MODELS FROM NATURE FOR INNOVATIVE BUILDING SKINS

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ABSTRACT

The general aim of this research is to transform the knowledge of biological systems (natural solutions) into architectural knowledge for the design of innovative building skins. The basic questions for research are formulated as follows: What are the best skin models in nature? How are these models utilized in the best way for building skin? What kind of building skins can be improved to adapt to changing conditions? In this context, the study aims to determine with a literature review, effects of biological paradigm to building skin design, innovative ideas and concepts produced in this process; how biological principles used in design on conceptual/experimental and applied projects by analysis study, what kind of solutions are produced. The analysis study reveals that an approach based on the principles of the models in the nature is a unique resource for presenting innovative ideas to architects and for solving problems experienced today.

Keyword: Nature, Biologic Principles, Biomimicry, Building Skins

YENİLİKÇİ YAPI KABUKLARI İÇİN DOĞADAN MODELLER

ÖZET

Bu araştırmanın genel amacı, yenilikçi bina kabukları tasarımı için biyolojik sistemler bilgisini (doğadaki çözümleri) mimarlık bilgisine dönüştürmektir. Araştırmaya temel olan sorular şu şekilde formüle edilmiştir: Doğadaki en iyi kabuk modelleri nelerdir? Bu modeller yapı kabuğu oluşturmak için en iyi şekilde nasıl kullanılır? Değişen koşullara uyum sağlamak için hangi tür yapı kabukları geliştirilebilir? Bu bağlamda, çalışma bir literatür taraması ile biyolojik paradigmanın yapı kabuğu tasarımına, bu süreçte üretilen yenilikçi fikirlere ve kavramlara etkilerini belirlemeyi; kavramsal/deneysel tasarımlar ve uygulanan projeler üzerinden, biyolojik ilkelerin nasıl kullanıldığını, ne tür çözümler üretildiğini analiz etmeyi amaçlamaktadır. Analiz çalışması, doğadaki modellerin ilkelerini esas alan bir yaklaşımın, mimarlara yenilikçi fikirler sunması ve günümüzde yaşanılan sorunlara çözüm üretmesi bakımından eşsiz bir kaynak olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Doğa, Biyolojik İlkeler, Biyomimikri, Yapı Kabukları

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1.INTRODUCTION

1.1. Problem Statement

The awareness about environmental issues like climate cahange, has attracted interest on buildings energy consumption. Building skin is mostly responsible for building's energy consumption. Because, building skin is one of the most important design parameters determining indoor physical environment related to thermal comfort, visual comfort and even occupancy working efficiency, thus affecting energy usages in buildings [1] for lighting, mechanical systems, and maintenance. Also, building skin is harmful to the environment due to their manufacturing, installation and maintenance. There are many problems of current building skins. The current building skins static. A static building or skin can not guarantee an optimal level of performance, and this will lead to a discrepancy between the building and the environment [2]. With seasonal variations, shifting weather patterns, and the ever-changing comfort needs and energy requirements of indoor occupants, static passive building skin design can not provide consistent climate control due to daily, even hourly changes in the weather [3]. The another problem with current building skins is that they are constructed from multiple dissimilar components. Which creates too many opportunities for material failure and leads to condensation, thermal bridging and wasteful material use [4]. Moreover, the perception of a building's identity is possible through its skin, making it a significant communication component. These are a few reasons why the challenges in the skin are a contemporary proble.

Considering the aforementioned problems, target for today and the future is, instead of the static building skins, new skin formation provide more comprehensive space activity, increase comfort of user, climate compatible, sustainable for people and environment, energy-effective and energy-active, multi-functional, modular, at the same time smart and communicative.

1.2. Solution for Problems: Nature/Biology

To solve problems, designers need new solutions. In this context, focus on biological solutions is important in terms of acquiring new perspective for building skins.

Eilouti [5] states that solutions which are produced according to the suggestion of natural organisms and such information described as biomimetic establishes the connection between building man-made products and solving design problems within the new perspectives models:

The “Biomimicry” term represents a concatenation of “bio” which means life and “mimesis” meaning imitation. Janine Benyus’ [6] book ”Biomimicry: Innovation Inspired by Nature” published in 1997 refers to a new scientific field that studies nature, its models, systems, processes and elements, and then imitates or takes creative inspiration from them to solve human problems sustainably. Biologists and ecologists have studied the environmental influences on animal and plant physiology and behaviour, but translating these observations and analysis into architecture has been largely unexplored. The resilience of species in a particular habitat can provide valuable lesson for long-lasting design. Mazzoleni state that just as animals have systems, such as skeletal, circulatory, immune, digestive, communication, and sensory, so too do buildings have systems of structure, circulation, protection, energy and water use, communication, and thermal regulation [7]. So, researches in biomimetic has encouraged architects, scientists and designers to dig deeper into the natural world-even to microscopic levels in a bid to seek answers to sustainable design questions by mimicking biological systems that have already solved them, solutions developed over billions of years of evolution [8].

2. MATERIALS AND METHODS

2.1. The process of the research

Firstly, by using the archive method, problems about building skin will be expressed and in order to solve these problems, the necessity of applying to nature’s solutions will be discussed in the framework of biomimicry. Then, skin types in the nature which are prominent in today’s building skins researches and their solutions when confronted with different environmental conditions will be expressed. Twenty designs were analyzed in order to create building skins inspired from the nature. In the results section, the results of the analysis are shown in tables and the concepts resulting from the natural solutions are discussed.

2.2. Research samples

In literature, there are a lot of projects created inspired from the nature. However, in this study, different sources were searched and especially the building skin designs inspired from the principles of natural skins were chosen. In the study, 20 other studies, which are applied today and were developed concept/experimentally, were included.

3. PRINCIPLES IN NATURAL SKINS

The term “skin” is used in this research on a general level to refer to any human, plant and animal coverings, including skin, hair, fur, feathers, scales, exoskeletons, and shells. Skin is a complex and incredibly sophisticated organ that performs various functions, including protection, sensation and heat and water regulation [7]. Yowel [4] stated that natural skins are an organism’s first line of defense to protect its interior from the exterior environment. But, a natural skin can regulate temperature and humidity, is often waterproof, yet permeable when needed, integrates systems in a very thin membrane, protects from sunlight, can repair itself and is beautiful. Plus it does all this with environmentally friendly manufacturing, done at the local level and will not be harmful to the environment at the ends of its life.

The harsh environmental characteristics create difficult conditions for living organisms. Living systems are not static. They constantly need to adapt themselves to changing internal and external conditions [9].

For example, some animals have thick coat with dense hair, it does not only protect animals from cold winter, but it insulates them from summer heat. A **polar bear’s fur** consists of three main layers: the clear hollow hair, a dark color skin, and a wooly fur layer underneath it all. Light penetrates the clear hollow hair, while the dark skin increases heat absorption and after that, the heat is preserved in the wooly fur layer and insulated by the 10cm layer of fat underneath it all [10].

Polar bear’s fur changes color in summer due to the structure of each hair and the dark color of the underlying layer of skin. Each hair is clear and hollow to allow light in [10]. Coloration is also an important factor in reducing of heat absorption in desert animals [11]. A desert **chameleon** becomes darker in the morning to increase its heat absorption and lighter during the day to reflect light [10]. Their colors are used for communication between other chameleons, and as camouflage from predators.

Sand lizard has hygroscopic skin to absorb moisture from the air and to produce enough water [11]. The **Namib desert beetle** is able to capture moisture however from the swift moving fog that moves over the desert by tilting its body into the wind. Droplets form on the alternating hydrophilic-hydrophobic rough surface of the beetle’s back and wings and roll down into its mouth [12]. **The thorny devil** (Moloch horridus) can gather all the water it needs directly from rain, standing water, or from soil moisture, against gravity without using energy or a pumping device [10]. Ribs or grooves are morphological adaptation for water transportation, e.g. barrel cactus. Besides the importance of ribs in allowing the **cactus** to shrink and swell, they provide channels fort he collected water to reach the roots [13]. Also, the cactus' spines serve is to help shade the plant from the intense sun.

Plant surfaces provide more than one solution for environmental conditions and can include, for example, light reflection, superhydrophobic or superhydrophilic surfaces [14,15]. For example, **lotus leaf** is the most superhydrophobic, hence it always remain clean in muddy and dirty ponds. In the rainy season, when the raindrops fall on the surface of lotus leaves, they immediately bead up like shiny spherical balls and quickly roll off the surface collecting dirt and debris along the way [17,18]. Koch and Barthlott [19] stated that superhydrophobicity is also a protection against plant pathogens such as fungi and bacteria, because germination of many microorganisms such as fungi and reproduction of bacteria are limited by water access. Animals such as **water stride, water spider** and **mosquito** exhibit excellent water repellent, superhydrophobic properties.

Dynamics in plants are generated due to their nastic structure [20]. **Heliotropism** is the movement of leaves following the sun and it is one of the ways to regulate light intensity on the surface. For example, **sun flower** track sun path throughout the day by bending towards light and maintaining radiation perpendicular surface [13]. Most plants must open and close their **stomata** during the daytime in response to changing conditions, such as light intensity, humidity, and carbon dioxide concentration. Also, some plants like **mimosa** fold its leaves when touched or exposed to heat. Many other plants also fold their leaves in the evening [21]. Flexibility is an important feature for protection in animals. For example, the **armadillo** has a hard outer shell and can curl up into a ball leaving no soft body parts exposed to danger (a bit like a woodlouse) [22]. Also, the **pangolin**'s scaly body can curl up into a ball when threatened, with its overlapping scales acting as armour. The scales are sharp, providing extra defense against unwary paws [23]. The **balloon fish** can triple its body volume by pumping water into its stomach for the purpose of defended itself against predators. Then, it shows off the pointy spines that cover their skin. So, fish skin exhibits striking structural and functional specialization for inflation [24]. Some animals respond to different conditions with specially designed nests. For example, **termits** construct their mounds to maintain a constant temperature. The insects do this by constantly opening and closing vents throughout the mound to manage convection currents of air-cooler air is drawn in from open lower sections while hot air escapes through chimneys [25].

4. TRANSLATING NATURAL PRINCIPLES FOR BUILDING SKINS

Those mentioned above shows that natural skins are good models for how building skins should behave. However, current building skin are seen as barriers from the outside world, instead of filters like a natural skin [4]. It is seen that when evaluating natural skins in a similar way building envelopes serve multiple roles, as they are the interface between the building inhabitants and environmental elements. [26]. Wigginton and Harris [27], in their book Intelligent Skins, argue that the use of the term “skin” is more than merely a metaphor; the building’s envelope can be considered quite literally as a complex membrane capable of energy, material and information exchanges. Emulating nature’s strategies to innovate design for building skin could be successful. The skin of nature’s organisms has similarities with the building skin and that makes it interesting to look to their strategies. The transformations of the strategies from biology to architecture is possible in different ways. Eilouti [5] states that nature can be imitated directly or indirectly as a metaphor to solve design problems and to develop environment-friendly functions, systems and solutions. According to the Gruber [28], abstraction is the key to transferring ideas from one discipline to another. Maibritt Pedersen Zari [29] stated that Biomimicry is the mimicry of an organism, an organism’s behaviour or an entire ecosystem in terms of its form, material, construction method, process, strategies or function.

4.1.Case Studies: Applied Designs

This part of the study, ten works that come to the fore in the literatüre are analyzed inspired by natural skins.

4.1.1. The Esplanade Theater: The Esplanade Theater in Singapore, designed by DP Architects and Michael Wilford. It was inspired by the durian plant while the shell of this building was designed. The thorny, multi-layered and semi-rigid pressurized shell of the plant protects the seeds inside. Similarly, with a layered shading system that resembles the shell of the plant from the outside, the building skin also prevents overheating of the interiors while allowing the sunlight to be taken from the interior [30] (Figure 1).

Figure 1. Durian plant and The Esplanade Theater [3]

4.1.2. The Minister of Municipal Affairs&Agriculture (MMAA) in Qatar: This building is designed by Aesthetics Architects. The skin of the desert cactus is applied to the design of the skin of a desert building. The cactus plant is exposed to more night sweats than the daytime to hold the water. Likewise, intelligent sun shading elements in windows are also opened and closed in response to heat. Thus saving energy [30] [31] (Figure 2).

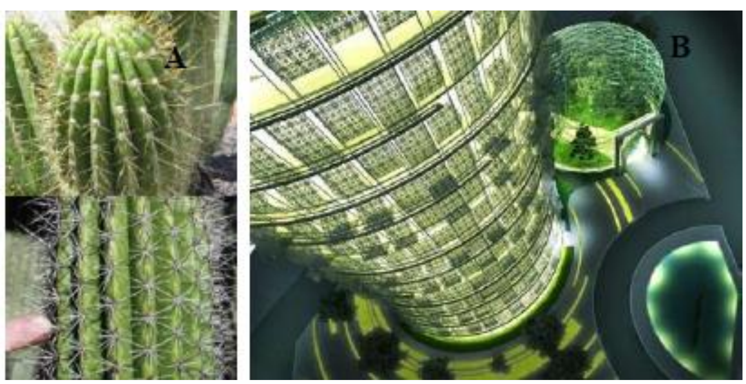

Figure 2. Cactus plant and MMAA Building [30] [31]

4.1.3. Al Bahar Towers: In Abu Dhabi, towers' facade is designed by Aedas Architects. The façade has an interactive relationship to the environment which is reminiscent to the opening of a **morning glory flower** to the sun. Flower-like shading elements in building skin are managed by the building automation system and are opened and closed in response to the sun [32] (Figure 3).

Figure 3. Morning glory flower and Al Bahar Towers [32]

4.1.4. Heliotrope House: Heliotrope House is designed by Architect Rolf Disch. This building is the first energy positive house in Germany. In the design of the house inspired by heliotropism, a phenomenon common to plants that live in the Arctic, where the growing season is short. During a never-ending summer day, Arctic poppies will follow the sun around and around, using its rays to warm their petals so as to attract insects. Similarly, Mounted on a pole, the house rotates (180 degrees) during the day depending on the direction of sunrise. The solar panels on top produce more than enough energy to make the home net energy positive. A unique hand railing system on the roof doubles as solar thermal tubing that heats the home’s water and radiators [33, 34] (Figure 4).

Figure 4. Arctic popies and Heliotrope House [34]

4.1.5. Self-cleaning coatings: A self-cleaning effect which was first discovered by Prof. Barthlott at the lotus leaf. Dust and other pollutions are rinsed off by raindrops from a lotus leaf. Many institutes and suppliers try to apply this effect on textiles, plastics, glass or other materials. StoLotusan Color protection, dirt runs off each time it rains to leave a beautifully clean and dry façade [35]. BalcoNano® is a hard, durable protective coating. Dirt and other deposits cannot cling to the glass surface and either wash away easily or can be easily cleaned with water and a cloth [36] (Figure 5).

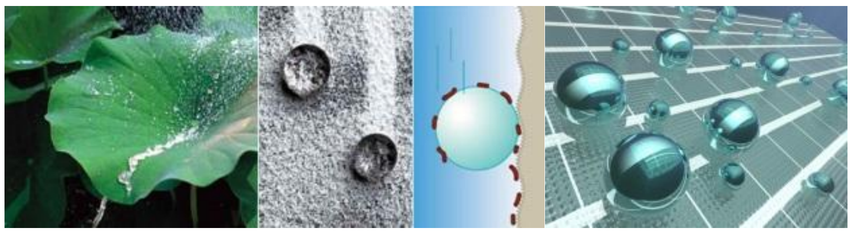

Figure 5. Lotus leaf and self-cleaning coatings [35] [36]

4.1.6. Waterloo International Terminal: This building was designed by Nicholas Grimshaw&Partners. The flexible skin of pangolin is imitated in the parts that fix the glass panels of the building so that the changes in the air pressure caused by the trains entering and leaving the terminal do not damage the building. So that the glass skin of the building can move in response to applied air pressure forces [37, 38] (Figure 6).

Figure 6. Pangolin and Waterloo International Terminal [37]

4.1.7. The Swiss Re (Gherkin) Tower: Tower was designed by Sir Norman Foster in London. It was inspired by the venus flower basket sponge. This special sponge hosts a lattice-like exoskeleton that appears glassy and glowing in its underwater environment. The various levels of fibrous lattice work help to disperse stresses on the organism in various directions and its round shape reduce forces due to strong water currents, both of which were applied to Foster's design of the tower [39]. The steel spiral "diagrid" structure creates an aerodynamic form that provides the lowest resistance to wind [40] (Figure 7).

Figure 7. Venus flower basket and Swiss Re Building [8]

4.1.8. Eastgate Tower: The architect Mick Pearce was inspired termit mound to design the Eastgate center In Zimbabwe where the temperature outside can vary from 3 °C up to 43 °C and where the air condition plays a significant role. The innovative building uses similar behavior in the design, and air circulation planning it stays cool without air conditioning and uses less than 10% of the energy used in similar sized conventional buildings. His solution was to have specially designed hooded windows, variable thickness walls and light colored paints as a part of a passive-cooling structure to reduce heat absorption. By doing so Eastegate uses 90% less energy for ventilation than conventional building [25] (Figure 8).

Figure 8. Termit mound and Eastgate Tower [25]

4.1.9. Council House 2 (CH2) Building: The ten storey building was designed by Architect Mick Pearce in Melbourne, Australia. The climate control of this building mimics the ventilation system of a termite mound. CH2 includes many innovative and technological features such as photovoltaic cells, chilled ceilings, blackwater sewage recycling systems. But by far the most striking features of CH2 are its recycled timber louvers controlled by photovoltaic cells and the five shower towers, in which water droplets evaporate slightly as they use up energy and thus cool the air. Other features worthy of notice are wind-powered turbines which will help cool the building at night, internal thermal mass, a gas fired co-generation plan, as well as the recycling of the waste heat generated inside the building for their heating/cooling system [41] (Figure 9).

Figure 9. Termit mound and CH2 Building [41]

4.1.10. Q1 Building: Q1 building was designed by JSWD Architetken in Germany. This building is not just a feathery design element- it also serves as a sophisticated sun shading system. The metal feather elements vary in shape from trapezoids to triangles and rectangles. Aside from the shading benefits, the different feather-like elements create a dazzling façade that sparkles like a fish's scales when the sun catches them just right. The metal elements block of the harsh sun while keeping the interior cool, reducing the need for air conditioning and climate control [42] (Figure 10).

Figure 10. Feather and Q1 Building [42]

4.2. Case Studies: Concept/Experimental Designs

Knaack [43] stated that every solution begins with a concept. The idea is the starting point for progress: concepts are visionary thougts, developed from a certain way of perception. The following ideas provide an extreme approach to solutions that are conceivable, yet far from realization. However, this can change over time and these ideas might be taken into consideration. So, this part of the study place is given to concept projects. These projects are selected from studies of researchers and acedemicians mentioned below and other studies in the literatüre.

One of the studies in recent years was investigated analogies between the biological skin and the technical skin at the TU (Vienna University of Technology) student's project. Now, these projects under the leadership of AIT (Austrian Institute of Technology), is being developed at a later stage as BioSkin. "BioSkin–Research aimed at the identification of potentials from nature for climate-adaptive energy efficient facades of the future. The study was conducted at the AIT Austrian Institute of Technology, Energy Department [44][45]. Prof. Dr. Ulrich Knaack founder the Facade Research Group and his team at the Chair Design of Construction in Technical University of Delf concentrates on exploring future possibilities for the building envelope. Key topics for this group are energy consumption and sustainability, typology, materialization, fabrication and assembly of facades. The ideas discussed by the group were collected in the book, "Facades" [43]. Also, Ilaria Mazzoleni and her students at the Southern California Institute of Architecture focused on the analysis and understanding of different types of animal skins [46] and translated the learned principles into the built environment These related to the topics of sensation, coloration, energy regulation, water management, and the use of local and renewable resources [40]. In her recently published book Architecture Follows Nature: Biomimetic Principles for Innovative Design, she presented twelve case studies about animal skins for the design of building skins [7].

4.2.1. The Habitat 2020: This skin was designed by Philips Design and was envisioned for China. The skin has been designed as a living skin, rather than a system of inert materials used only for construction and protection. The skin behaves like a membrane which serves as a connection between the exterior and interior of the habitat. Alternatively, the skin may be considered as the leaf surface having several stomata cellular openings involved in gaseous exchange and transpiration in plants. The surface would allow the entry of light, air and water into the housing. It would automatically position itself according to the sunlight and let in light. The air and wind would be channeled into the building and filtered to provide clean air and natural airconditioning. The active skin would be capable of rain water harvesting where water would be purified, filtered, used and recycled. The skin could even absorb moisture from the air. The waste produced would be converted into biogas energy that could be put to diverse uses in the habitat [47] (Figure 11).

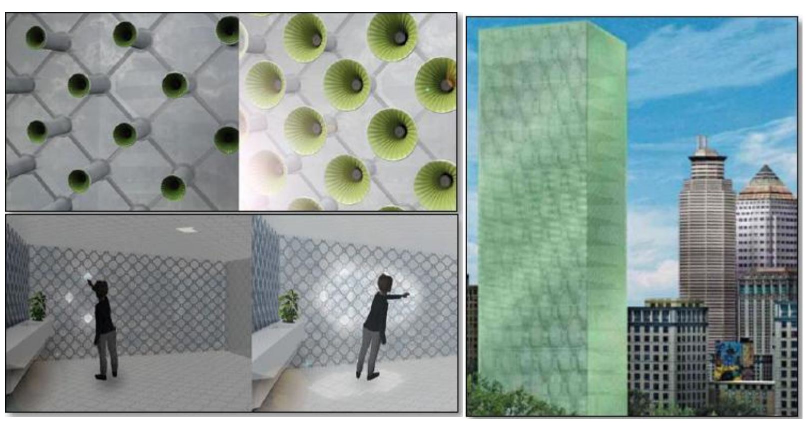

Figure 11. The Habitat 2020 [47]

4.2.2. Stoma brick: This evaporative cooling system (SB) for building skin was designed by L. Badarnah, N. Y. Farchi and U. Knaack (The Facade Research Group). It was designed based on principles of several natural systems. These include stoma of a plant, pine cones, hair protecting eyes in the desert, and human skin. The system consist of four integrated parts. Stoma brick: made of porous material. It has outer layer of hairy structure to filter the air passing through the envelope. A veneer shutter to control opening/closing in accordance to humudity gradient. The most inner layer is spongy to hold moisture for evaporation. The mono-brick: it includes an irrigation cycle that irrigates through holes the SBs, which are inserted into the mono-brick to allow a continuous performance vertically. The steel framing: is load bearing structure of the cooling system. Th inner layer: filter fora ir cleaning or a double acrylic glass for lightening and visual contact with the exterior environment [48] (Figure 12).

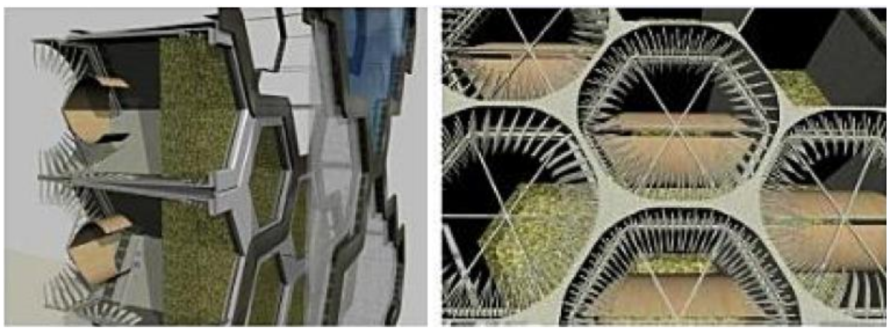

Figure 12. Details of stoma brick [48]

4.2.3. Foliage façades: This facade was designed by Ulrich Knaack (Facade Research Group). Integrating fern of foliage from other deciduous plants into the space between two glass panels will function as periodic sun shading. In winter, the plant has shed its foliage and lets the sun penetrate, but in summer there is good shading. The elements have to fill a reservoir with rainwater to let the plants grow [43] (Figure 13).

Figure 13. Fern and foliage façade [43]

4.2.4. AeroDimm: This facade was designed by Stefan Pfaffstaller and conducted by Petra Gruber in Vienna University. In the design of pneumatic facade is inspired by the color changing skin of cephalopod. The color change in the two-layered facade is caused by the volume change of the elastic membranes by pneumatic pressure. This technique provides color change as well as darkening of the facade [49] [44] (Figure 14).

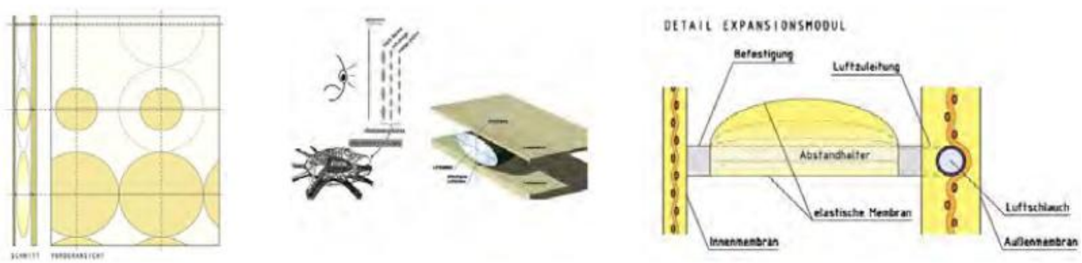

Figure 14. Cephalopods and AeroDimm [44,49]

4.2.5. S.C.A.L.E.S. (Smart, Continuous, Active, Layered, Environmental, System): This project was designed by Ilaria Mazzoleni and her students (Yuan Yuan and Juan San Pedro). It is a project that takes inspiration from the characteristics of the side-blotched lizard (uta stansburiana). The team created a residence in Palm Springs, California for the desert climate which mimics the behaviors and translated physiological characteristics of the lizard's skin. Scales in the skin of the lizard, number, shape and thickness according to function and position in the body and is also linked to a continuous surface. Similarly, flexible membrane used in walls of the house, special covered with photovoltaic panels. Also, similar to the lizard in the desert, the main concern of the design is the comfort of the residents in hot, arid days and cold nights. This example demonstrates how a user help meet their requirements and provide thermal regulation [46] (Figure 15).

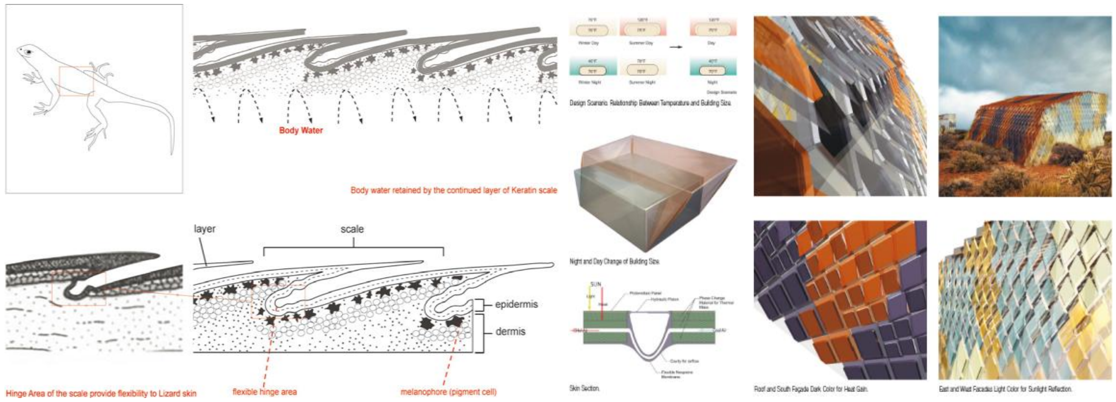

Figure 15. Lizard and S.C.A.L.E.S. project [46]

4.2.6. Polar bear-Keep It Warm: This project was designed by Ilaria Mazzoleni and her students. It mimics the polar bears physiological adaptation developed in order to survive to some of the planet's harshest weather conditions. The living units designed in the arctic region (0 ° C in the summer and -34 ° C in the winter) are partially buried in the earth, not dissimilarly from the bear's hibernation den. The units are also southwest oriented so that they can provide the most suitable heat gain from the sun. The solar energy (heat and light) is collected by an active shell consisting of glass tubes, such as hollow, steerable fur. The energy is conducted through the tube to the insulating strata where is stored, conserved and slowly released. Moreover, embedded in the phase changing material, phosphorescent cells allow the accumulation of light which then gets slowly released at night [50] (Figure 16).

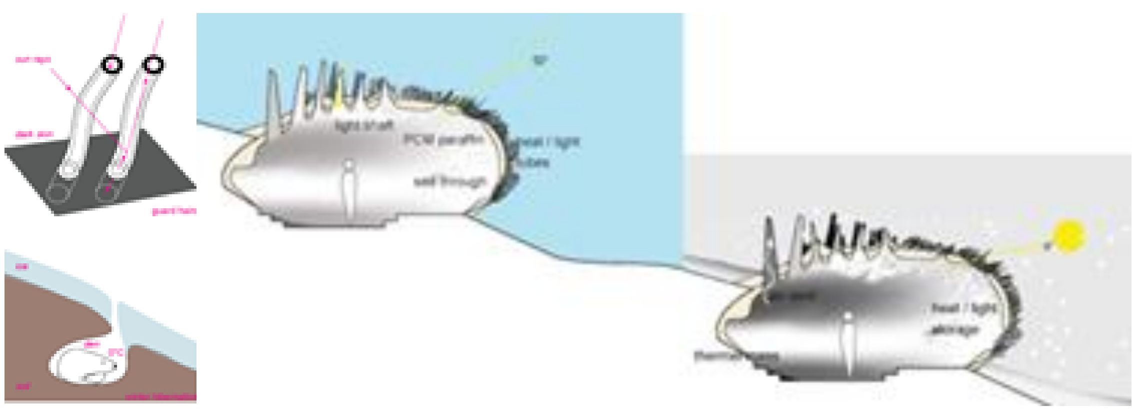

Figure 16. Building skin inspired by polar bear [50]

4.2.7. Porous wall claddings: These wall claddings was designed by S. Turner and R. C. Soar. They suggest porous wall coverings that act like a low-pass filter for turbulent winds, similar to the porous wall structure of termite nests. In this instance, an interior space of a building could be wind-ventilated without having to resort to tall chimneys, and without subjecting the inhabitants to the inconvenient gustiness that attends to the usual means of local wind capture, namely opening a window [51] (Figure 17).

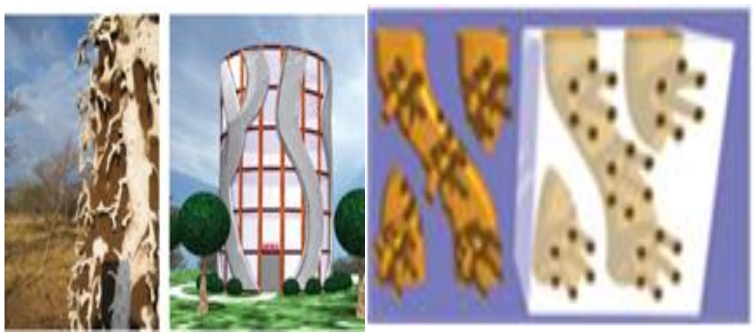

Figure17. Termit mound and porous wall claddings [51].

4.2.8. The Las Palmas Water Theatre: This theatre was proposal project for the city of Las Palmas in the Canary Islands and designed by Grimshaw Architects. Design follows the similar principles as the Namibian fog basking beetle. To heat the sea water going to the evaporators, solar thermal panels are placed in the roof of this structure. The wind brings moisture back to the theater. the air is condensed by the cooling and fresh water is collected. Then, it is used in drinking or irrigation [52] (Figure 18).

Figure 18. Namibian beetle and The Las Palmas W.Theatre [52]

4.2.9. Hydrological Center for the University of Namibia: This building was designed by Matthew Parkes of KSS Architects. In the design of the center that researches sustainable development and water use in West Africa, water collection technique of the Namibia Desert beetle is based. This technique is also called fog catcher [53]. The collects on the mesh screen and because of its shape and vertical orientation, the water naturally runs down the mesh into gutter system located at the bottom of the screens. The water is then transported through the gutters into large cisterns that keep the water at an appropriate cooler temperature so that the water does not evaporate [54] (Figure 19).

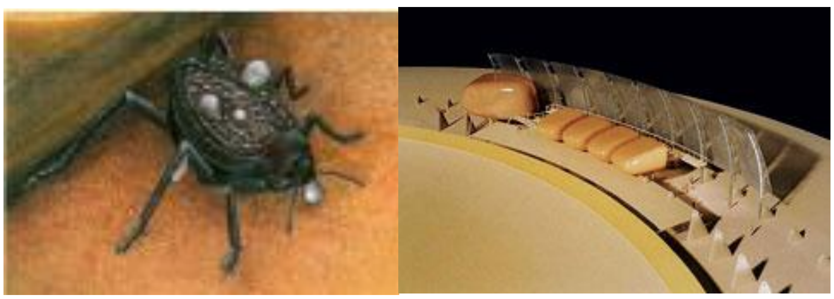

Figure 19. Namibian beetle and Hydrological Center [53]

4.2.10. Deep skin: The idea of “deep skin” is inspired by the skin of the shark for façade design of a tower in Manhattan, New York. The analysis of the configuration of a shark skin, especially how it is formed in macro and micro scales has led to the idea of deep skins in which, different inner volumes of the tower is derived from various skin types[55] (Figure 20).

Figure 20. Building skin inspired by shark skin [55]

5. RESULTS AND DISCUSSION

In this section, Table 1 [56], which shows the skin systems of the organisms and the features of the building skins of today and future, was created.

Table 1. Properties of the skin systems in nature and the architectural medium [56]

PROPERTIES OF SKIN SYSTEMS			
NATURE	**ARCHITECTURE**		
	TODAY		**FUTURE**
	CONVANTIONAL	**INNOVATIVELY**	**CONCEPT/EXPERIMENTAL**
• **Adaptable** • **Growing** • **Changable** • **Responsive** • **Multi-functional** • **Dynamic** • **Flexible** • **Self-repair** • **Self-renewable** • **Sustainable** • **Minimum material** • **High-performance** • **Energi generating** • **Complex integrated systems**	• Non adaptable • Non growing • Unchangable • Unresponsive • Multi-functional • Static • Rigid • Non self-repair • Non self-renewable • Ephemeral • Maximum material • Low-performance • Energy comsumption • Simple relationship	• Adaptable • Modular growing • Changable • Smart and interactive • Multi-functional • Dynamic • Flexible • Non self-repair • Non self-renewable • Sustainable • Minimum material • High- performance • Energy generating • Complex integrated systems	• Adaptable • Growing • Changable • Responsive • Multi-functional • Dynamic • Flexible • Self-repair • Self-renewable • Sustainable • Minimum material • Maximum performance • Energy generating • Complex integrated systems

After the samples were analyzed, Table 2, which shows the solutions for building skins with the principles of natural skins, was created.

The tables clearly show that, organisms live in harmony with their environment by showing anatomical, physiological and behavioral features and sometimes by changing these features in order to survive. Adaptation principle of nature ensures that the building skin is flexible, transformable and responsive. This makes the building skin multifunctional and necessitates each system (function-form-structure-material) of the building skin to integrate. Moreover, change and transformation in the nature, along with the developments in technology and materials, lead to a change and transformation in concepts. Building skin which gained the feature of intelligence, as it reacts to its environment, can be programmed, arranged and controlled with digital technologies. The above mentioned features make the building skin very dynamic and free.

Table 2. Principles of natural skins and solutions for building skin (Created by authors)

	CASE STUDY	ORGANISM	NATURAL PRINCIPLES	SOLUTIONS FOR BUILDING SKIN
APPLIED DESIGN	**The Esplanade Theater**	Durian plant	Thorn-covered husk Multilayered, semi rigid skin Structural geometry	Effective shading systems Climate adaptive shading skin Deployable surfaces
	MMAA	Cactus	Responsive stomata permeability Self-shading ribbed morphology Water conservation	Folding systems on the windows Effective shading systems Wastewater management system
	Al Bahar Towers	Morning glory flower	Response to the sun's path Foldaple flowers	Deployable components Intelligent skin
	Heliotrope	Arctic poppies	Heliotropism Response to the sun's path	Rotatable, dynamic structure Responsive skin
	Self-cleaning coatings	Lotus leaf	Self-cleaning effect Water resistant	Self-cleaning material and skin Ice and snow free surface
	Waterloo International Terminal	Pangolin	Overlapping, flexible, sharp scale Extra defense Regulating the temperature Allow to air circulation	Flexible structure Movable panels Responsive skin Flexible skin materials
	Swiss Re Tower	Venus flower basket	Complex, lattice-like, glass skeleton Strong structural stability Round shape	Spiral, diagrid structures Aerodynamic skin Aerodynamic form
	Eastgate Tower	Termit mound	Passive ventilation Chimneys and air passages	Passive ventilating skin Climate adaptive skin
	CH2 Building	Termit mound	Passive ventilation Chimneys and air passages	Passive ventilating skin Climate adaptive skin Recycling materials and systems
	Q1 Building	Feather	Special morphological arrangements Regular division Low conduction	Modular elements Sophisticated sun shading system Effective shading systems
CONCEPT/EXPERİMENTAL DESIGN	**The Habitat 2020**	Living skin Stoma	Connection between the exterior and interior Elasticity and expansion	Active, breathing, living skin Interactive skin Flexible, dynamic skin
	Stoma brick	Stoma Pine cones Hair protecting eyes Human skin	Elasticity and expansion Response to changes in moisture Protection against dust, small particles Cooling through evaporation	Integration of multiple function Layered, deployable, dynamic skin A flexible perforated skin Climate adaptive skin
	Foliage façades	Fern	Sunlight interception capability	Effective sun shading systems
	AeroDimm	Cephalopod	Colour change Camouflage	Flexible, pneumatic, integrated skin Color-changing, communicative skin Responsive skin
	S.C.A.L.E.S.	Side-blotched lizard	Flexible, interconnected scales Colorful and textured skin Moisture harvesting	Smart sun tracking system Colorful and textured skin Water regulating skin
	Polar bear-Keep It Warm	Polar bear	Insulation Color change	Active skin Phase changing material and skin
	Porous wall claddings	Termite mound	Passive ventilation	Passive ventilating skin
	The Las Palmas Water Theatre	Namibian beetle	Collects water from fog Collecting water in driest weather	Water colleting skin
	Hydrological Center	Namibian beetle	Collects water from fog Collecting water in driest weather	Water colleting skin Fog and frost-free surfaces
	Deep skin	Shark	Micro and macro scales Aerodynamic Bacteria control	Adaptive skin Aerodynamic skin Bacteria, dirt, snow free surface

Building skin, which can adapt to all kinds of conditions with different techniques, can also integrate with its environment and therefore becomes sustainable as well. Principles, properties and solutions of natural skins in Table 1 and Table 2 revealed the different concepts such as nature-inspired, biomimetic, bio-inspired, responsive, active, intelligent, (climate) adaptive, smart, interactive, high-performative, meteorsensitive, kinetic, dynamic, breathing, living skin and so forth. It is observed that these concepts are also used in the case studies. It is aimed that future building skin designs will have the features of natural skins.

As a result, natural world acts as a great idea bank for architectures to create ideas and to transform them into designs. In this context, biological solutions should be well identified and understood taking into account the problems in building skin designs. The architect should have the ability to interpret nature laws (from micro to macro levels) while creating the architectural object/building skin. Knowledge transformation process necessitates for architect to cooperate with various disciplines such as civil engineering, biology, physics, chemistry, climatology, physiology, psychology, ecology, computer engineering, cybernetics and artificial intelligence.

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