature tend to attain the flow of energy, they generate a lot of energy through reaction, thereby augmenting the total energy amount on the building. In these cases, buildings must be modernized by methods such as new energy-efficient devices or the newest intelligent energy management tools. Thus, the idea of abstraction and the transfer of nature's strategies needs a wider point of view.

In natural skin, adaptation is the consequence of ecological circumstances, on the one hand, and the metabolism and equilibrium of energy and resources, on the other. in addition to given coded response and adaptation strategies in the genes of creatures, the skin adapts to the current circumstances and maintains its adaptation status. Presently, in architectural envelopes, one of the performance-driven envelopes goals is putting a similar framework to our buildings, highlighting on joined and complete optimization of many quantifiable of buildings services. In this respect, despite the fact that there were many dissimilar approaches to architectural performance, in most cases they were limited by performance relative to the building physical environment.

This research discusses the importance of creating building covers and their adaptability to extend the lifetime of buildings. It emphases on adapting the envelope of the building to its surrounding environments. Biological systems and architectural designs for protective covers are open to the similar ecological circumstances and requirements. Therefore, in nature the requirements for coverings and the building shell are similar. The research purposes to extract lessons from nature to improve the adaptability of buildings by designing the shells of buildings. From a biomimetic point of view, the project genes must be encoded form in order to interact with the construction or processing of the building and development with it in the initial design stages till demolition of the building. As in nature, the idea of adaptation is integrated into the design as a vital and multi-layered process, in which all the building systems are involved. This view not only allows the creation of sustainable buildings but also extends the service life of existing buildings.

Facades play a significant role in regulating the waste of energy in constructions in general. But, most of them are made to offer solutions that require a lot of energy to reach internal comfort levels. However, the biological adaptation solutions are complex, multifunctional and highly responsive. The research provides a biomimetic study of the connection that might be settled among ecological environments (nature) and constructions (architecture) and ground-breaking solutions for the design of architectural facades. It is guide lines to architects for improving energy efficiency of buildings skins and to be helpful at the beginning of the design phase of the building facades. This study focusses on animals and wildlife because the animals have adapted to the environment and developed special ways of interacting and cooperating with varying external problems and different environmental conditions.

Research Hypothesis

Biomimicry could provide guide lines to architects for improving energy efficiency of buildings skins and be helpful at the beginning of the design phase of the building facades. The main question in this study is:

- “Can we use biomimicry as a way to reduce the energy consumption in building skins?”

The sub-question of the research is:

- "Is it possible creating a design mapping that helps architects design energy efficient building skin by using Biomimetic principles?"

Research Objectives:

The study is analogously conducted between the protective coverings of buildings and biological systems. The goal in this study is to provide a design mapping for energy efficient building skin which is basic guidelines that help designers decide at the beginning of the design phase of a building façade about the nature of the skin in nature and the design of envelopes. The subject of the investigation is very large and certain boundary conditions must be established. The study could be carried out with particular attention to the different coverage of nature: animal skins, peels, outer plant coatings, *etc*. Because they better serve the purpose of research with their different coping strategies, animal skins are selected as biological models for this research to examine.

The goals of this study are:

- Study and build relationships between the skin in nature and the building envelope in architecture.
- Study the potential of biomimicry and its application in architecture.
- Recognize the Identification of natural skin and building adaptation strategies.
- Explore the potential to define the idea of adaptation in a biomimetic representation in architecture.
- Provide guidelines for designers to achieve more energy efficiency.

Methodology

Biomimetics involving several academic disciplines. For this reason, it cannot be estimated using traditional methods of architectural design. Because this complex and multidisciplinary field of biomimetic research is mainly studied, and appropriate methods discussed. Initiatives have been taken to develop methods for biomimetic design, but in the creation of design concepts, a general method can still be established.

This research is concerned with transferring adaptation strategies of animals into innovation technologies. The literature review of the thesis examines the development of adaptive skins in architecture, counting biomimetic envelopes. In addition to the revised construction projects, other scientific researches will be examined and compared. The methodology part of the thesis presents an overview of animal adaptation strategies. In addition, new ideas for the optimization of energy efficiency are being presented and discussed, and also provided some probable applications in building envelopes that address various environmental problems in adaptive systems then respond to varying environmental circumstances of the climate. After reviewing the literature to organize information on wildlife and its collaboration with its environment, a methodology was proposed to design a biological simulation. This methodology leads to conceptual projects of adaptive engineering skins. A design mapping is proposed to enable the transfer from natural stage to architectural stage.

The suggested methodology as exemplified and applied in Table 5.3, Table 5.5, Table 5.7, Table 5.9, Table 5.11, Table 5.13 is separated into two main phases to know how animals' principles might be used to produce envelopes could adapt in architecture: the first is how strategies and adaptation mechanisms are defined in animals in dissimilar climate zones in nature. Second, it indicates to architecture and carefully chosen ideas and how to convert them into groundbreaking solutions to architectural building envelopes. The Biological Phase is associated with further investigative studies and systematic ideas and climatic changes are concerned, The Architecture Phase is inspired and inferential while primarily concerns the climate changes too to accomplish more adaptability in all kinds of environments.

Biological Phase (Nature)

This first phase gives a general overview of the biological organisms studied, and this thesis depends on animals' studies. It is divided into three important questions: what animal adaptation is examined? why this animal made this adaptation and how did it?

The First Question: WHAT? investigating a general description of the animals' adaptation by studying information like the general adaptation types (morphological, physiological or behavioral). The biomimetic approach is also described (Design Looking to Biology, Biology Influencing Design).

The Second Question: WHY? And here the natural challenges are investigated to define the function. What challenges does this animal face to adapt and be able to live in this climate zone? Or we can ask. Why should this animal need to do this strategy?

The Third Question: HOW? exploring how animals improve particular functions, how a specific animal handles the water storage, in addition to, how these animals able to prevent dryness and how to continue living while there are large temperature variations. for recognizing these particular adaptation behaviors, and its specific tasks, the connotation among function and structure is examined. The essential ideas such as process, and function are defined. For reaching the needed challenge, the function is required, therefore, we extract them, for example. Opening, reflecting, controlling or absorbing. The function will be crucial to the achievement of the design idea. The process defines how these animals have improved these exact adaptations, and also helps to know why these animals have the ability to live in this climate zone.

Design Phase (Architecture)

In this phase, abstracting the animal's adaptation principles and turn them into practical results and applications for building envelopes and at the same time adaptive like animal's skin. This phase is determined with three essential thoughts: application concepts, innovation and design concept generation.

Application Ideas**:** These thoughts and ideas here indicate to one of adaptability types, for example: static or dynamic adaptive envelope. The animal's adaptations can be ordered into a collection of information based on movement and environmental considerations. Adaptive Envelopes in architecture can also be separated into two different approaches: adaptive behavior might be depending on motion or material properties. The adaptability in building envelopes suggests that there is some kind of noticeable movement, which leads to changes in the envelope shape by the moving parts. Movement types might be: folding, fanning, slipping, extending, wrinkling, revolving, winding, inflating, twisting. The second type of the adaptive envelope, any variation influences the material structure from inside.

Innovation**:** Envelope design standards can decrease energy requirements for HVAC systems (Pacheco, Ordóñez, & Martínez, 2012) and addressing energy efficiency issues requires advanced solutions. (Omrany, Ghaffarianhoseini, Ghaffarianhoseini, Raahemifar, & Tookey, 2016) The adapting Animals have faced a lot of challenges over time to their surrounding environment and these challenges can increase innovation. thus, based on the design challenges and advantages, some innovative thoughts are suggested. Why is this solution better than the current one? These ideas seek to demonstrate the biomimetic design benefits.

Concept Design**:** The design notion originates from biological noticing. The new design idea is a transformation of animal's adaptations by observing it and its function to something new and at the same time has the ability to be adaptive to surrounding environments. The initial illustrations and the helpful particulars built on the animal's adaptation analysis to provide a conceivable practical implementation.

The comfort side of individual performance must be taken into account in addition to the physical requirements. Therefore, must keep in mind that individual behavior is an important aspect. It is necessary to be considered throughout the design process of the practical application.

Limitations and assumptions

The current study provides six selected examples from Ilaria Mazzoleni's (2013) book "Architecture Follows Nature: Biomimetic Principles for Innovative Design" since it is the only source that provide proto-architectural projects inspired from animals' skins. The projects used to exemplify the conceptual framework outlined in this thesis, each design project is organized to explain the biological research, inspiration, and subsequent development of the architectural project. Furthermore, the hypothesis of this study is predicated on the assumption that, the analyzed six examples from Mazzoleni's book are enough to figure out the research's goals and verify the hypothesis.

2. LEARNING FROM THE BEST IDEAS FOUND IN NATURE

2.1. The Definition and a Historical Background on Biomimicry

Biomimicry means to imitate life and derives from Greek roots bios means life, and mimesis means imitate. It has been published by Janine Benyus as a new discipline that studies nature's greatest concepts and ideas then copies the designs and process to solve human problems (Benyus, 1997). Zari notes that an obstacle faced by architects is the lack of a clear definition from the diverse options that architects can apply in their project That's why it's important to analyze the appropriate approach to fully apply the best method of Biomimicry to fully utilize the advantages (Zari, 2007) .Furthermore, Gruber explains Biomimicry as the study of overlapping fields of biology and designers that demonstrate inventive potential for solving architectural problems (Bar-Cohen, 2005). Thus, biomimicry is defined as an “innovation process encouraging the transfer of ideas, concepts and strategies inspired from the living world, with the objective of designing human applications aiming at a sustainable development” (URL-1).

Biomimicry history returns back to 500 B.C where, the Greek philosophers have seen natural organisms as models for a rhythmic equation and proportion between the sections of a design that is equivalent to classical perfection of beauty. Scholars and researchers who have studied biomimicry and biological field are considering the earliest example was Leoanardo da Vinci's (1452-1519) studies of birds and the human flight. Most of da Vinci's observations and notes were not used in his lifetime but have affected a lot of inventors since then and he never succeeded in flying. Da Vinci designed and built the parachute in 1483 and examined in 2003 by Adrian Nichols (Figure 2.1) (Gruber, 2011).

Figure 2.1. Leonardo Da Vinci's drawings for the flying machine; one of earliest biomimetic designs in the 13th century(ElDin *et al*., 2016)

Despite his flying machine was never finished, just principle of being inspired by nature provides da Vinci as a biomimicry pioneer (ElDin *et al*., 2016) . Then Joseph Paxton designed the Crystal Palace for the Great Exhibition in 1851 and the inspiration came from the leaf of a water lily see (Figure 2.2).

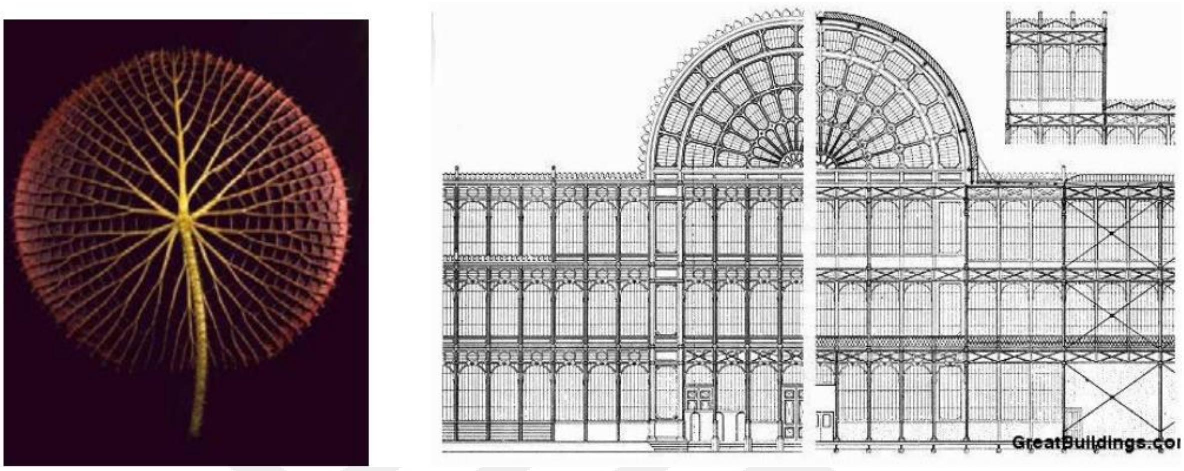


Figure 2.2. On the left water lilly; on the right crystal palace (Eldin, Abdou, & Elgawad, 2016)

Manned flight continued a challenge till the end of the 19th century, when Otto Lilienthal, Igo Etrich and Wilbur und Orville Wright (Wright Brother) made their additions to progress. Wilbur und Orville Wright one of the most famous pioneers in human flight who succeeded for the first time in flying. The Wright brothers' model, especially the wings' control system inspired by the way birds use air currents to gain lift and simplifies changes of directing (Gruber, 2011).

In 1941 George De Mestral first conceptualized hook and loop after a trip with his dog in the Alps (Vincent, Bogatyreva, Bogatyrev, Bowyer, & Pahl, 2006). After erasing some of the burdock burrs that kept attaching to his clothes and his dog's fur, the Inspiration came by the prickly seeds' tiny hooks. The result was two pieces product of fabric: first one hooks the other one loop. The term “Bionics” provided in 1958 by Jack E. Steele (Radwan & Osama, 2016) . He has defied it as "the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues."(McCarty, 2009; Vincent, 2009).

The term "Biomimetics" has been used for the first time by American biophysicist, Otto Schmitt. in his paper at the International Biophysics Congress in Boston in 1969 (Vincent *et al*., 2006).

The term “Biomimcry” appeared for the first time in 1982. Biomimicry was popularized by biologist and author Janine Benyus in her book” Biomimicry: Innovation Inspired by Nature” in 1997 and defied it as a "new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems". Also, she asks us to look to Nature as a "model, measure, and mentor" and asserts sustainability as an goal of biomimicry (Benyus, 1997) . Moreover, the gains of sustainability, using biomimicry to create innovations in systems, materials and architecture.

2.2. Design Approaches in Biomimicry

Approaches to biomimicry as a design process typically fall into two categories. First is defining a human need or design problem and looking to the ways other organisms or ecosystems solve. The other one is identifying a particular characteristic, behavior or function in an organism or ecosystem and translating that into human designs (Benyus, 1997).

2.2.1. Design looking to biology

This approach also is known as the problem-based approach, suggests that designers may look to the living world for solutions. This way is also allowing designers to recognize problems and then let the biologists match these to organisms that have found solutions to similar issues. This approach is efficiently ran by designers identifying initial goals and parameters for the design (Zari, 2007). This approach might be a way to initiate transitioning the built environment from an unsustainable to efficient to effective paradigm (McDonough & Braungart, 2010).

For instance, of such an approach is Bionic Car (DaimlerChrysler’s prototype Figure 2.3). The design for the car was based on the boxfish. The car achieved more efficient in fuel usage because of its aerodynamic body. Also, achieved more materials efficient through using the minimum amount of material in the car's body (Zari, 2007).

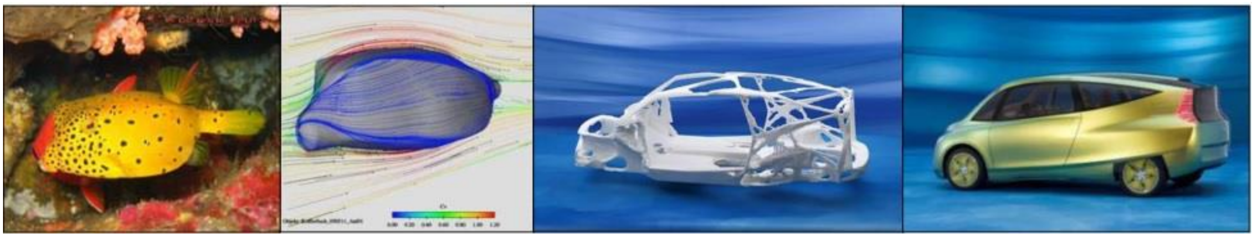


Figure 2.3. DaimlerChrysler's prototype (Bionic Car) inspired by the box fish and tree growth patterns (Zari, 2007)

Computer modeling method used in designing the Bionic Car in to decrease the stress concentrations, and this inspiration came from tree growth patterns which is helped to clarify the minimum amount of material demand in the car's body (Vincent *et al*., 2006; Zari, 2007).

2.2.2. Biology influencing design

It is also called as the solution-based approach. According to Zari "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 ". An example for this approach is the lotus flower emerging clean from swampy waters, which helped to find many innovations later (Figure 2.4) (Zari, 2007).

Figure 2.4. Lotus Flower (Zari, 2007)

2.3. Levels of Biomimicry

A widely-accepted classification done by Zari claims those three main levels of Biomimicry can be applied to architecture: form, process, and ecosystem. Through analysing the organism or ecosystem, form and process, a solution can be brought by nature. For this application, it is important to determine which aspect(s) of biology is to be mimicked (Mazzoleni, 2013; Zari, 2007).

The information inserted in every organism can appear in many levels, which is epitomized in (Table 2.1), probable features that can be achieved from an organism and its biomimicry are analyzed using three levels. Every level is related to a layer of the design of an organism. The first includes aspects and characteristics of a creature as a whole unit. The second includes other features that concentrate on the relationships between an organism and its living community. The third level concentrate on systems and eco- solutions that can be achieved from relationships between an organism and its context/environment (El-Zeiny, 2012) .

Table 2.1. A Framework for the Application of Biomimicry adapted from Zari, (2007)

	ORGANISM LEVEL (Mimicry of a specific organism)	BEHAVIOR LEVEL (Mimicry of how an organism behaves or relates to its larger context)	ECOSYSTEM LEVEL (Mimicry of an ecosystem)
FORM	The building looks like a termite.	The building looks like it was made by a termite; a replica of a mound.	The building looks like an ecosystem (a termite would live in).
MATERIAL	The building is made from the same material as a termite; a material the mimics termite exoskeleton skin for example.	The building is made from the same material as a termite; a material the mimics termite exoskeleton skin for example.	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium
CONSTR-UCTION	The building is made in the same way as a termite; it goes through various growth cycles for example.	The building is made in the same way that a termite would build i.e. piling earth in certain places at certain times for example.	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used.
PROCESS	The building works in the same way as an individual termite it produces hydrogen efficiently through metagenomics for example.	The building works in the same way that a termite; by careful orientation, shape, material selection and natural ventilation for example or it mimics how termites work together.	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water
FUNCTION	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.	The building functions in the same way it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example. It may also function in the same way that a termite mound does in a larger context.	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilizing the relationships between processes; it is able to participate in the hydrological, carbon and nitrogen cycles in a similar way to an ecosystem.

2.3.1. Organism level

The organism level examines the inventive ideas of the entire organism or part of it , then mimics it in order to offer new sustainable and durable solutions to solve human problems (Zari, 2007). The world's fastest railway lines are running in Japan, known as "Ballet Trains", which are considered as an organism level of learning from nature.

A bullet-shaped was developed to use the high-speed movement of these trains. When the fast-moving train comes out of a tunnel, it builds a pressure wave that causes a loud booming sound. The noise was obviously a problem for the surrounding areas and a new design was needed to fix it. In order to find a solution to the problem a birdwatcher on the team, he turned to nature and discovered a Kingfisher who dives into the water from the air without disturbing the surface. The kingfisher’s beak is streamlined shape, which is acting as a wedge plied the surface for a low-splash entry. As shown (Figure 2.5), the team applied a beak design to the ball train, which not only helped to eliminate the booming sound, but also achieved more aerodynamic reduction in energy demand. It now moves 10% faster and uses 15% less electricity (URL-2).

Figure 2.5. Kingfisher bird and bullet train (Abbasli & Selcuk, 2016)

2.3.2. Behavior level

Behavior level can be explained as an action that the organisms do to survive in nature by providing inventive solutions (Zari, 2007). The Eastgate Centre, the largest commercial complex and business offices of Harare Zimbabwe is one of the most well-known architectural examples of biomimicry, designed by Mick Pearce (Figure 2.6). In such a climate like Harare's climate, the maintenance of the old air conditioning for the building was expensive, so needed environmentally friendly and sensitive adaptations. To regulate the temperature at a comfortable level for the staff and occupants were needed some creation of self-regulating ventilation system. Pearce looked at the termite mound and then inspired by models of internal climate control in the termite hills.

Termite mounds could keep the constancy of indoor temperature by having a physical structure that allows passive cooling. Termites build huge mounds inside which they plant fungus for food. The fungus must be kept in degrees 30 ° C during daytime. The termites open and block the series of heating and cooling openings all over the mountain during daytime. It follows the same cycle with termites digging new openings and clogging the old ones to control the temperature, the ventilation system works in similar way (URL-3).

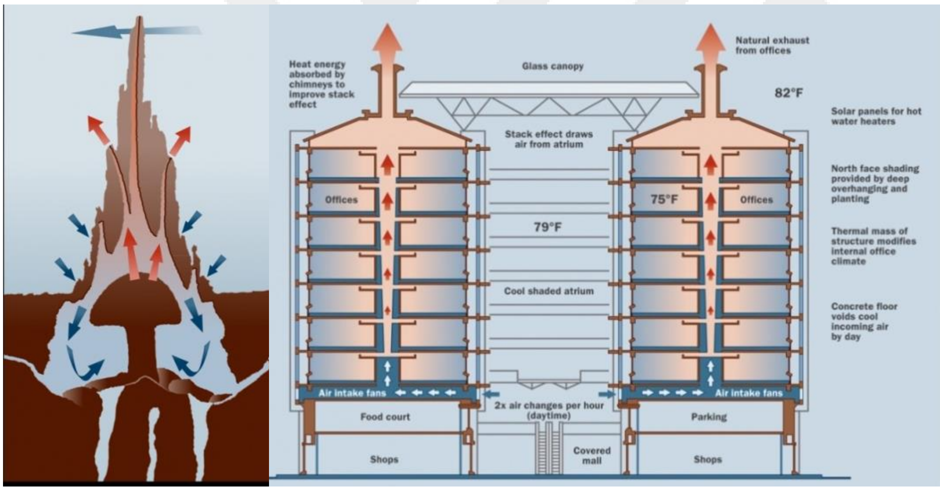


Figure 2.6. Termites mound and the Eastgate Center Building (Abbasli & Selcuk, 2016)

In the construction of the Eastgate Centre building, high thermal materials were used to help maintain and release the heat of the environment. Fans running in cycle time are used to increase heat storage during the hot day and to release the heat for a cool night. Many openings over all the building further lets wind driven airflow. As shown in (Figure 2.6), these design features work in cooperation to reduce vicissitudes in the temperature level inside the building (URL-3).

2.3.3. Ecosystem level

In order to learn and emulate current ecosystems in nature, first knowing what principles and factors are needed to work and how it works effectively. The master plan of the island of Zira seems to be perfect design of this form of biomimicry. It was developed by Bjarke Ingels (2009), founder of BIG Architects.

Zira Island is located on the Caspian Sea in Baku Bay, Azerbaijan. The project aims to become a zero-energy complex and entertaining city. Although it seems impossible to create a zero-energy resort that consumes a 1,000,000 m^2 island, BIG has found a solution for its successful implementation. This project was initiated by the Azerbaijani minister because he encouraged when he saw previous projects proposed by BIG. The minister thought it was great to rebuild mountains outside of architecture, as Azerbaijan is considered the Alps of Central Asia.

According to Bjarke Ingels (2009), the proposal for Zira Island rests the natural landscape of Azerbaijan (URL-4). It is not only the iconic silhouettes of the seven peaks, but more importantly, an autonomous ecosystem allowing the air flow, heat, water and energy to be channeled in most natural ways. As shown in (Figure 2.7), a mountain can make biotopes and Eco-niches, to channel water, to keep heat, as well as to provide attractive sceneries, valleys, access and shelter. The Seven Peaks of Azerbaijan is not a metaphor only. In fact, it exemplifies living models of the Azerbaijanian mountainous ecosystems (URL-5).

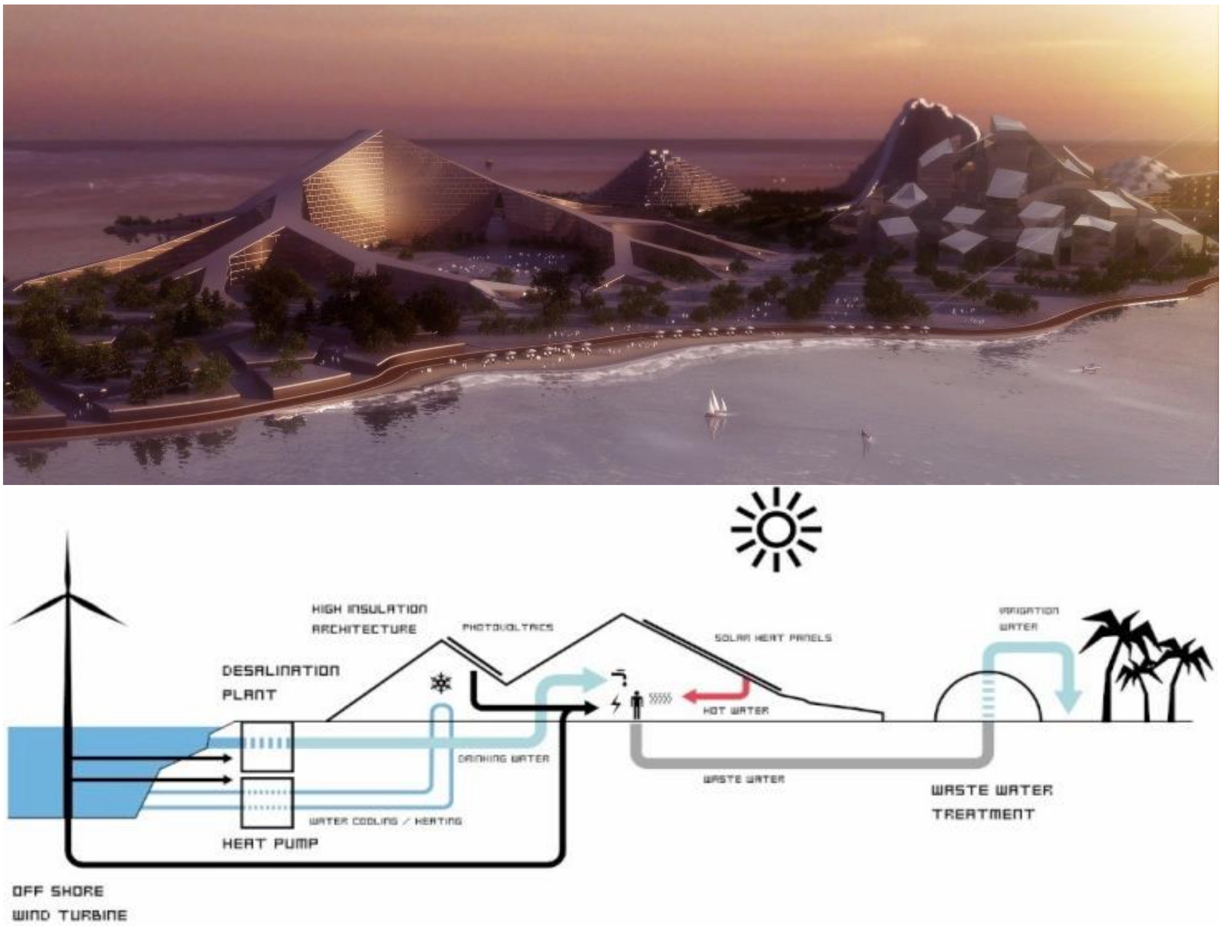


Figure 2.7. Zira island concept view and ecosystem working principle(Abbasli & Selcuk, 2016)

2.4. Applications of Biomimicry in Different Fields:

<u>Toxics</u>

The lotus leaf considered as water-repellent leaves. Many people think that the leaf is unruffled and smooth for the reason of its quality, but quite the reverse, the lotus leaf is coarse. Although it is microscopic, it is sufficient to trap an air labyrinth which the drops of water float on, thus purifying and washing the leaf. A professor at the University of Bonn developed a lotus leaf-based surface. This information has directed to an original different generation of tints and surfaces to lessen biochemical needs or tedious cleaning (Figure 2.8) (Lurie-Luke, 2014).

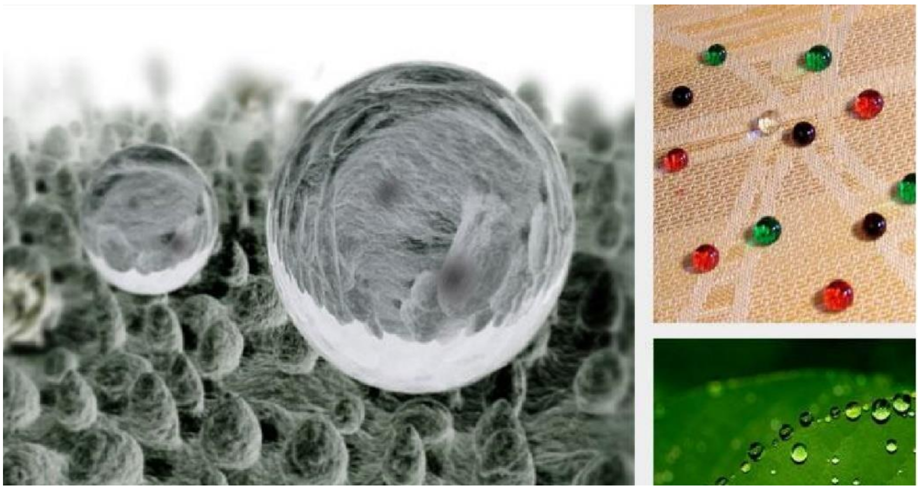


Figure 2.8. Lotus plants teach how to clean (Arnarson, 2011)

Energy

The humpback whale is heavy and voluminous, weighs about 36,000 kilograms, and at the same time is very dexterous, and especially for its flippers after investigating it nearly, it has bumps called tubercles. This results in better control as the bumps allow the whale to more easily divide by swimming and turning. Currently experts have tested the flippers aerodynamics with tubercles and without it, the outcomes are impressive (Figure2.9).

Figure 2.9. Humpback whales teach how to make effective wind turbines (Arnarson, 2011)

There is an 32% reduction in drag with tubercle and 8% improving in lift. Recently this results is being applied by WhalePower company to design wind turbines to rise productivity and efficiency in addition to have the potentials to improve the aircraft's performance and safety, fans and other similar technologies (Lurie-Luke, 2014).

Medicine

The chemicals that showed promising result in the human treatment was invented from veronica genus plant. The scholars who watched the apes found how they would behave when they were ill and how they usually were looking for veronica plant. Although about one in four medicines comes from a plant, there is only a fraction of the plant world known to mankind. Learning from different types and knowing that these types have collected through thousands of years or maybe millions, to facilitate examination and exploration for original medicinal Plants (Figure 2.10) (Lurie-Luke, 2014).

Figure 2.10. Learning from chimpanzees how to heal ourselves (Arnarson, 2011)

Human safety

For under water information transference, EvoLogics designed an advanced modem inspired from the dolphin's ability of communication and processing sound data correctly and strictly. The problem so far was how untrustworthy the sound waves are once they move out of water due to the critical intrusion with each other.

At the present time, EvoLogics created a technique to make it exceedingly correct and exact by emulating dolphin's ability of communication by having numerous hesitancies in every transference. This showed an innovative way and superiority in the safety tools which is utilized to inform commonalty if a danger is coming to hit the land like tsunami. The tools, which consists of sensor, buoy and satellite, the sensor must be deep in water around 6000 meters, the satellite and buoy on the external surface, which transmit data to a primary threatening center. Based on dolphins data , the motions from the sensors to the buoy is exceedingly trustworthy, which leads to better human security (Figure 2.11) (Arnarson, 2011).

Figure 2.11. Dolphins teach how to inform publics about danger like tsunami (Arnarson, 2011)

Manufacturing design

looking carefully at a tree, you realize how the tree acts, how it optimizes the intensity, solidity and reduces the pressure, adds material in addition arranges the fiber as required. As the skeletons go on, a step more than that by eliminating parts where it is not required, it is the variance of why the skeleton must tote loads (Figure 2.12).

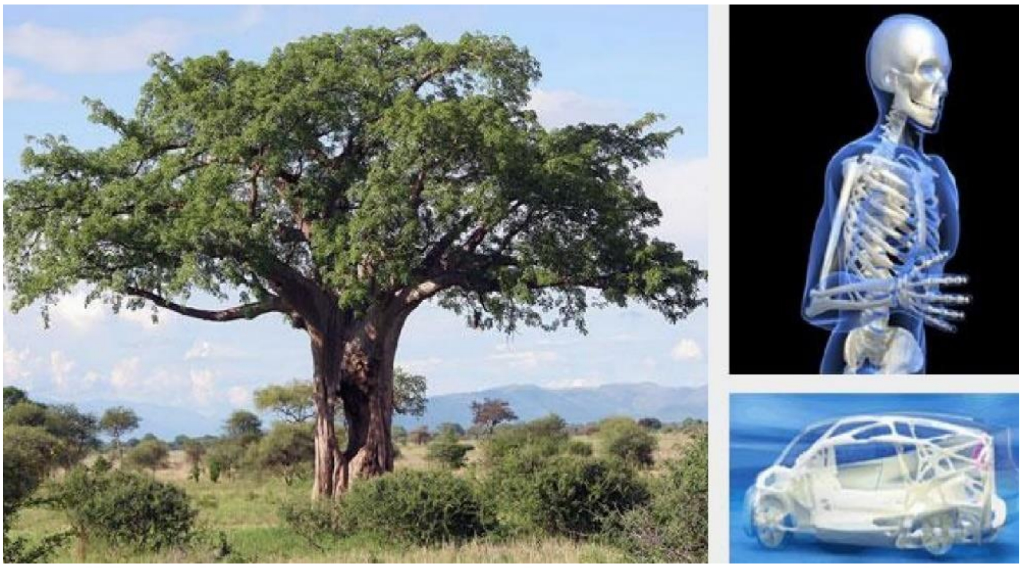


Figure 2.12. Trees and skeletons teach how to optimize strength and materials (Arnarson, 2011)

2.5. Biomimicry in Architecture

All over the world, enormous amount of primary energy is wasted due to the inefficient design of buildings. The architectural field is trying to reduce its impact on the natural environment. In this context, it is possible to learn from the lessons of natural systems and they can be applied to architecture to minimize environmental impacts of buildings. As architects there are many buildings around the world had inspired by nature, can show how the adaption strategies from nature had been applied to architecture field, there are some of these examples:

2.5.1. MMAA Office Building, Qatar

The new building of the Ministry of Municipal Affairs and Agriculture (MMAA) in Qatar is a striking example based on biomimetic principles. Qatar is relatively arid covered by desert and have rate yearly rainfall of 3.2 inches (URL-6). Bangkok Aesthetics Architects GO Group chose to design the MMAA building, inspired by a desert plant, cactus that has survived productively in scorching, dry environments. Inspired by the method of these plants manage the desert weather. The office building will mimic the cactus that survives successfully in the desert in a way that how it works (process) and what it can do (works), which of course helps (Figure 2.13).

Figure 2.13. MMAA Office building inspired by desert cactus and a cactus plant (URL-9)

As an example of biomimicry from the desert, the usage of biomimicry appeared by achieving more energy efficient and utilizing sunshades on the windows. relying on the strength of the sun through daytime, the sunshades could be opened or closed to prevent overheating. This is like cactus deciding to do transpiration in nocturnal time instead of diurnal time to keep the water. At the base of the tower there is a dome adapted to be garden, which could be used in additional green areas comprising an edible garden and using plants to clean up waste water (URL-6). These are sunglasses that act as a filter, with sunlight penetrating the rooms. They can vary up and down, open or close, relying on required internal heat for adjusting the quantity of daylight and temperature that is moved to the space (URL-7). This result helps MMAA office building to reduce the quantity of non-natural cooling needed for MMAA offices to 5-10%; Therefore, around 40-45% of the annual costs can be deducted and the energy consumption of the HVAC can be reduced to 50%. The environmental benefits of this "learning process" can be enumerated as follows:

1. Ensure natural lighting
2. Compatibility with external environmental factors such as (wind-sun)
3. Depending on the weather, use a large amount of glass. This increases the transparency of the building and allows integration between it and the environment.

2.5.2. The Gherkin Tower, London

The Gherkin Tower in London city was designed by Foster & Partners. This hexagonal skin (form) was inspired by " Venus Flower Basket Sponge ". This remarkable sponge hosts a lattice-like exoskeleton that looks glowing and glassy underwater. In addition, designers have imitated the way of Venus flower basket sponge works (process) distribute stresses to the body in different directions and their round shape reduces forces due to strong water currents. (Figure 2.14). The windows let sunlight and natural air to enter the structure. The curves of Gherkin Tower permit the wind to easily bypass its shape. Rectangular buildings deflect wind down and hit the road in windy climate. A hole in each floor called atrium exposes the beams. This reduces the air conditioning by 50% (URL-8).

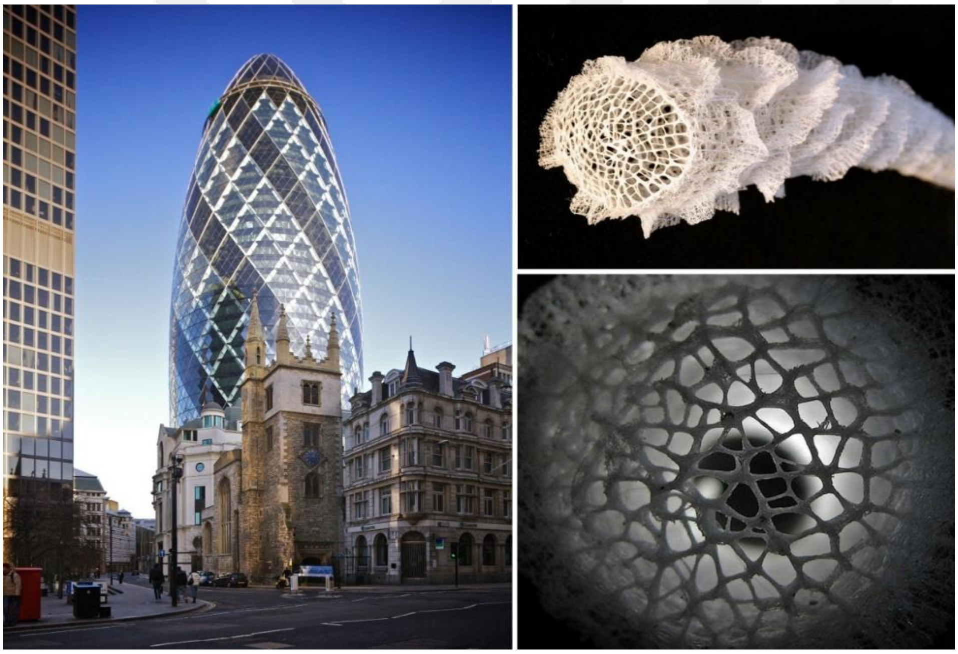


Figure 2.14. Gherkin Tower and Venus Flower Basket Sponge (URL-10)

The Gherkin Tower stands out not only with its incomparable design, but also with its energy efficiency. Inspired by a sea sponge, which dramatically increases the strength of the structure and reduces energy consumption, open shafts were built to ventilate the building and to let the passive heat and sunlight to penetrate deep into the building. As a result, the building uses only half the energy of a traditional tower of similar size (URL-8). The environmental benefits of this imitation can be listed as follows:

1. Natural ventilation system integrated into a double skin.
2. Minimal impact on the local wind environment.

3. Comfortable environment for the users.
4. Permits sunlight to go in the building but keeps the inside from overheating.
5. Good physical and visual connection between soils and the environment.

2.5.3. Water Cube Building, Beijing

The Water Cube, or the Beijing National Aquatic center designed and built 2007 by PTW Architects and Arup. The concept of biomimicry was represented in the building through imitating soap bubbles shape which represented the key concept of swimming pool too. (Figure 2.15). Ethylene tetrafluoroethylene (ETFE) was selected for the external envelope (URL-11). This material weighs 1% of glass and consider as improved thermal nonconductor. Moreover, about 20% of natural energy is trapped and utilized for heating (Figure 2.15).

Figure 2.15. The Beijing National Aquatic Center, soap bubbles, design principles of typical section (URL-12)

By covering the building with ETFE cushions, the center is good lit throughout the daytime, with abundantly of sunlight, visual comfort and visual connection. Up to 55% savings in the use of lighting energy in the leisure pool hall, less savings in other areas. The environmental benefits of this imitation can be listed as follows:

1. Energy costs have been decreased about 30%.
2. Non-natural lighting reduces about 55%.
3. New water transparency experience for guests.
4. Rainfall in winter is gathered and recycled by backwashing systems.
5. About 20% of sun’s energy is collected and utilized for heating purposes.

Nature is still giving great quality and simple solutions for maximal success by using minimum effort. The building need to achieve a wide range of variable often conflicting requirements, such as maximizing daylight inlet whilst minimizing thermal overheating, using thermal storage whilst applying light weight constructions, which it is trying to maximize energy efficiency, adaptively and comfort whilst using minimum of natural resources and epitomized energy, this focus on biological solutions shall bring to us a new innovative addition for the future.

3. THE BUILDING ENVELOPE

Animal skin is organ responsible for assistance the metabolism, increase impregnability, keeping bacteria outside their bodies and controlling body temperature. The skin is a stretchy membrane that allows activity and function as a surface for sensual perception (tactile). Consisting of a diversity of compound systems and layers. The skin performs as a border between internal and external environment (Figure 3.1). Shows how ancient people utilized animal skins to make their building skins; so it refers to an old tradition. (Yowell, 2011)

Figure 3.1. A Prairie Camp (Yowell, 2011)

Natural skins are examples for how building skins must perform. And it also considered as a primary line of protection to save the organism's internal organs from the outside threats. At the same time organism's membrane has the ability to control humidity and temperature, is regularly water-resistant, permeable when required, assimilates internal organs and systems in tinny envelope, guards from strong daylight, heals its own damages. Also, it does all this with environmentally manufacturing, and will be useful to the environment during its life (Yowell, 2011).

The cladding (envelope) of the building is regularly pointed to building skin, which guards the center from environmental destruction. The envelope of building also splits and defends the juxtaposition surroundings and lets the necessary transference process between different areas. The cladding of the building is considered as the first impression of the building, seen by people from outside as well as from inside, similar to natural skin (humans). The façade structure can also effect the inner environment, which effects comfort levels, toughness and energy, output and happiness of the residents and visitors (Gunderson, 2015). In this chapter, the envelope of the building is considered as a border among the construction center and the external surroundings.

3.1. Novel Approaches in Architectural Envelopes

The envelope development is one of 20th-century design innovation goals, it is associated with advances in engineering, in addition to improvement in computer technology as well, cybernetics and artificial intelligence. In addition, novel technologies, resources, and disseminated systems have stimulated the introduction of biological models to understand how the building systems behave and control. We often use the term "skin building" in relation to the outer layer of the building. Michael Wigginton and Jude Harris argue in their book Intelligent Skins that using the term "skin" is more than just a metaphor. The architectural envelope might be like a complicated surface that can exchange energy, data and materials. This surface or membrane has the ability to work “as part of a holistic building metabolism and morphology, and will often be connected to other parts of the building, including sensors, actuators and command wires from the building management system.” (Wigginton & Harris, 2013).

Terms like “responsive”, “adaptive” "intelligent" or "smart" were often utilized and interchangeable, which caused confusion about their exact meaning and theoretical connection to design and construction act.

3.2.1. Smart

In design disciplines, the word "smart" utilizes regularly for materials and surfaces (Addington & Schodek, 2005). According to Addington and Schodek, Smart materials considered as systems with "integrated technological functions" which include exact and particular replies from the environment and operate through changes in internal physical properties or through the exchange of external energy. They define the properties of smart materials as: “immediacy, transiency, self-actuation, selectivity and directness” (Addington & Schodek, 2005) .This kind of surfaces and materials have ability to provide an important contribution in the most kind of envelopes due to its essential characteristics.

Some smart materials have been utilized in construction envelopes: like micro-encapsulated wax and window glazing. It can convert their physical goods, form to swap energy without any external energy needs. Therefore, smart materials very important for engineers who want to raise functionality, efficiency, performance and reducing energy consumption at the same time. Manuel Kretzer and some students have improved a prototype “Shape Shift”; active envelope, layered, self-sufficient part which distorts once it charged (Figure 3.2) (Trubiano, 2013).

Figure 3.2. Prototype Of Dynamic Skin “Shape Shift” (Velikov & Thün, 2013)

While these systems are still in the study field, a current instance of smart envelope in Media- TIC building, built in Barcelona in 2011 and designed by Cloud Nine and building skin experts Vector Foiltec Ltd. (Figure 3.3).

Figure 3.3. Smart skin comprised of ETFE developed for he Media-TIC Building (Trubiano, 2013)

However, in a high-performance design that is necessary for being intelligence or responsiveness, it is often necessary to respond to a much wider variety of performance conditions and requirements. The skin may be necessary to facilitate more complex communications system of the building, respond to the occupants needs, and adapt and learn over time. Smart materials are often integrated into building envelopes with sophisticated thermal management systems, a pairing that would make them intelligent (Dewidar, Mohamed, & Ashour, 2013).

3.2.2. Intelligent

The term "intelligent" was widely used in the construction industry, as the automation of construction and telecommunications was more prevalent in the Sixties and Seventies, in the decade of 1980 getting more widespread currency because of the programmable areas of building air-conditioning systems, heating and ventilation. The intelligent building skin’s aim is to enhance the building’s systems relative to climate, human comfort and energy balance, normally based on predictive models. This usually achieved through physically adaptive elements like smart material assemblies, louvers, building automation and sunshades. Brian Atkin, describes intelligent buildings in his book Intelligent Buildings as those that “know” what the conditions of environmental inside and outside, that “decide” how to present comfortable atmosphere for inhabitants, and that “respond” immediately to occupant needs.(Atkin, 1993).

The Buckminster Fuller’s façade considered as one of the newest automated climate-adaptive envelopes was built for Montreal Expo in 1967 by the United States pavilion. In this geodesic dome skins, they used a transparent covering of acrylic panels, with internal canvas sunshades and regulate their location relative to the sun (Figure 3.4) (Gorman, 2005).

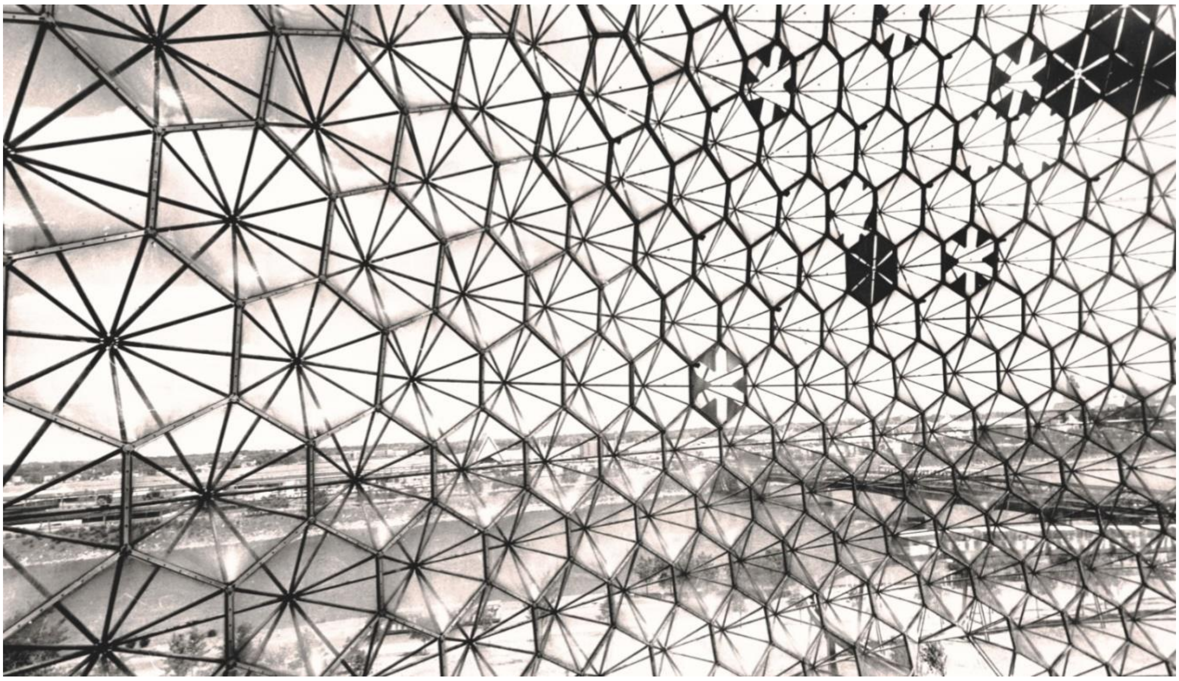


Figure 3.4. The Buckminster Fuller’s façade (automated climate-adaptive envelopes) (Trubiano, 2013)

More newly, the house built for the Solar Decathlon Competition 2007 US, incorporated an external envelope comprised of computer-controlled louvers made from wood with photovoltaic panels that created power while shielding the internal of the house from the sun. The differences between terms “smart” and “intelligent” is that in the case of the previous functionality outcomes from essential material goods, whereas in the latter performance is mainly controlled through computation and automation. The performance profile of intelligent building skin is naturally more changeable than that of smart envelopes; the smart building envelopes operation is typically more limited in control, while intelligent building envelopes typically need exterior power to reach their goals (Figure 3.5) (Velikov & Thün, 2013).

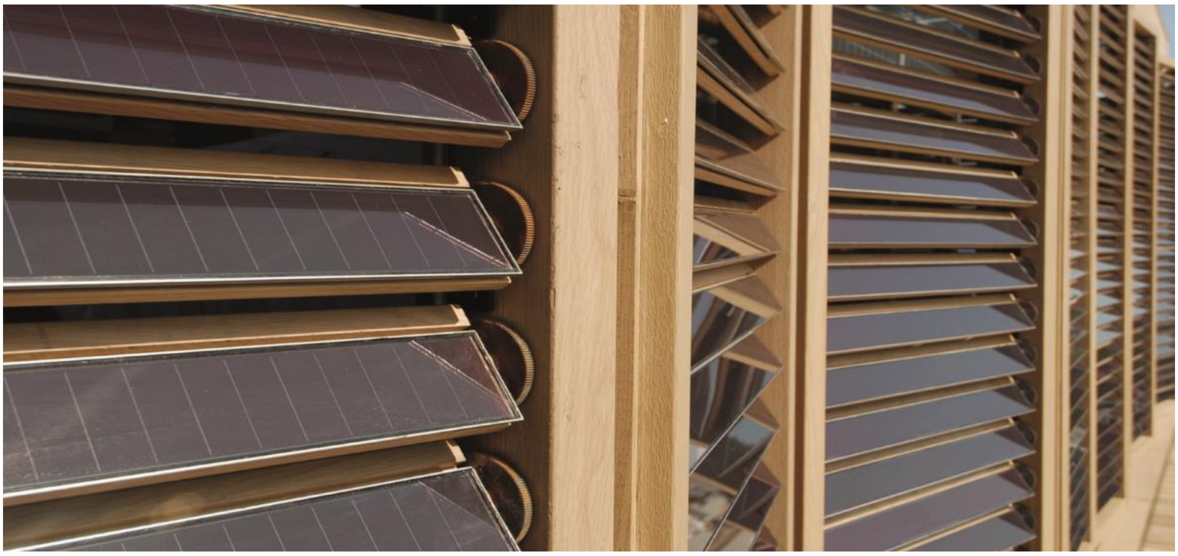


Figure 3.5. Intelligent façade of automated wood louvers (Velikov & Thün, 2013)

3.2.3. Adaptive

The term "adaptive" has two utilizations according to Dewidar *et al*. (2013): The first use refers to an evolution of the morphogenetic design, which is based on ecological design parameters in the examination to get better flexibility in the result of the design through a variety of reiterations ; another use discusses to the real corporeal adaptation of the design to the neighboring climate based on the parameters that established before an exploration of a better symbiosis among natural environment and the made one. Then they described "adaptation" as a design method that aims to unify multi-scalar factors to achieve an energy symbiosis solution to design efficiency. Adaptive building system lead to optimization in terms of functionality and has the ability to contribute to an important lessening in energy exhaustion. Particularly, after the act of the building is improved in terms of weather protection, the benefits of sustainability are found (Dewidar *et al*., 2013).

The system of Strata of the facade of Helium Trace, with adaptive covering system, can be provided as an instance here. (ABI) is a smart shells element called the Adaptive Buildings Initiative has established by Buro Happold with Chuck Hoberman, the design unit has improved a series of shading systems and kinetic panels, including the Strata system (Figure 3.6). The system is aimed to dramatically raise daylight during the reduction of solar heat-gain effects for inhabitants around 81% yearly. In the on-site analysis, the system reached a 42% lessening in whole energy consuming for The building (Trubiano, 2013).

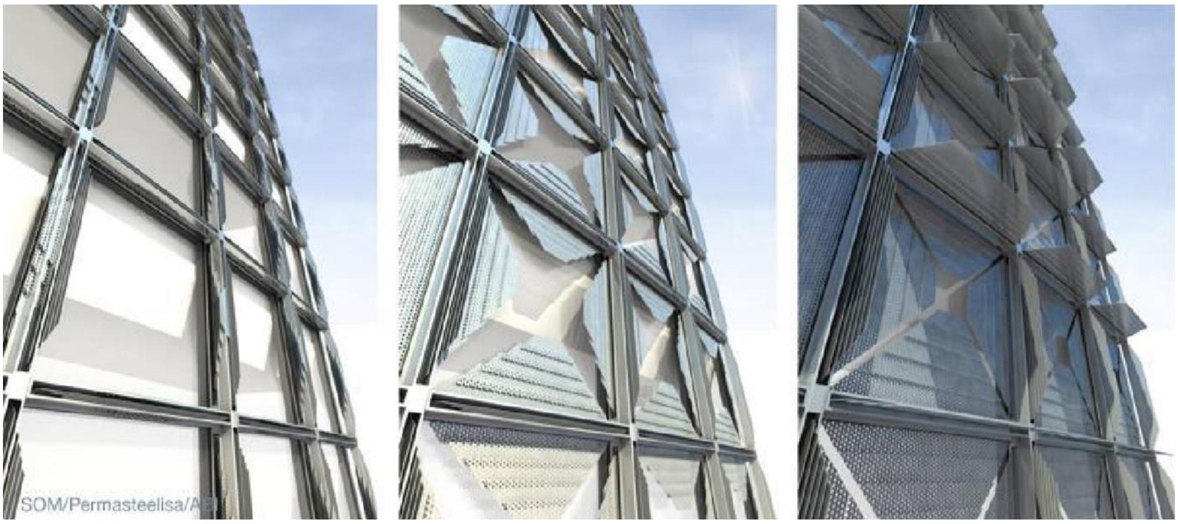


Figure 3.6. Heliotrace system components: moveable external sunshades (Velikov & Thün, 2013)

3.2. Adaptive Building Skins “Envelope”

As mentioned in this research term “building skin” is describing the building envelope, enclosure, cover, cladding or building shell, and of course with emphasis of its connections with the responsive and protecting nature of human skin. For periods of time, designers have tried to emulate the adaptive properties in the building skin to promote interior living conditions. Moreover, since the seventies and eighties, energy and climate change have been an important driving force behind new developments in the facade and roof industry. A lot of building components started to be provided within the building skin in order to contribute maintaining a suitable balance between environmental performance and optimal interior conditions (Goia, Perino, Serra, & Zanghirella, 2010).

Presently, there is a worldwide consensus that the climate of our planet is changing and the rules on energy managing are tightening, from here the design of buildings have to take adaptability in mind to handle the challenges ahead. However, several studies argue that there are no strategic or legislative planning frameworks to guide the design or assessment of adaptation to climate change in buildings, both at the regional and international levels (Dave, Varshney, & Graham, 2012). There is also little obvious number of definitions for adaptive climatic buildings and for alternative expressions used to describe them (Hasselaar, 2006). Many expressions are frequently used to refer to interchangeably building envelopes for environmental conditions changing. For example: adaptive (Gregory, 1986), intelligent, resilient, smart (Compagno, 2002), (Wigginton & Harris, 2002), (Battle & McCarthy, 1994), dynamic (Konstantoglou, Kontadakis, & Tsangrassoulis, 2013), (DiBartolomeo, Lee, Rubinstein, & Selkowitz, 1996), responsive (Kirkegaard, 2011) (Thün & Velikov, 2012),), active (Xu & Van Dessel, 2008), (Goia, Perino, Serra, & Zanghirella, 2010), advanced (Selkowitz & Aschehoug, 2003), switchable(Lampert, 1998) interactive (Fox & Kemp, 2009), (Sullivan, 2006), and kinetic (Moloney, 2011).

Climate Adaptive Building Shells or (CABS) have been often utilized in previous research to describe these kinds of building envelopes. This definition in this research is taken as reference, since it means the need for adaptation to the users, as well as to the changing climatic conditions, at the same time as improving comfort and reducing energy consumption. Adaptability refers to the ability to be adjusted or respond to new situations or conditions. The main goal of architectural adaptation is to reduce the likelihood of a building or building component of becoming obsolete over time (Dave *et al.*, 2012). However, the building skins responsiveness and adaptability can be understood in different ways. The environmental control and building conditioning approaches need a high understanding of how inhabitants react to all the variables of local indoor environments(Rodriguez & D'Alessandro, 2014).

Therefore, a relatively "sophisticated" level of dynamic control is required so that the desired building impact remains relatively constant, but the external impacts of climate are extremely variable. Providing this high level of exterior and interior dynamic change, it is supposed that building skins should improve the ability to react and respond 'intelligently' to any change to lessen the building energy requirements (Wigginton & Harris, 2013).

Following this principle, the development of different competitive directions for the optimization of the building envelope has emerged. For example, some strategies involve the use of computer systems that are integrated into the building skin and can be programmed to act and perform as a "brain" that collects information, processes it, and uses it to control the behavior of the skin, at the same time as controlling internal comfort conditions (Fox, 2016) .The new improvements and developments in biomimicry and nanotechnology field have also promoted the application of smart materials on building skin that respond to specific eternal incentives by adjusting their properties and in return helping to control the environment inside the building .

These systems also considered as regulator to integrated kinetic devices in many cases because they are physically and actively transformed to regulate internal climatic conditions in unison with external environmental changes. The transformation of these devices means a change in position, size, constitution or shape. The changes like the position of the skin, the extent, the action plan, the degree of coverage and the shape, determine a variety of possible designs (Figure 3.7).

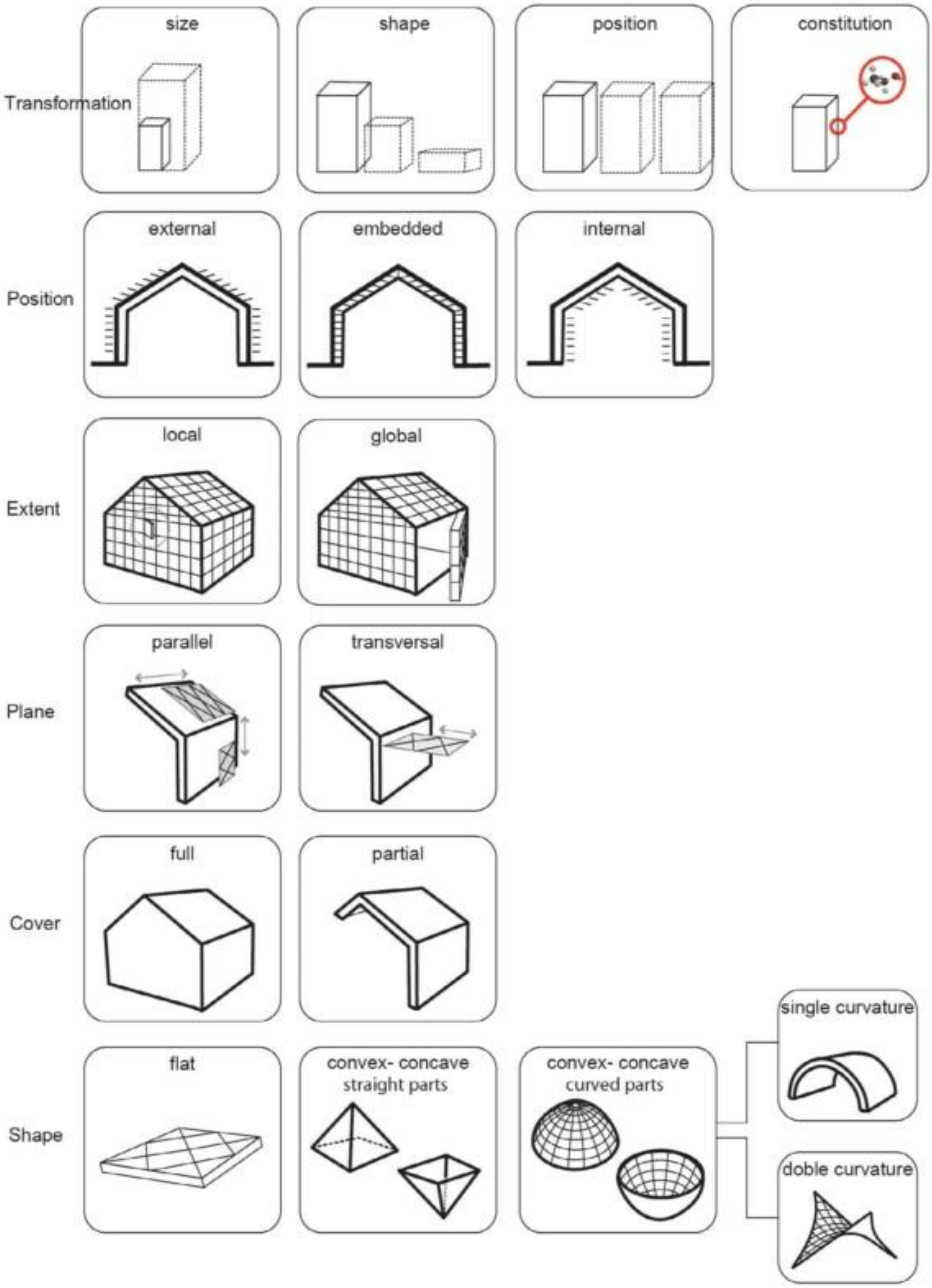


Figure 3.7. Variables for formal transformation in adaptive components (Rodriguez & D’Alessandro, 2014)

Transformations can be obtained by geometric operations: rotation, translation, or a combination of the two (Figure 3.8).

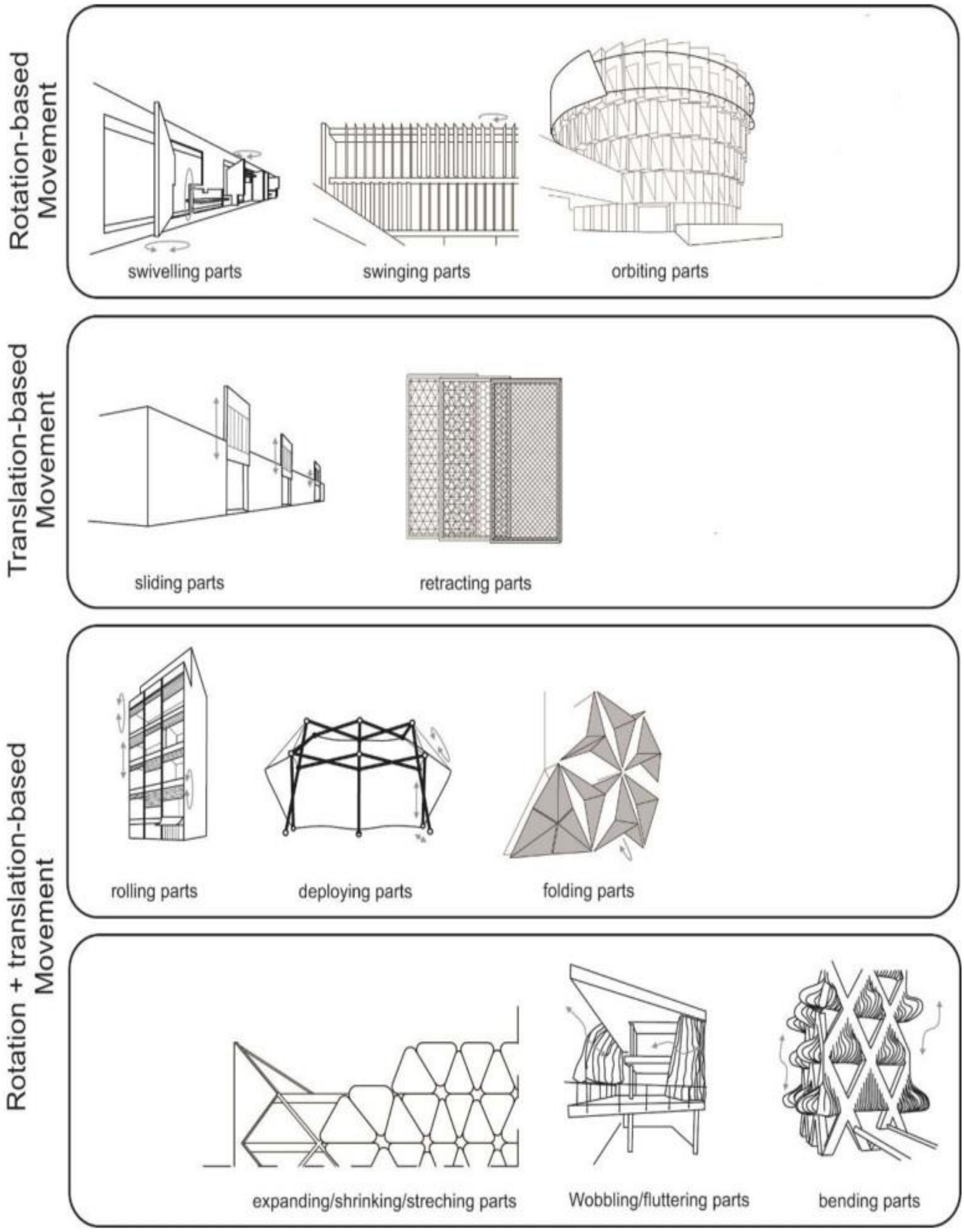


Figure 3.8. Transformation by geometric operations (Rodriguez & D'Alessandro)

In Jean Dollfus's book on the facets of popular architecture worldwide, Jean Dolvos argues that although there are differences in produced by local customs and tradition, the main appearances and properties of established construction techniques rely on the local climate environment. Additional studies that have compared different approaches to sustainable design, conclude that environmental control strategies in buildings are not global, and that what works for a part of the world may not work for another one. Therefore, design solutions are unmeaning if they are not considered in a culturally specific context. This applies to the design of climate-adaptable building skins, where local parameters can determine different ways in which formal materials, technologies and configurations are used (Rodriguez & D'Alessandro, 2014).

3.3. Adaptive Building Skins and Biomimicry

Observing behavior patterns and models of living creatures and trying to learn them offers the opportunity to improve adaptive strategies for building skins. These adaptive strategies can be learned from nature. In fact, living organisms have evolved through evolution, a variety of strategies to adapt in any different climatic environmental conditions. Investigating and analyzing these strategies and their main principles is an important first step in translating these strategies into the building skins. The fact that nature offers a great source of adaptation strategies requires a specific methodological design that meets the needs of adaptable building envelopes (Badarnah Kadri, 2012).

Living beings are based on principles like energy saving, recycling, optimizing forms, using affordable local materials, adapting to the environment and sustainability. Although the aims might not be similar, these principles apply in the construction industry to achieve energy-efficient, more efficient and durable materials and solutions, reduce costs or enhance performance and sustainability (Llorens Duran, 2008). It is about using benefits of knowledge that evolution offers over millions of years. There is a solution for every problem provided by nature, and it is more efficient and sustainable than any industrial process: generating energy, collecting water or producing materials sustainably. Therefore, nature becomes from a resource that can be used to something alive can be learned. Another factor integrating biomimicry into building skin design is its essential role as a driver of innovation in architecture field.

The use of Biomimics opens a range of application domains related to architecture, not only the design of building skins, like environmental design inspired by ecosystems in nature, new systems and ways of manufacturing materials, structural systems, new solutions to existing problems based on living models (Rodriguez & D'Alessandro, 2014).

3.4. Biomimetic Building Skin

The skin is a complex and extremely advanced piece of the body that performs a variety of functions, including protection, feeling, water regulation and heat regulation. In the same way, the envelopes are interface between the occupants of the building and the ecological elements. they provide ventilation, privacy, security and protection. The resultant envelope design works and responds; they take into account, enhance and support dynamic local environmental conditions, making a more sustainable way of building. Every building envelope, similar to animals and plants utilized like a source of inspiration, is improved and perfect for its surrounding environment. Generally, every project tries to use an exclusive characteristic for designing an optimal envelope for its surrounding environment.

In this chapter some examples from animals and plants were presented. Some examples on animals have been studied by Ilaria Mazzoleni and her students during in 2010 at the Southern California Institute of Architecture. These examples relate to subjects of sensation, water management energy regulation, coloration and the usage of native and renewable resources. Four proto-architectural projects were presented by animal's analysis. Animals were selected to imitate a diversity of kinds of skins from different climate zones (Mazzoleni, 2010).

3.5. Inspirations from Adaptive Animal Skin for Architectural Envelopes

Animal skins and building envelopes are a departing point for bio-inspired design approach. They provide an essential element for connection and integration of inside and outside, of built and unbuilt. The following part presents a few proto-architectural projects based on in-depth analyses of individual animal skins and associated systems.

3.5.1. Hippopotamus (*Hippopotamus amphibious*)

This project is managing the sunlight and temperature by using hippo-skin as a model for thermal regulation, sun protection and permeability. Hippo Skin is capable for keeping the sun's UV light out when the Hippo is outside the water by excreting a liquid from glands deep inside the skin which is function as sunscreen. This protection quality considered as the main important thing of inspiration to achieve more energy efficiency through architectural envelope (Figure 3.9).

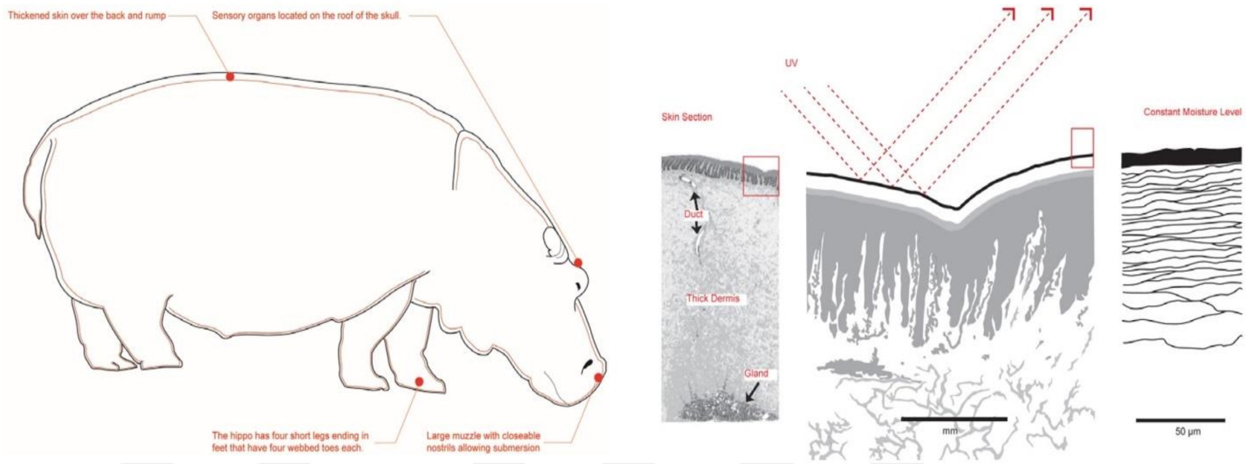


Figure 3.9. Hippopotamus’s skin (Mazzoleni, 2010)

The Hippo is a pachyderm, an animal with thick skins, with a skin containing two layers: dermal and epidermis. Skin depth differs, it is coarser in the back, and more thin and flexible in the abdomen and limbs. In the same way, the external facade of the project is a system, capable to filter the light ray according to the depth. The finer sections allow in more light while the other sections perform as a sun screen. The first thing can be done to regulate temperature is managing how much sunlight inters the building (Mazzoleni, 2010).

The Hippo lifestyle is partly living on land and partly in water, this make him capable to inform the basic physical and organizational structures and facilities design of the buildings to cool the building. The project location in Botswana. The weather in winter season is dry and cold with hot and rainy in summer season during the floods of the Delta River. The hippo can benefit from the plentiful water for refrigeration in summer. By putting together, the concepts of different thickness and water for refrigeration usage, a structure of transportable panels is made for regulating the internal temperature and achieving more comfort levels. Through humid and hot summer season, the panels are placed in a position like the (Figure 3.10), so the water can go in through the building external layer to cool it from inside. Once the panels are placed in second position like the (Figure 3.10), more light rays are capable to break through the façade and heat up the spaces. The variable thicknesses regulate the heat transfer among the outside and the inside of the envelope, altering the cells angles manages light rays' direction entering the building (Mazzoleni, 2010).

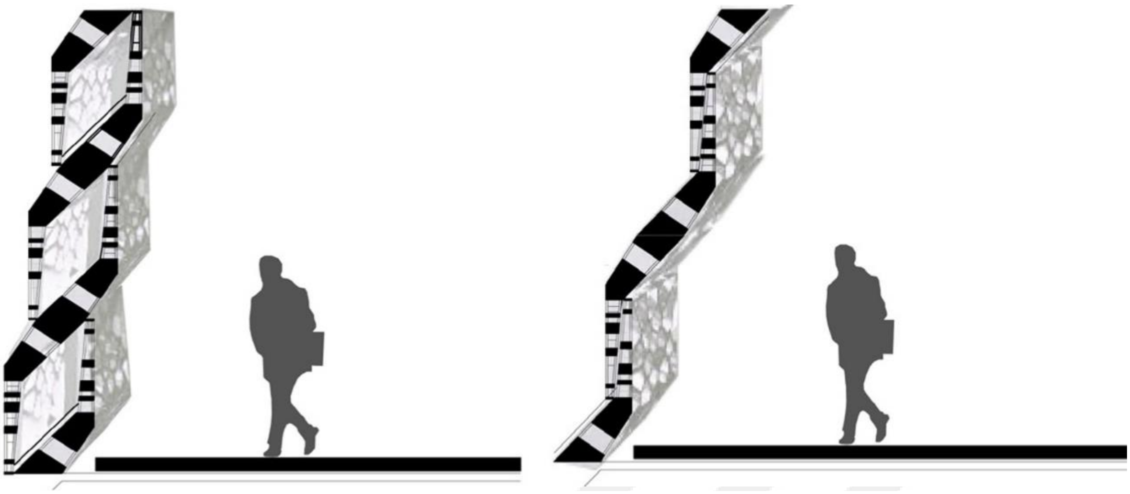


Figure 3.10. Summer condition -intake of light, winter condition -intake of light (Mazzoleni, 2010)

3.5.2. Violet-Tailed Sylph Hummingbird

The Violet-Tailed Sylph, the color scheme for pavilion designed inspired from Ecuadorian hummingbird, which has a good-looking blue, violet and green iridescent plumes. The pavilion in Quito city, Ecuador. The project's site leads to a moderate weather, high moisture, but chiller temperatures of an average of 65 ° F (Figure 3.11). Color is a device for attraction and aesthetics at the same time has a powerful communication means. It attracts people and records the dynamic changes in the atmosphere. Particularly shining colors might be influential devise for communication and mediator actions that are recorded and occur. In addition, the color links energy and enthusiasm so that the person who lives the space from the inside and at a distance starts to have multiple sensory reactions to the physical environment.

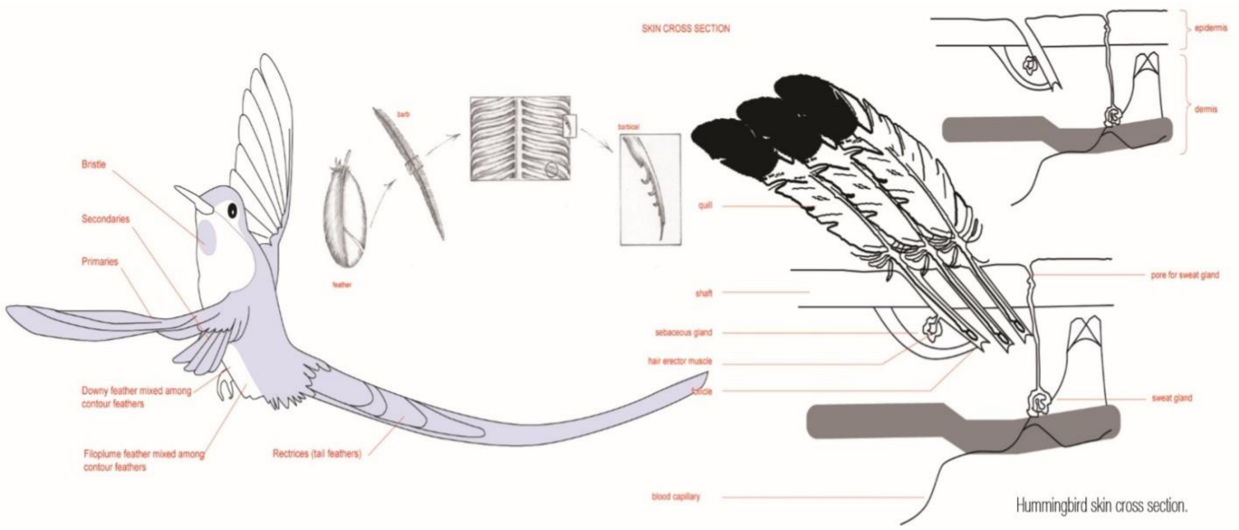


Figure 3.11. Violet-Tailed Sylph Hummingbird’s Skin (Mazzoleni, 2010)

The paneling joint system of the pavilion has inspired from the hooked barbules of the hummingbird plumes. The panels consist of semi-transparent resin and a layer of glass to deliver extra refraction. The hooked connection makes the small water pods creation that cause the desired refraction of light then increases the iridescence of the colors (Figure 3.12) (Mazzoleni, 2010).

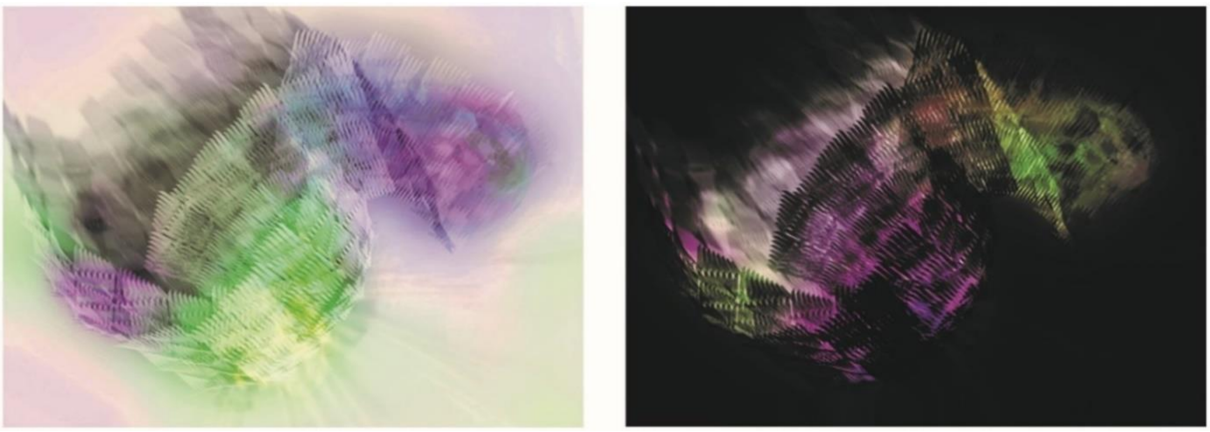


Figure 3.12. Daytime-Shaper shines to the exterior, nighttime-color lights more inside (Mazzoleni, 2010)

3.5.3. Snow Leopard (*Uncia Uncia*)

The inspiration from fur of this animal helped Ilaria Mazzoleni’s design team to settle a façade system for a small pod. The pod is in the Himalayans’s mountainous regions, the natural homeland of the animal, and might have one or two explorers. Because of some difficulties such as: politics, weather, and hard topography, a little number of researches have been conducted on the snow leopard. This pod aims to ease the exploration of the snow leopard (Figure 3.13).

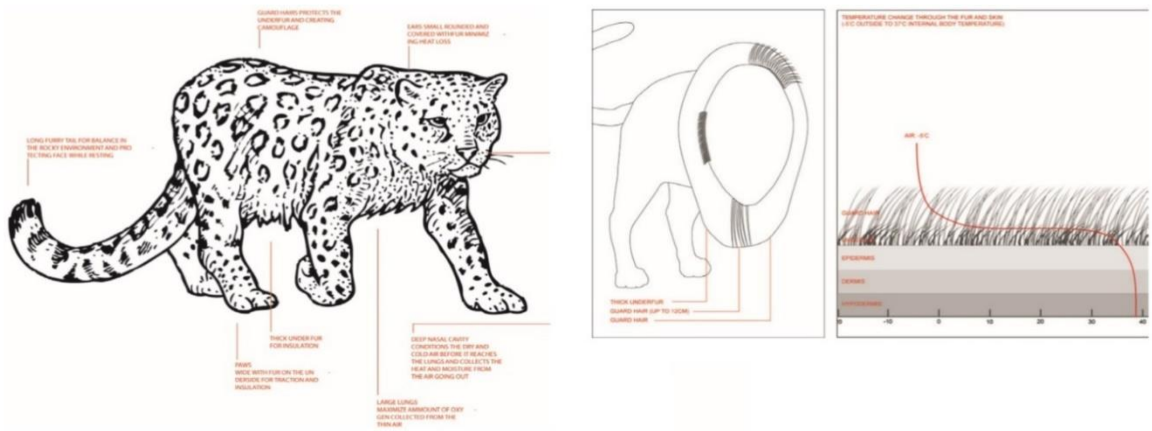


Figure 3.13. Snow Leopard’s Skin(Mazzoleni, 2010)

The Snow Leopard is good prepared for cold, snowy weathers, mountainous and hilly lands. Its body’s properties like wide paws, dense and thick fur make it easy to live in the snow. Similarly, the research pod is made mainly to sequester and protect scholars from dangerous temperatures changing which is between -25 ° F and 60 ° F. The form is shaped by a spherical structure protected through a transforming isolated sheet. The entire system allows the building to enlarge and contract making the external area bigger and smaller according to the climate and time of year. “*Telescopic skeleton”*: a structure on the inner body consisting of telescopic rods, which forms a geodesic dome. This skeleton enlarges and contracts by expandable cushions. Rods: every joining point in the dome has a circular platform supporting several rods. A water-resistant membrane stretched over the ends of the rods unfolds when the structure enlarges; Due to its dark color, the airbag heats up on a sunny day. From aesthetical point view, the form of the pod’s membrane might consider a stylized image of peaks such as the neighboring Himalayan Mountains (Figure 3.14) (Mazzoleni, 2010).

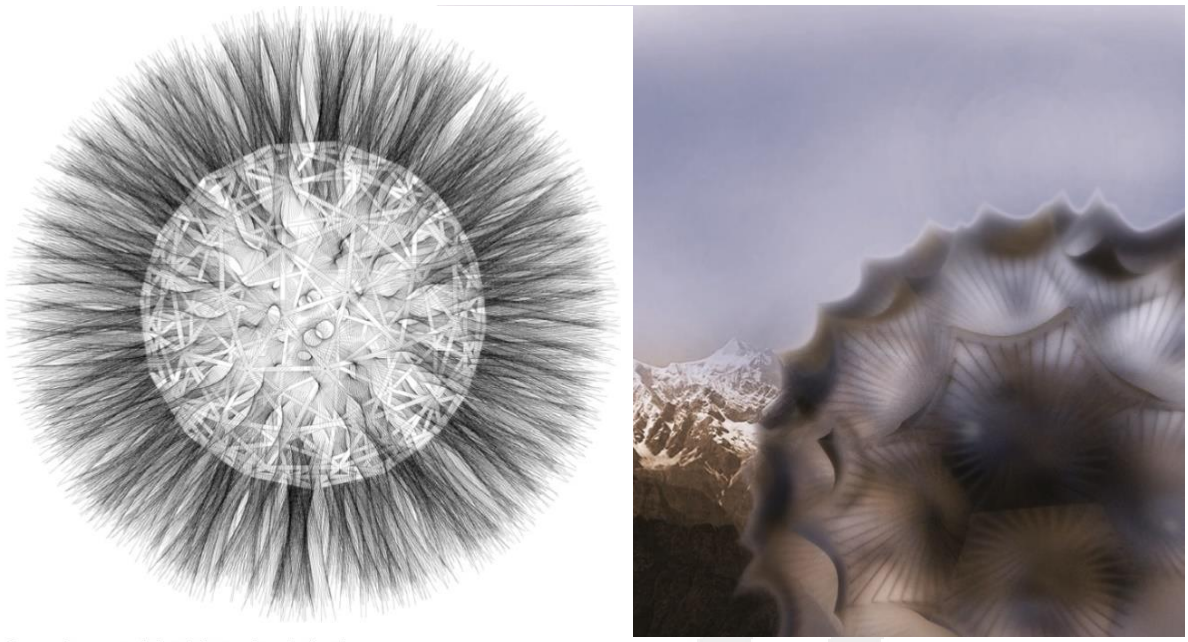


Figure 3.14. Open state-Summer, closed state-winter (Mazzoleni, 2010)

3.5.4. Side-Blotched Lizard (*Uta Stansburiana*)

S.C.A.L.E.S. project has inspired from the Side blotched Lizard's properties (*Uta stansburiana*). Ilaria Mazzoleni's team mimicked and imitated the behaviors of the lizard's skin and translated its physiological characteristics to make a residence for the desert climate. Lizards ' scales ' are not detached, but an epidermis sheet continues. The scales shape changes relying to movement degree of the body part experience (Figure 3.15).

The portions of Lizard body that have further motion experience have minor size scales than other fewer motion portions. The color pattern of the skin is usually a dark color on the lizard back for the absorption of light rays and a bright color in the abdomen to reflect the ground heat. Besides the properties of the skin, the animal's behavior contributes to its Thermoregulation.

This animal regulates the position of the body vertical to the sunlight to absorb heat or parallel to the sunlight while bending the toes to prevent temperature increase. It hides in the shadows to cool once it overheats (Figure 3.16) (Mazzoleni, 2010).

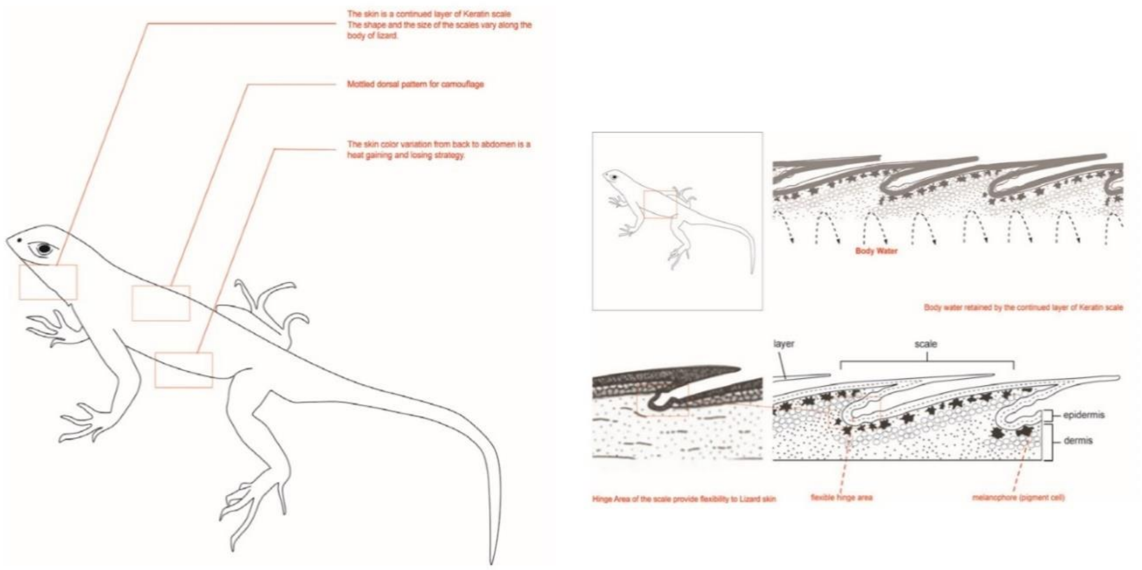


Figure 3.15. Side-Blotched Lizard’s Skin (Mazzoleni, 2010)

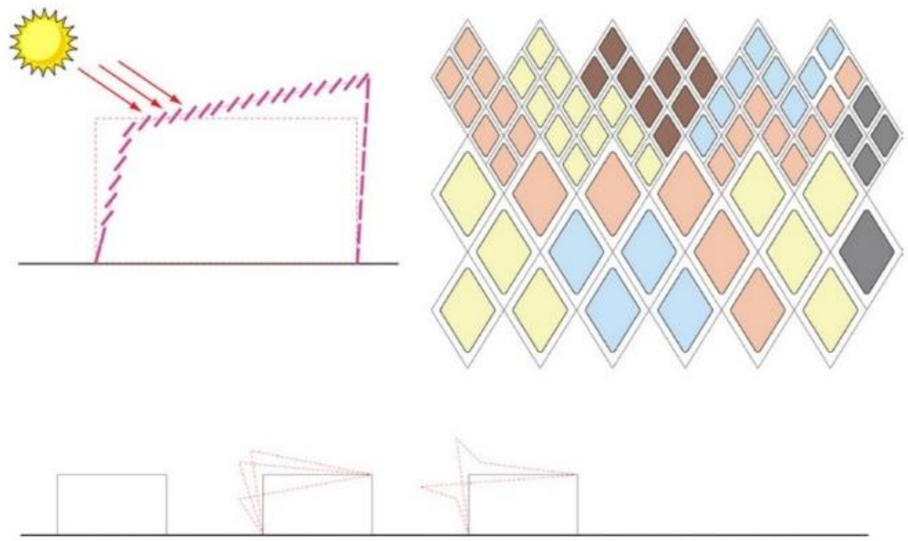


Figure 3.16. Pattern-Allowing for flexibility between unit ad subdivisions (Mazzoleni, 2010)

Like the lizard in the desert, the key design concern is the residents’ comfortable existence during dry, hot days and cold nights. The place of the residence is located in Palm Springs, California and is for the operation at the maximum experienced temperatures in a daytime. The lizard skin’s physiological feature informs the house walls. While the lizard’s behavioral features are translated into the "smart" sun chasing system of the building and are activated by the hydraulic system. The walls of the residence consist of surfaces - colorful photovoltaic panels- with hydraulic pistons and a flexible neoprene membrane between every panel. The membrane allows the extension and rotation of the wall panels, the optimization of the panels' angle to the sun and the changing of the surface area. The panels have two layers of stage change material (PCM) and a flexible air passage that is inserted between them. This permits the air to influx between the thermal mass and gain heat or to cool down, depending on time (Figure 3.17).

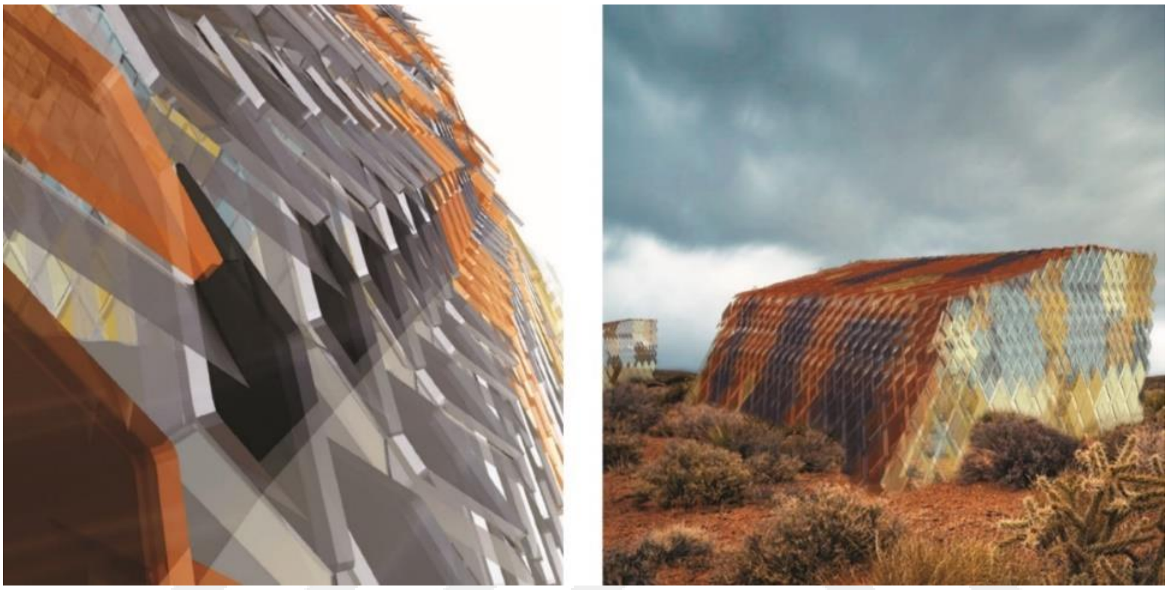


Figure 3.17. Dark color for temperature increase, light color for sunlight reflection (Mazzoleni, 2010)

3.6. Inspirations from Plants for Envelopes

Recently, a lot of research has attempted to develop several methods to develop novel architectural covers grounded on biomimetic principles. And here are some of projects inspired by plants and response continuously to the environment changing. They have been collected in terms of building skins and the collaboration with the surrounding environments through the exchange of energy and improving efficiency.

3.6.1. Strelitzia Reginae flower

The first example is Flectofins by ITKE. The innovation was inspired from the mechanism of valvular pollination of this plant. The inspiration of Strelitzia reginae flower includes a reversible deformation once an exterior force is applied (López *et al*., 2017) .This plant advanced a protuberant perch and perform as a landing stand . After birds stand on plant's structure to reach the reward nectar, the weight makes the perch bend downward as in the (Figure 3.18).

Figure 3.18. Strelitzia Reginae Flower (López et al., 2017)

The adaptive behavior of Strelitzia Reginaehas is materialized and abstracted as Flectofins: a system of hinge-less louver can support its fin 90 degrees through the spine's inducing and bending stresses by displacement resulting by temperature varying in the lamina. One of Flectofins principle's applications is an adaptive external shading system (Figure 34). The functional advantages of an well-organized shading system would be the reduction of energy consuming in power-driven refrigeration systems and the capturing of passive energy in winter season, this is considered as a significant reduction in energy consumption potential (López *et al.*, 2017).

Figure 3.19. Adaptive architectural envelopes: Flectofin(López, Rubio, Martín, & Croxford, 2017)

3.6.2. One Ocean Thematic Pavilion

The second example in Korea done by SOMA and Knippers Helbig Advanced Engineering for Yeosu Expo 2012, which is called "One Ocean Thematic Pavilion" (Figure 3.20). It is an adaptive covering system like the Flectofins, The inspiration was from the studies on kinematic mechanisms and plants movements (López *et al*., 2017). The kinematic fins' concept provided from Knippers Helbig. The facades and the shading system has the ability to acclimatize to physical building conditions and light conditions and respond to varying light rays through daytime.

Figure 3.20. One ocean thematic pavilion (URL-13)

Its height between 3 and 14 m and its total length 140 m, and it can resist the very high wind speeds. The façade consists of curved panels that supported at the top and bottom by double hinged corners. In the other double corners, a slight force is applied in the fin plane, which produces a planned buckling. It demonstrates less local strains than Flectofin® but it is not fully open. It adapts skillfully to the original purposes of the designers and provides a favorable proportion of structural steadiness and energy (Figure 3.21).

These fins are made of plastic material reinforced with glass fibers. They measure up to 14m high, 1.25m wide and only 9mm thick with extra reinforcement on the side with less elastic deformation. In the open state, the curved geometry associated with remaining pressure state provides an inflexible system that only bends some millimeters under wind's high loads. When it is locked, the adjacent panels are clamped together, so that the envelope resists the strong storms without causing any harm (Knippers & Speck, 2012).

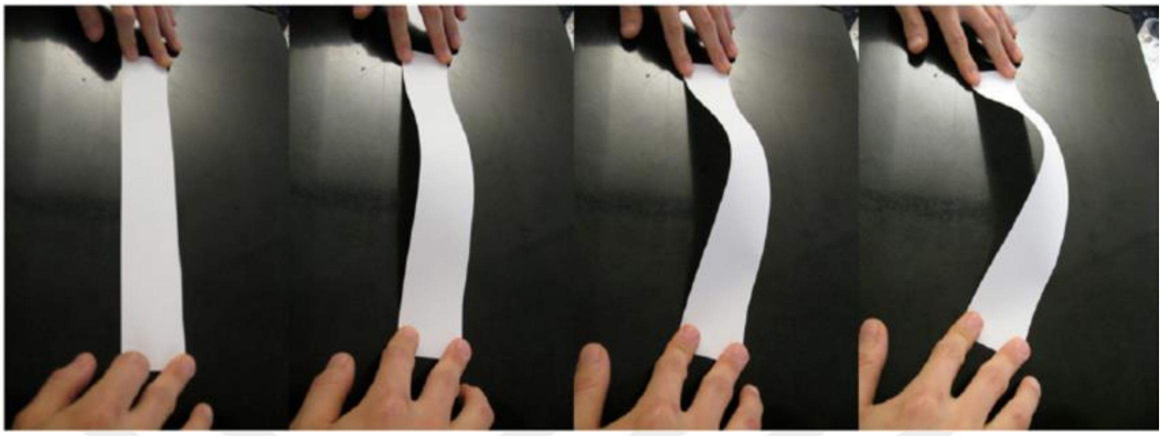


Figure 3.21. Yeosu Facade’s Kinematic Principle (Knippers & Speck, 2012)

3.6.3. HygroSkin-Meteorosensitive pavilion

The final example is a meteor sensitive pavilion called HygroSkin in Germany (Figure 3.22) designed at (ICD) University of Stuttgart by Achim Menges in teamwork with Steffen Reichert and Oliver David Krieg. The HygroSkin is a genius of architecture, and a live reminder of the dynamism of the natural world. The pavilion envelope is grounded on motions seen in spruce cones as a passive reaction to variations in humidity. The project utilizes the material reactivity, using relative humidity as a green trigger to cooperate with the surrounding environment. The wood dimensional variability in terms of humidity content is used to construct a climatic sensitive shell that will automatically open and close in response to climate change but doesn’t need the supply of operating energy or any sort of power-driven or electric control (Krieg, 2016).

The openings respond to changes in relative humidity and modulate visual permeability of the external envelope and the translucency of the light. The research potential has developed an adaptive architectural envelope that does not need sensual devices or electrical stimuli (Krieg, 2016).

Figure 3.22. Scientific development: humidity responsive wood composites, photo of Hygroskin (URL-14)

4. THEORIES AND POSTULATE

Human beings have driven significant and harmful effects on the planet throughout history. Like technology has grown and inhabitants have grown-up, the amount of changes made by humans have climbed quickly. The reason that caused these harmful environmental impacts is reluctance to change even in the face of the damage we are experiencing. This chapter discuss the changing in global climate that facing the earth, and how the animals have adapted to many different climate environments through their skin, and some chosen functions that helped animals to adapt to this climatic changing.

4.1. Climate

Nowadays the variations in global climate consider a big problem facing the earth. The growing of carbon dioxide in the atmosphere, mainly because of using fossil fuels, and the emission of greenhouse gases have some important effects too on weather conditions globally and regionally. Every zone of the world is described by main vegetation kinds named biomes, and every biome is related to specific conditions of the climate. The word "climate" denotes to a number of variables for instance: temperature, moisture, daylight from the sun and wind that describe a zone after observed over for long time. wide-ranging weather patterns are controlled through the shape of the earth, the inclination around its hub besides the orbit around the sun.

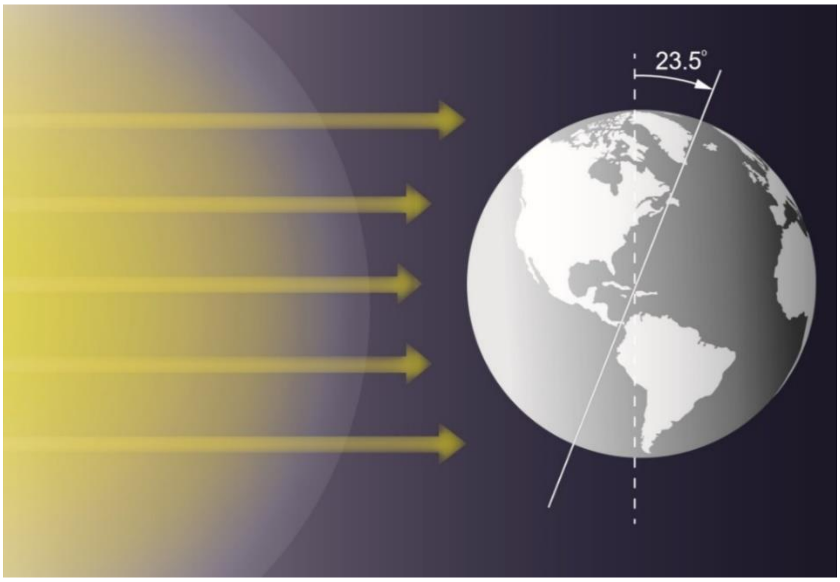


Figure 4.1. The Earth Sphere-Shaped and The Sun’s Rays (Mazzoleni, 2013)

The worldwide temperature patterns can be determined through the angle at which the sunlight reaches the earth. Because of The Earth globular form, the equator obtains more sun’s rays each unit area than the areas closest to the poles; so, the equatorial areas are hot. Higher latitudes are colder, and the reason is the similar sun’s rays amount extends over a bigger part of the earth and moved more to reach the surface of the earth (URL-15).

The seasons, yearly temperature variations and precipitation fluctuations, are happened because of the inclination of the Earth at 23.5 ° on its hub as seen in (Figure 4.1). Summer season happens when the northern or southern hemisphere is more inclined to the sun as the earth plant revolves around it, and winter season happens when every hemisphere moves away from the sun. The equatorial areas do not have big temperature variations, but precipitation differs (URL-16).

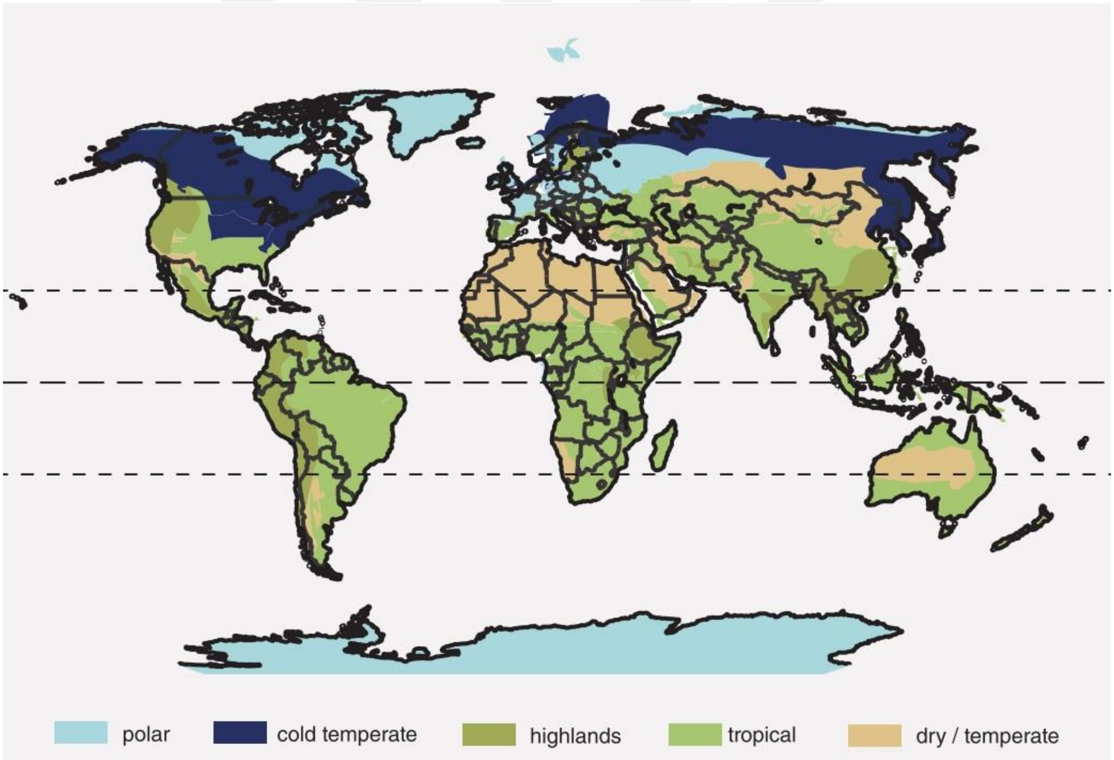


Figure 4.2. Köppen Climatic Classification System (Mazzoleni, 2013)

The “Köppen system” is the most widely used climatic classification system, which describes five main types of climate: tropical, dry, highlands, cold temperate and polar (Figure 4.2). These main kinds of climate classifications can be subdivided into minor classifications. Biomes are inclined to have similar animal groups or communities because of the similar conditions of the weather that animals have grown up in. However, the weather has altered over time and, as a result, the animal's spreading on Earth has altered too (Mazzoleni, 2013).

These climatic design data is the initial idea and at the same time the important basic point to this research because animals are dealing with the climate zone which they are living, in some very special unique strategies, and we seek to improve new adaptation solutions in building skins (envelopes) at places have different climatic properties. Thus, this information about climate can be applied to architectural phase and nature (biological) analysis phase, it is the methodology core theme.

4.2. Skin Composition and Functions

The variety of animal skins offers a productive base for a biologically inspired design. Animals have adapted to many different climate environments with high ranges of rainfall and temperatures, and groups of animals have spectacular wide range methods to deal with the climate in which they live (Mazzoleni, 2013). The skin in general is perfect part in the body that can be used as a source of inspiration in too many fields and particularly in architecture field because of it has many functions that can be useful for the building skin (Figure 4.3). It does several complex tasks, but it is a definable and easily visible body system. The skin forms the threshold among the inner and outer zones; it is the linking part between the two (Gruber & Gosztonyi, 2010).

The skin has the ability to do many important functions. It considers as a defensive fence against pathogens, and the skin also helps to regulate the temperature by conferring gain and loss of heat. It controls the balance of water in the body too by avoiding its loss. It is a permeable barrier that lets the diffusion of main elements such as oxygen and nitrogen. (Madison, 2003) In the skin there are nerve endings which is replying to any fluctuations in temperature and pressure, causing variations in feeling. The skin's pattern and color can achieve significant communication tasks. Through all these different skin's tasks, the skin has the ability to aid in invention, development, and improvement in building envelops designs (Madison, 2003).

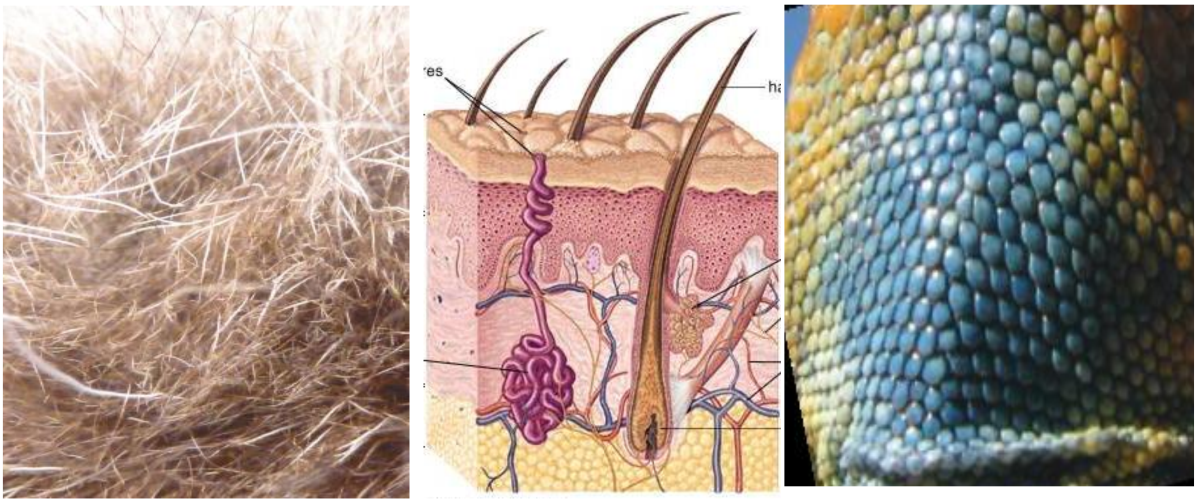


Figure 4.3. Feline fur, human skin, and amphibian scales (Mazzoleni, 2013)

4.3. The Four Chosen Functions

Badarnah mentioned that the adaptations types which based on the method of expressing genetic changes are three: behavioral, physiological, and morphological (Badarnah Kadri, 2012). Physiological and morphological adaptations include functional signs that support the body adapt to surrounding atmosphere, while behavioral adaptations refer to the viability of organisms (Badarnah Kadri, 2012). Because of these kind of adaptations, the natural skin of animals has changed and become varied. Environmental changes affect the metabolism and equilibrium of energy and resources, so the skin may differ from animals of the same species.

Mazzoleni focused in her book “Architecture Follows Nature” on four main functions in animal skins which are: water balance, communication, protection, and thermoregulation. Trying to discover the connection between building envelopes and animal skins. The book also pursues to prove that there are too many methods to implement the developed methodology and expand it by others. These specific topics have been chosen because they are related to architecture field and design applications. Learning from nature how these functions are performed might drive us to new spectacular methods to reduce the environmental impact of the built world by providing new ways of designing building envelopes.

4.3.1. Communication

The communication is one of the most important reasons for animals to survive. Additionally, communication strategies are diverse. Communication modes offer a good vision of architectural research, designers can get to know animals through the information exchange in the surrounding areas and environments. Mazzoleni focused on a predominant form of communication in nature which is coloration. This way of communication can be utilized for the animal’s sexual attraction, warning, disguise, and for its protection. In architecture field, designers can provide lot of amazing inspiration by getting to know the animal’s connection to its ecosystem and surrounding environments (Mazzoleni, 2013).

Communication serves as a type of skin adaptation which might be used for sexual attraction signaling. To this reason, animals present a range of colors and body models that communicate data about themselves, for example partner ability to fight others, age, and sex (Taylor & McGraw, 2007). The color model used in pattern species recognition and philandering should be clear and distinct (Endler, 1978).

4.3.2. Thermoregulation

Animals generally rely on its thermoregulation to maintain body temperature within specific limits. For animals or organism’s extreme temperatures changing pose enormous bodily challenges, and numerous mechanisms for controlling temperature fluctuations have advanced. Endotherms keep the body internal temperature while in other cases temperature controlling is just one of its exterior environment tasks (Kearney, Shine, & Porter, 2009).

Thermoregulation is reached by noticeable behavioral and physical methods. One of the greatest architectural challenges is to offer specific critical limits of thermal comfort to residents, especially in risky situations once the body doesn't have the ability to adapt to such difficult external circumstances. Animals and its systems have a lot to learn about temperature regulating and controlling the energy consumption (Mazzoleni, 2013).

4.3.3. Water balance

The relationship between life and water on our plant is very close and intimate. All creatures are consisting mainly of water; the hole cells in our bodies are made from it. Water is necessary for many biochemical processes in living bodies and can dissolve and delivered vitamins, nutrients, and other molecules. In term of saving water, the animals have developed numerous new strategies to gather it and stop water loss, especially in arid environments. Also, in designing filed, there is a lot to learn from animals such as how they avoid water loss, thus this is can increase people's ability to stay alive in arid and unfriendly environments by applying systems that decrease, collect, keep and reuse water (Mazzoleni, 2013).

Animals adapted to the desert have developed innovative strategies for extracting water and avoiding water loss. Some hold water in fatty tissue in the body; Once fat is metabolized, water is freed out into tissues and might be utilized by animals (Schmidt-Nielsen, 1965).

4.3.4. Protection

The skin's first function is protection the body from marauders, hurts and the environment which might happen in several ways. The animal kingdom can teach us namouras new adaptations that have been developed by different animals. The Shelter is typical component in architecture, the basic idea of the shelter is a structure that gives protection against marauders and any threat. Over time, the nature and meaning of human accommodations has been added. The accommodations originally served as protection against bad climate, and other human inhabitants (Mazzoleni, 2013).

Protection is another suitable function of the skin, completed by the help of reinforcement and coloration strategies. Like buildings, the external shells of animals have to manage the mechanical stress. Usually this is done by strengthening the external layer. For example, the turtle shell developed from its ribs and performs like a shield. This adaptation strategy offers better mechanical protection (Jablonski, 2008).

5. A NEW APPROACH FOR BUILDING FACADES IN DIFFERENT CLIMATE REGIONS: BIOMIMETIC SKIN

This part has six examined cases in five different climate regions, in order to explain the main two design phase that we have in this research (Biological and Architecture phase) and to clarify the biological studies on the animals' skins, inspiration, and following progress of the building envelops. Then provide main guidelines for the next designers. Each case study showed a significant model in its climate conditions. They are related to subjects of sensation, water management energy regulation, coloration and the usage of native and renewable resources.

5.1. Urania Moth "*C. rhipheus*"

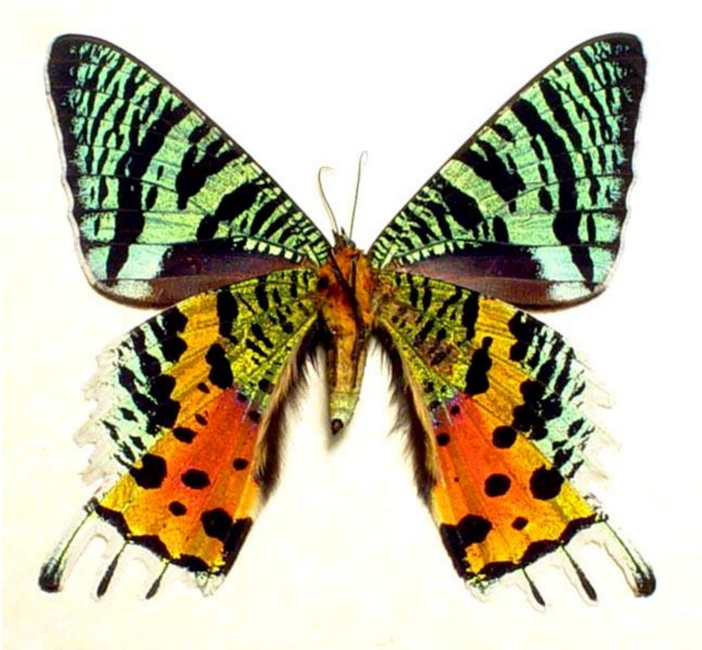


Figure 5.1. Urania Moth "*C. rhipheus*"(URL-17)

Table 5.2. Urania moth's scientific classification

Urania Moth's Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Arthropoda	Lepidoptera	Pholidota	Uraniidae	*Chrysiridia*	*C. Rhipheus*

Tropical climate

The Malagasy Sunset Moth is present on the Island of Madagascar. The weather of the island differs much in the longitudinal direction (Figure 5.2). Some parts of the country help tropical forest environment due to business and monsoon winds along the east coast like eastern part, producing a lot of rain. Winds lose moisture as they move west, making the island's major part much drier. Additionally, considered much cooler because of higher heights.

the island's western part is generally dry and has some semi-desert environments in the island's southwest part. Two major whether periods are well-defined: a hot and rainy season, which lasts from November to April, and a cooler and drier season, which lasts from May to October. Nearly in all parts of Madagascar the sunset moth is existing, and they change their homeland during the year in response to variations of some plants which they need it to survive.

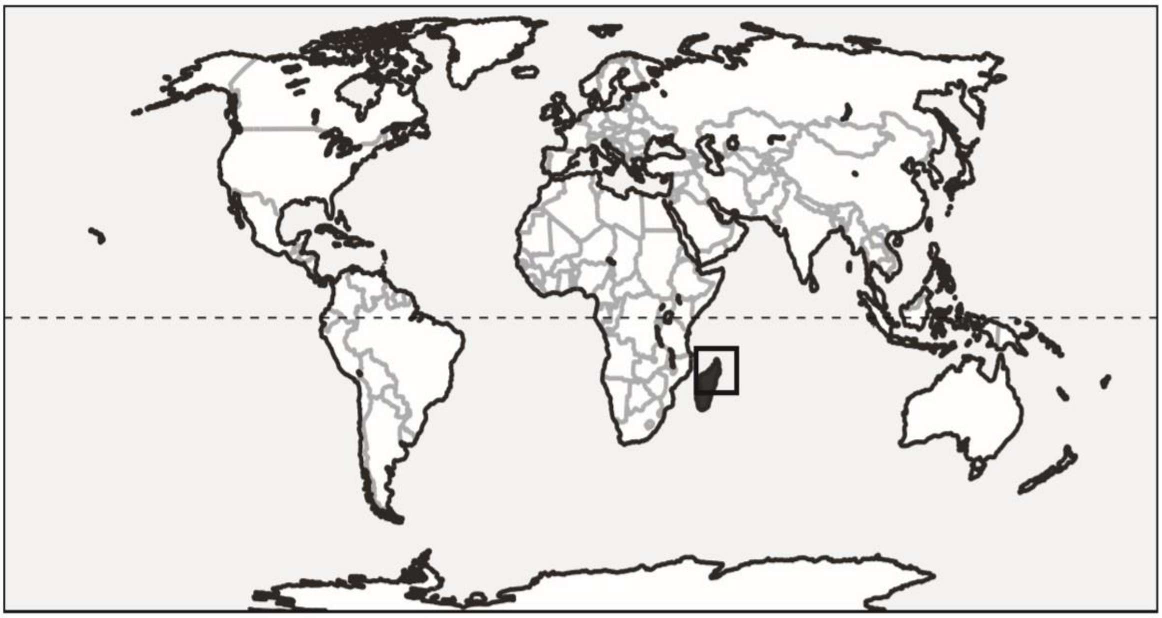


Figure 5.2. The western region of Madagascar where Urania moth lives (tropical climate zone) (Mazzoleni, 2013)

Animals' morphological features

The Madagascan sunset moth's behavior is different from a lot of moths, since it is active through daytime. the moth's coloration styles like cautionary indications to let potential murderers recognize that it is poisonous. The toxicity derives from big and small plants of the type Omphalea. The caterpillars eat the plant's toxic things for survival, which are usually stowed by their development (Yoshioka & Kinoshita, 2007).

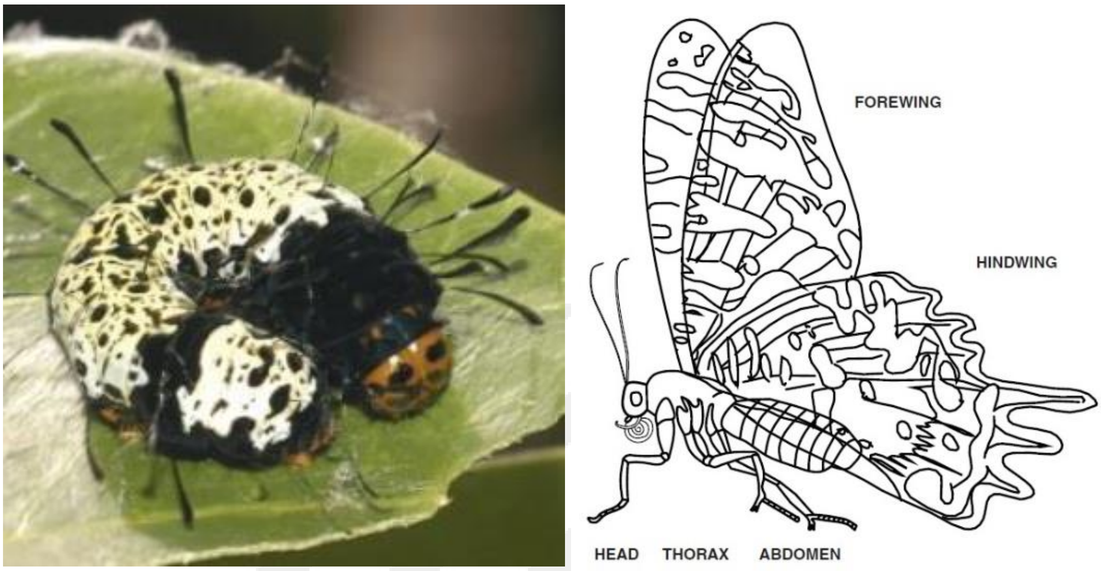


Figure 5.3. *Chrysiridia Ripheus*'s main physical element(Mazzoleni, 2013)

The moths depend strongly on the host plant that the moths change their homeland during the year to various groups of the host plant; In particular, they travel from the west where is the dry forest to the east where is the rainforest is existing. The caterpillars of the moths have some harmful impacts on the populations of Omphalea, and the reason is they feed on fruit and flowers of the whole plant (Figure 5.3) (Yoshioka & Kinoshita, 2007).

<u>The skin and exterior world</u>

The characteristic of the *Chrysiridia Ripheus* is that it has multicolored wing structure, which contains parts of bright iridescence which is described as the exterior of the structure, which is can vary its color once the observing viewpoint or light angle is changed. Iridescent colors are heading to be more shining and cleaner than colors made from dyes (Mazzoleni, 2013).

The wings of the *C. rhipheus* and butterfly are made up by a lot of partially overlapping scales (Figure 5.4), and at the same time the scales structure has influenced the reflecting way of light. *C. rhipheus* comprised of double layers of scales on its wings: the internal layer and exterior or it calls cover scales. Each cover shell is structure has many layers formed by cuticles tinny layers between tinny air spaces. The cuticle layers are carried by tinny columns and spaced out from the cuticle. The cuticle layers and air spaces might have various thicknesses, which produces the wings color differences (Stavenga, Giraldo, & Leertouwer, 2010).

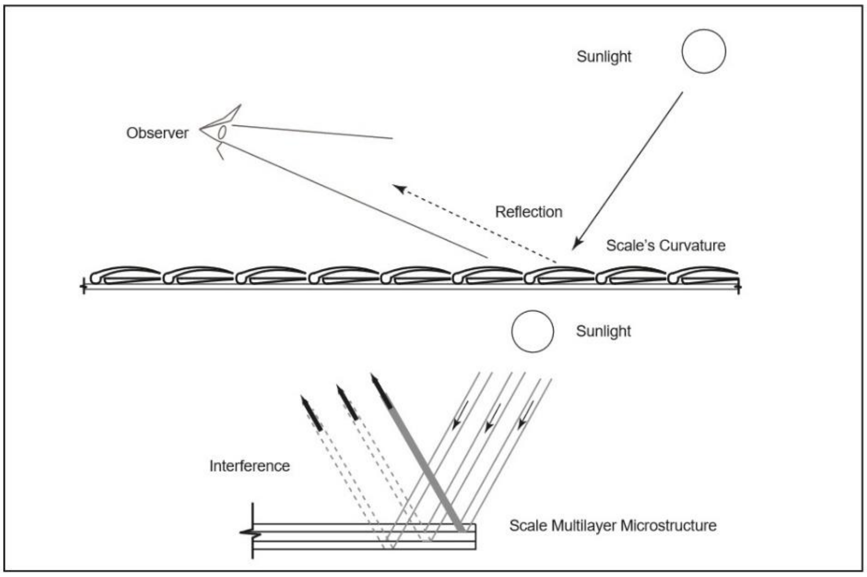


Figure 5.4. The light reflection & interference going through several exteriors(Mazzoleni, 2013)

<u>Interconnection between animal's inner systems and the skin</u>

Various dyes might be produced within scales, in addition mixture of surfaces that have many layers of cuticle, several iridescent colors might be gotten. Once light illumines in the cuticle first layer, part of the surface is reflecting it back and others reach the next level. At every level, light enters, additional light is reflected down. The reflected light of every plane moves far from the layers of the cuticle Light happens in wave lengths, and when wavelength peaks overlap, they increase the reflection outcome. If the wave lengths are aligned with each other, strong coloration does happen. This is what has named "constructive interference", besides it reason of iridescence (Mazzoleni, 2013).

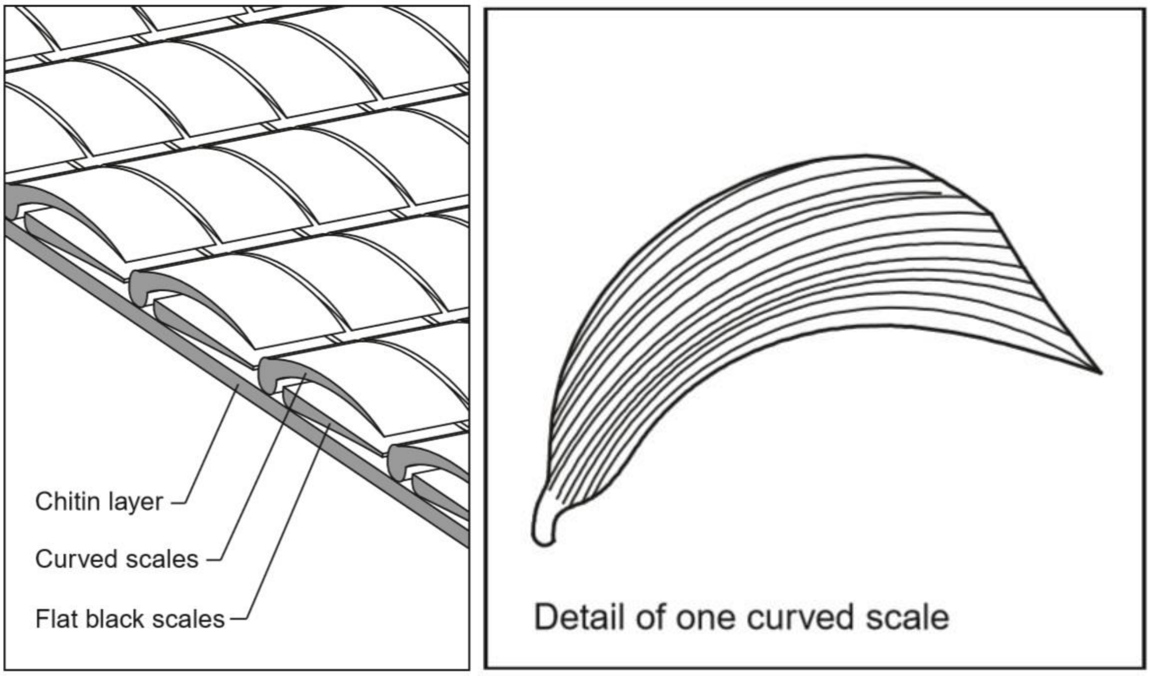


Figure 5.5. The wings of the moth , detail of one curved scale (mazzoleni, 2013)

Proto-architectural project

The project in a dry city in the west of Madagascar which is the moth's homeland. The building envelope design was imitated from the *C. rhipheus's* reflective and refractive characteristics and from varicolored and multi-layer moth wings. A new fresh water system for drinking produced by the building, in addition to the rainwater is gathered for the community. Plus, a system for filtration that pushes the roof water into the skin of the building, which has been designed for backing the reusable vials that gather water by a structural grid the bottles angle adjusts according to the water volume gathered in every bottle: if they are empty, the bottles are stand vertically to the exterior envelope and when the vessel is filled with water, it moves parallel toward the building envelope. The light can do an important role with the bottle's shape that has been filled up with water and its angle too to make remarkable reflection view (Figure 5.6).

The building envelope communicates the water availability through showing bottles dissimilar colored sections. The bottle is green or blue except the bottle's base is black, typical colors utilized for improving the passive processes of solar cleansing. The layer of bottles is arranged to exploit the light playing via the bend of the bottles to produce dissimilar reflection views. This layer method, associated with the structure's general circular geometry, changes the reflection angle since every bottle has a matchless location related to the sun, therefore producing a kaleidoscopic impact. The building envelope explores the color idea as some helpful earnings of communication and the light's physical characteristic (Mazzoleni, 2013).

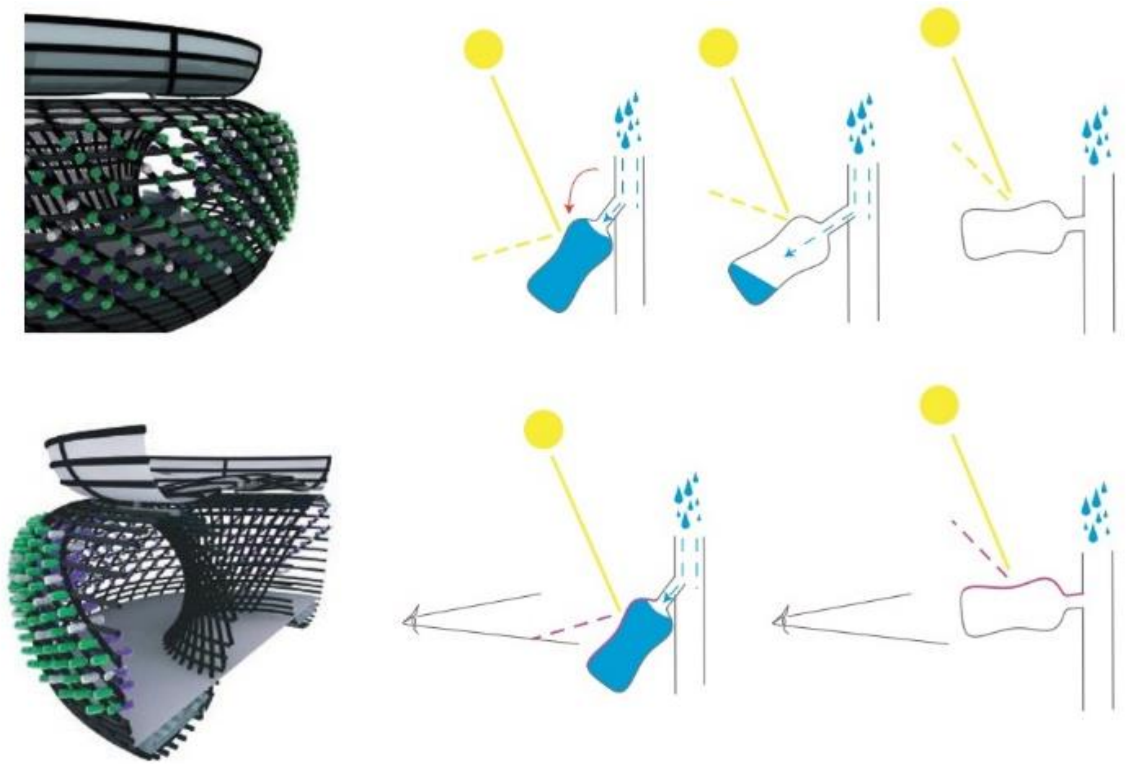


Figure 5.6. The bottles layer is exploited the light playing via the bend of the bottles to produce dissimilar reflection views (Mazzoleni, 2013)

Table 5.3. Design mapping of Urania moth’s skin and building envelope in tropical climate zone (prepared by author)

URANIA MOTH

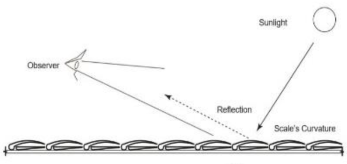
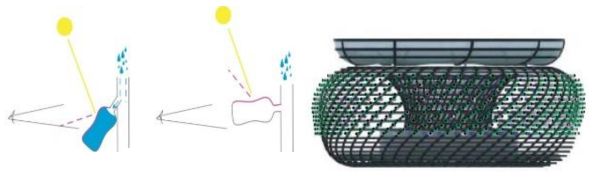
CLIMATE

`

Polar | TROPICAL | Cold Temperate | Dry | Highlands

TARGETED FUNCTION

COMMUNICATION | Water Balance | Protection | Thermoregulation

BIOLOGICAL PHASHE			ARCHITECTURAL PHASHE		
WHAT	WHY	HOW	APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
BIOMIMETIC LEVEL Behavioral	CHANLENGE Sending a warning signals to let potential predators know the moths are toxic.	FUNCTION Reflecting	ADAPTIBILITY Dynamic adaptive envelope	CHANLENGE create varying moments of reflection	TECHNICAL IMMPLENTA TION 
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS the surface of a structure that changes color when the viewing angle or angle of lighting is changed	APPLICATION A new system of clean drinking water where rainwater is collected and creating spectacular moments of reflection	BENEFIT enhance passive solar purification processes	TECHNICAL FEATURE Motion such as folding
THE INSPIRATION FROM NATURE			THE IMPLEMENTATION IN ARCHITECTURE		
 					

5.2. Snow Leopard "*Panthera Uncia*"

Figure 5.7. Snow Leopard (URL-18)

Table 5.4. Snow leopard's scientific classification

Snow Leopard's Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Chordata	Mammalia	Carnivora	Felidae	*Panthera*	*P. uncia*

Cold temperate climate

The genus Panthera has five types, which are generally called "big cats." Snow leopards (*Panthera uncia*) live in the highlands of Central and South Asia, covering almost two million square kilometers (Figure 5.8). *Panthera uncia* typically live at a height of 3000 to 5,400 m. Here the temperatures medium is stiff and strong and start normally from -30 to -15 ° C. The regions which have highland climate usually are dry and cold, with little amount of rain in the summer seasons. And therefore, the mountain hills are covered with a small amount of vegetation. *P. uncia* prefers these rocky hills, as they offer a perfect overview and help them to survive. The cruelty of these environments makes it hard to study snow tigers in their natural habitat (Rodney Jackson & Suryawanshi., 2014).

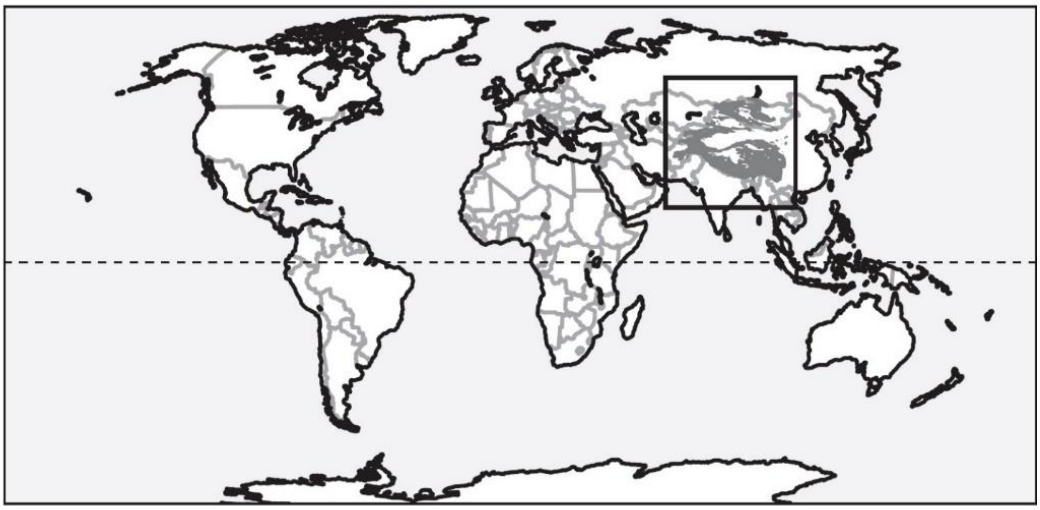


Figure 5.8. The highlands of central and south Asia (cold temperate zone) (Mazzoleni, 2013)

Animals’ morphological features

Adults measure about 60 cm in the shoulders, 1.8-2.3 m between the nose and tail and weigh 35-55 kg. Males are usually one on three bigger than females. *P. uncia* characteristics or most of them are related to thermal regulation. Snow Leopard bodies are more resistant and seeking to reduce the surface to avoid heat loss. Their body figures like strong chest, short legs in the front, and long hind legs help them to quickly follow the victim on the unstable ground (Figure 5.9). At high altitude, the snow leopard has a large nasal cavity and lung volume recompense little oxygen concentrations. Dry and cold air is heated and fine-tuned, passed through a thin tissue that also absorbs heat and humidity with each exhalation to maintain body temperature and maintain precious water (Rodney Jackson & Suryawanshi., 2014).

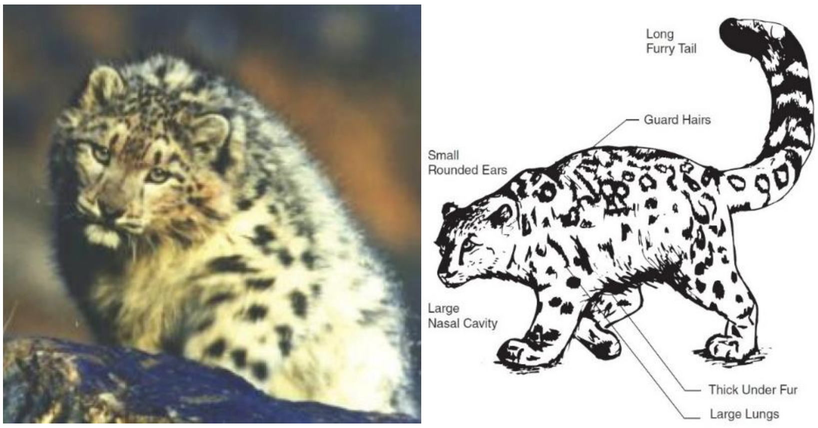


Figure 5.9. The Snow Leopard’s main physical element (Mazzoleni, 2013)

The skin and exterior world

Snow leopard has a thick insulating layer of fur. The length of hair on the abdomen can reach 12 cm. White furs with gray spots or brownish spots in winter, become a black brown with light gray spots in the summer. The coloration gives and excellent camouflage throughout the year, the patches are mainly on the back of the Snow Leopard and consist of straight protective hair up to 70 mm long and 40 to 60 microns in diameter, the latter consists of soft, slightly curved, non-weak bristles, with a thickness of 5 to 20 micrometers. the hair-thin layer provides a huge advantage of heat-regulating properties of the animal's fur. The thick tail is used as a counter-balance for hunting and climbing (Figure 5.10).

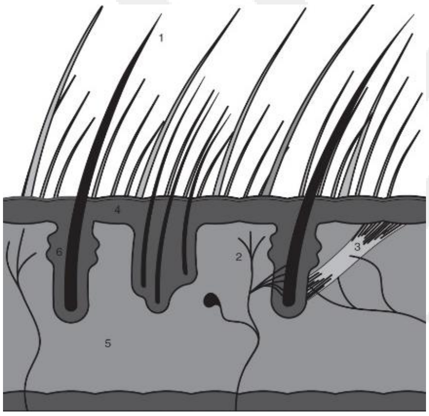


Figure 5.10. Cross-section of snow leopard’s skin (Mazzoleni, 2013)

Interconnection between animal’s inner systems and the skin

Although fur is a protective layer of the skin, cold air always enters the lungs because of the needed breathing process. P. uncia lungs are large in proportion to cats of the same size to increase oxygen uptake from the air at high altitude. However, the cold air cools snow leopard's body and dries the lungs, thus decreasing total respiratory capacity The bones of the nasal turbinate are covered in moist with a high blood vessel known as respiratory epithelium. This part does an important role in helping to heat and moisturize gulped air into snow Leopard’s lungs and decreases internal temperature cooling. The turbinate surface cools when cool air is pulled, but it can absorb excess warmth and moisture from the exhalation air, restore most of the energy and lessen water waste (Matthiessen, 2008).

Proto-architectural project

The project aims to provide the research environment for researchers by creating a structural envelope that can be transported on the slopes of the mountains. The structure helps like a base and home for scholars who wish to conduct field investigations on animals. The primary task of the building structure is the heat regulation, which essentially protects the internal space from external temperatures variations' which are between -30 to 15 ° C. Protection from difficult climatic conditions and cold is significant to stay alive in these mountain areas. The dense fur, body figure, and respiratory system of the Snow leopard are excellent models of the ability of nature to transact with the cold habitat. The Snow leopard provides multilayered building skin simulates the animal's structural relations. The fixed internal structure depends on the geodesic semi-sphere with inmost isolated slabs, which act as a deeper isolating layer. The telescope system connected to the snow leopard's internal shape a geodesic dome which extends and shrinks. The structure of the ring system includes a large number of articular bars and rotors that connect one end to the platform and the other to the opposite axis. once the structure extends, the platforms separate, leading to the flattening of the bars and the opening of each group. The last black water-proof envelope extended over the end of the rails then the hot air pocket is extended by solar heating (Figure 5.11) (Mazzoleni, 2013).

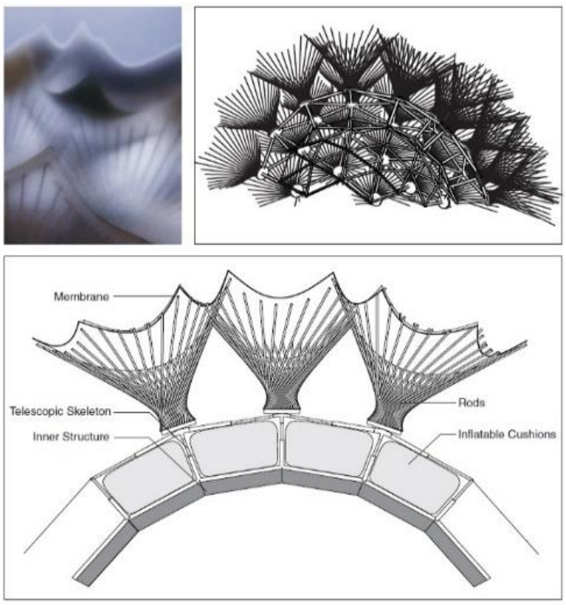


Figure 5.11. the Building geodesic structure and An axonometric envelope view(Mazzoleni, 2013)

Table 5.5. Design mapping of snow leopard’s skin and building envelope in cold temperate climate zone (prepared by author)

SNOW LEOPARD

CLIMATE

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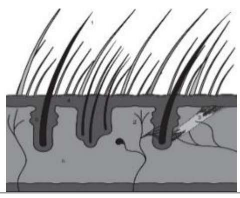
Polar	Tropical	COLD TEMPERATE	Dry	Highlands

TARGETED FUNCTION

Communication	Water Balance	Protection	THERMOREGULATION

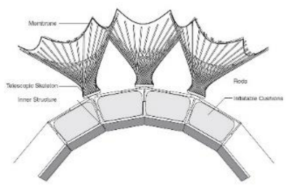
BIOLOGICAL PHASHE		
WHAT	WHY	HOW
BIOMIMETIC LEVEL Behavioral (the anatomical interactions between the animal’s systems.)	CHANLENGE Protection from cold, harsh weather is important for survival in these mountainous regions	FUNCTION insulation
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS respiratory epithelium surface warms and moistens inhaled air passing to the lungs and reduces cooling of core temperature.

THE INSPIRATION FROM NATURE



ARCHITECTURAL PHASHE		
APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
ADAPTIBILITY multilayered envelope	CHANLENGE protecting the interior from exterior temperatures varying	TECHNICAL IMMPLENTATION 
APPLICATION The inner static structure is based on a geodesic semi-sphere with highly efficient vacuumed insulated panels, which function as the innermost layer of insulation	BENEFIT heating the air through solar heating.	TECHNICAL FEATURE expanding and contracting

THE IMPLEMENTATION IN ARCHITECTURE



5.3. Polar Bear “*Ursus Maritimus*”

Figure 5.12. Polar Bear (URL-19)

Table 5.6. Polar bear’s scientific classification

Polar Bear’s Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Chordata	Mammalia	Carnivora	Ursidae	*Ursus*	*U. maritimus*

<u>Polar climate</u>

The Polar Bear’s family is Ursidae, which has eight living types. The polar bear can be found in Asia, Europe, and North America (Figure 53). This kind is usually considered as marine mammals and rely on a snow platform for hunting. The Project’s central area is Hudson Bay in Canada. this area in summer season, the sun angle is 56 ° and the medium air temperature around 10 ° C and in winter season, the sun angle is 6° and the average air temperature is -23.5 ° C. Some parts of the Arctic are wrapped with ice throughout the year, and at the same time others are losing ice, letting some vegetation can thrive (Stirling, 2009).

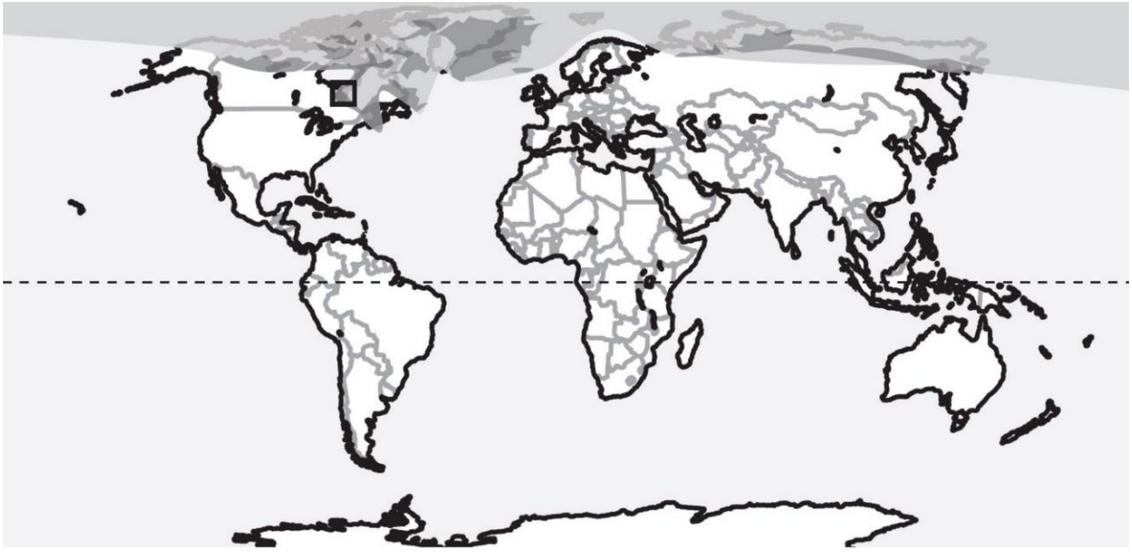


Figure 5.13. The Hudson Bay region in Canada (polar climate zone) (Mazzoleni, 2013)

Animals' morphological features

Polar bears are extremely tall. Males length up to 3 m and weigh around 500 kg. Female polar bear can measure as much as half of the male in weight. The huge mass of polar bear joint with the extremities and short ears decrease the relationship between the area of the body surface and the heat loss. the insulating grease and fur are the main means of insulation and protection against the exterior arctic cold, in summer they travel great distances over the ice looking for seals. sharp claws and wide legs provide a snowshoe-like help while walking on the snow. Polar bears are great swimmers and they can stay in water for long time (Figure 5.14) (Mazzoleni, 2013; Stirling, 2009).

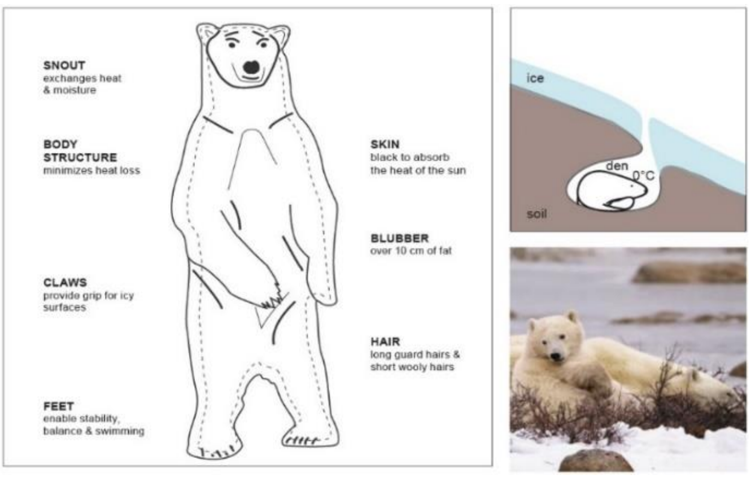


Figure 5.14. Polar bear's main features(Mazzoleni, 2013)

The skin and exterior world

The temperatures average through winter in arctic is around -45 ° C. The main resistance of the polar bear from the cold is the skin. Outwardly, there is a thick layer of fur covers the polar bears' whole body and isolated them from surrounding environment. The polar bear's fur has two layers. the primary source of insulation is the thick white layer, which is trapping hot air near to the skin and, on the contrary, avoiding contact with ice. The hairs in the exterior layer are longer, protective, blank and diaphanous, without pigments which also serve as a disguise in the snow (Figure 5.15) (Stirling, 2009).

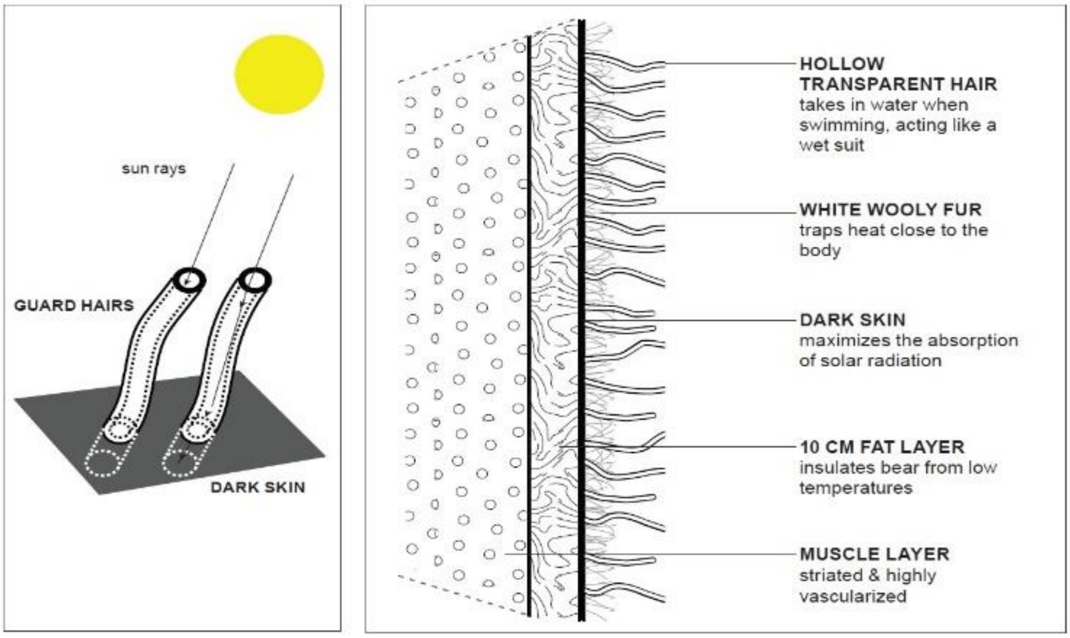


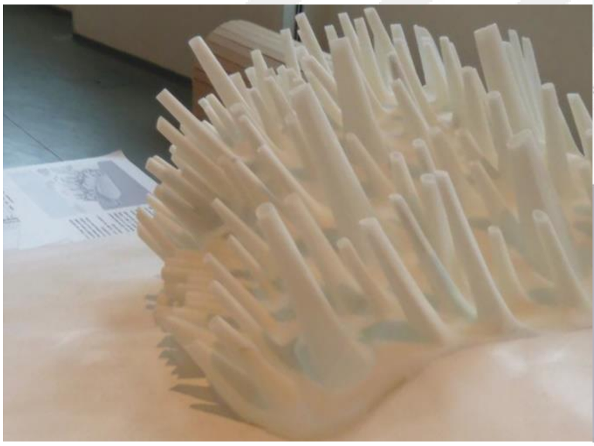
Figure 5.15. Polar Bear's Fur (Mazzoleni, 2013)

Interconnection between animal's inner systems and the skin

Such as other mammals, they are endothermic, i.e. polar bears produce their own internal heat. Its huge body mass, joint with small ends, dense insulating fats and fur, makes them particularly effective at storing body heat. indeed, overheating is a problem for polar bears even at temperatures below zero. This stops them from undergoing long running.The ways to cool polar bears down is rubbing in the snow and swimming. Seen through an infrared camera, they are nearly unseen; just the hot air that comes out of the nose and the flow of superficial blood to the less calcified head provide vital signs (Mazzoleni, 2013; Stirling, 2009).

Proto-architectural Project

The project imitates the behavioral and functional adaptations that helped the polar bear to stay a live under the most adverse climate situations on the earth. The project seeks to improve native natural resources to offer the energy wanted to control people thermal comfort. Compact units are partially recessed into the ground, like the Bear Dormitory. The southwest location of the units enhances the heat gain of the sun. Solar heat and light are collected from the active envelope of the building, consisting of hollow and redirected glass tubes that move to the insulating layers where energy is stored, stored and slowly released in a compressed capsule. The light that is freed tardily at night, making an atmospheric ceiling similar to the sky. The architectural shell is a storage of light and heat that reduces the energy consumption without the need to many active systems in the building and arise the need to passive systems. The heat storage and light storage change from season to another (Figure 5.16) (Mazzoleni, 2013).



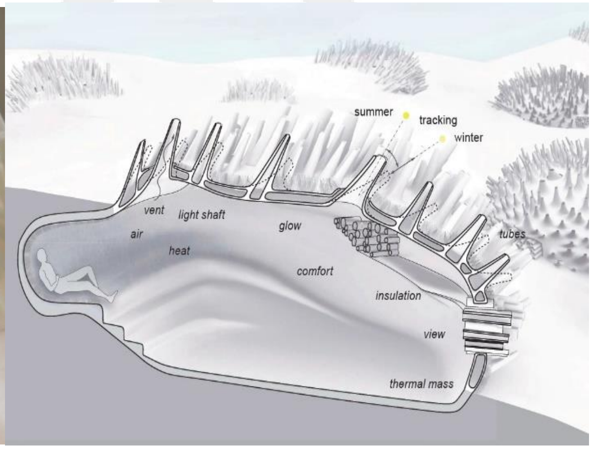


Figure 5.16. The proto-architectural project’s modeling (Mazzoleni, 2013)

Table 5.7. Design mapping of polar bear's skin and building envelope in polar climate zone (prepared by author)

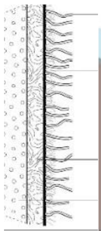
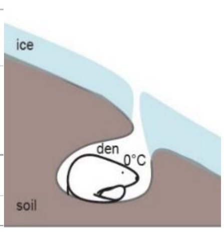
POLAR BEAR

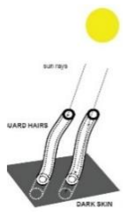
CLIMATE

POLAR | Tropical | Cold Temperate | Dry | Highlands

TARGETED FUNCTION

Communication | Water Balance | Protection | THERMOREGULATION

BIOLOGICAL PHASHE		
WHAT	WHY	HOW
BIOMIMETIC LEVEL physiological and behavioral	CHANLENGE surviving in the planet's harshest weather conditions.	FUNCTION insulation
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS The dense white underfur provides the main source of insulation by trapping warm air close to the skin and, conversely, by preventing contact by ice and water.
THE INSPIRATION FROM NATURE    		

ARCHITECTURAL PHASHE		
APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
ADAPTIBILITY active building envelope and a storage for heat and light	CHANLENGE protecting the interior from exterior temperatures varying	TECHNICAL IMMPLENTA  TION
APPLICATION The envelope is a storage for heat and light which reduces the use of active systems and maximizes the use of passive systems.	BENEFIT optimizing natural local resources to provide the energy needed to regulate human thermal comfort.	TECHNICAL FEATURE Rotating and tracking
THE IMPLEMENTATION IN ARCHITECTURE  		

5.4. Banana Slug "*Ariolimax Columbianus*"

Figure 5.17. Banana Slug (URL-20)

Table 5.8. Banana Slug's Scientific Classification

Banana Slug's Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Mollusca	Gastropoda	Geophila	Ariolimacidae	*Ariolimax*	*A.columbianus*

<u>Mediterranean climate zone</u>

A. dolichophallu , *A. columbianus* and *Ariolimax californicus* are types of banana slug. The *Ariolimax californicus* lives in Pacific coastal in wooded environments. The maximum rate temperature in winter season almost 15 ° C and about 22 ° C in summer season. The Mediterranean climate is arid and showery in winter months, and in summer months is hot and warm. Although the climate presents areas from Mediterranean region but there are some different places on the earth have different distribution of temperatures like California, USA, some parts in southwestern of South, Central Asia and Chile consider Mediterranean climate zone too (Figure 5.18). The yearly rainfall rate is about 495 mm, with maximum precipitation from November to April, while rainfall in summer season is low or zero. The yearly rainfall rate is 70 days. But in Monterey Bay is usually hazy and cold in summer months(Mazzoleni, 2013; Wiebe, 2009).

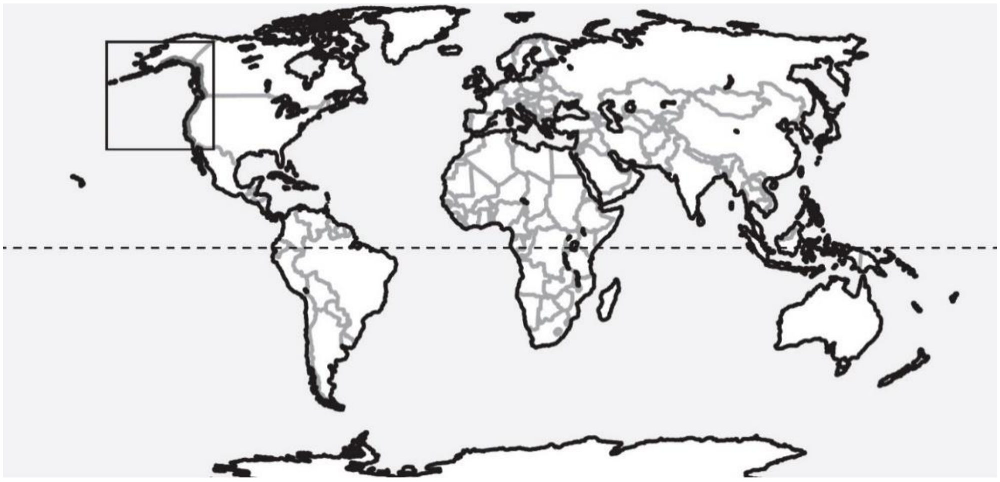


Figure 5.18. California State, USA (Mediterranean climate zone) (Mazzoleni, 2013)

Animals' morphological features

after rain the Banana slugs (*Ariolimax californicus*) are more active in moist soil, but in summer season usually it is covered under fallen rocks because it looks for wet areas. it Breathes through the lungs, a highly vascularized tissue in the body back or mantle, which lets and helps in the exchange of gases. and there is a hole in the mantle calls pneumostome allows air through the lungs (Figure 5.19). Banana Slug breathes through the skin too by letting the exchange happen among the animal and the surrounding environment. There are four tentacles in the head of the projectile, which serve to recognize their environment: the two imposing optical tentacles detect moving and light, and lower tentacles observe and recognize chemical things. in the base of slug's head situated the mouth and uses the tongue to collect the food (Mazzoleni, 2013).

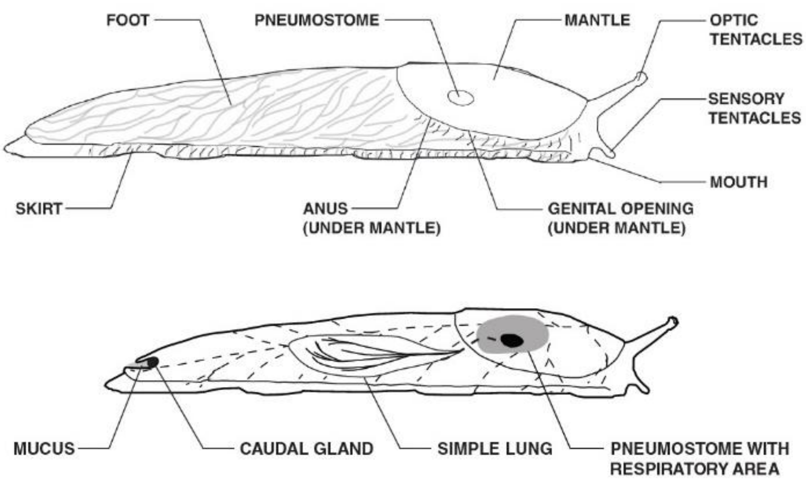


Figure 5.19. The banana slug contains a pneumostome (Mazzoleni, 2013)

The skin and exterior world

Banana Slug survives in moist inhabitants to keep their skin wet. Banana slugs excrete mucus to stop and avoid dehydration, help to breathe through a wet surface, look for and have a partner, help in moving process, among other things. Slime contains narcotic and it also has the ability to discourage ravenous and dangerous animals through the uniformity. In disadvantageous climatic conditions, like hot temperatures or cold temperatures, Because of their distinctive yellow color, they slice are called" banana slug". Their forms are gold color with some black points. but, they show color changes and might be brown, white and occasionally black. The color patterns might differ depending on age, variations in diet, humidity, and accessibility to light, and health (Leonard, Pearse, & Harper, 2002).

Interconnection between animal's inner systems and the skin

Banana Slug makes numerous kinds of mucus, such as thin-liquid mucus and thick-viscous mucus, and at the same, it performs and does a variety of job. animal's body needs a thick mucus to avoid the dehydration, keep it far from the soil, and promotes movement (Figure 60). and with muscle cramps of the foot, it helps the animal to progress. The other layer is hydrous and thin. Typically, mucus consists of fibers which block sliding on the perpendicular exteriors. the mucus has variable properties too, that is if the slug is steady, the mucus is placed in a relatively solid block, but once it begins moving, it will change to be liquid (Gervais, Traveset, & Willson, 1998; Leonard *et al*., 2002).

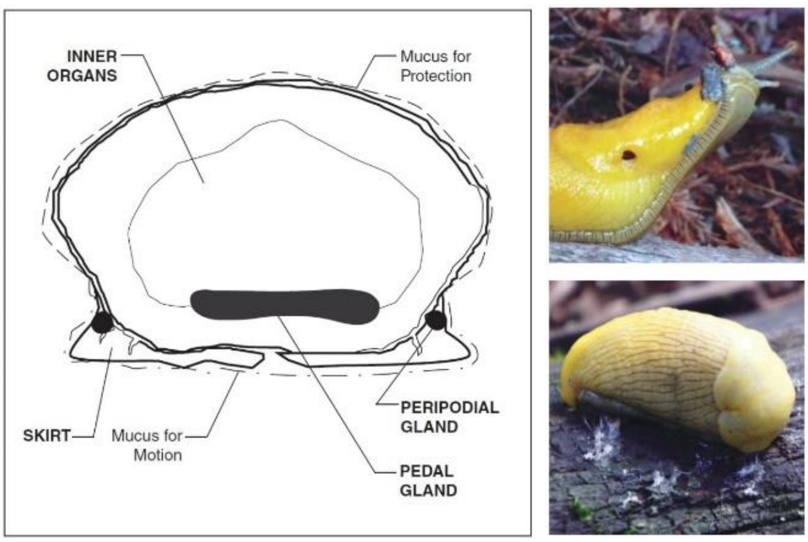


Figure 5.20. Banana Slug's Mucus Trail (Mazzoleni, 2013)

Proto-architectural project

This project located in the city of Santa Cruz, California where the forest ecosystems can be explored and studied. Some features of Banana Slug were examined and investigated associated with the building design: 1) permeability and porosity of the skin, allowing it to respire. 2) protecting the animal from hunters, predators, and dehydration; 3) become acclimated to changes in temperature and humidity associated with the environment; 4) the animal's capability to keep the communication and balance with the environment. The building skin fluctuates, and the interior environment changes so that the sunlight, rainwater, and air can freely enter inside and in other cases protect the plant cover from the elements. The building is a steel grille that keeps all elements in place. While most cushions are made of a two-layered silicone full of water, the roof is a single layer to gather the rainwater and showing to the outside and the water can be added from the outside and directly into the structure. It can be transferred through a secondary plastic pipe in the building envelope (Figure 61) (Mazzoleni, 2013).

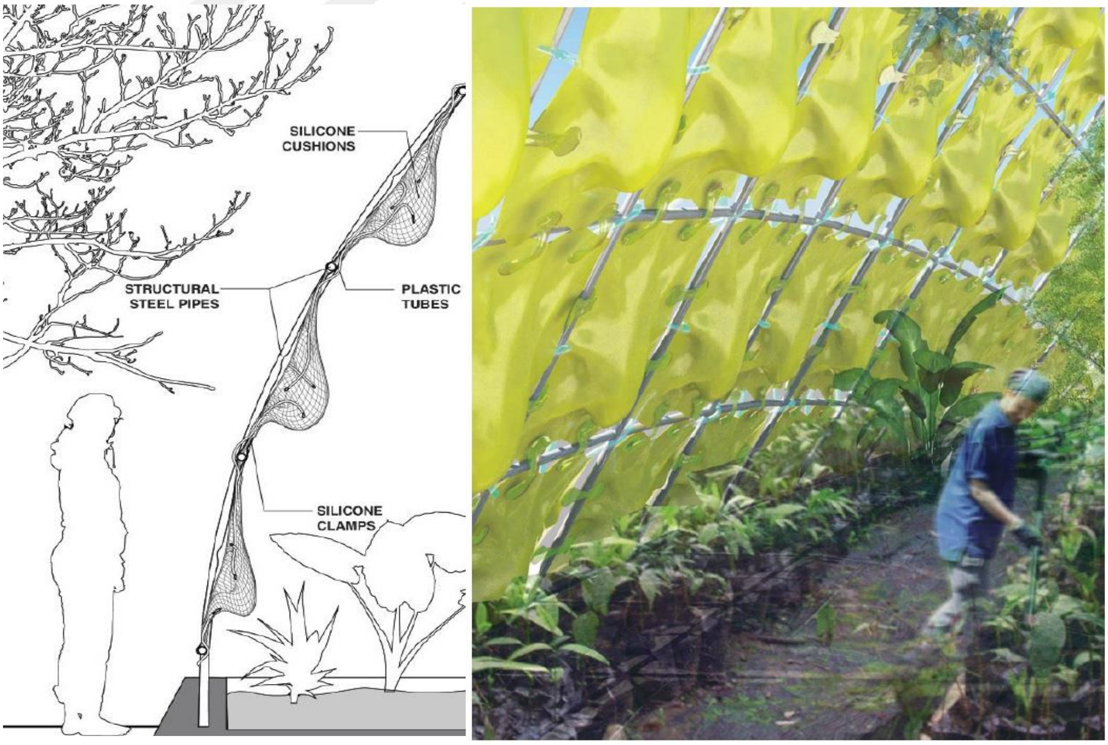


Figure 5.21. A wall section provides details of the integrated systems within the envelope (Mazzoleni, 2013)

Table 5.9. Design mapping of Banana slug’s skin and building envelope in highland climate zone (prepared by author)

BANANA SLUG

CLIMATE

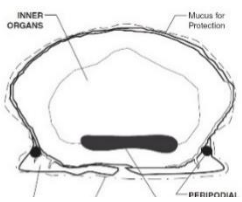
Polar | Tropical | Cold Temperate | HIGHLANDS | Dry

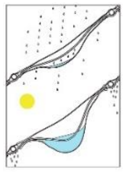
TARGETED FUNCTION

Communication | WATER BALANCE | Protection | Thermoregulation

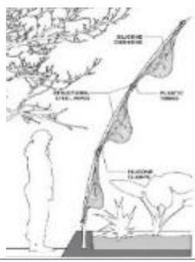
BIOLOGICAL PHASHE		
WHAT	WHY	HOW
BIOMIMETIC LEVEL physiological and behavioral	CHANLENGE secreting mucus to prevent desiccation, aid in respiration across a moist surface, and aid in movement.	FUNCTION ensure moist skin
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS Together with the foot’s muscular contractions, the mucus helps the slug move forward, protects the slug’s body prevents desiccation.

THE INSPIRATION FROM NATURE



ARCHITECTURAL PHASHE		
APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
ADAPTIBILITY adaptive envelope	CHANLENGE Collecting rainwater	TECHNICAL IMMPLENTATION 
APPLICATION A new steel grid structure which holds the aggregation of bladders, or cushions, in place. And collect rainwater	BENEFIT adapting to changes in humidity and temperature in relation to the surrounding environment	TECHNICAL FEATURE inflating or deflating

THE IMPLEMENTATION IN ARCHITECTURE



5.5. Dyeing Dart Frog "*Dendrobates Tinctorius*"

Figure 5.22. Dyeing Dart Frog (URL-21)

Table 5.10. Dyeing Dart Frog's scientific classification

Dyeing Dart Frog's Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Chordata	Amphibia	Anura	Dendrobatidae	*Dendrobates*	*D. tinctorius*

<u>Dry climate</u>

Poisonous frogs come from the humid environment of South and Central America and belong to the family *Enterobatidae* (Figure 5.23). A lot of them are poisonous and have colorful skin patterns. *Dendrobates tinctorius* is found in the eastern shield of Guiana, northeastern Brazil, southeastern, and in French Guiana. Dyeing Dart Frog usually take place in secluded inhabitants in the Guiana Highlands and prefer a height of two to six hundred meters. They do not favor low-lying woodlands, maybe because they live mainly on the ground and experience seasonal flooding. The annual average of rain is 373 cm. The annual relative humidity in the summer months averages 76.5%, peaking in May (83%) (Mazzoleni, 2013).

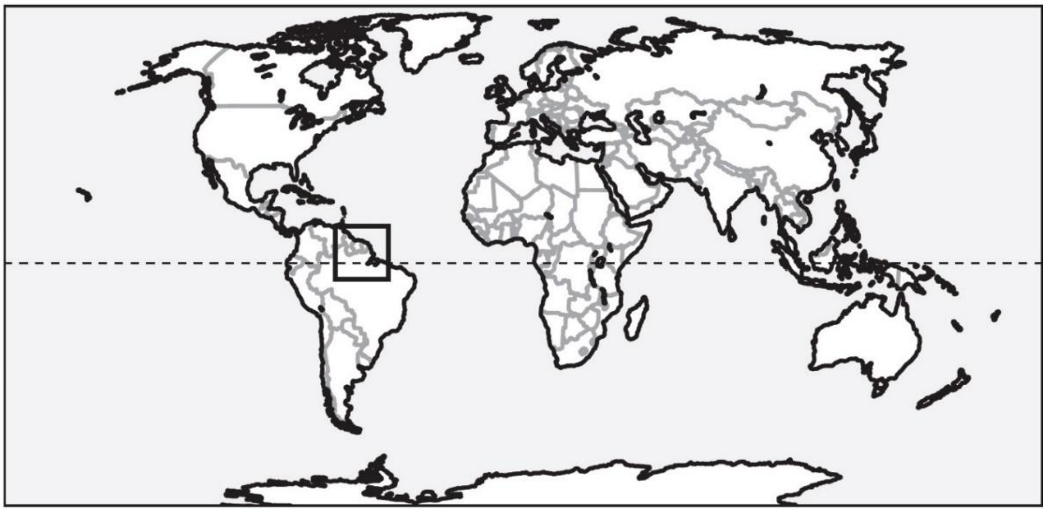


Figure 5.23. South and Central America (Dry climate zone) (Mazzoleni, 2013)

Animals' morphological features

Dyeing Dart frog lives in very humid places, generally close running water, similar to different other poisonous frogs. In the rainy season They are more active than the dry season. In the dry season, they fall back to saved places in plants in general and eat less. Additionally, *D. tinctorius* is diurnal, they are active in the morning and at the end of the afternoon. Frogs are different from other vertebrates; frogs skin is not impervious to water. and frog's way of life is closely related to water. as a matter of fact, the evolution of larvae happens in the water. Although the lungs work in gas exchanging, they respire mainly through their skin. Through the help of the mucous glands of the skin which they work to keep the skin humid (Figure 5.24) (Mazzoleni, 2013).

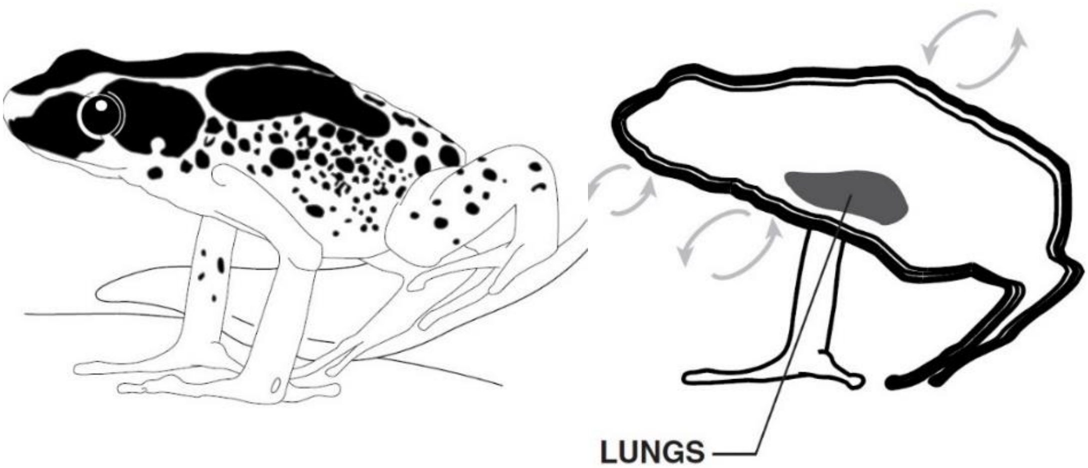


Figure 5.24. The pigment melanin and gas exchanging through the animal skin(Mazzoleni, 2013)

<u>The skin and exterior world</u>

Dyeing Dart frog exterior membrane is moist and permeable. Its skin is composed of two essential layers, the dermis (internal layer) and epidermis (exterior layer). Poisonous frogs' bright coloration patterns help to alert the frog from dangerous animals. And their poison is located in the internal layer produced by specialized glands. These Poisons consider neurotoxins, because it performs and absorbs in the animal nervous system. Around The glands there are muscle cells, once it contracts the venom is squeezed out from the glands. Toxicity is believed to be due to food because captive frogs predominantly lose their toxicity. The mucous glands make mucus to hold frog's skin wet and they are smaller (Ouboter & Jairam, 2012).

<u>Interconnection between animal's inner systems and the skin</u>

The exchange of gases takes place in the lungs and in the skin. Oxygen goes straight out of the skin and into blood vessels. When the lungs are used, the frogs breathe by the nose and the mouth to let the air to flow. As oxygen enters the bloodstream, blood enriched with oxygen enters the heart, which consists of three chambers. The oxygenated blood is introduced into the blood-vessels and spread to the entire body, whilst the poorly oxygenated blood is enriched out of the lungs and skins and thereafter dispersed accordingly (Figure 5.25) (Mazzoleni, 2013; Ouboter & Jairam, 2012).

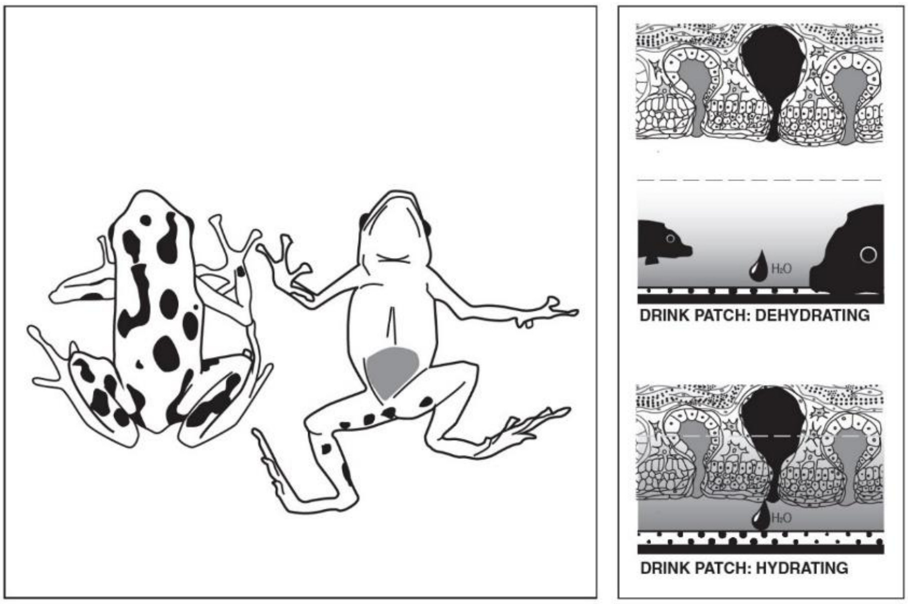


Figure 5.25. The drink patch on the Dyeing Dart Frog's Skin(Mazzoleni, 2013)

Proto-architectural project

The Matoury museum is devoted to the civilized and cultural past of the Amazon. It houses both native and majestic artifacts and works of art. the museum is designed to manage heat regulation and moisture. Humidity resistant objects are nearer to the perimeter, while more sensitive artifacts are located in the center. Inspired by D. Tintorius, the museum provided a new architectural idea that mediates moisture levels from the outside to a close and interior space. Curved surfaces and Density, they all do an important turn in its aesthetics, but the most important thing is that they dehumidify spaces of the museum. Instead of catching the abundant water in the jungle, it is exploring how to retain the moisture out. Moisture control is mainly passive, but additional power-driven systems are designed for use in extreme climatic conditions (Figure 5.26) (Mazzoleni, 2013).

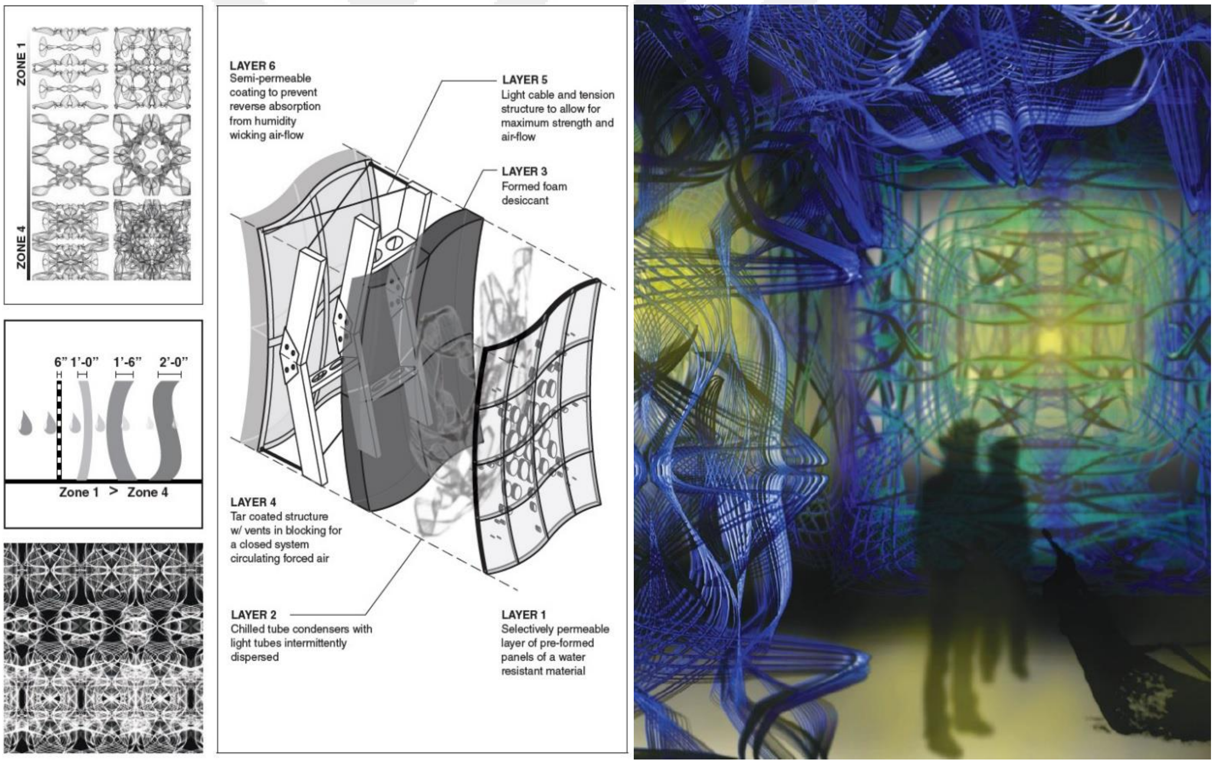


Figure 5.26. Exploded wall section illustrating(Mazzoleni, 2013)

Table 5.11. Design mapping of dyeing dart frog's skin and building envelope in dry climate zone (prepared by author)

DYEING DART FROG

CLIMATE

`

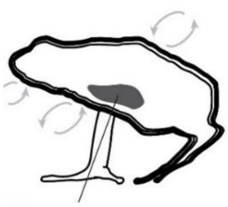
Polar | Tropical | Cold Temperate | DRY | Highlands

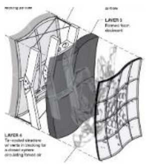
TARGETED FUNCTION

Communication | WATER BALANCE | Protection | Thermoregulation

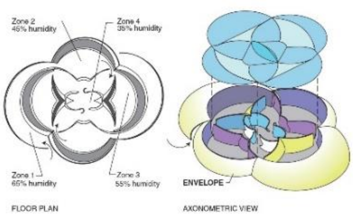
BIOLOGICAL PHASHE		
WHAT	WHY	HOW
BIOMIMETIC LEVEL behavioral	CHANLENGE producing mucus to keep the skin moist, also preventing desiccation	FUNCTION gases exchanging and prevent desiccation
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS Oxygen passes directly through the membranous skin and into an extensive network of blood vessels.

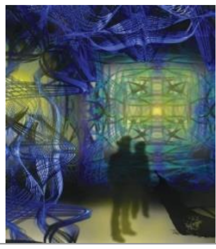
THE INSPIRATION FROM NATURE



ARCHITECTURAL PHASHE		
APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
ADAPTIBILITY multilayered envelope	CHANLENGE dehumidify the museum space	TECHNICAL IMPLANTATION 
APPLICATION The first layer is the permeable one, a hard material with perforation. The second layer is a paneled network of tubes filled with chilled water	BENEFIT Mediating humidity levels from an exterior expanse to the interior, intimate spaces.	TECHNICAL FEATURE Curving

THE IMPLEMENTATION IN ARCHITECTURE





5.6. Tree Pangolin "*Manis Tricuspis*"

Figure 5.27. Tree Pangolin (URL-22)

Table 5.12. Tree pangolin's scientific classification

Tree Pangolin's Scientific Classification					
Phylum	Class	Order:	Family	Genus	Species
Chordata	Mammalia	Pholidota	Manidae	*Manis*	*M. tricuspis*

<u>Tropical Climate</u>

Pangolins have eight different types. Tree Pangolin (*Manis tricuspis*) lives in tree-covered areas, like tropical forests in the lowlands of West Africa. The project located in Ghana, which considered home to numerous kind of animals and plants, also for endangered animals (Figure 5.28).

The annual rate of air temperature is between 26 and 33 degrees Celsius. The project location is Kakum National Park and receives a large amount of rainfall almost ranges annual rate of 1100 mm / year, which is equivalent to about 57 rainy days. The medium air moisture in the morning hours 96% and the night hours rate is 79%. The average natural radiation time interval ranges from 425 to 75 watts / m 2 and the average time period for each normal illumination period ranges from thirty-five thousand to five thousand lux(Mazzoleni, 2013).

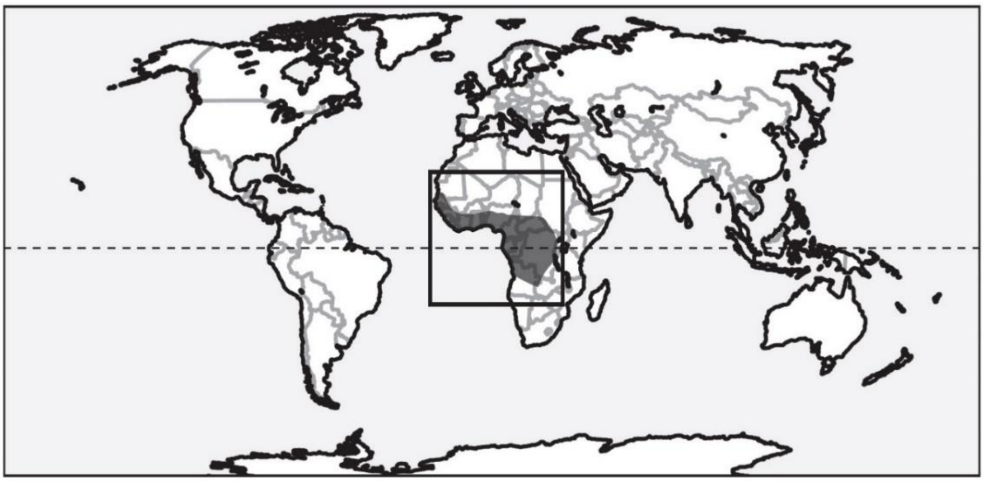


Figure 5.28. Tropical forests in the lowlands of west Africa (Tropical climate zone)(Mazzoleni, 2013)

Animals’ morphological features

Tree Pangolin weighs between 4.5 and 14 kg and is 31 to 45 cm long, the animal's sides and back are enveloped with big keratin scales that overlap comparable to our fingernails. In the risky situations, pangolins coil into a narrow ball, making a protective layer against hunters, bugs, and insects. Tree pangolins solely eat and live on termites and pismires, because of their lack of teeth. The tongue extends to the neck with long, strong muscles that stem from the breastbone. The large viscous salivary glands exceptionally work on the lubrication of the tongue and provide a sticky surface where ants can be stuck and trapped. Tree Pangolin has provided a big, muscular tail that acts as a balancing load, the fifth member to help in commentary on the branches (Figure 5.29) (Abayomi *et al*., 2009).

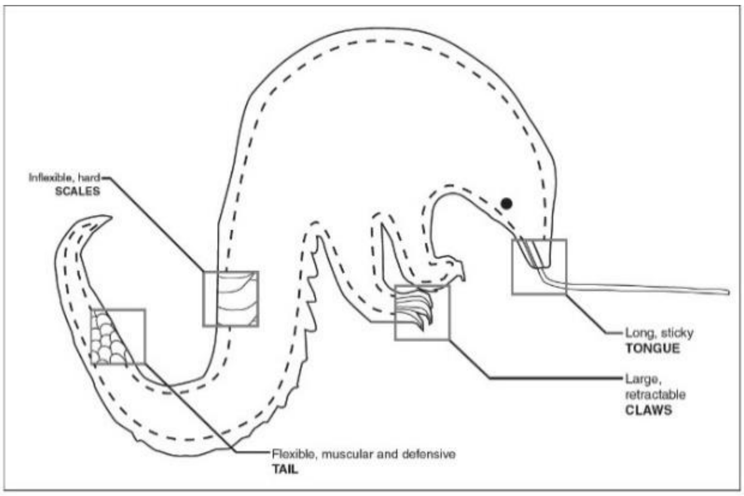


Figure 5.29. The Tree Pangolin’s primary morphological features (Mazzoleni, 2013)

<u>The skin and exterior world</u>

The Tree Pangolin skin consists of three main layers: the hypodermis, dermis, and cuticle. Nevertheless, the Tree pangolin's bodily outside looks big, strong, and platelike scales that defend him from hunters, killers, and prey. The young pangolin's scales characterized by being Soft but crucified when they grew up. The external and internal face of the scales might fray through wear but are only changed by keratinized cells of the central layer. The *Manis tricuspis's* skin system offers a strict defense system that preserves adequate flexibility for pangolins to do their normal activities such as climbing and digging. It has a corrugated exterior that avoids extreme local injury from daily wear (Abayomi *et al*., 2009).

<u>Interconnection between animal's inner systems and the skin</u>

Pangolins are frequently compared to an artichoke or cone. Although they tend to move slowly, the flexibility offered by the shield compared to the hard casing means that this animal has the ability to move more quickly if necessary. in risky situations, pangolins support the hind legs and use the tail to maintain balance. If Pangolins feel endangered and cannot protect its selves, it rolls up into a ball and use its tail for hiding (Figure 5.30). Pangolins are able to produce toxic secretion, which can fright hunters too. by defensive eyelids, pangolin can fight ants, termites, and attacks and feed comparatively readily (Abayomi *et al.*, 2009; Mazzoleni, 2013).

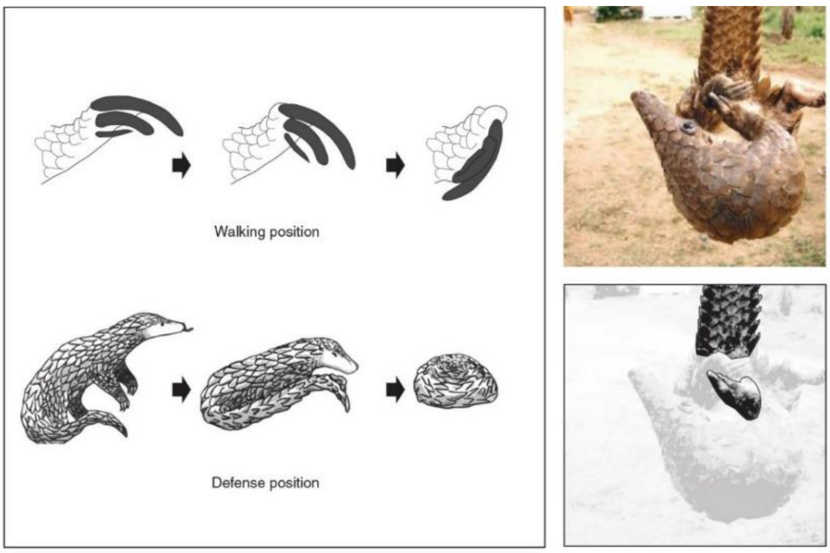


Figure 5.30. The diagram illustrates the pangolin's retractable claws (Mazzoleni, 2013)

Proto-architectural project

The project reconnoiters the double flexible and defensive properties of Tree Pangolin's skin system, combining flexible envelope from hard and solid scales. This project concentrates on the premise of establishing and enhancing a temporary and adaptable structure to adjusts to different site's conditions. In this case, the main concern is to provide emergency shelters for medical teams. The panels are assembled jointly according to the tensegrity principle in order to provide the necessary structural loading capacity for helping the panels and create a good living environment. This project is prepared from main parts which are easy to transfer: 1. PV panels 2. an umbrella-like structure. 3.flexible transparent fabric. While its skin protects Pangolin from hunters and predators, this project is made to protect against unwanted environmental circumstances. To meet the need for energy, modular is prepared with photovoltaic panels, consequently that energy is easily obtainable. Shelters installation is the multi-step procedure which starts by expanding the structural umbrella to extend the protective fabric. The PV panels are then connected to the basic modules, which are then installed to form a fixed bracket that provides structural stiffness. Lastly, the rows of the modules are repeated till the wanted stone space is reached (Figure 5.31) (Mazzoleni, 2013).

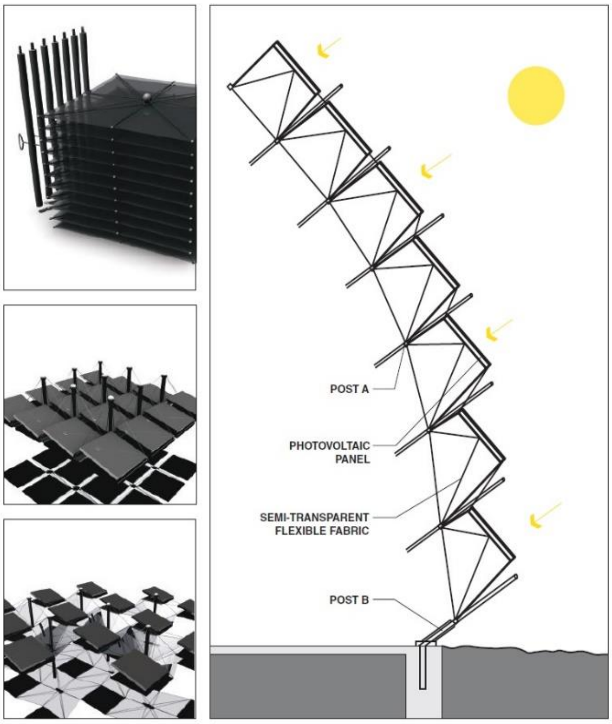


Figure 5.31. The diagrams illustrate the flexibility derived through the shelter's kit-of-parts assembly (Mazzoleni, 2013)

Table 5.13. Design mapping of tree pangolin’s skin and building envelope in tropical climate zone (prepared by author)

TREE PANGOLIN

CLIMATE

`

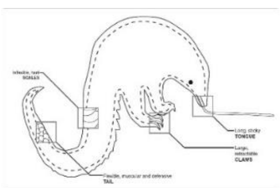
Polar | TROPICAL | Cold Temperate | Dry | Highlands

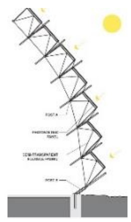
TARGETED FUNCTION

Communication | Water Balance | PROTETION | Thermoregulation

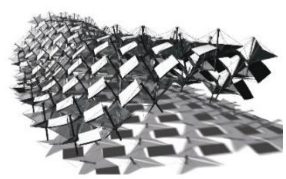
BIOLOGICAL PHASHE		
WHAT	WHY	HOW
BIOMIMETIC LEVEL behavioral	CHANLENGE Providing a sufficient flexibility for the animal to climb or dig.	FUNCTION protecting the animal from predators and prey.
BIOMIMETIC APPROACH Design Looking to Biology		PROCCESS pangolin will roll up into a ball, using its prehensile tail to over its face.

THE INSPIRATION FROM NATURE



ARCHITECTURAL PHASHE		
APPLICATION IDEAS	INNOVATION	DESIGN CONCEPT
ADAPTIBILITY dynamic envelope.	CHANLENGE Making an emergency pavilion for post natural disaster.	TECHNICAL IMMPLENTATI  ON
APPLICATION The shelter is designed for transportability, also to be a deployable and temporary structure	BENEFIT adapting to varying site conditions and terrains.	TECHNICAL FEATURE Moving and changing

THE IMPLEMENTATION IN ARCHITECTURE



6. CONCLUSION AND FUTURE REMARKS

In numerous cases, natural creatures incorporate technologies similar to those of humans, but in a smarter efficient way. In essence, biomimetics means translating the spirit of nature and its intelligence to people to figure out brand new ways to solve their problems. In contrast to the historically dominant point of view, biomimetics has introduced a systematic path to transferring knowledge from nature to too many different areas. Biomimetics overcomes the analogy and implements on different levels, like ecosystem, body, and behavior. Through the increasing influence of biomimetics, a novel way has been identified in numerous areas like material science, agriculture, medicine, engineering, manufacturing, and fashion. In architectural field, many modern approaches are working on mimicking natural strategies from nature. Nevertheless, a lot of research sees the relationship between nature and architecture stay in form-based level.

Recently, several important efforts have been made to improve a biomimetic approach to the building envelope such as Mazzoleni, Gruber, and Badarnah-Kadri. These studies focus mainly on learning from nature and trying to imitate it to achieve much more efficiency in the use of resources and energy in architectural envelopes. The researches see the nature as a mentor, model, and a measure too. Meanwhile the skin might be used as a measure for the building envelope design, additional explorations might be debated in this area. Achievements in adaptive building covers can become an upcoming substitute to the traditional ones, whose characteristics are not an ideal result for efficiency. Adaptive design approaches might decrease energy consumption and energy costs, leading to substantial enhancements in energy savings.

This thesis looks at the progress of adaptive building envelopes, counting those created on principles of biomimetics, and new ideas are proposed for improving the energy efficiency of the building, inspired from animal skins, which face various ecological problems for practical applications. Dissimilar from other biomimetic researches, this thesis is relying solely on the skin of animals and their adaptation strategies for different climate conditions.

Animals are uncovered and unprotected to the ecological variations and whether fluctuations, exactly like buildings, so they must withstand in front of the climate conditions that have influences on them. Thorough examination and evaluation of adaptation strategies of animal skin to the environment in different weathers around the world is the thesis main idea, which distinguishes it from other researches. Thus, this research is looking at the strategies of animals to face the climate in which they exist to advance exclusive solutions to acclimatize the covering to buildings in various places.

To answer the research's main questions, which are "Can we use biomimicry as a way to reduce the energy consumption in building skins?" and "Is it possible creating a design mapping that helps architects design energy efficient building skin by using biomimetic principles?" some design mappings were generated (Table 5.3, Table 5.5, Table 5.7, Table 5.9, Table 5.11, Table 5.13) in every climate zone for providing adaptive building envelopes that control ecological characteristics and suitable circumstances grounded on adaptation strategies of animals' skins. And at the same time, they are new guide lines to architects to improve energy efficiency of buildings skins and to be helpful at the beginning of the design phase of the building facades. These tables make a connection that might be settled between biological environments (nature) and designs (architecture) and ground-breaking solutions for the design of architectural facades. A comparison has been made between architectural and biological data to recognize how to use the animals' systems to create adaptive envelopes that integrate and work like animal skin in each different climate zone.

Through studying the literature review many goals have been achieved like studying and realizing the potential of biomimicry and its application in architecture through (Chapter 2), recognizing the identification of natural skin and building adaptation strategies, and exploring the potential to define the idea of adaptation in a biomimetic representation in architecture, and making relationships between the skin in nature and the building envelope in architecture through (Chapter 3), understanding the changes in global climate that facing the earth, and how the animals have adapted to many different climate environments through their skin, and some chosen functions that helped animals to adapt to this climatic changing through (Chapter 4), and also providing guidelines for designers to achieve more energy efficiency have been achieved through generating some design mappings (Table 5.3, Table 5.5, Table 5.7, Table 5.9, Table 5.11, Table 5.13) through (Chapter 5).

The research hypothesis “biomimicry could provide guide lines to architects for improving energy efficiency of buildings skins and be helpful at the beginning of the design phase of the building facades.” is verified as seen in (Table 5.3, Table 5.5, Table 5.7, Table 5.9, Table 5.11, Table 5.13). For example, the Polar Bear as seen in the (Table 5.7) lives in polar climate region and the function that has been targeted is thermoregulation, the climate and chosen function should be specified in the beginning, through biological phase the designer must ask him self what animal adaptation is examined? why this animal made this adaptation and how did it? Then what challenges does this animal face to adapt and be able to live in this climate zone? Or we can ask. Why should this animal need to do this strategy? The question of how is exploring how animals improve particular functions, how Polar Bear handle the thermoregulation? In design phase, the designers should abstract the Polar Bear’s adaptation principles and turn them into practical results and applications for building envelopes and at the same time adaptive like its skin. This phase is determined with three central thoughts: application ideas, innovation and design concept generation.

In this research methodology, some diverse phases lead to the transmission of biological data from nature to architecture is provided, applying the methodology let us generate tables for each climate zone, these climate zones contain a specific study of animal’s skin adaptations to its surrounding environments and climatic conditions to offer some novel ways to save energy, balancing water, protecting, and communication through building facades, in addition to achieving the interior comfort taking in mind the human factors should be satisfied. If more energy efficiency can be achieved to build external envelopes, by imitating nature than using the traditional processes, the study offers many mechanisms and strategies for solving design problems.

In summary, the methodology for producing a collection of adaptation strategy data from animal skins and providing a design mapping of the animal kingdom to architecture, opens up new perspectives for novel practical solutions and demonstrates the potential of animal’s adaptation to ecological conditions in a particular weather to improve adaptive building envelopes.

For the future studies the transformation into engineering solutions for adaptive buildings covers needs a lot of experiments and researches with novel skills, counting advances in materials science, multilayer three-dimensional printing, and usage of simulation software.

Also, the same way of classification and categorization can be tracked and an extendable database for novel patterns and adaptive appropriate building envelope designs can be created, and the generated design map of the skin can be used for increasing the fitting ability to existing building.

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